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

Final Report

Prepared for the 2015

Sea Scallop Research Set-Aside

NA15NMF4540056

May 2017

Submitted By

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Introduction

The Atlantic sea scallop (*Placopecten magellanicus*) fishery is one of the most valuable in the world, with revenues of $465 million in 2014 (NEFSC 2014). After the establishment of the rotational closed management areas on Georges Bank in 2003, scallop harvest stabilized and increased compared to historic values (NEFMC 2003, NEFSC 2014). Yet in 2013 there was a drop in scallop abundance, indicating this important resource is still vulnerable to fluctuations (Stokesbury et al. 2012, NEFSC 2014). Because Atlantic sea scallop stocks exhibit variability, and given the economic value of this species, efforts to stabilize the available resource have been substantial (Cliché and Giguère 1998, Smolowitz et al. 1998, Stokesbury et al. 2012). Fortunately, the productivity and life history of sea scallops makes this species an excellent candidate for enhancement.

The current rotational management program relies on natural recruitment processes, making it dependent on incoming year class strength. Larval dispersal patterns seem to be highly variable (Trembley et al. 1994), both spatially and temporally, with some areas and year classes sustaining the fishery in the past. In recent years, however, recruitment failures have been common on Georges Bank (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. However, it may be possible to enhance recruitment, and thereby biomass, by moving adult scallops from areas where environmental conditions are suboptimal to areas where scallops should thrive.

Recent dredge survey estimates from the Nantucket Lightship (NLS) extension area are alarming, with estimates dropping from 7,093 mt. in 2015 to 1,697 mt. in 2016 (Peros 2016). Additionally, there is mounting concern among managers that growth has slowed dramatically in the southern portion of the NLS area, once a highly productive scallop fishing ground that is currently densely populated. It may be possible to harvest small scallops from areas of poor survival/growth and transplant them to areas where environmental conditions may be more suitable. This could decrease competition for resources among the densely populated natural set of scallops, increasing growth rate and the odds of survival. In addition, transplanting into areas of low density, combined with subsequent monitoring, provided valuable information regarding growth and survival conditions that can be applied to other fishing grounds. Monitoring transplants for an initial period of up to 12 hours provided further information regarding post-transplant survival, mortality, and general behavior. Moreover, moving these scallops to areas where no scallops presently occur may create recruitment events in presently unseeded areas. HabCam surveys were conducted in these areas in 2013, providing additional valuable habitat information.

Scallop Dispersal and Local Distributions:

While the geographical distribution of sea scallops can be correlated with their preferred temperature range and benthic substrate (Brand 2006), the factors influencing their distributions on a smaller spatial scale are not as well understood. Dispersal of scallops occurs through passive (via currents) or active (via swimming) transport.

Posgay (1981) conducted tagging studies on *P. magellanicus* on Georges Bank, with tags returned by commercial fishermen, and found that 37% of tagged scallops were recaptured within 2 miles of their release and 85% were recaptured within 10 miles of their release. Melvin et al. (1985) conducted a similar study with sea scallops on Georges Bank and in the Great South Channel, and tag returns indicated that scallops moved ~9 km per year. Both studies indicated that net movement was in the direction of prevailing currents, suggesting that scallop dispersal over long distances is primarily through passive transport.

However, studies on sea scallops swimming in flume tanks and a shallow tidal channel showed that in current speeds of under 1 m/s, larger scallops (30-80 mm shell heights) swim in random directions, while smaller scallops (under 30 mm shell heights) swim in directions that are displaced from the mean current vector by 35-45 degrees (Carsen et al. 1996), suggesting that even small scallops do not simply let the prevailing current determine their travel directions. *P. magellanicus* are strong swimmers that can swim distances of over 10-20 meters in one swimming effort (Brand 2006). They swim to escape predators, divers, and other disturbances (Caddy 1968, Brand 2006, Siemann et al. 2015), and the high numbers of scallops seen swimming up in the water column during HabCam IV surveys suggests active transport via swimming may play an important role in post-settlement dispersal (NEFSC 2015). Moreover, Hamilton and Koch (1996) presented evidence that bay scallops (*Arcopecten irradians*) actively swim toward their preferred habitat using visual cues.

Scallop Enhancement Projects:

Scallop resource management 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 Atlantic sea scallops and most wild scallop fisheries. In 1935, Japanese researchers started developing a program to decrease recruitment variability (Ito and Byakuno 1989). 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 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 (Caddy 1989). The harvest is stable from year to year and is an order of magnitude larger than the previous wild harvest fishery (Caddy 1989). There are over 1,900 scallop harvesting firms in the Mutsu Bay region alone, and many other regions also produce cultured scallops (Caddy 1989).

Since the 1970s, countries in all parts of the world have begun scallop culture operations based on the Japanese model (Paul et al. 1981, Naidu and Cahill 1986, Reyes 1986). Some collect spat; others use hatcheries to produce the spat and conduct commercial scale bottom culturing of scallops. France and New Zealand have successful scallop enhancement practices, and Canada may soon enjoy a successful scallop aquaculture industry (Ansell et al. 1991, Bull 1991, Emerson et al. 1994). The scallop enhancement technique is very useful, helping to restore depleted stocks and spread harvestable seed to areas of lower predation/fishing effort.

Another technique, recently employed in the US, involves the successful transportation and seeding (transplant) of scallops to enhance production. This 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 management 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, benthic 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 management and demonstrated effective methods for transplanting and monitoring seed.

Coonamessett Farm Foundation Sea Scallop Enhancement Research:

Since 2013, CFF has been committed to developing best practices for scallop enhancement along the New England coast. Over the last three years, over 2.3 million scallops have been transplanted by CFF in three separate operations.

During these operations, multiple methods were developed to retain live scallops during transportation. Most recently we developed a system to overcome warmer water temperatures in the summer. Previously, scallops were shaded with tarps and sprayed with a seawater sprinkler system, which was only successful in spring/fall months. To overcome warmer summer temperatures, we employed stackable fish totes with flow-through seawater chilled by a radiant cooling system. This new method was very successful.

CFF has developed and/or tested a range of monitoring methods, including the University of Massachusetts, Dartmouth School for Marine Science and Technology (SMAST) video pyramid, a Teledyne Mini-Benthos ROV, the HabCam II towed sled, a bottom-contacting towed video sled, and the Woods Hole Oceanographic Institution Remote Environmental Monitoring UnitS (REMUS) autonomous underwater vehicle with and without location transponders. Each of the methods has associated costs and benefits, and the experience has given CFF a clear understanding of the difficulties in open-ocean monitoring of scallops. Our attempts to monitor seeded scallop dispersal using these monitoring vehicles have enjoyed some success, with higher densities of scallops found immediately after transplant experiments in Closed Area 1 (CFF 2014a). Long term location of scallops was problematic in previous experiments, but our data from the SMAST drop cam surveys indicated this may be due to dispersal. Few clapper scallops were identified, and predator densities were relatively low during the experiment (CFF 2014b). However, because we were not able to locate seeded scallops on or near the drop site in the weeks and months following transplant, we shifted focus to short-term retention of seeded scallops, with an emphasis on the drivers of dispersal (active vs passive and predation) and their effects on different size classes of scallops. Based on experiences from the previous projects, we

were able to develop a camera rig that drops the scallops on bottom and maintains a view of them from above. The cameras were able to take time-lapse photos every one or three minutes for 4 or 12 hours, respectively. Preliminary results indicate that predators may impact scallop dispersal immediately after they are moved to new locations.

Project Goals and Objectives

The U.S. Atlantic sea scallop (*Placopecten magellanicus*) industry is dependent on natural recruitment processes, unlike more productive scallop fisheries around the world, such as Japan's Yesso scallop fishery, were scallop beds are enhanced by supplementing natural sets with hatchery-reared spat or spat from collectors. In the U.S., recruitment varies with natural fluctuations in the biotic and abiotic processes that impact growth and survival during early scallop life history stages. Understanding these processes can help to develop stock enhancement strategies that decrease recruitment vulnerability. When combined with scallop surveys (e.g., HABCAM, SMAST Drop Cam, and VIMS trawl surveys), a greater understanding of how these processes affect scallop recruitment success could provide needed information to optimize scallop productivity, and, thus, yield in the scallop fishery.

