



Drivers of Dispersal and Retention in Recently Seeded Sea Scallops

Final Report

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Coonamessett
Farm Foundation,
Inc

277 Hatchville
Road
East Falmouth,
MA 02536

508-356-3601 FAX
508-356-3603
contact@cfarm.org

www.cfarm.org

Submitted By

Ricky Alexander, Liese Siemann, Samir Patel, and John Ceccolini
Coonamessett Farm Foundation, Inc.

Summary of Past and Current Enhancement Projects Completed by Coonamessett Farm Foundation

Despite the recent financial success of the U.S. sea scallop fishery, the stock and the industry that depends on it is vulnerable to fluctuating recruitment events. Outside the U.S., many countries are able to stabilize scallop stocks through enhancement programs that supplement natural recruitment and promote natural growth. Projects completed by Coonamessett Farm Foundation (CFF) (RSA projects NA13NMF4540009, NA14NMRS2003822, and NA15NMF4540056) have proven that CFF is capable of collecting large numbers of scallops, transporting them to a secondary location, and releasing and tracking the scallops' movement and/or mortality in the short-term using a first-generation camera array and drop box. These projects revealed that seeded scallops either are predated upon or disperse over a large area, rendering their ultimate fate unknown. Building on these successes the current study focused on the 12-48 hours following seeding. Scallops were transplanted from a growth-inhibited area (i.e., Nantucket Lightship [NLS] Extension Area) to areas where scallops have thrived in the past. The transportation system was improved upon, the drop box was replaced with a more efficient scallop release system, and the camera stand array was significantly updated to provide oceanographic data and sharper images that can be programmed to collect data at a specified interval. Images annotated using the R software package were used to track scallop movement behavior for 12-48 hours post-release. Scallop movement was not directional and did not differ significantly between deployments. Scallops generally did not react to the presence of predators unless physical contact was made. Transplanted scallop piles attracted a wide diversity of marine life. Future work will focus on getting a better understanding of longer-term dispersal of transplanted scallops through acoustic telemetry and optical surveys.

1 Purpose

This research addressed 2016 Scallop RSA **High Priority #3**: scallop area management research, specifically research to actively manage spat collection and seeding of sea scallops. The ultimate goal of CFF's ongoing enhancement projects is to enhance and stabilize scallop biomass and yield under an optimized rotational management program. We consider this an overarching high priority for the scallop fishery. This project contributed ecological information to assist managers in considering potential future "enhanced access areas." It also provided data relating seasonal oceanographic, deck handling, and biological variability to scallop transplant survival and movement. Our main objectives were as follows:

- Seed marked scallops back onto the harvest site and onto secondary sites to investigate the relative contributions of active (swimming) versus passive (advection by current) transport and predation to seeded scallop dispersal by monitoring the marked scallops daily for 12-48 hours following seeding.
- Test a new cost-effective technique for marking and tracking scallops by size class.
- Investigate seedbed characteristics (oceanographic conditions, habitat, and predator abundance) at the seeded sites to provide insight into factors driving survival and movement.

2 Approach

Background

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 (\$465 million in 2014; NEFSC 2014), efforts to stabilize the available resource through stock enhancement have been substantial (Cliché and Giguère 1998, Smolowitz et al. 1998, Stokesbury et al. 2012).

Recent dredge survey estimates from the NLS extension area indicate biomass estimates dropped from 7,093 mt. in 2015 to 1,697 mt. in 2016 (Peros 2016) after the area was harvested as part of the planned rotational management. However, the lack of new recruitment in what has proven to be a productive area is concerning. Fortunately, the productivity and life history of sea scallops makes this species an excellent candidate for stock enhancement. For example, CFF has shown that it is possible to harvest small scallops from areas of poor survival/growth and transplant them to areas where environmental conditions may be more suitable (CFF 2014a, CFF 2014b, CFF 2017). 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, would provide valuable information regarding growth and survival conditions that can be applied to other fishing grounds. Moreover, moving scallops to areas where no scallops presently exist could create recruitment events in presently unseeded areas.

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 recruitment failures have been common on Georges Bank (Stokesbury et al. 2012). The impacts of biotic (i.e., predation, fishing pressure, incidental fishing mortality) and abiotic (i.e., substrate, habitat, and oceanographic dynamics) variables on recruitment are poorly understood. However, it may be possible to enhance recruitment, and thereby biomass, by moving juvenile/early mature scallops from areas where environmental conditions are suboptimal to areas where scallops should thrive.

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. 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 (5.6 miles) 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.

Previous studies performed by CFF's precursor Coonamessett Farm have demonstrated the feasibility of seabed management and were the first to develop effective methods for transplanting and monitoring seed. For example, 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), utilized a 24-square-kilometer research area, located 15 kilometers south of Martha's Vineyard, for aquaculture management and research. The area was closed to mobile gear and, 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 up 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; however, mortality was relatively high, some bottom cages were destroyed (presumably by commercial fishing gear), and re-locating bottom seeded scallops proved difficult.

Since 2013, CFF has committed to developing best practices for scallop enhancement along the New England coast (CFF 2014a, CFF 2014b, CFF 2017). Over the last four years, over 2.3 million scallops have been transplanted by CFF in three separate operations. 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).

Data from the SMAST drop cam surveys indicated CFF's difficulty in scallop relocation was likely due to dispersal, since few clapper scallops were identified and predator densities

were relatively low during the experiment (CFF 2014b). However, because re-locating seeded scallops on or near the drop site continued to be challenging in the weeks and months following transplant due to funding limitations, we shifted focus to short-term observations of seeded scallops, with an emphasis on the drivers of dispersal (i.e., active, passive and predation) and their effects on different size classes of scallops (CFF 2017). Based on experiences from the previous projects, CFF developed a camera system designed to drop scallops below the camera. Intervalometer-equipped GoPro action cameras were able to take photos every one or three minutes for 4 or 12 hours, respectively. Results indicated that predators may impact scallop dispersal immediately after they are moved to new locations (CFF 2014b). Results from the previous three CFF projects informed the direction of the current project.

3 Methods

CFF performed camera drops on three trips between June 2017 and May 2018. Of these, some image sets were lost due to hardware failures and some images were not analyzed due to low image quality. In total, five drops were analyzed, ranging from 10.8 hours to 49.8 hours (Table 1). On all drops, images were collected every 60 seconds. The camera systems are equipped with a Hydrolab DS5X data sonde to collect several water quality metrics concurrent with images, but technical and user errors limited the usefulness of the data collected.

Table 1. Dates, duration, bottom temperature and depth for each drop of the project.

Drop Number	Date Deployed	Duration of Drop (hours)	Bottom Temperature (°C)	Depth (m)	Mean Shell Height \pm SE (mm)	Stocking Density (scallops/m ²)
Drop 1	June 29, 2017	24.88	9.4	59.2	112.0 \pm 0.4	36
Drop 2	June 29, 2017	23.92	9.4	58.0	112.0 \pm 0.4	80
Drop 3	Dec 8, 2017	12.75	11.4	27.1	121.5 \pm 1.9	13
Drop 4	Dec 8, 2017	10.75	11.4	27.1	121.5 \pm 1.9	48
Drop 5	May 9, 2018	47.50	5.6	28.7	100.4 \pm 3.0	57

Camera systems:

The initial tetrad of deployable stationary camera rigs, designed by Shea Miller (CFF) and fabricated by Charlie Quinn of Quinn Fisheries, New Bedford, MA in 2015, were significantly modified and improved upon during this project. The new design features a 2x6 ft (0.6x1.8 m) rectangular top, as opposed to a central beam in previous design. Each rig is approximately 1.8 meters tall, with four legs extending from a corner of the rectangular top, and weighs approximately 250 lbs (113.4 kg), eliminating the need to attach weights to each foot. The base of the legs form a 3-m² footprint on the seafloor. Additional equipment, including two large (27.2 kg) external batteries, two stereo-mounted Sony alpha 5000 DSLR cameras in deep-sea housings and rigged with an intervalometer, and a Hydrolab DS5X were incorporated into the frame. The DLSR cameras were mounted near the center of each stand, with about 30 cm separating the two camera lenses, to allow for stereo images to be captured (Figure 1). Image coverage was approximately 2.6 m². Light-emitting diode (LED) pucks were mounted on the top of the frame facing the seafloor. LEDs were programmed to flash in sync with image captures to minimize the effect of light on animal behavior. Through these modifications, we were able to

expand the clarity and coverage of the time-lapse photography from one image a minute for 4 hours to stereo images once a minute for up to 55 hours. Additionally, we started using DSLR cameras instead of GoPro action cameras, which greatly increased image resolution. The improvements on the original design are a significant step forward in our work.

