Final Report

Development of Side Scan Sonar Methodology to Survey Derelict Lobster Pots in Simple and Complex Habitats in Massachusetts

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Introduction

Marine debris from fishing gear lost or abandoned underwater endures and accumulates (Carr and Harris, 1994). Loss prevention is challenged by its many causes: shift in location due to storms, tidal and wave action, entanglement and conflicts with other fishermen, vessel traffic, vandalism, and other reasons (Macfadyen et al., 2009).

Derelict (lost or abandoned) fishing gear that continues to actively catch fish is known as ghost gear (Smolowitz, 1978). Ghost gear often causes unobserved, unaccounted mortality of the target species and others (Chopin et al., 1996; Chuenpagdee et al., 2003; Dealteris et al., 2008). Biodegradable components can be built into static fishing gear to inactivate its fishing ability if lost or abandoned (Bilkovic, et al., 2012; He and Pol, 2010). However, the degradation of these gear items is often far slower than expected due to biofouling, user interference, need for air exposure to trigger hog-ring oxidation time, or illegal modifications (Gilman et al., 2013; Massachusetts Division of Marine Fisheries, 2012). Additionally, use of durable materials, such as coated wire, prolongs the fishing ability of the gear (Dealteris, et al., 2008; Pol and Carr, 2000; Smolowitz, 1978). Even derelict gear that does not actively fish entangles protected species, conflicts with other fishing gear, and damages habitat and ecosystems (Arthur et al., 2014; Clark et al. (eds.), 2012 ; Laist, 1996; Macfadyen et al., 2009).

Fishermen experience economic loss from derelict fishing gear primarily due to replacement costs of the gear itself as well as lost revenue from ghost fishing mortalities (and lost population growth from those mortalities). Surveys conducted from a recent NFWF-funded project led by Massachusetts Division of Marine Fisheries (MADMF) estimated the cost to replace lost pots within Massachusetts waters to be between $676,000-$1,587,000 annually (MADMF, 2012). Mortality rates of lobster and other species in ghost gear are high: 4.8 lobsters pot^{-1} year^{-1} in Cape Cod Bay and 3.6 lobsters pot^{-1} year^{-1} in Buzzards Bay. In order to determine total mortalities from derelict pots, pot abundance estimates are required. Abundance estimates of derelict pots in the Northeast are relatively rudimentary (Dealteris, et al., 2008; Gilman et al., 2013; Laist, 1996; Mcfadyen et al., 2009). Further, quantifying overall abundance of and mortality from derelict pots using survey methods such as diving or grappling in known high pot density areas has met with limited and mixed results (MacMullen et al., 2003).

Side scan sonar offers the potential to quantify abundance of lost lobster pots broadly and quickly since it can create a wide acoustic image of the bottom. Previous sonar work has had success identifying pots in featureless bottom (Center for Coastal Studies, 2014). In structurally complex habitats, pot detection has been shown to be more difficult, since pots and rocks can be hard to differentiate in the sonar imagery and acoustic shadows from rocks can hide pots (Stevens et al., 2000). Pot loss is likely more common in these habitats, where lobster fishing often occurs. We have identified only one past research project (Clark et al. (eds.), 2012) that has tested the accuracy of pot detection in sonar surveys. Assessment of the detection rate, or the frequency with which pots are identified in sonar imagery, is necessary to evaluate the accuracy of estimates of the number of derelict pots and subsequent mortality from them. This detection rate likely varies for simple (lacking features, sandy) and complex (cobble, rocky/boulder) habitats.

Total loss in yield to the fishery due to ghost pots can be more accurately estimated if sonar surveys can reliably be used to quantify density of derelict gear. This information could also be used to inform and to improve accuracy of stock assessments for affected species (Arthur et al., 2014). Information regarding the total impact of derelict gear and ghost fishing can also be used to encourage pot retention or recovery, an approach successfully employed in the Pacific Northwest (SeaDoc Society, 2009). An effective sonar method would also map lost gear and set the stage for removal efforts.