This research project addressed a Scallop RSA high priority aimed at understanding recruitment processes. The goal was to enhance scallop biomass and yield under an optimized rotational management program. We consider this a ubiquitous, high priority for the scallop fishery. This project contributes ecological characterization, habitat characterization, and behavioral information regarding interactions between scallops and other marine organisms. Additionally, CFF sought to gather important information regarding the rate of spread of, predation on, and mortality of recently transplanted scallops. This data is essential in deciding whether or not transplanting or seeding offshore are viable forms of stock enhancement, and should be used to assist managers when considering potential future enhanced access areas.

Our primary objectives included:

1. Performing an additional seeding operation by transplanting seed and monitoring environmental and biological conditions at the transplant site.
2. Evaluating the success of the transplant using video technologies (Autonomous Underwater Vehicles (AUVs) and camera stands) by quantifying scallop and predator densities as well as scallop survival and dispersal rates.
3. Investigating seedbed characteristics (oceanographic conditions, habitat, and predator abundance) at the enhanced seedbed to provide insight into factors behind transplant success or failure.

Table 1. *Project calendar*

Task	**Date**	**Notes***
2015 transplant and monitoring with REMUS AUV – trip 1	7/29 - 8/1/2015	Cancelled mid-trip due to REMUS AUV failure
Started collaboration with Gavia AUV group	8/2015	
Gavia AUV sent for repairs	10/2015	
2016 Experimental Fishing Permit submitted	11/12/2015	
Permit accepted	3/11/2016	Permitted 3/11 - 9/30/2016
AUV finished repairs and calibration	4/22/2016	
Test run of AUV	5/3/2016	
Collaboration with Gavia AUV group cancelled	6/20/2016	Significant price increase above agreed upon rates
2015 transplant and monitoring with camera stands – trip 2	8/28 – 9/3/2016	Results presented in this report

** Additional details about project complication in* ***Appendix 1***

Methods

Camera systems:

A tetrad of deployable stationary camera rigs were designed by Shea Miller (CFF) and fabricated by Charlie Quinn in New Bedford, MA (**Figure 1**). Each rig is approximately 1.8 meters tall, with four legs extending from a central beam, and weighs approximately 250 lbs. The base of the legs form a 2-m^2 footprint on the seafloor, with legs extending upward to a 1.8 meter long steel backbone. Two GoPro Hero 4 silver cameras were mounted to the central beam of each stand, with 130 cm separating the two camera lenses. This allowed a small overlap between images, providing a stitched image coverage of nearly 3 m^2. GoPro cameras (in waterproof housings) were bolted to a thin tab of aluminum which in turn was bolted to the backbone of the rig. The GoPros faced down with the horizontal view perpendicular to the main beam. Only ambient light was used to film after scallop transplant operations, so image data collection was limited to daylight hours.

The cameras on three of the stands were set for short-term data collection and deployed in the morning and afternoon. These short-term cameras took time-lapse images every 60 seconds. The camera batteries typically lasted ~4 hours. The fourth camera rig was outfitted for long-term deployment, utilizing GoPros equipped with Blink time-lapse intervalometer backpacks. These cameras were set to take a picture every three minutes for 12 hours a day. Thus, standard cameras provided a slightly higher resolution on biological behavior data compared to Blink-equipped cameras.

Figure 1. *Camera rig set-up showing three drop camera frames and the locations of the cameras.*

Site selection:

The site chosen for transplant was near the 2014 sites in the northwest section of the Nantucket Lightship Closed Area (NLCA) (**Figure 2**). Scallops were collected in the vicinity of the camera drop locations. The site was selected for its large area of level bottom, relatively low tidal currents, and abundance of scallops. High densities of scallops allowed for shorter tows to catch the needed scallops.

Scallop harvesting:

Due to the amount of camera gear on board, only one dredge was taken out to sea. The FV Liberty conducted one ten-minute tow using a standard 15-ft New Bedford-style scallop dredge. Depth at harvest locations was approximately 35 fathoms. High catch rates in the initial tow caused CFF to reduce subsequent tows to 3-minute durations. Tow speeds were maintained between 4.8-5.1 knots. In an effort to minimize deck/handling time, we did not use a lined dredge and sort the catch to select only scallop seed (under 40 to 60-mm shell height for sea scallops: Robinson et al. 2016), and no catch data was recorded. Four bushel baskets were filled with commercial-sized scallops and placed into totes for transport. After harvesting, the vessel steamed north to shallower waters (25 fathoms depth) to deploy the camera systems.

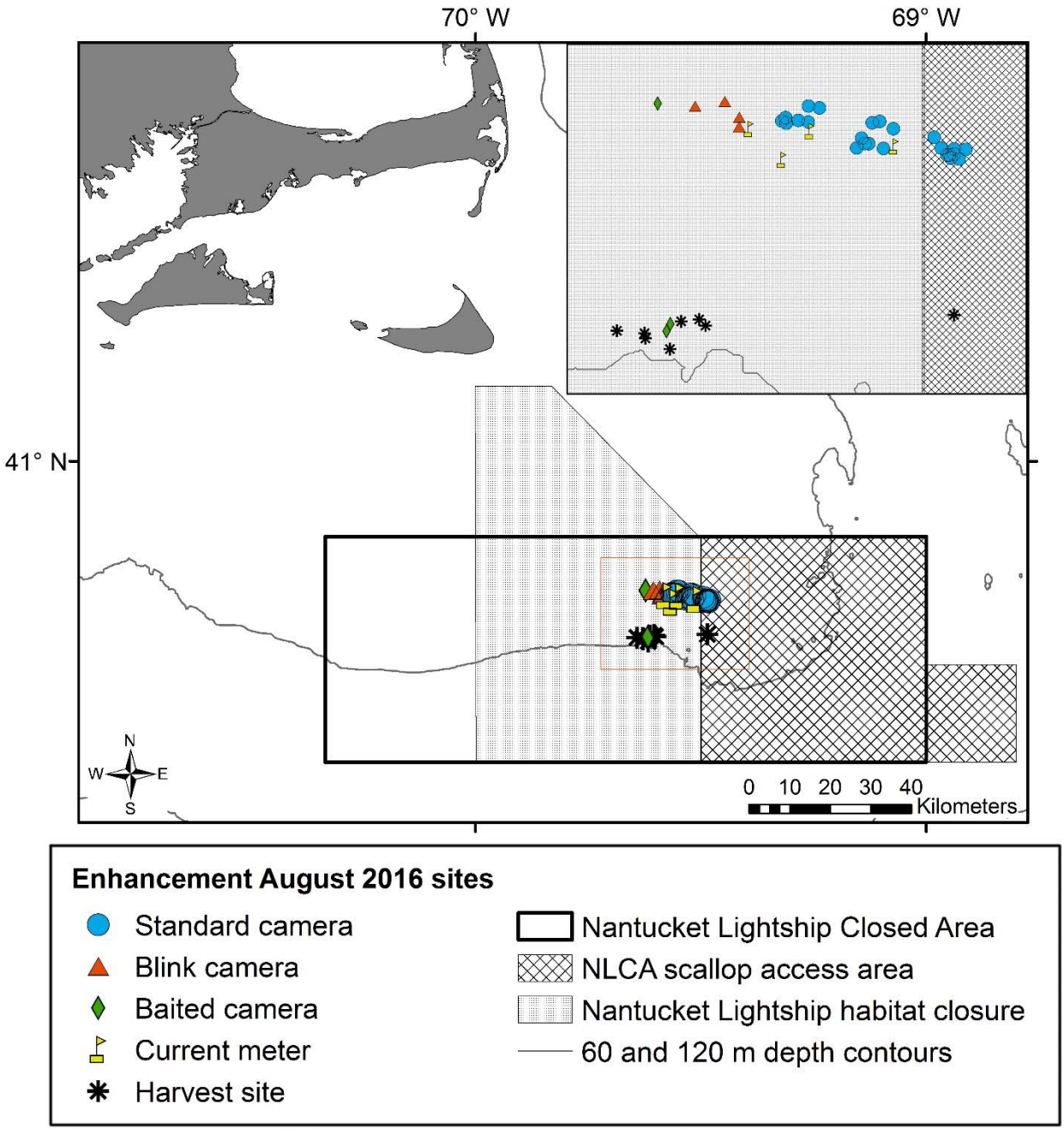

Figure 2*. Map of standard, Blink-equipped, and baited camera sites; harvest locations; and current meter deployment sites for August 2016 transplant project. Scallops were seeded directly below the camera stands. Upper right inset shows a zoomed-in view of the project locations.*

Chiller System:

Scallops were held in fish totes filled with chilled sea water between harvest and transplant (**Figure 3**). A closed system was set up on deck between a 1/3 hp. drop-in chiller (Frigid Units Inc.) installed in a 55-gallon drum and a sump pump. The chiller maintained the water temperature at approximately 15° C.