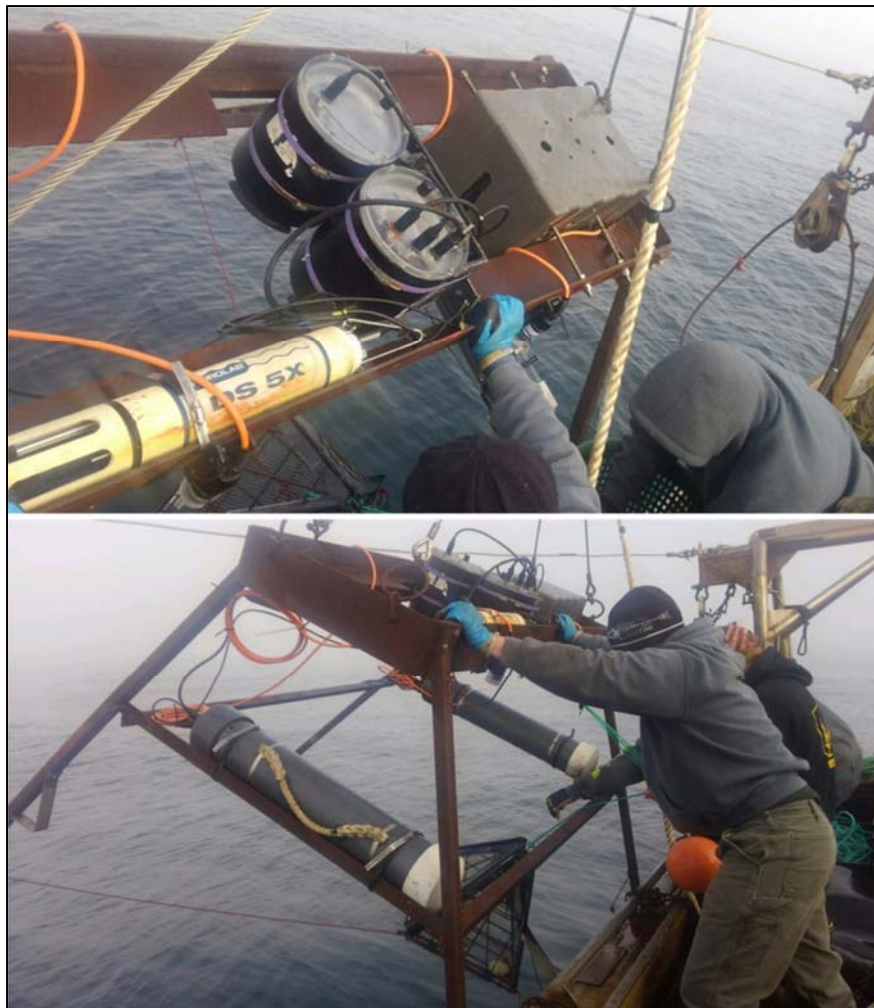


Figure 1. CFF camera stand featuring two large external batteries (grey tubes on side of stand), Sony alpha 5000 DSLR stereo cameras equipped with intervalometers housed in deep sea housings, integrated LED pucks, and integrated Hydrolab DS5X data sonde. Crab trap used to deploy scallops is shown, as well.

Improvements were also made to the scallop deployment system. In previous enhancement work, CFF deployed scallops by shoveling them overboard, and later by lowering a bushel basket with a secondary line used to dump scallops on bottom (CFF 2014, 2014b). Both of these methods resulted in loosely distributed scallops on bottom. In the 2015 project, a small quick release box was created to transplant the scallops below the cameras once the stand was on the seafloor (CFF 2017). A plastic box with an opening hatch on the bottom was bolted onto the center of the central beam. The box was held closed with a small tag line attached to a quick-release shackle, which was pulled to release scallops once the stand was on bottom. In June

2017, however, strong offshore currents made this style of deployment problematic; the vessel would drift either over or away from the tag line (used to release the shackle which allows the tote doors to open and scallops to be released), which altered the angle of pull and often did not allow the scallops to be released. Additionally, the weight of the scallops would lie on the doors of the tote, partially opening them, which allowed many scallops to escape while the stand was in transit to the sea floor. Thus, CFF explored alternative methods of remotely transplanting of scallops below the image frame, eventually settling on a version of a Maryland crab trap as described in the methods.

Site Selection:

Each trip had different goals in terms of site selection relative to harvest (**Figure 2**). The June 2017 trip moved scallops from one area in the NLS to an area in the central portion of the NLS. The second trip moved scallops from the eastern NLS to a nearshore area suitable for scallop growth and survival. The final trip moved scallops from an area near the Block Island Wind Farm north and west to another area near the Block Island Wind Farm. Moving scallops nearshore, when possible, is cost effective in terms of fishing and monitoring, so finding suitable grow out sites nearshore is important for future scallop enhancement strategies.

Chiller System:

For transport in June, scallops were held the same system as used in previous years (CFF 2017), which consisted of fish totes filled with chilled sea water. 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. Transport in December and May did not warrant the use of this system, as thermoclines were not established, making surface water a proxy for bottom water, to which scallops are acclimated. Thus, survivorship was not influenced by water temperature in these trials.

Scallop tagging and harvesting:

The substantial improvements in the camera systems allowed CFF to use 3/4" flexible disc tags (FloyTag) to track individual scallop movements. Tagging was performed in small (~30 scallops) batches, to minimize air exposure to scallops. Scallops were wiped dry with a paper towel prior to applying a small amount of cyanoacrylate glue and a tag. Prior to returning scallops to the transport system, scallops were held for an additional 2 minutes after the final scallop in a batch was tagged to ensure the glue had adequate drying time. No tag loss was noted when placing scallops in drop boxes (June) or crab traps (Dec and May). Docile scallops were checked for reflexes by running a pencil across the gill prior to transplant to ensure that the tagging and storage processes did not induce mortality.

Due to the amount of camera gear on board, only one dredge was taken out to sea. In June 2017, FV Thunder Bay conducted two tows using a standard 15-ft New Bedford-style scallop dredge in the NLS. Depth at harvest locations was approximately 30 fathoms. Low catch rates in the initial ten minute tow caused CFF to move locations for the second tow. Tow speeds were maintained between 4.8-5.1 knots. Scallops retained for transplant were transferred to bushel baskets and placed in the transport system. Scallops collected ranged from 92-143 mm. All bycatch (scallops not selected for transplant and non-target animals) was promptly returned to the sea. Six bushel baskets were filled with commercial-sized scallops and placed

into chilled totes for transport. After harvesting, the vessel steamed north to areas where scallops do not exist naturally to the deployment site.

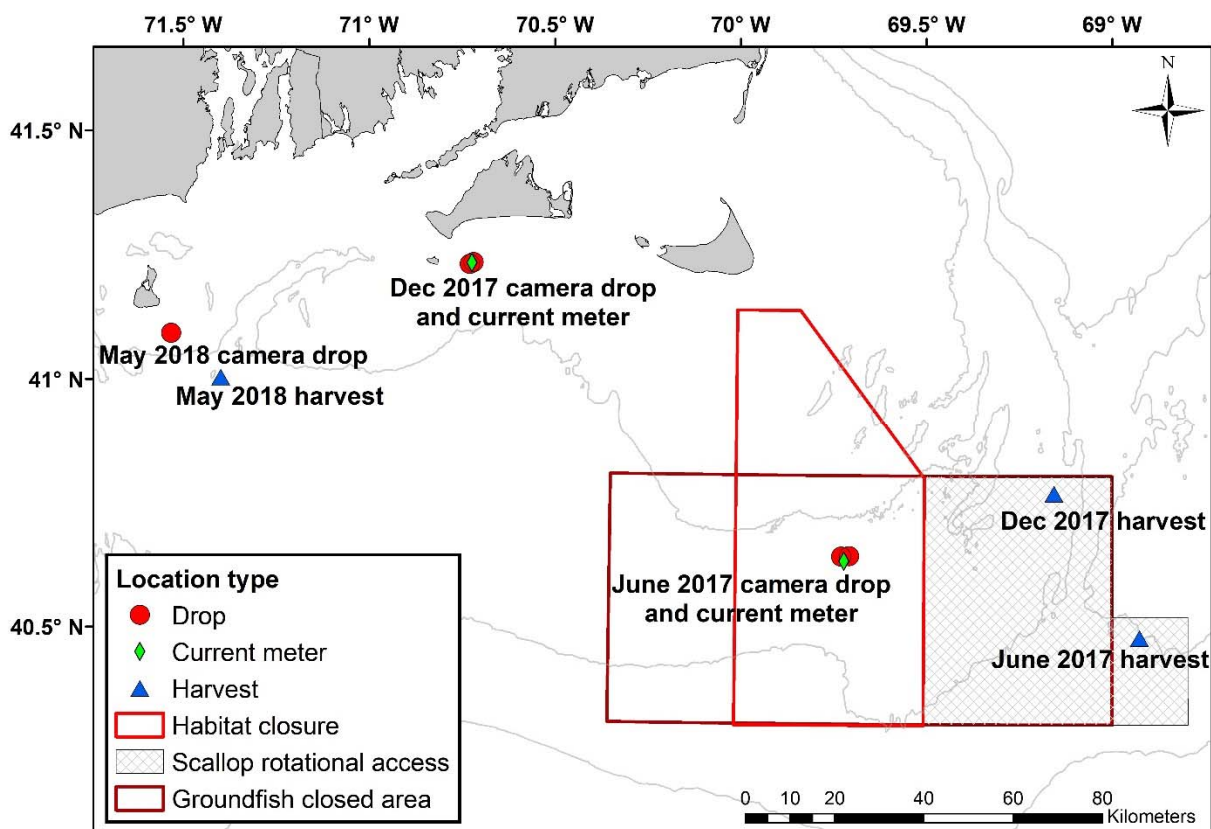


Figure 2. Map displaying drop locations, harvest locations, and current meter deployment locations in the context of management areas.