Our goals in this project are to determine the detection rate for side scan sonar pot identification on simple and complex habitats and then apply the detection rate to a pilot survey to provide an estimate of the abundance of derelict pots in the pilot survey area.

Methods

This project included field reconnaissance and two project phases. The goal of Phase 1 was to conduct field trials to determine lobster pot detection rates for side scan sonar over two habitat types, simple and complex, by placing lobster pots within the work area, and then surveying that area with sonar. Phase 1 work included a baseline survey, substrate classification procedure, and lobster pot detection trials. The goal of Phase 2 was to use side scan sonar in a pilot survey area containing the two habitat types and use the pot detection rates from Phase 1 to estimate the number of pots within it. In Phase 2, we also planned to determine the imaged area required (percent coverage) using side scan sonar for future, larger surveys.

Environmental data (wave height, wind speed and direction, tidal direction, and weather conditions) were recorded for each field day to explore possible effects of these factors on pot detection rates.

Equipment

Side scan sonar data were collected using a towed Klein System 3000 dual-frequency (100/500 kHz) single beam sonar. The Klein simultaneously collects data at 132 kHz and 445 kHz frequencies with a horizontal beam width of 0.7° and 0.21° respectively. A Garmin GPSMAP 76 was used to provide GPS data. The data were collected in the field using Klein Marine System's SonarPro v. 14.0.

Lobster pots were standard design (rectangular), coated wire, 1.0 x 0.5 x 0.3 m (40 x 21 x 13.5 inches) in size, with dual entrances with circular stainless steel rings and held together with aluminum clips. Three bricks were situated inside of pots for ballast, one on each length-wise side and one in the parlor section along the side. Pots were set singly and marked with surface buoys and standard cordage.

Side Scan Sonar Mosaic Methodology

Side scan sonar data from each survey were processed for water column removal and slant range and beam angle corrections with SonarTRX Pro v. 15.1 and exported as GeoTIFF mosaics for each transect line. Overlapping swath images were not removed or merged; they were layered in ArcGIS to provide additional data.

Field Reconnaissance

Field reconnaissance work was conducted 3/8/2016 from the F/V *Andrea C.*, a 13.7 m (45 ft), 420 HP lobster vessel based out of Fairhaven, MA owned and operated by Captain Aaron Cebula.

Site Selection

We used existing backscatter and bathymetric charts of Buzzards Bay, MA (NOAA 1995; Ackerman, 2012) to identify several approximately 1-mile^2 sites south of New Bedford, MA that contained an approximately equal amount of both “simple” and “complex” habitat, as well as several other characteristics: relatively level, lightly or not fished, limited vessel traffic, low wave energy (to avoid shifting of existing derelict gear after a baseline survey), and easy accessibility. We reviewed the sites with the vessel captain and visited several potential sites during the field reconnaissance survey.

The Phase 1 baseline survey area was selected based on consideration of field logistics (distance from port), the absence of static fishing gears (pots for targeting lobsters, fish, conch, etc.) based on the lack of buoys used for marking existing, actively fished gear, and the site’s location well outside of shipping lanes (Figure 1). Also, Captain Cebula did not believe that this area was regularly used for static gear fishing. After the initial baseline survey day, the final Phase 1 survey area for pot detection trials was further refined to ensure that transit, pot deployment, side scan surveying, and pot recovery could all be achieved in a single day (8-10 hours).