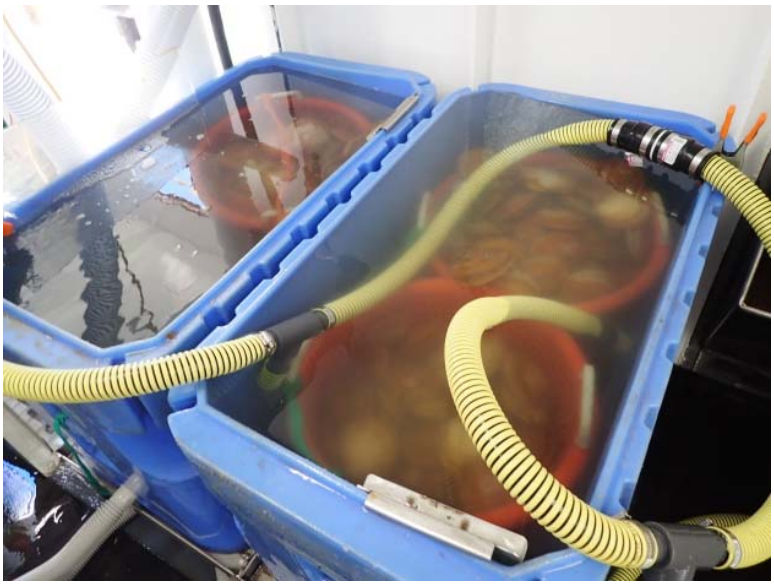

Figure 3. *The cooling system showing two bushel baskets that fit side-by-side in each fish tote.*

Scallop transplant:

A new method for transplanting scallops directly on the bottom was tested during the first project trip (August 2015) to minimize issues that resulted from surface drops during previous project years. A weighted fish tote (25 lb. plate weight tied to the bottom) with pre-drilled holes was loaded with scallops and lowered over the side of the vessel. A second rope, attached to the bottom of the tote, was tied off to the vessel. This line was adjusted so the scallops were dumped a few meters off the bottom, allowing for some dispersal but no major drifting or spreading (**Figure 4**).

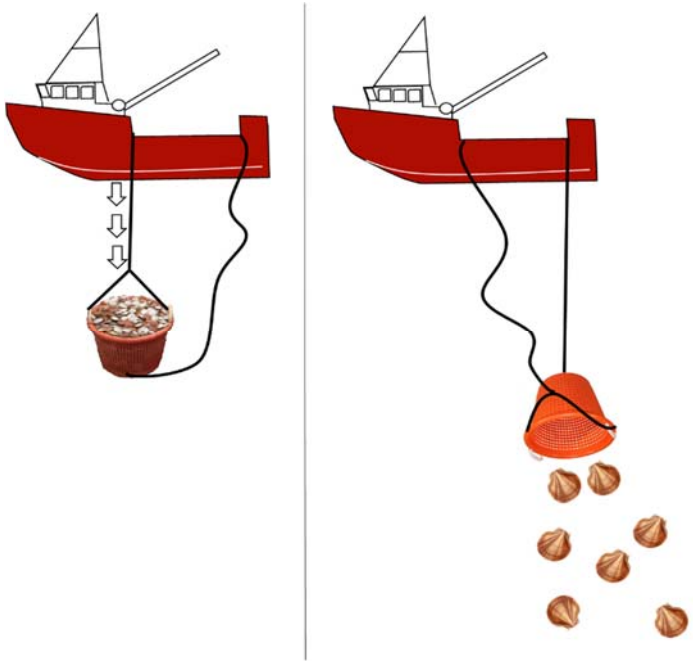

Figure 4*. Method for transplanting scallops near the bottom.*

This method was modified to drop scallops below the camera stands. A small quick-release box was created to transplant the scallops below the cameras once the stand was on the seafloor. A plastic box with an opening hatch on the bottom was bolted onto the center of the central beam (**Figure 5**). The box was held closed with a small line attached to a quick-release shackle. The quick-release line was flaked into a bucket prior to deployment. Approximately 30 scallops were loaded through a slot on the side of the box for each camera deployment.

Figure 5. *Close-up views of the quick-release box used to drop scallops onto seafloor in camera view.*

Camera deployment*:*

A bridle was shackled to the main beam of the camera array for ease of deployment/retrieval. A hard trawl float was attached to the bridle to prevent the line from getting tangled in the rig or dropping into the camera view. Two consecutive loops were tied above the float, providing an easy spot to put the hook in for the take-out winch. The bottom 50% of line was floating line (to keep line away from the rigging and cameras) and the top section sinking (to prevent line from getting caught in the wheel). The terminal end of the line was attached to a large poly-ball and highflyer attached with whale safe-quick releases to aid in visibility when retrieving.

Once scallops were loaded into the box and cameras set to record, the rig was deployed. When the rig hit the seafloor, the quick release was pulled, dropping the scallops inside the box onto the seafloor.

Current Meters:

Tilt current meters (Lowell Instruments) were deployed between the stands (**Figure 2**). Each current meter was connected to a piece of line passed through a weighted eight-foot section of PVC pipe and set with a 22-lb Danforth anchor (**Figure 6**). Placing the current meters and the end of a long stretch of pipe ensured room for the tilt meters to swing freely in all directions.

Figure 6. *Tilt current meter attached to a line through PVC pipe.*

Preliminary baited video deployments:

Because CFF will be conducting baited video surveys in future projects, we ran some preliminary baited video sessions at night. Bait, which varied depending on what was available, was attached to monofilament line that ran between the camera stand legs. GoPro cameras and dive lights (FIX NEO 1200DX) were attached to augment the camera lights, and the cameras recorded video overnight until the batteries died.

Image analysis:

The images taken by the GoPro cameras were analyzed using a custom annotation program written in R (R Core Team 2015). The R code is included in **Appendix 2**. To make annotation easier in images with low light, annotation was done on the original image while a high contrast color-equalized image was shown to allow further confirmation of hard-to-see scallops.

Because we discovered that the scallops were only visible in images from one camera per frame, analysis was done on only these images. Prior to beginning image annotation, the image data was viewed to determine which animals should be included in the analysis. Based on this review, scallops, snails, lobsters, crabs, sea stars, and fish were counted in each image. As each image was processed, the annotator clicked on each animal to be counted, and the point location was stored for further analysis. All images were annotated by one trained reviewer.

For the first two sets of images we analyzed, all images were annotated. The data from these image sets were reviewed, and based on the noted changes in scallop numbers and predator presence in these images, we started annotating every fifth image in the remaining image sets taken with standard GoPro cameras and every other image (6-minute interval) in the image sets taken by GoPros with Blink intervalometers. Animal counts were determined by summing the

number of click points per species, with click locations (X- and Y-coordinates) stored for additional analysis.

Data analysis:

The text files of the annotated image sets were summarized in Excel. Scallop loss was summarized in two ways. Overall loss for each image set, with loss defined as reductions in the number of scallops in the image frames, was calculated as

$$\%\ loss = {\#\ scallops\ in\ Image\ 1 - \#\ scallops\ in\ Image\ L}/{\#\ scallops\ in\ Image\ 1}$$

where Image 1 was the first image with scallops after the drop and Image L was the last image with visible scallops that could be counted.

Because the amount of time before the camera batteries died or darkness fell varied, we also summarized scallop loss per hour as

$$\%\ lossHr = \%\ loss * \frac{60}{totalMinutes}$$

where totalMinutes equaled the time between the first and last image with visible scallops.