In December 2017, FV Reflection conducted a single ten minute tow in the NLS. Three bushel baskets were filled with commercial-sized scallop and placed into totes with flow-through seawater. Because the trip occurred in December, a chiller was not used. Tow speeds were maintained between 4.8-5.1 knots. Scallops collected ranged from 103-138 mm. All bycatch was promptly returned to the sea. After harvesting, the vessel steamed north to a nearshore area approximately 3 miles east of Nomans Island, Chillmark, MA to deploy scallops. This location was selected because it is close to shore and impending weather conditions warranted a need for quick egress from the area.

In May 2018, FV Mr. G collected a half bushel basket during normal commercial fishing operations and retained them for deployment the following day. Fishing operations occurred off the coast of Block Island, RI. Scallops were transported to the vessel's dock in a covered fish tote with flow-through seawater. Scallops were stored in a lobster pot tied to the dock overnight and placed back into a fish tote with flow through water for the ~4 hour commute to the drop location near the Block Island Wind Farm. Scallops used for this drop ranged from 74-132 mm.

Camera and scallop deployment:

A bridle was shackled to the upper corners of the camera array for ease of deployment/retrieval. A hard trawl float was attached to the central portion of 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 location for the take-out winch to re-hook the camera stand. The bottom 50% of line was floating line (to keep the line away from the rigging and cameras) and the top section sinking (to prevent line from getting caught in the propeller). The terminal end of the line was attached to a surface system (large poly-ball and highflyer attached with whale safe-quick releases) to aid in visibility when retrieving.

Just before deployment, CFF scientists loaded a target number of scallops (10-60 individuals) into the large, ruggedized version of a Maryland style crab trap (**Figure 3**). The base of the trap is 2 ft² (0.61 m²), and the trap stands roughly 22 inches (55.9 cm) tall when closed. Once scallops were loaded into the trap and cameras set to record, the rig was deployed. To deploy, the main winch was used to lift the frame over the rail, at which point crew members pushed the legs over the side. The take-out winch was used to relieve tension from the main winch, which was then removed from the frame. When the frame was set alongside the vessel and ready to deploy, the frame line was cleated off, then the frame lowered until the line took the weight, then the take-out winch was removed, leaving the frame hanging off the side of the vessel with all of its weight on the cleat. The line was then slowly taken off the cleat until the weight of the frame slowly pulled the line out. The frame was lowered to the bottom in this fashion. When the system hit the seafloor, the quick release was pulled, dropping the scallops inside the box onto the seafloor. To retrieve the camera system, the surface system was pulled onto the boat and the line was hauled in using either a crab pot hauler or a dredge winch. The frame was pulled onboard in the opposite fashion as was deployed.

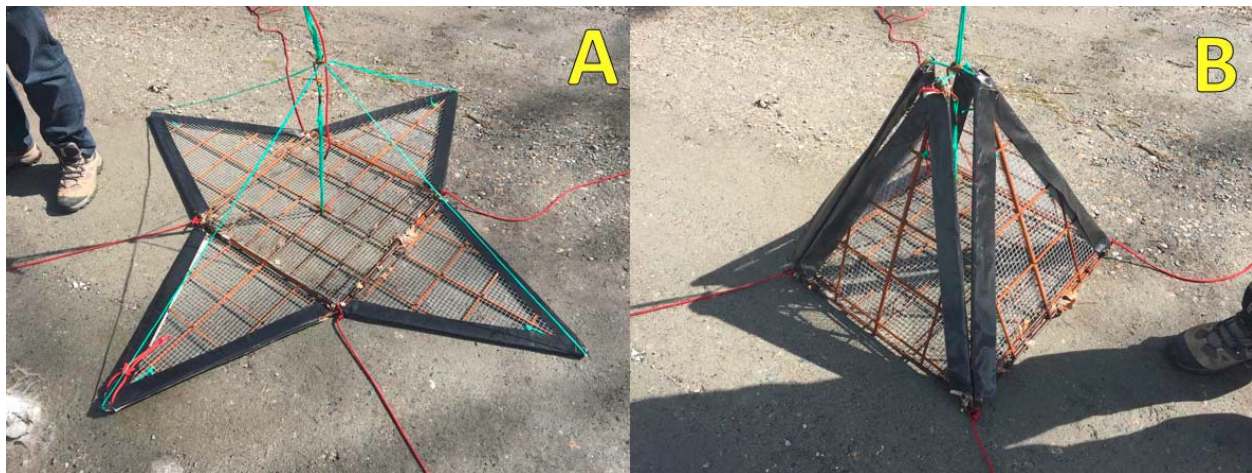


Figure 3. Modified Maryland crab trap used to deploy scallops below camera frame. When haul line (central line) is slack, the trap lies open (**A**). When haul line lifts the trap, the corners pull up and towards the center, creating a pyramid shape (**B**). Scallops are placed on the base of the trap while it lies open on deck. The haul line is tied off to the camera stand so that when the stand is lifted by the winch, the trap closes, preventing scallop escape. A 10 lb (4.54 kg) weight is attached to the bottom of the trap to prevent the trap from descending slower than the camera stand, which would allow the trap to open and scallops to escape.

Current Meters:

Tilt current meters (Lowell Instruments) were deployed alongside the stands in June and December 2017. 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. 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.

Image analysis:

The images taken by the GoPro cameras were analyzed using a custom annotation program written in R that included counting of scallops and scallop predators and tracking of five individual scallops per image set (R Core Team 2015). Tracking was performed on four of the five image sets; high turbidity in one image set forced us to exclude it from this type of analysis. The R code is included in **Appendix 1**.

For the first set of images we analyzed, all images were annotated. The data from this image set 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 to reduce annotation time and reduce likelihood of reviewer error. As each image was processed, the annotator clicked on each animal to be counted, and the point location was stored for further analysis. Images were annotated by two trained reviewers.

Animal counts were determined by summing the number of click points per species, with click locations (X- and Y-coordinates) stored for additional analysis. Five individual scallops were tracked by clicking on five randomly selected scallops in the first image and then clicking on these same five scallops in the same order for all remaining images in the set. If a selected scallop left the image frame, no new scallops were selected for tracking.

Data analysis:

The text files of the counts from the annotated image sets were summarized in Excel. Scallop loss was summarized in two ways based on the number of scallops that emigrated (exited the image frame) and the number predated (scallops removed or killed by predator) as follows:

$$\% \text{ emigrated} = \frac{\# \text{ scallops emigrated}}{\# \text{ scallops in Image 1}}$$

where Image 1 was the first image with scallops after the drop and # scallops emigrated is the total number of scallops observed to exit the image frame independently. If the number of scallops in Image 1 increased within the first hour after the drop as the pile settled and shifted, exposing scallops that were covered at the start, the highest number within this image group was used instead of the count for Image 1.

$$\% \text{ predated} = \frac{\# \text{ scallops predated}}{\# \text{ scallops in Image 1}}$$

where Image 1 was the first image with scallops after the drop and # scallops predated is the total number of scallops observed to be predated throughout the image set. Predation events were qualified by visual confirmation that the predator was attacking a scallop; in the case of moon

snails this included entering the scallop or engulfing the scallop, and in the case of crabs this included when the crab was reaching into the scallop and pulling out fleshy pieces of gill/mantle material. If the scallop didn't move after a predation event, it was assumed to be dead, and, thus, predated. Some scallops seemingly experienced predation events but moved afterward, sometimes exiting the image frame. Predated scallops that exited the image frame were counted as emigrants rather than predation victims.

Total 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 4**). 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, with pixels converted to centimeters (1 pixel = 0.0374 cm based on images of size standards taken with camera stand underwater). The tracks of five individual scallops were overlaid on the first image from the drop for four of the five image sets to look for trends in scallop movement.

Counts of moon snails and crabs were summarized as the mean and maximum numbers in an image during each image set. The impact of predator presence on scallop behavior was summarized with plots showing the number of scallops, snails, and crabs in each image. Current meter data was summarized using feather plots created in R for 10-minute averages over the whole trip. Current meters were not deployed in May due to deck space constraints.