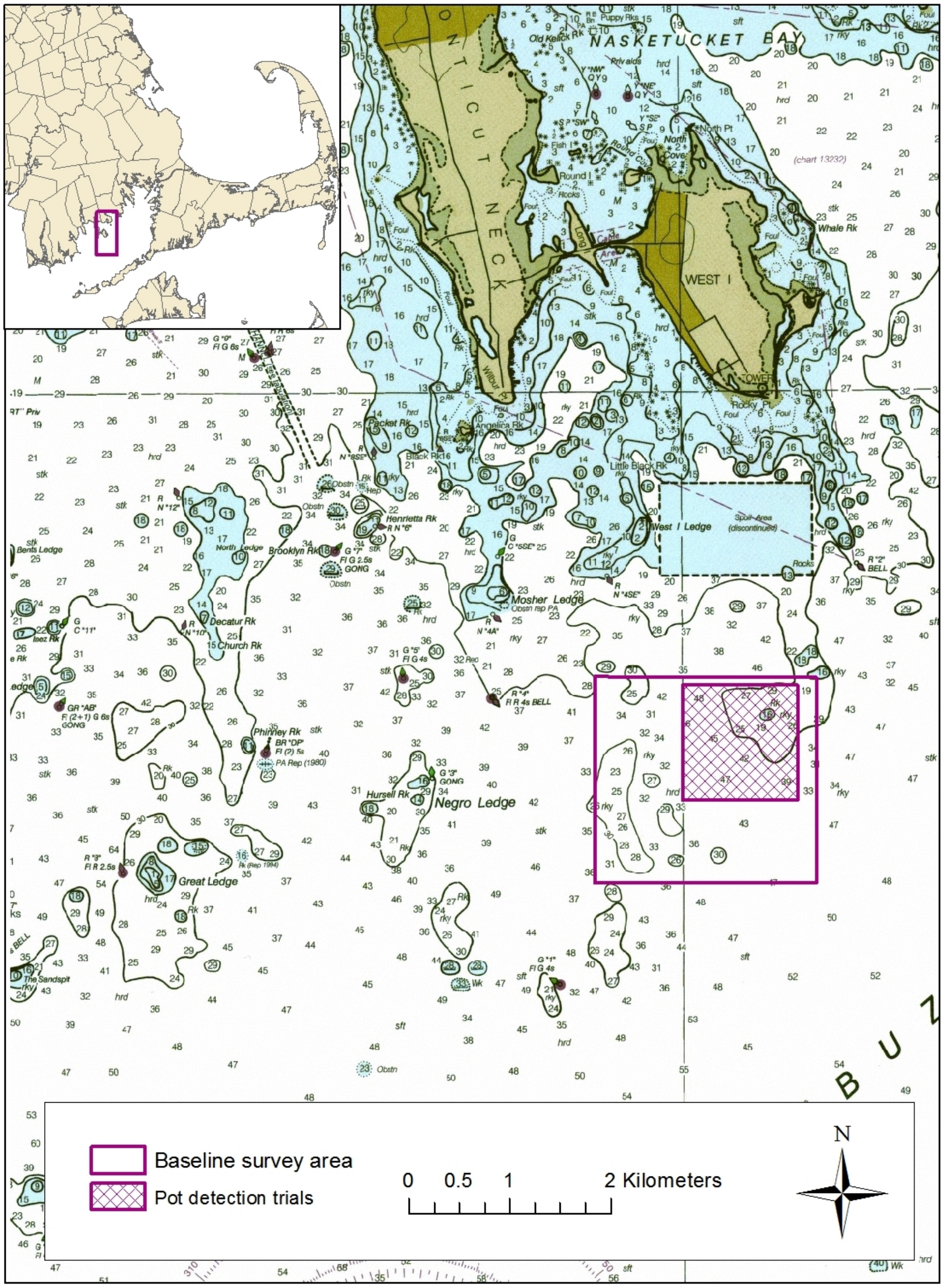


Figure 1: Baseline survey and Phase 1 work areas in Buzzards Bay, MA. The large purple box indicates an initial survey and baseline area (4.5 km^2); the smaller box with purple hatch lines indicates the Phase 1 pot detection trial area (1.3 km^2). The inset map shows the work area within greater Massachusetts.