Scallop movement was summarized using two statistics based on changes in the average distance between the scallops in a seeded group (a measure of spread) and the movement of the whole group) (**Figure 7**). Spread by the scallop pile between two images was calculated as the ratio of the mean Euclidean distance between scallops in the first image and the mean Euclidean distance between scallops in the second image. Movement by the scallop pile was calculated based on the distance between the centroid of the pile in the first image and the centroid of the pile in the second image.

Counts of potential predators were summarized as the mean and maximum numbers in an image during each image set. The impact of predator presence on scallop behavior was examined by correlating scallop loss per hour, mean and maximum scallop spread, and mean and maximum scallop movement with the mean and maximum numbers of each predator per image set. To determine if scallop movement might be related to predator numbers in a less obvious way, we also plotted scallop percent loss with the maximum number of predators after sorting the image sets by scallop loss.

Current meter data was summarized using feather plots created in R for 30-minute averages over the whole trip and 5-minute averages over one day.

Results

Image annotation data is summarized in **Table 2**. For the majority of the image sets, most of the approximately 30 scallops loaded into the drop box could be seen in the first image. Over the course of each visible recording session (i.e., time with sufficient ambient light), an average

of 48.6% of the scallops remained in the image frame, with 12.5% of the scallops leaving the image frame per hour. Scallops tended to land upside-down when first dropped, and over the course of each image set, scallops would flip over and frequently move short distances within the image frame. Consequently, because we didn't label individual scallops and click points could not be assigned to specific scallops, we were unable to determine how many scallops moved and which scallops left the image frame.

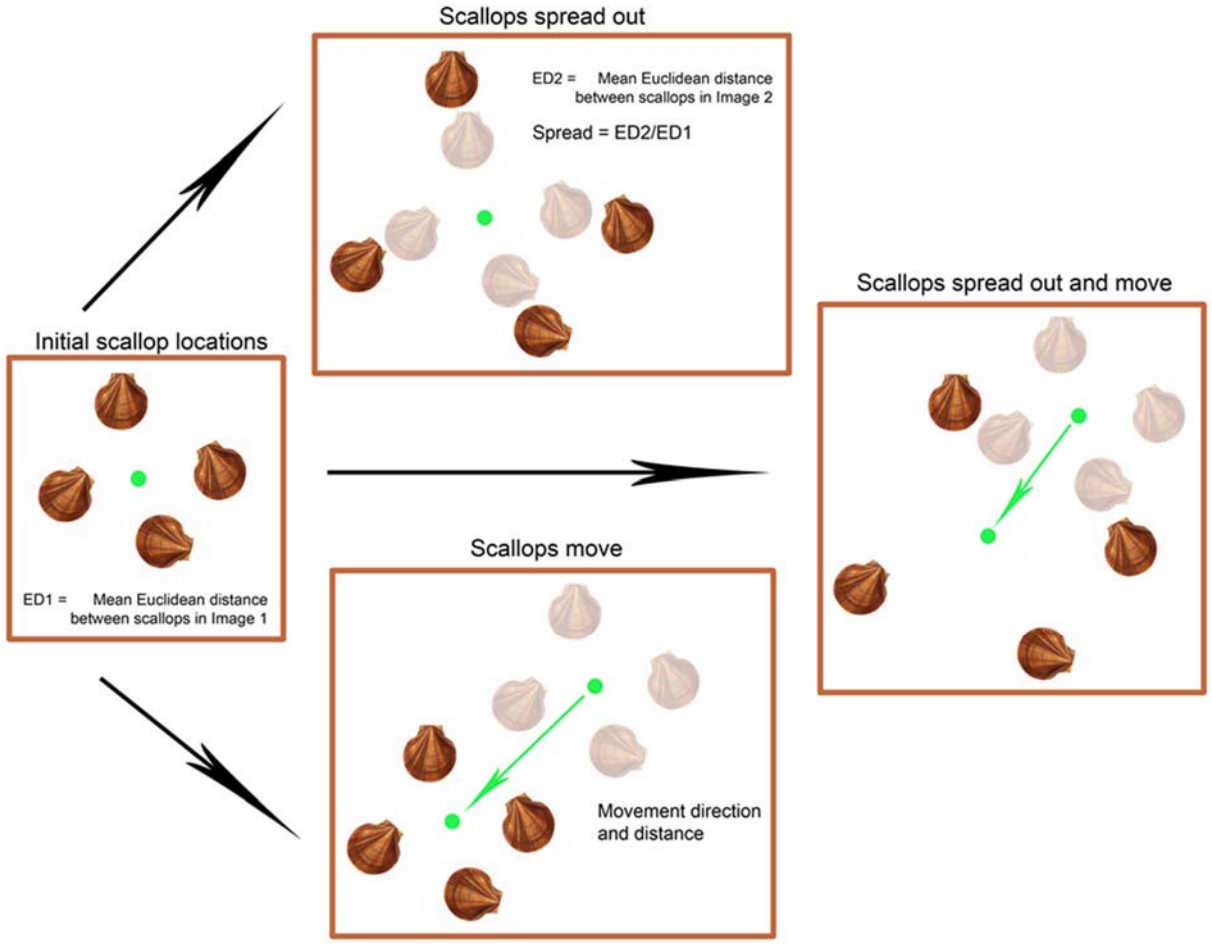

Figure 7. *Summary of statistics used to summarize scallop movement*

Drop cameras captured 60 instances of other animals interacting with recently seeded scallops. The majority of interactions consisted of snails approaching scallops, inducing a swimming (escape) response in some cases (**Figure 8**). Lobsters, crabs, and various fishes also approached scallops. In two instances, scallops were engulfed by snails, then subsequently drifted/rolled out of the image frame, possibly utilizing the current to move the scallop.

Scallop loss, spread, and movement were not highly correlated with the presence of predators (**Table 3**). In addition, scallop percent loss did not increase linearly with time (**Figure 9**). Visual examination of scallop loss versus predator numbers did not reveal any other trends (**Figure 10**). The image sets with the largest percent loss of scallops were not taken during camera deployments when the highest numbers of potential predators entered the area.

Table 2. *Summary of image annotation data.*

Date	# at start	# at end	Proportion Remaining	Mean % loss/hour	Total time (minutes)	Max # of snails	Max # of crabs	Max # of fish	Max # of lobster
Standard GoPro Time-Lapse Cameras									
08/30/2016	12	8	0.667	0.070	285	1	0	2	0
08/30/2016	15	4	0.267	0.226	195	1	0	1	0
08/30/2016	28	26	0.929	0.016	270	2	1	1	0
08/30/2016	28	17	0.607	0.136	173	0	0	1	0
08/30/2016	13	5	0.385	0.211	175	1	0	0	0
08/30/2016	30	17	0.567	0.149	175	1	0	0	0
08/30/2016	31	23	0.742	0.119	130	0	0	1	0
08/30/2016	16	8	0.500	0.231	130	1	0	1	0
08/31/2016	25	7	0.280	0.139	310	8	1	2	0
08/31/2016	30	13	0.433	0.125	273	6	1	1	0
08/31/2016	31	21	0.677	0.062	310	1	0	0	0
08/31/2016	22	18	0.818	0.066	165	0	0	0	0
08/31/2016	19	13	0.684	0.074	255	1	1	2	0
09/01/2016	30	26	0.867	0.030	270	1	0	1	0
09/01/2016	31	16	0.516	0.106	275	1	0	1	0
09/01/2016	29	11	0.379	0.166	225	2	0	1	0
09/01/2016	21	8	0.381	0.165	225	0	1	1	0
09/01/2016	28	14	0.500	0.105	285	0	0	1	0
09/01/2016	15	3	0.200	0.160	300	1	1	1	0
09/02/2016	29	18	0.621	0.076	300	1	0	1	0
09/02/2016	28	11	0.393	0.162	225	2	1	1	0
09/02/2016	20	7	0.350	0.173	225	1	1	1	0
09/02/2016	23	4	0.174	0.171	290	2	0	1	0
09/02/2016	16	10	0.625	0.080	280	2	0	2	0
09/02/2016	12	4	0.333	0.140	285	1	1	1	1
Mean	**23.28**	**12.48**	**0.516**	**0.126**	**241.24**	**1.48**	**0.36**	**1**	**0.04**
Blink-equipped GoPro Cameras									
08/30/2016	27	11	0.407	0.289	123	2	2	1	0
08/31/2016	31	6	0.194	0.059	822	3	2	1	0
09/01/2016	19	5	0.263	0.063	645	5	2	0	0
09/02/2016	21	7	0.333	0.069	630	2	3	2	0
Mean	**24.50**	**7.25**	**0.299**	**0.120**	**555.00**	**3.00**	**2.25**	**1.00**	**0**
Overall mean	**23.45**	**11.76**	**0.486**	**0.125**	**284.52**	**1.69**	**0.62**	**1.00**	**0.03**