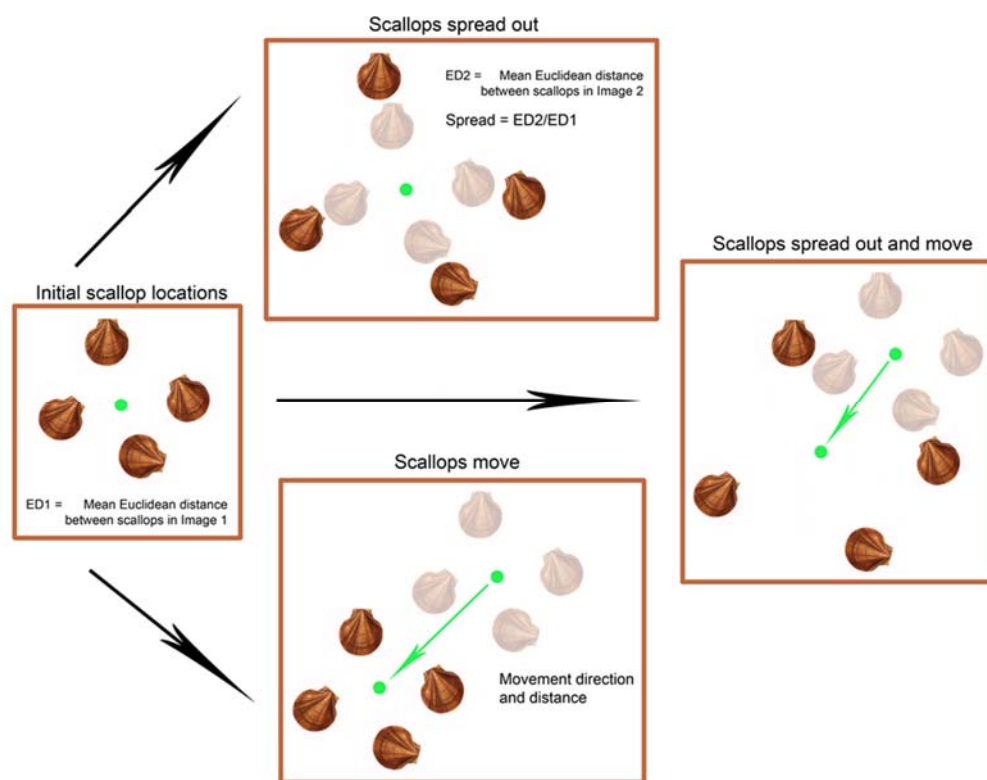


Figure 4. Summary of statistics used to summarize scallop movement

4 Results

Examination of image data indicated little to no loss of scallops between the surface and sea floor. Initial scallop densities ranged from 13 to 80 scallops/m², which is within the observed range of densely bedded scallops in the NLS (30-50 scallops/m², CFF HABCAM 2017).

Image analysis:

Image annotation data is summarized in **Table 2**. Every deployed scallop moved, indicating there was no initial mortality associated with transplant. Predation rates ranged from 0 to 7.89% per drop, with a total predation rate of 3.3% (5 of 153 scallops). Emigration rates (number of scallops that left the image frame) ranged from 34-66% of scallops per drop, with a total emigration rate of 47.1% (72 of 153 transplanted scallops). Although the highest emigration rate (66%) was associated the longest drop (47.5 hrs), this trend was not consistent; that is, time at large does not dictate emigration rate. There was no clear relationship between scallop predation, emigration, or spread and moon snail or crab presence.

Table 2. Summary of image annotation and scallop movement data.

Start date	# at start	# emigrated	# predated	Total time (hours)	Percent emigrated	Percent predated	Scallop spread	Scallop movement (cm)	Max # of snails	Mean # of snails	Max # of crabs	Mean # of crabs
6/29/2017	23	9	1	24.88	39.13	4.35	0.99	14.77	1	0.279	2	0.111
6/29/2017	53	18	1	23.92	33.96	1.89	1.07	14.03	5	1.357	2	0.45
12/8/2017	8	3	0	12.75	37.50	0.00	2.43	39.82	2	0.286	5	1.078
12/8/2017	31	17	0	10.75	54.84	0.00	1.82	16.67	3	0.923	4	1.815
5/9/2018	38	25	3	47.5	65.79	7.89	2.72	23.73	5	0.513	3	0.28

Examination of the tracks of five scallops from four deployments did not indicate a preferred direction for scallop movement. Scallop movement direction and distance was highly variable (**Figure 5**). Although no formal size-based analysis could be completed, the greatest amount of movement was observed in May, when the smallest scallops were deployed (**Table 1**). Examination of predator tracks in relation to scallop tracks indicated that scallops do not necessarily move in response to predator presence (**Figure 6**). This is supported by sustained scallop numbers when predators are present (**Figure 7**).

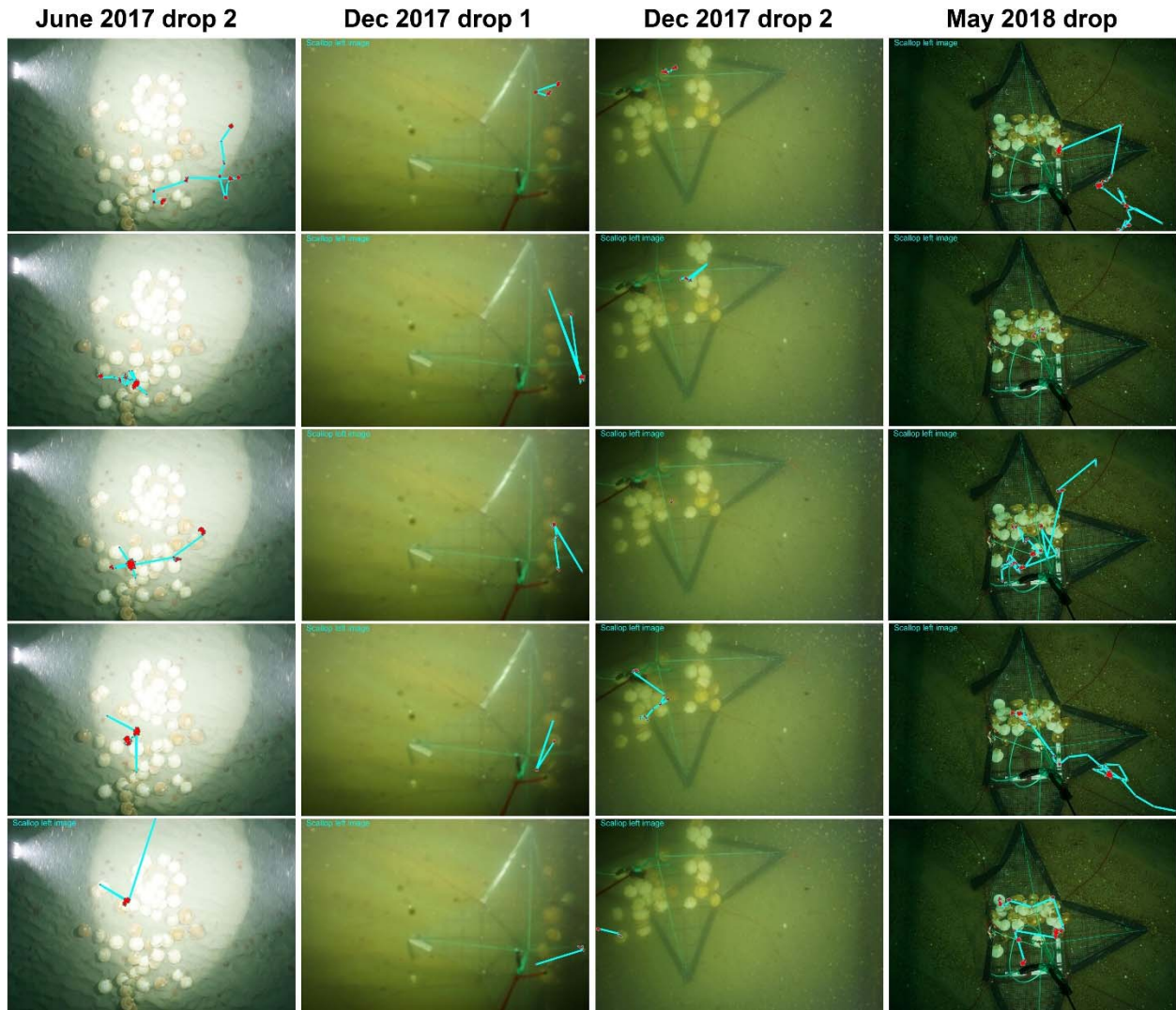


Figure 5. Movement paths of five tracked scallops for four drops.

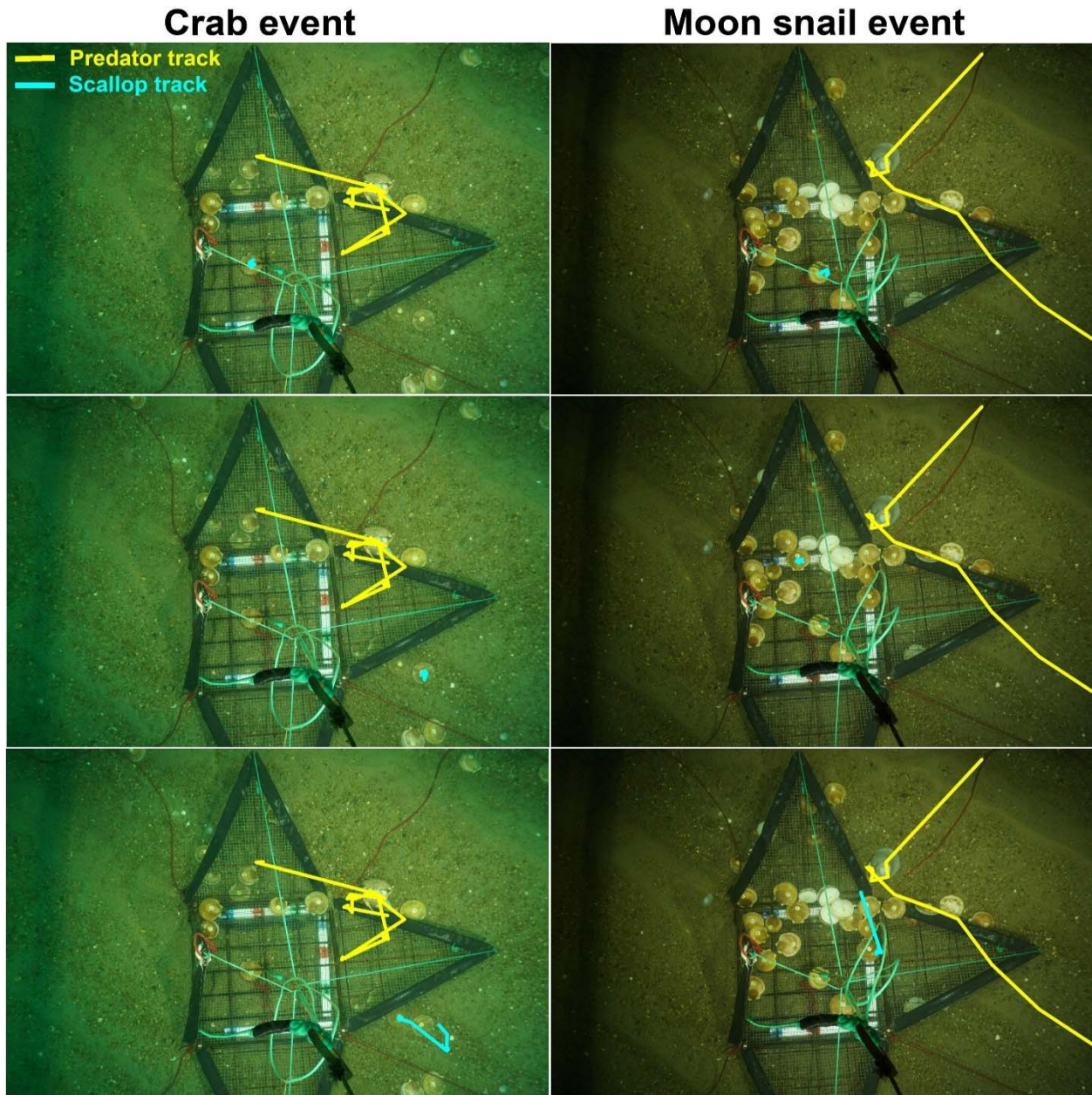


Figure 6. Examples of predator tracks and scallop responses for crab (left) and moon snail (right) predation events. Each image within a set shows a different scallop track and the same predator track. The crab predation event spanned 24 minutes, and the moon snail predation events spanned 17 minutes.

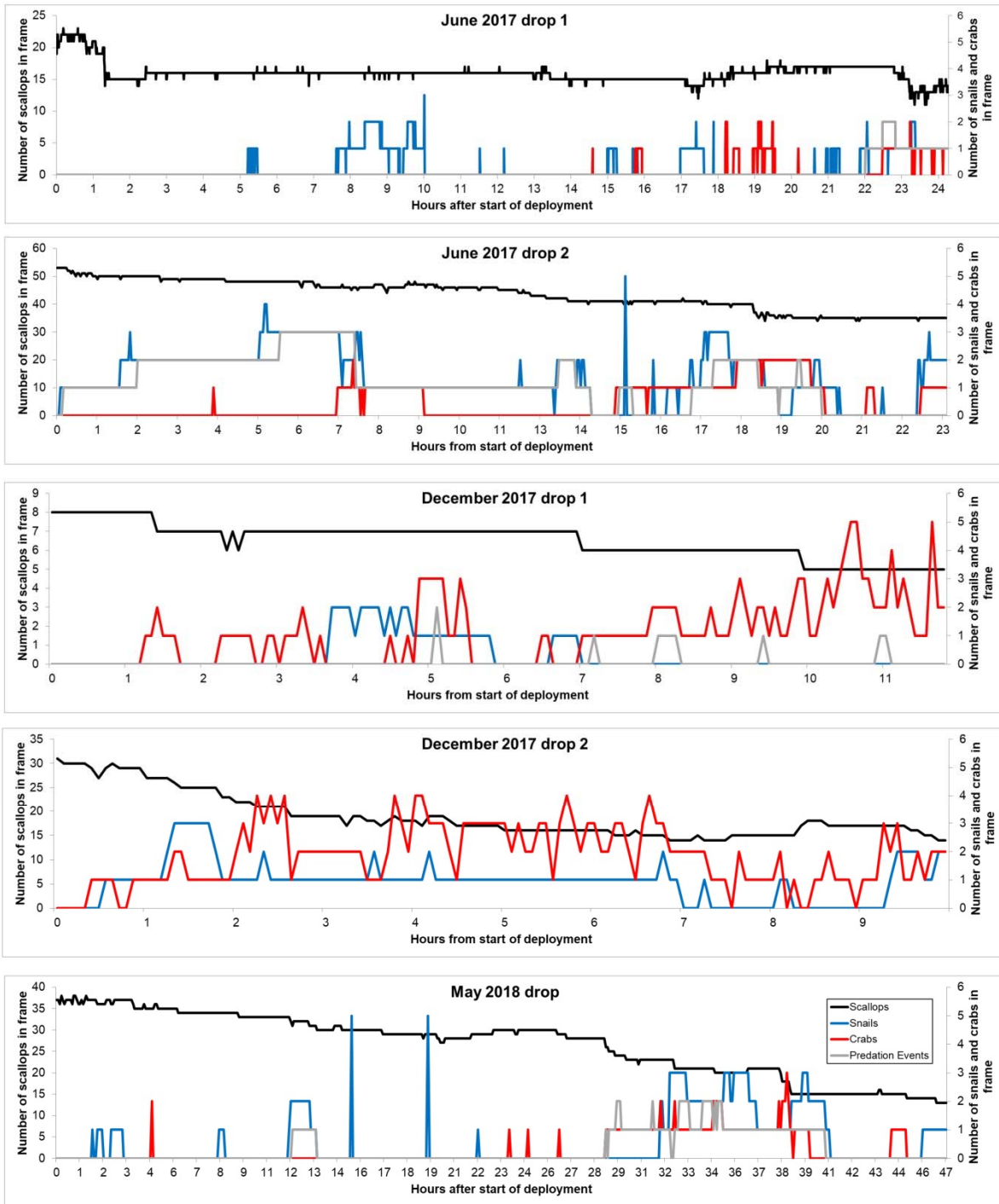


Figure 7. Number of scallops (black line), snails (blue line), crabs (red line), and predation events (grey line) in each image. Timeline runs from deployment on the left to retrieval on the right.

Current meters were deployed near the camera stands during the June and December 2017 trips. 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 hourly (**Appendix 2**). Scallops did not appear to be swimming up into the water column, indicating that movement was more likely active swimming in response to external cues rather than advection. This was further evidenced by changes in sediment pattern in a linear direction associated with moving scallops, presumably from the jet propulsion exhibited by swimming scallops.

Results as related to each project objective:

1. *Seed marked scallops back onto the harvest site and onto secondary sites to investigate the relative contributions of active (swimming) versus passive (advection by current) transport and predation to seeded scallop dispersal by monitoring the marked scallops daily for one week following seeding.*

We were able to seed scallops back onto harvest sites and onto secondary sites. As stated, the original intent of this project was to use an AUV to monitor transplanted scallops daily for one week. However, initial trials using the AUV yielded low quality images. Our collaborator was able to correct this in trials but raised the price significantly after doing so, making that option unfeasible. Thus, CFF shifted focus to studying the immediate movements and behaviors of scallops by developing the camera stands described above. This allowed us to monitor marked scallops every minute for up to 55 hours post-transplant. This continual focus on the first two days of movement, gave us a much clearer understanding of the interactions between scallops and predators than we could have using an AUV. The data from the drops we did on harvest sites were lost due to hardware failure (corrupted hard drive used for data storage). To prevent this in the future, CFF has invested in waterproof, ruggedized, solid state hard drives for offshore data storage.