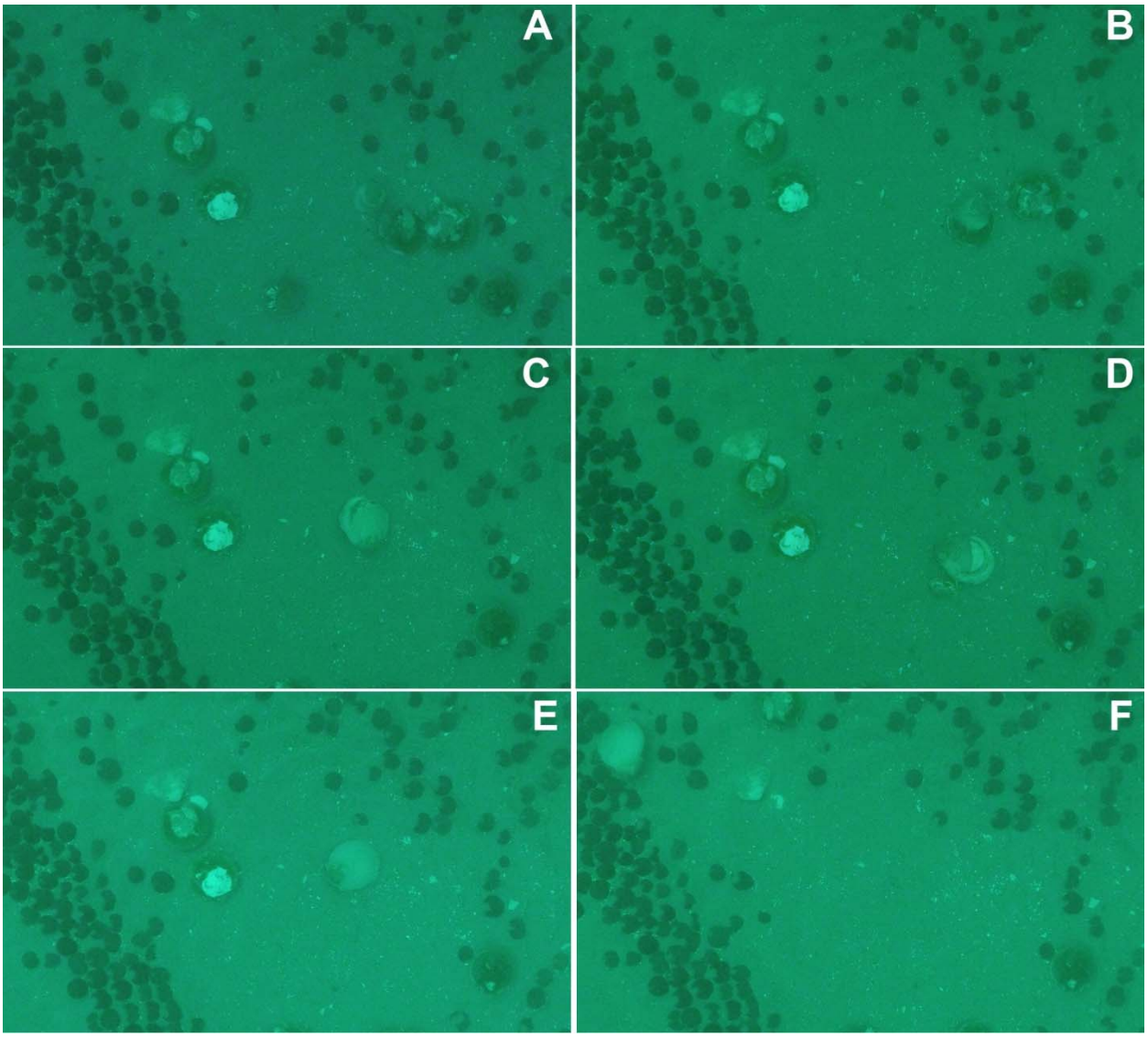

Figure 8. *Time-lapse images of a scallop being engulfed by a snail. A) A snail approached a scallop. B) The snail moved onto the scallop. C-D) The scallop tried to escape from the snail. E) The snail fully engulfed the scallop. F) The snail moved away with the scallop.*

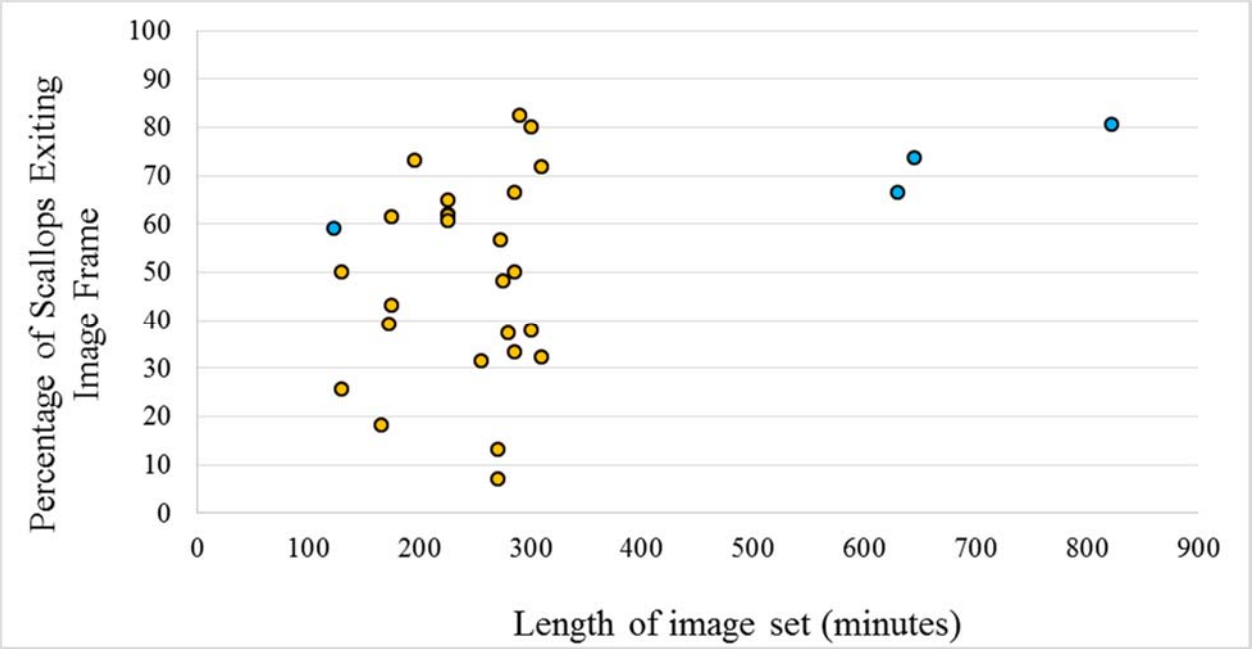

Figure 9. *Percent loss of scallops throughout each image set for standard and Blink-equipped stationary GoPro camera. Orange circles - standard GoPro camera arrays. Blue circles - Blink-equipped GoPro camera arrays.*

Table 3. *Correlations between scallop percent loss per hour, scallop spread, and scallop group movement with the mean and maximum numbers of predators in each image set. Only the maximum number of lobsters were included because only one lobster was recorded in all of the image sets.*

	Snails		Crabs		Fish		Lobster	
	Max # per image	**Mean # per image**	**Max # per image**	**Mean # per image**	**Max # per image**	**Mean # per image**	**Max # per image**	**Mean # per image**
Scallop % loss per hour	-0.05	0.07	-0.12	-0.10	-0.05	0.09	0.04	-
Scallop mean spread	0.23	0.23	0.03	0.12	0.19	0.03	-0.20	-
Scallop max spread	0.12	0.04	-0.19	0.06	0.21	0.02	0.43	-
Scallop mean movement	-0.05	-0.21	-0.32	-0.03	0.20	0.15	0.01	-
Scallop max movement	-0.01	-0.12	-0.32	-0.07	0.10	0.00	0.37	-

Current meters were deployed near the camera stands. However, because the orientation of the camera stands could not be verified, we were unable to correlate current direction and strength with scallop movement. Examination of current meter output indicated that current strength and direction in the transplant areas changed strength and direction daily (**Appendix 3**).