2. *Test a new cost-effective technique for marking and tracking scallops by size class.*

We were able to purchase FloyTag ¾" flexible shellfish disc tags for \$0.43 per tag, plus \$40 for setup. This includes number and custom print. Averaged across 1,000 tags, this comes to \$0.47 per tag. Importantly, the cost goes down when you buy more (for example, the price per tag for 5000 tags is \$0.38 per tag). Each scallop needs two tags, one for the top valve and one for the bottom valve, to ensure that the camera will be able to view the tag regardless of the orientation of the scallop. This works out to \$0.94 per scallop, or \$470 to monitor 500 scallops, which is relatively inexpensive compared to other types of tagging (acoustic, satellite, etc), which range from hundreds to thousands of dollars. Disc tags can be labelled with a code or ordered in multiple colors to be used to track size classes. We measured each scallop and recorded its tag numbers, which allowed us to track animals by size. However, all transplanted scallops were relatively similar in size, so no analyses comparing movement at size could be made for this project.

3. *Investigate seedbed characteristics (oceanographic conditions, habitat, and predator abundance) at the seeded sites to provide insight into factors driving survival and movement.*

Bottom type varied from sand (June), sand-silt (December), to sand-gravel (May). Water clarity was also variable (**Figure 8**), sometimes within a given drop. Bottom temperature and depth were also variable, ranging from 5.6 to 11.4°C and 27 to 59 meters, respectively (**Table 1**). None of these variables seemed to be strongly correlated with scallop movement. There is some indication that scallops from the June drop emigrated and spread less compared to other sites (**Table 2**). This is likely due to the duration of on-deck storage; although the chiller kept the water at relatively low temperatures, a lack of flow resulted in a large sediment deposit in the bottoms of the storage totes containing scallops. The June drops were the last drops of an 8-day trip; the scallops had been in deck storage for about four days and were pulled from the sediment deposit in the totes prior to deployment. Although we checked each scallop for reflexes (rubbing a pencil along the gills) to ensure they were alive, it is possible these animals were much more stressed than scallops deployed in other drops, which would explain why scallops spread less and moved smaller distances in June compared to other drops (**Table 2**). All scallops deployed in December and May were stored for less than 24 hours. Managers of future transplant projects should be aware of these constraints.

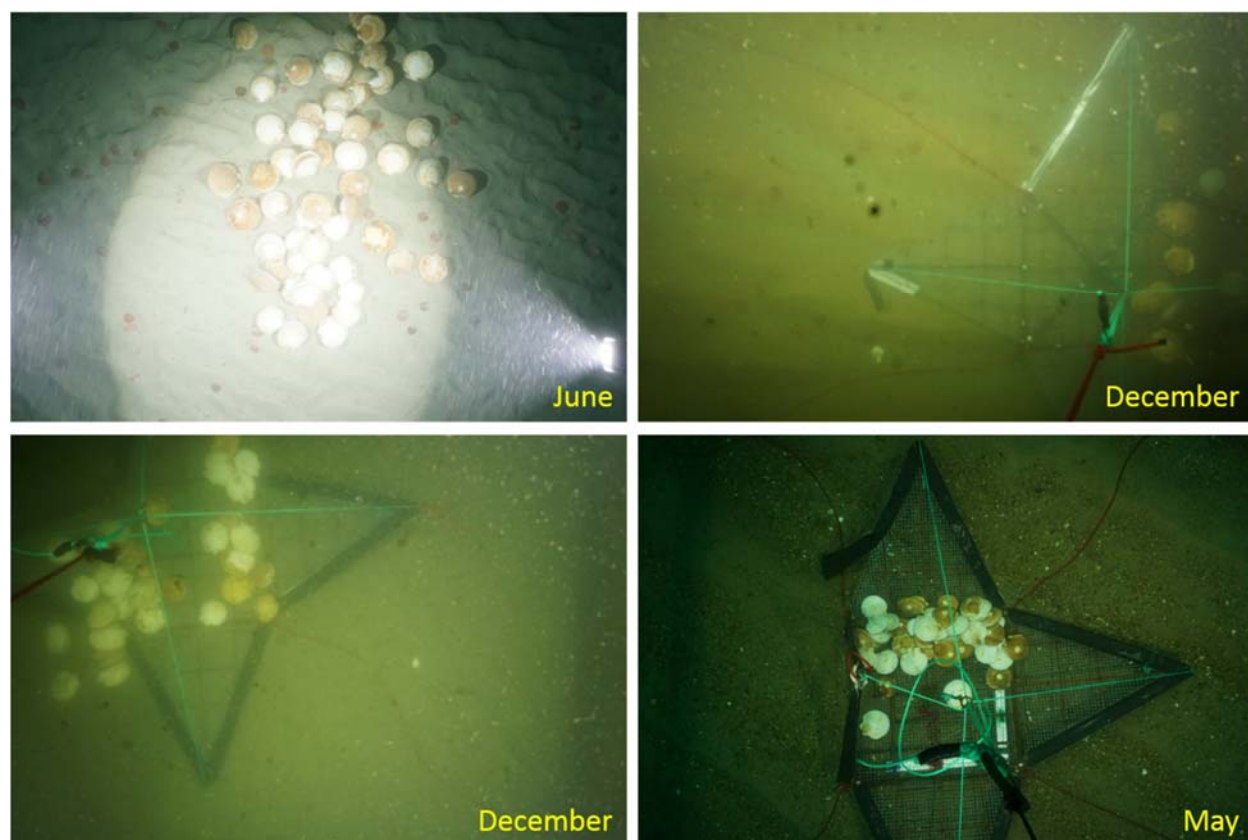


Figure 8. Example images from each drop location illustrating the variability in image quality between locations, time of year, and depth. June images were collected in the NLS (59 meters), December images were collected near Nomans Island (27 meters), Chillmark MA, and May images were collected near Block Island Wind Farm, RI (29 meters).



Figure 9. Image from May 2018 showing multiple predation event; a Jonah crab and a black sea bass feeding on a scallop. This scallop was previously preyed upon by a small moon snail.

The predation rate seen during this study (3.3%) is much lower than observed in similar studies (Barbaeu et al. 1996, Hatcher et al. 1996), presumably due to the size difference between this study and those which focused on seeding juvenile scallops. Additionally, these scallops were monitored over a longer timeline (weeks to months) than attempted here. Although there was no clear correlation between predator presence and scallop movement, there is some indication that predator abundance may influence movement. For example, starting around hour 32 in the May drop, there is a large increase in predator abundance, with multiple individuals of multiple species being present (**Figure 7**). This coincides with a sustained drop in scallop counts. Anecdotally, image reviewers noted that scallops generally only responded to predator presence when the predator made physical contact with a scallop.

CFF's improved camera system was able to record multiple predation and behavior events, sometimes with multiple predators feeding on the same scallop (**Figures 7 and 9**). Most predation events were initiated by moon snails. Interestingly, larger moon snails engulfed the entire scallop and dragged the scallop out of the image frame, possibly to seek refuge to devour its prey (**Figure 10**). Smaller moon snails pried the scallop open and crawled inside the valves, devouring the scallop (**Figure 11**).

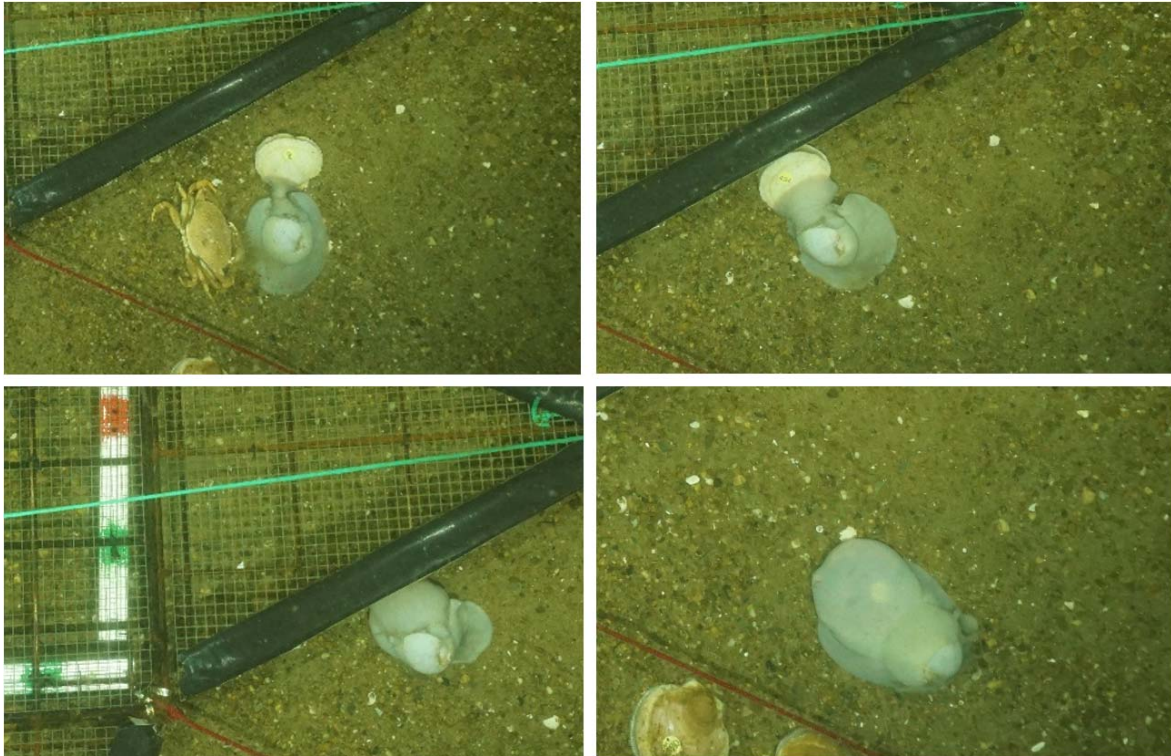


Figure 10. Example of typical large moon snail predation



Figure 11. Example of typical small moon snail predation.