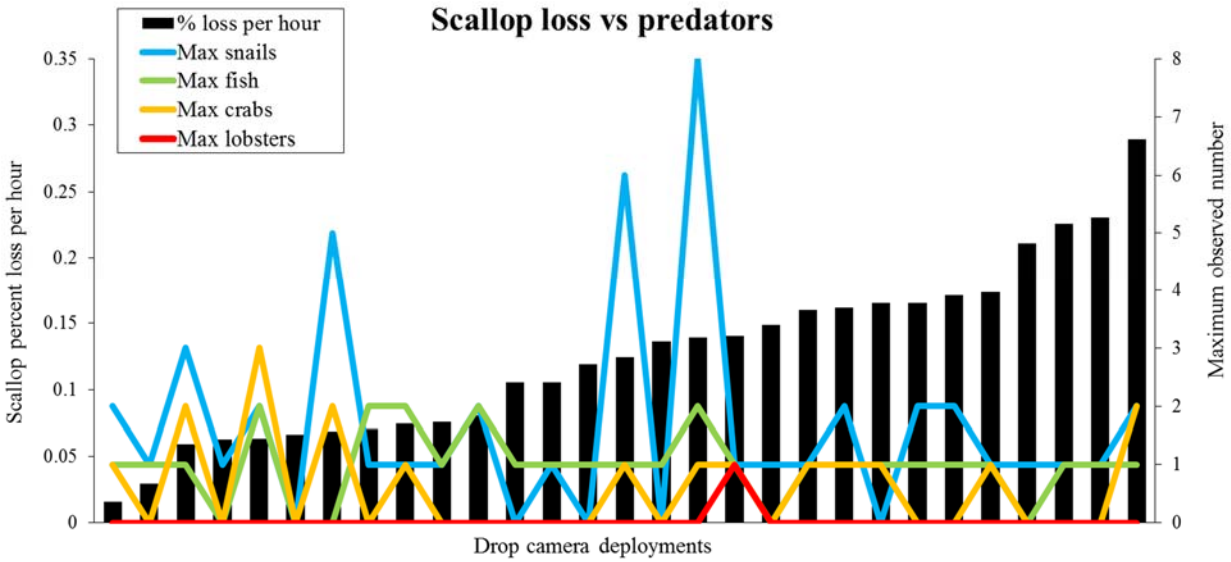

Figure 10. *Plot of increasing values for percent scallop loss per hour with the maximum number of predators that were counted in an image frame over the whole image set.*

Video footage captured using the camera stands with baited video showed great promise. We collected footage of scallop swimming and escape behavior (**Figures 11**) and other predation events, including a summer flounder eating a hake (**Figures 12**).

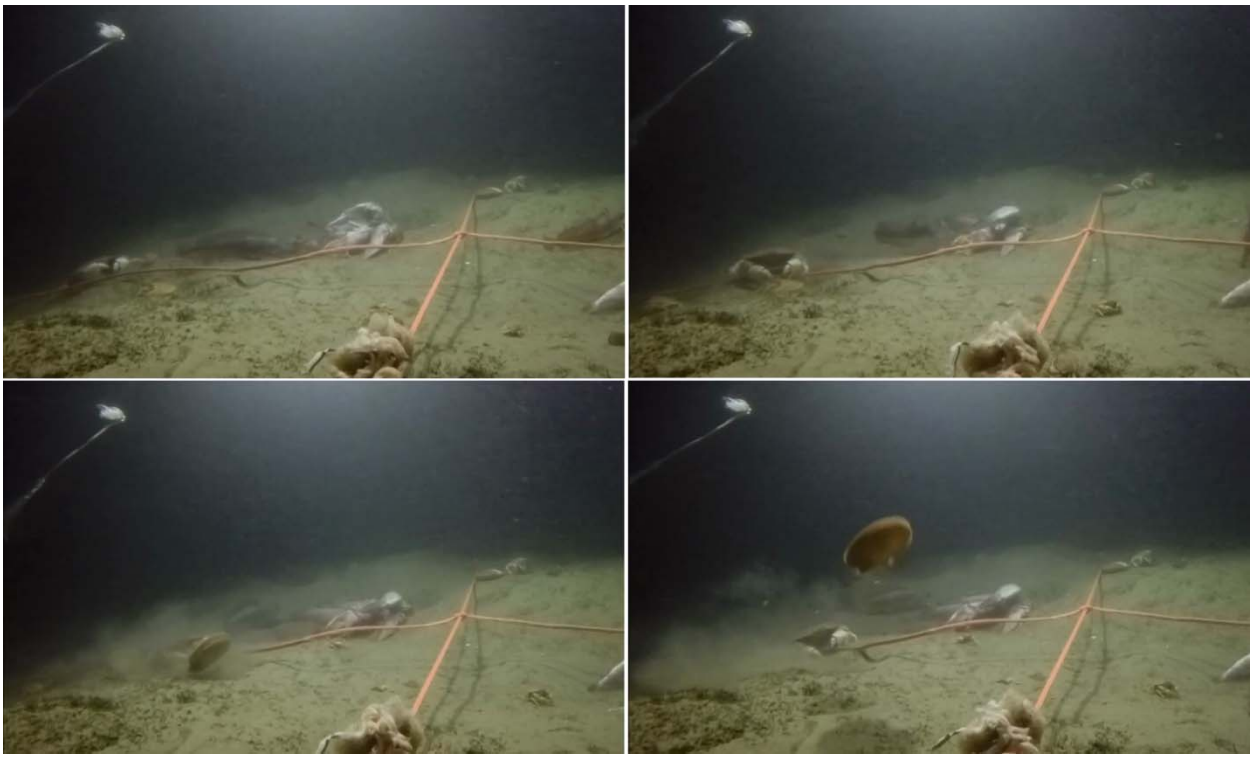

Figure 11. *Screen grabs from video footage of a scallop swimming away from a crab.*

Figure 12. *Screen grabs from video footage of a summer flounder grabbing a hake.*

Conclusions

The main objectives of the project were successfully completed, despite complications that led to changes in the experimental design of the project. A small-scale transplant operation was conducted in late August 2016. Sea scallops were successfully transplanted alive to a new area and monitored on the bottom after being moved. Data was collected to study the influence of oceanographic conditions, habitat, and predator abundance on recentlytransplanted sea scallops.

CFF will be continuing similar research during the summer of 2017. We have designed and built a sturdier camera stand with improved cameras, lights, and batteries. We plan to photograph and film transplanted scallops for 24-48 hours, and by incorporating a compass into the stands, we will be able to correlate current velocity and direction with scallop movement. A Hydrolab data logger has been added to one camera stand to collect additional environmental data including conductivity (salinity), pH, dissolved oxygen, chlorophyll concentration, turbidity, and depth. Scallops will be marked with group-specific tags to improve our ability to track the seeded scallops and discriminate between these new scallops and those already on site. A subset of scallops will be individually marked and tracked over the entire image set to investigate the behavior (e.g. flipping, movement, responses to other animals etc.) of single scallops. Due to the improved quality of images from the new camera systems, it will be possible to determine if these scallops are alive (scallops ventilate or move over 24-48 hours) and therefore estimate mortality rates, due to consumption by predators or death during or after transplant, for the seeded group as a whole. By making these improvements to our scallop-monitoring systems, the

CFF scallop enhancement program will continue to provide more refined data needed to assess the practicality of scallop transplant and enhancement programs.

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Appendix 1

Notes about project complications:

Multiple hurdles have complicated this project; permitting, weather, equipment failure, and cost have disrupted the timing and approach of this project. Despite this, we have learned much throughout this process, including logistics of what does and does not work.

Initially, the 2016 schedule was delayed due to unexpected difficulties in the regular maintenance of the AUV. The AUV was repaired and returned to the University of Delaware (UD) on April 8, 2016. Calibration of cameras and testing kept the AUV unavailable until April 22, 2016. During this time, safety concerns for the launching of the AUV from a commercial scallop fishing vessel were voiced by the UD AUV team. After reviewing the procedures used in the 2015 launches it was decided that the research vessel (RV) Daiber would be a safer deployment platform, as it has a history of successful AUV surveys. A request for a research letter of acknowledgement (LOA) for the expansion of the potential experimental areas was submitted April 12, 2016, allowing for the possibility of using the UD research vessel Daiber for AUV deployment. The request triggered a change in scope for the project. The changes to the scope and the LOA covering the project were accepted on June 20, 2016.

On May 10, 2016, a test run of the AUV on the RV Daiber was conducted. The vessel left out of Lewes, DE on the morning of the 10th. We laid strings of scallops marked with reflective tape on the bottom and programmed the AUV to conduct surveys of the area. The AUV performed its programmed survey tracks accurately. Unfortunately, the AUV had recently been outfitted with a new strobe, which was extremely bright and caused a flash burn over the bottom of the image and leaving the top of the images completely dark. Because of this, CFF deemed the images unsuitable for analysis. The UD team was asked to run some lab tests to see if they could get better images. CFF never received images from lab testing to indicate that the AUV was capable of capturing useable images. On July 27, CFF was provided images from a recent UD research trip, which were of slightly better quality. After reviewing the images, CFF decided to try the AUV for surveys. Due to the substantial delays from the original deployment dates, a new quote was requested from the UD AUV team. UD added charges and substantially increased day rates, while the available dates for surveys had started to fill up. Based on these changes, CFF decided to drop the UD AUV from the project.

To replace the AUV, plans and tools had to be quickly adapted. An experimental survey date was set for August 28, 2016. A Teledyne Minirover ROV (ROV) was retrofitted to conduct bottom surveys and a deployable stationary camera system was developed. These changes also required substantial outfitting of the commercial fishing vessel Liberty. The data collection tools and vessel adaptions were complete by August 26th. The Liberty left port on August 28 and conducted surveys for 5 days before being pushed back into port by foul weather. Analysis of collected data is ongoing.

Appendix 2: R code for image annotation and quantification of scallop movement

CountScallopPlus annotation program

```
# load needed libraries
library("EBImage")
library("stringr")
library("tcltk")
library("abind")
# identify all files in working directory that are GoPro jpg files
Images = Sys.glob("G*.JPG")
# count the number of images
Len = length(Images)
# create empty vectors for the data
numScallops = numeric(length=Len)
numSnails = numeric(length=Len)
numLobsters = numeric(length=Len)
numCrabs = numeric(length=Len)
numSeastars = numeric(length=Len)
numFish = numeric(length=Len)
notes = character(length=Len)

for (i in 1:Len){
        ImgOrig = readImage(Images[i])
        ImgRGBlevel = ImgOrig
        Rimg = ImgOrig[,,1]
        Gimg = ImgOrig[,,2]
        Bimg = ImgOrig[,,3]
        maxIR=max(Rimg)
        maxIG=max(Gimg)
        maxIB=max(Bimg)
        ImgRGBlevel[,,1]=(Rimg/maxIR)
        ImgRGBlevel[,,2]=(Gimg/maxIG)
        ImgRGBlevel[,,3]=(Bimg/maxIB)
        ImgExtreme = equalize(ImgOrig, range=c(0,1), levels=256)
        Img = Image(abind(ImgRGBlevel, ImgExtreme, along=1), colormode="color")
        # to get image titles to fit in frame
        par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
        display(Img,method="raster") #open raster window
        title(main = "Select scallops")
        scallops = locator(type='p',pch=18,col='red',cex=1.5) #get scallop click points
        numScallops[i] = length(scallops$x)
        graphics.off()
        par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
        display(Img,method="raster")
        par(oma=c(0,0,1,0))
```

```
        title(main = "Select snails")
        snails = locator(type='p',pch=18,col='red',cex=1.5)
        numSnails[i] = length(snails$x)
        graphics.off()
        par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
        display(Img,method="raster")
        par(oma=c(0,0,1,0))
        title(main = "Select lobsters")
        lobsters = locator(type='p',pch=18,col='red',cex=1.5)
        numLobsters[i] = length(lobsters$x)
        graphics.off()
        par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
        display(Img,method="raster")
        par(oma=c(0,0,1,0))
        title(main = "Select crabs")
        crabs = locator(type='p',pch=18,col='red',cex=1.5)
        numCrabs[i] = length(crabs$x)
        graphics.off()
        par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
        display(Img,method="raster")
        par(oma=c(0,0,1,0))
        title(main = "Select sea stars")
        seastars = locator(type='p',pch=18,col='red',cex=1.5)
        numSeastars[i] = length(seastars$x)
        graphics.off()
        par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
        display(Img,method="raster")
        par(oma=c(0,0,1,0))
        title(main = "Select fish")
        fish = locator(type='p',pch=18,col='red',cex=1.5)
        numFish[i] = length(fish$x)
        graphics.off()
        notes[i] <- readline("Enter any notes about image and press ENTER when finished: ")
        notesChar = notes[i]
        # check count values before closing last image
        CountVector <-c("scallops", numScallops[i], "snails", numSnails[i], "lobsters",
        numLobsters[i], "crabs", numCrabs[i], "sea stars", numSeastars[i], "fish", numFish[i])
        print(CountVector)
        locsFilename = paste0(Images[i],"_locations.RData")
        save(scallops, snails, lobsters, crabs, seastars, fish, notesChar, file=locsFilename)
        }

CreatureCounts <- data.frame(Images, numScallops, numSnails, numLobsters, numCrabs,
numSeastars, numFish, notes)
fileName <- tclvalue(tkgetSaveFile()) #include .csv in name
write.csv(file=fileName, x=CreatureCounts)
```

distancesRdata to track spread and movement of scallop centroid

```
# load needed libraries
library("stringr")
library("tcltk")
# identify all files in working directory that are image data files
ImgData = Sys.glob("*.RData")
# count the number of files
Len = length(ImgData)

Dist = numeric(length=Len)
DistSD = numeric(length=Len)
NNI = numeric(length=Len)
centroidX = numeric(length=Len)
centroidY = numeric(length=Len)
centroidDistFirst = numeric(length=Len)
centroidAngleFirst = numeric(length=Len)
centroidDistPrev = numeric(length=Len)
centroidAnglePrev = numeric(length=Len)

First = load(ImgData[1])
FirstMat = do.call(cbind, scallops)
FirstDistMat = dist(FirstMat, method = "euclidean")
FirstDistVec = as.vector(FirstDistMat)
FirstDist = mean(FirstDistVec)
FirstDistSD = sd(FirstDistVec)
FirstX = sum(scallops$x)/length(scallops$x)
FirstY = sum(scallops$y)/length(scallops$y)
Dist[1] = FirstDist
DistSD[1] = FirstDistSD
NNI[1] = FirstDist/FirstDist
centroidX[1] = FirstX
centroidY[1] = FirstY
centroidDistFirst[1] = 0
centroidAngleFirst[1] = 0
centroidDistPrev[1] = 0
centroidAnglePrev[1] = 0


for (i in 2:Len){
        File = load(ImgData[i])
        centroidX[i] = sum(scallops$x)/length(scallops$x)
        centroidY[i] = sum(scallops$y)/length(scallops$y)
        Mat = do.call(cbind, scallops)
        DistMat = dist(Mat, method = "euclidean")
```