Other predators included cancer crabs, lobster, and, in one instance, a black sea bass. Interestingly, moon snail abundance seems to be loosely correlated with initial stocking density

(**Figure 12**), indicating that stocking density could be an important factor when planning future transplanting projects. This is consistent with other work done with Atlantic sea scallops (Barbeau et al. 1996).

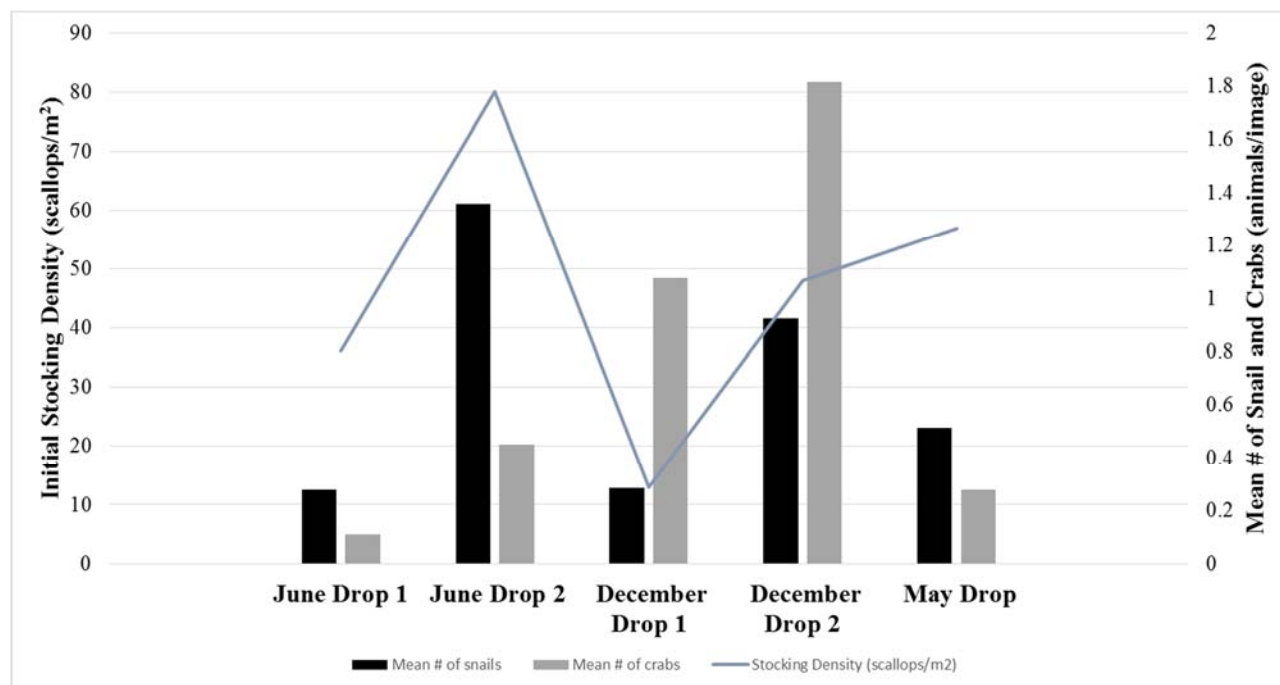


Figure 12. Bar chart displaying mean number of moon snails and crabs for each drop. The blue trend line shows initial stocking density.

In May, one scallop seemed to be injured, allowing a Jonah crab to feed on its gill, and, later, allowing a small moon snail to enter its valves. After several hours, the snail departed and a Jonah crab begins preying upon the scallop; in some images, the crab is extracting the scallop gill with its claw. Interestingly, the scallop does move multiple times following these events, indicating that the predation events may not have induced mortality, or perhaps the scallop simply displayed post-mortem muscle twitches. There were other instances of predation after which the scallop moved multiple times and/or exited the image frame. The ultimate fate of these scallops is unknown, but this behavior suggests that scallops may be resilient to some degree of predation.

In addition to predator attraction, the addition of scallops to a new environment draws in a lot of marine life. Hake, for example, seem to be attracted to transplanted scallops (**Figure 13**). Similarly, cancer crabs seem to be attracted to transplanted scallops, even if they ultimately do not prey upon them. Interestingly, there were several instances of crabs displaying territorial/dominance behavior (**Figure 14**). Occasionally, monkfish (**Figure 13**) and Conger eel (**Figure 15**) are attracted to the pile as well. One conger eel entered the underside of the crab trap and remained there for 19 hours.



Figure 13. Monkfish (left) and red hake (center, left, and bottom) attracted to transplanted scallop pile.

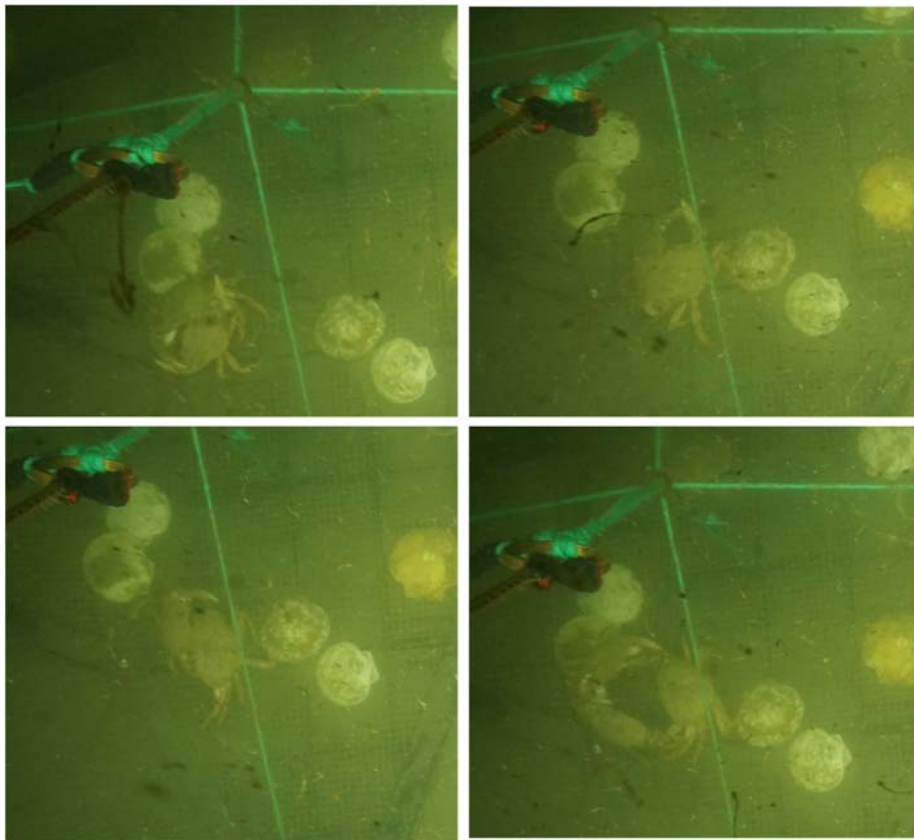


Figure 14. Example of crabs displaying territorial behavior.

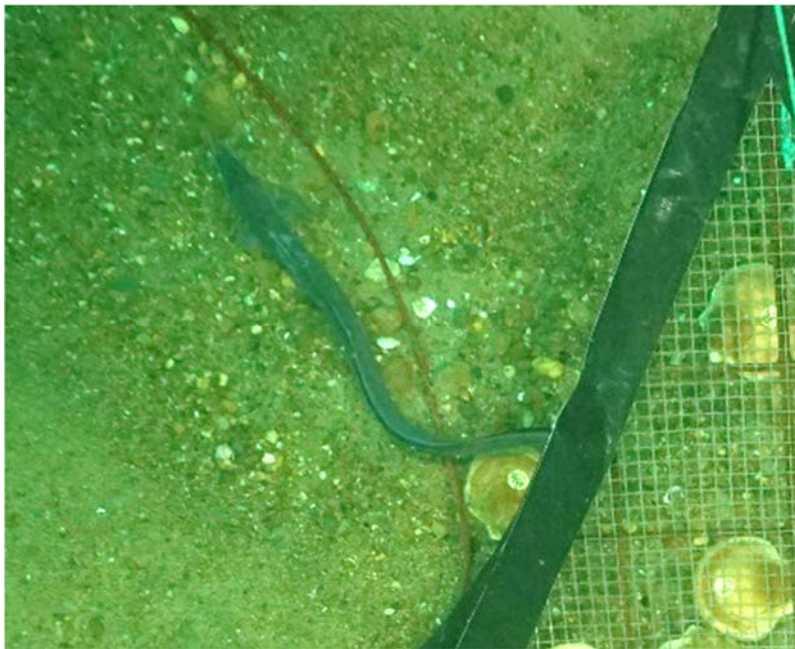


Figure 15. Example of Conger eel attracted to scallop pile.

5 Conclusions

The main objectives of the project were successfully completed, despite initial complications that led to changes in the project design. Five successful transplant operations were completed and images were collected and analyzed to investigate scallop dispersal and predation to seeded scallops by monitoring the marked scallops daily for 12-48 hours following seeding. Predation accounted for only a 3.3% mortality rate. All scallops survived the transportation and transplanting, and the majority left the frame of the camera, apparently due to active swimming on their part. Tagging using Floy tags proved to be an inexpensive way to tag and track scallops visually, and different color tags could be used for different sized scallops. Oceanographic conditions, habitat, and predator abundance at the seeded sites were documented and analyzed. The improved camera and scallop deployment systems proved highly successful in monitoring scallop and predator behavior for the first 48 hours after deployment.

Next Steps

Throughout the four enhancement projects funded by the Scallop Research-Set Aside program, CFF has proven its ability to collect large numbers of scallops, transport them to a secondary location, release scallops in clusters on the seafloor, and track the movement and behavior of scallops and their predators. CFF has continually improved and enhanced its camera stand to allow vastly improved images, video, and analytical abilities.

To get a better handle on longer term movements of scallops, CFF will propose to use acoustic tags to track movements and re-locate scallops, and use towed or self-powered optical systems to monitor scallops to get a better understanding of dispersal and growth. For this work, “Peter Pan” scallops would be moved from the deep southern areas (>70m) to shallower northern areas of the NLS or to a less dynamic nearshore environment that would be more accessible to

researchers and would limit scallops' ability to move via advection due to currents (current and tide strength are milder nearshore). In order to relocate beds of transplanted scallops from previous projects (including this one), CFF will propose to track scallops, imitation scallops (as a proxy), and stationary objects with acoustic transmitters, and follow up transplant events with dredging at or near the drop site to see if we can collect some transplanted scallops.

6 Literature Cited

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7 Project Management

All work was performed in collaboration with the sea scallop fishing industry, including two LA vessels and one LAGC vessel; June 2017 trip occurred on FV Thunder Bay (LA fleet, New Jersey), December 2017 trip occurred on FV Reflection (LA fleet, Massachusetts), and May 2018 trip occurred on FV Mr. G. (LAGC fleet, Rhode Island). All other work was performed in house by CFF employees. Ricky Alexander was responsible for project management, trip planning, gear maintenance, report writing, and image annotation. John Ceccolini performed image annotation. Liese Siemann performed image and data analyses. Liese Siemann and Samir Patel helped resolve camera and deployment issues, including field testing.

8 Fish Caught

All bycatch and un-selected scallops were promptly discarded to minimize stress and increase likelihood of survival. Three tows were performed over the duration of this trip, all in the NLS. Catches were very clean, with minimal bycatches of monkfish (10 lbs), red hake (2 lbs), and winter/little skate (25 lbs). One tow caught roughly 700 lbs of sand dollars. Discarded scallops are estimated at 500 lbs, whole live weight. All catch weights were visually estimated by the project PI and the vessel captain.

9 Appendices

Appendix 1: R code for image annotation and quantification of scallop movement

CountScallopsPredatorsPlusFive annotation program

```
# to run script from command line type the following:
source("CountScallopsPredatorsPlusFive.R")

# load needed libraries
library("EBImage")
library("stringr")
library("tcltk")
library("abind")

# identify all files in working directory that are RGB tif files
Images = Sys.glob("DSC*.JPG")

# count the number of images
Len = length(Images)

# create empty vectors for the data
firstFiveScallops = numeric(length=Len)
numScallops = numeric(length=Len)
numSnails = numeric(length=Len)
numEels = numeric(length=Len)
numCrabs = numeric(length=Len)
numBass = numeric(length=Len)
numHake = numeric(length=Len)
numOther = numeric(length=Len)
notes = character(length=Len)

for (i in 1:Len){
  Img = readImage(Images[i])
  display(Img,method="browser")
  # 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 first five scallops")
  fiveScallops = locator(n=5,type='p',pch=18,col='red',cex=1.5) #get first five scallop click
  points
  # when one of the chosen scallops is missing, click above the image in the graphics
  window
  sum5=sum(fiveScallops$y>0)
  par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
  display(Img,method="raster")#open raster window
  points(fiveScallops$x,fiveScallops$y,pch=20,col='yellow',cex=2)
```

```

title(main = "Select rest of scallops")
scallops = locator(type='p',pch=18,col='red',cex=1.5) #get scallop click points
numScallops[i] = length(scallops$x)+sum5
#graphics.off()
par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
display(Img,method="raster")
par(oma=c(0,0,1,0))
title(main = "Select snails")
snails = locator(type='p',pch=18,col='red',cex=1.5)
numSnails[i] = length(snails$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 eels")
eels = locator(type='p',pch=18,col='red',cex=1.5)
numEels[i] = length(eels$x)
graphics.off()
par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
display(Img,method="raster")
par(oma=c(0,0,1,0))
title(main = "Select crabs")
crabs = locator(type='p',pch=18,col='red',cex=1.5)
numCrabs[i] = length(crabs$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 black sea bass")
bass = locator(type='p',pch=18,col='red',cex=1.5)
numBass[i] = length(bass$x)
graphics.off()
par(xpd=NA, oma=c(0,0,2,0), mar=c(0,0,1,0))
display(Img,method="raster")
par(oma=c(0,0,1,0))
title(main = "Select hake")
hake = locator(type='p',pch=18,col='red',cex=1.5)
numHake[i] = length(hake$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 other")
other = locator(type='p',pch=18,col='red',cex=1.5)
numOther[i] = length(other$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],"eels",numEels[i],"crabs",numCrabs[i],
  "bass",numBass[i],"hake",numHake[i],"other",numOther[i])
print(CountVector)
locsFilename = paste0(Images[i],"_locations.RData")
save(fiveScallops, scallops, snails, eels, crabs, bass, hake, other, notesChar,
  file=locsFilename)
}

```

```

CreatureCounts <- data.frame(Images, numScallops, numSnails, numEels, numCrabs, numBass,
numHake, numOther, notes)
fileName <- tclvalue(tkgetSaveFile())
write.csv(file=paste0(fileName, ".csv"), 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])
FirstMatOther = do.call(cbind, scallops)
FirstMat5 = do.call(cbind, fiveScallops)
FirstMat = rbind(FirstMatOther, FirstMat5)
FirstDistMat = dist(FirstMat, method = "euclidean")
FirstDistVec = as.vector(FirstDistMat)
FirstDist = mean(FirstDistVec)
FirstDistSD = sd(FirstDistVec)
FirstX = sum(FirstMat[,1])/length(FirstMat[,1])

```

```

FirstY = sum(FirstMat[,2])/length(FirstMat[,2])
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])
  MatOther = do.call(cbind, scallops)
  Mat5pre = do.call(cbind, fiveScallops)
  Mat5df=as.data.frame(Mat5pre)
  Mat5df_noNeg=subset(Mat5df, y>0)
  Mat5 = as.matrix(Mat5df_noNeg)
  Mat = rbind(MatOther, Mat5)
  centroidX[i] = sum(Mat[,1])/length(Mat[,1])
  centroidY[i] = sum(Mat[,2])/length(Mat[,2])
  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

```

createTrackImages to visualize tracks of individual scallops

```

# load needed libraries
library("EBImage")
library("stringr")
library("tcltk")
# identify files

```

```

ImgData = Sys.glob("*.RData")
Images = Sys.glob("DSC*.JPG")

Len = length(ImgData)

for (N in 1:5){
  pointsX = numeric(length=Len)
  pointsY = numeric(length=Len)
  for (i in 1:Len){
    File = load(ImgData[i])
    if (fiveScallops$y[N]>0){
      pointsX[i] = fiveScallops$x[N]
      pointsY[i] = fiveScallops$y[N]
    }else{
      pointsX[i] = 0
      pointsY[i] = 0
    }
  }
  tmp=data.frame(pointsX,pointsY)
  points=subset(tmp, pointsY>0)
  LenTmp=length(tmp$pointsX)
  LenPoints=length(points$pointsX)
  Img = readImage(Images[1])
  jpeg(filename = paste0("May 2018 Scallop",N, "_track.jpg"), units = "px", width = 6000,
  height = 4000,quality=75)
  display(Img, method="raster") #open raster window
  points(points$pointsX,points$pointsY,type="l",col="cyan",lwd=10)
  points(points$pointsX,points$pointsY,type="p",col="red",pch=20, cex=5)
  if (LenTmp>LenPoints){
    text(100,100,"Scallop left image",cex=14,pos=4,col="red")
  }
  graphics.off()
}

```

Appendix 2. Feather plots showing current direction and velocity in the June and December 2017 drop locations.

Current meter output averaged every 10 minutes for the entire trip