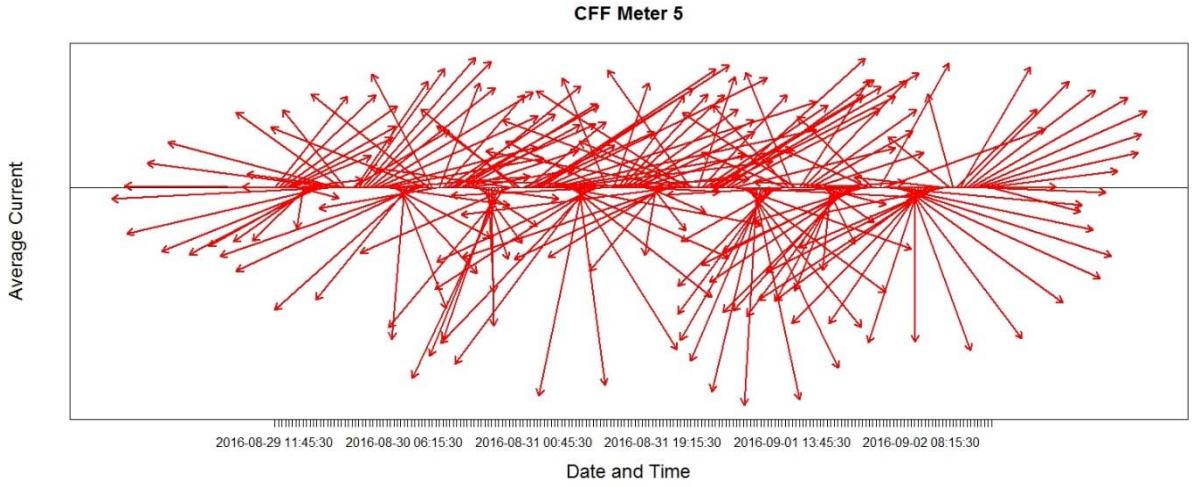
```
        DistVec = as.vector(DistMat)
        Dist[i] = mean(DistVec)
        DistSD[i] = sd(DistVec)
        NNI[i] = Dist[i]/FirstDist
        tmp = matrix(c(centroidX[i],FirstX,centroidY[i],FirstY),nrow=2, ncol=2)
        centroidDistFirst[i] = as.vector(dist(tmp, method = "euclidean"))
        centroidAngleFirst[i] = atan(abs((tmp[1,2]-tmp[2,2])/(tmp[1,1]-tmp[2,1])))*180/pi
        tmp = matrix(c(centroidX[i],centroidX[i-1],centroidY[i],centroidY[i-1]),nrow=2, ncol=2)
        centroidDistPrev[i] = as.vector(dist(tmp, method = "euclidean"))
        centroidAnglePrev[i] = atan(abs((tmp[1,2]-tmp[2,2])/(tmp[1,1]-tmp[2,1])))*180/pi
        }

DistanceData <- data.frame(ImgData, Dist, DistSD, NNI,centroidX, centroidY,
centroidDistFirst, centroidAngleFirst, centroidDistPrev, centroidAnglePrev)
fileName <- tclvalue(tkgetSaveFile()) #include .csv in name
```

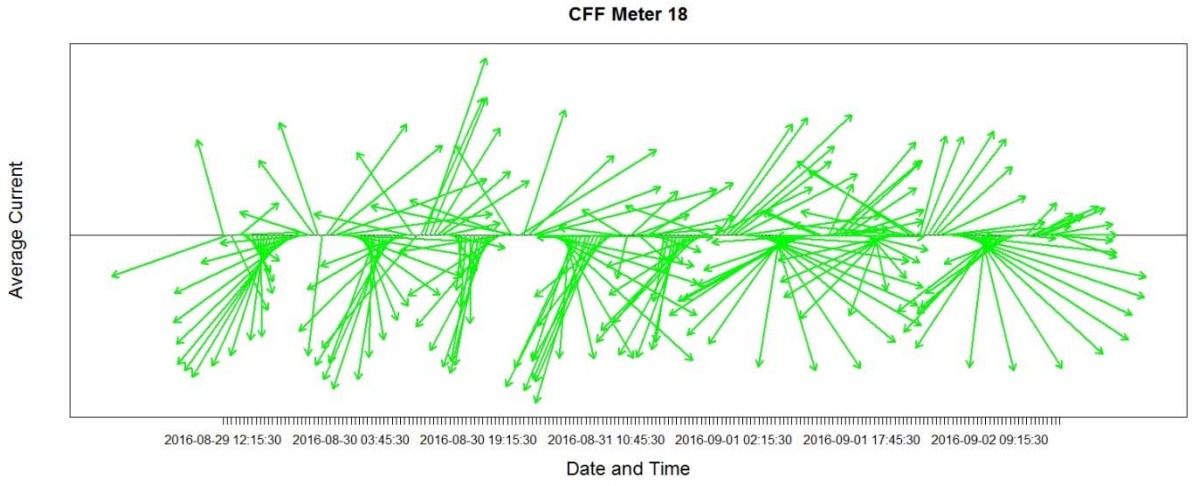
makeCSVfromRData to make text file from folder of RData files if annotation program crashes

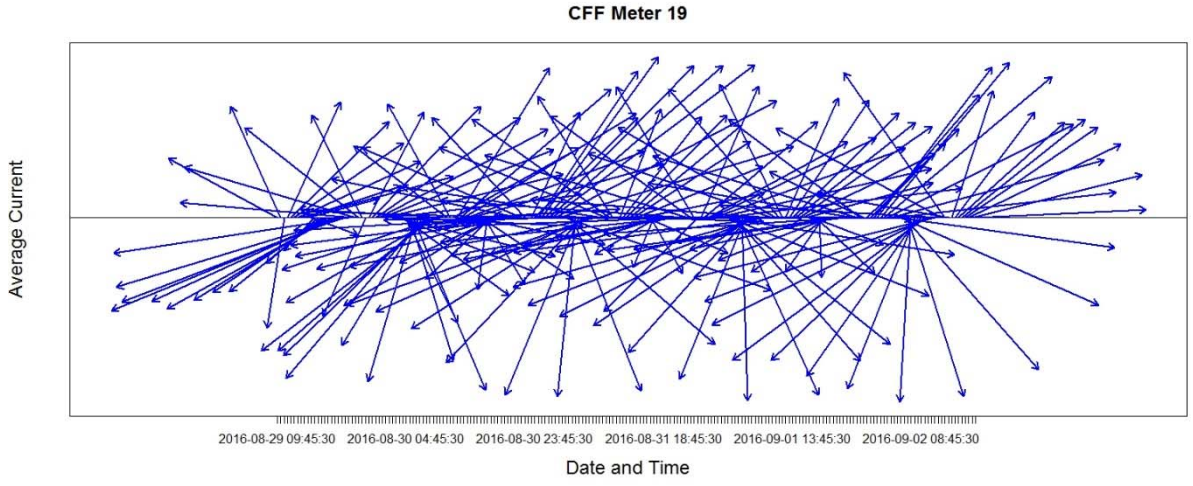
```
# load needed libraries
library("stringr")
library("tcltk")
# identify all files in working directory that are image data files
ImgData = Sys.glob("*.RData")
# count the number of files
Len = length(ImgData)

numScallopsNew = numeric(length=Len)
numSnailsNew = numeric(length=Len)
numLobstersNew = numeric(length=Len)
numCrabsNew = numeric(length=Len)
numSeastarsNew = numeric(length=Len)
numFishNew = numeric(length=Len)
notesNew = numeric(length=Len)

for (i in 1:Len){
        File = load(ImgData[i])
        numScallopsNew[i] = length(scallops$x)
        numSnailsNew[i] = length(snails$x)
        numLobstersNew[i] = length(lobsters$x)
        numCrabsNew[i] = length(crabs$x)
        numSeastarsNew[i] = length(seastars$x)
        numFishNew[i] = length(fish$x)
        notesNew[i] = notesChar
        }

CreatureCounts <- data.frame(ImgData, numScallopsNew, numSnailsNew, numLobstersNew,
numCrabsNew, numSeastarsNew, numFishNew, notesNew)
fileName <- tclvalue(tkgetSaveFile()) #include .csv in name
write.csv(file=fileName,x=CreatureCounts)
```

<u>Appendix 3.</u> Feather plots showing current direction and velocity in the transplant areas. Current data is shown for only three tilt meters because the fourth tilt meter malfunctioned. Output from each current meter is shown in a different color.

Current meter output averaged over 30 minutes for the entire trip







Current meter output averaged over five minutes for one day (8/31/2016)