Side Scan Sonar Calibration and Determining Sonar Precision

During the field reconnaissance survey, calibration and precision of the sonar was measured. The Klein 3000 side scan sonar unit towfish was deployed off a block at the vessel's stern until the tow-fish reached a height of approximately 5-10 m off-bottom, the approximate minimum height for safe operation. A layback correction based on the amount of cable out was input to the SonarPro sonar acquisition software. The vessel maintained speeds between 5-6 knots; faster speeds would create too much drag on the cable to allow the side scan sonar to reach the desired depth; slower speeds would reduce maneuverability due to cross-winds, wave action, and/or currents on the vessel. Four pots were set individually in simple habitat locations (identified from the depth sounder and side scan sonar images).

The calibration pots were imaged multiple times and in multiple directions as the vessel and towfish passed over them. Different sonar ranges were tested to balance resolution for pot identification and range for survey coverage; 100 m range was ultimately selected.

Sonar images of pots identified during the calibration were used as reference images during Phase 1 and Phase 2 surveying, and during a post-processing procedure which included replaying raw sonar imagery and reviewing the backscatter mosaic. Two calibration images were selected for reference with acoustic shadows cast lengthwise and widthwise (Figure 2).

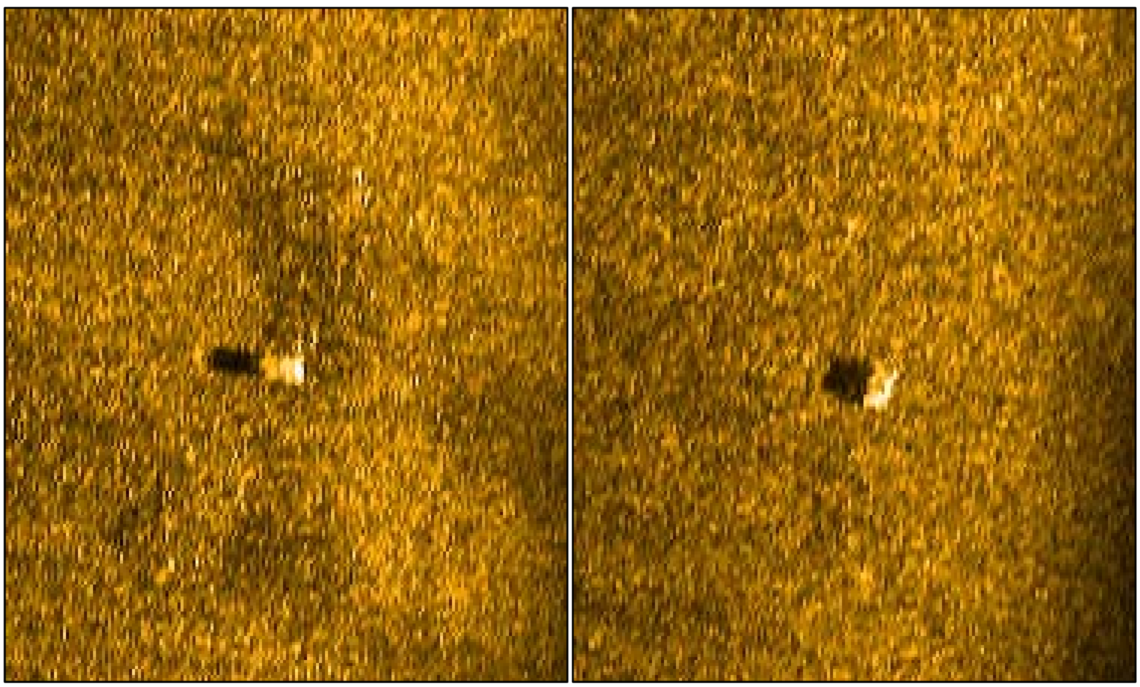


Figure 2: Selected pot calibration images at 100-m resolution. Acoustic shadows are cast by a pot detected lengthwise (left) and widthwise (right).

Positional error (sonar precision) was measured as the distance between identical GPS georeferenced pot targets in replicate sonar images. Single pots observed over several passes measured the precision of the side scan sonar positioning to be 24.4 m (80 ft). That is, the georeferenced location of a known pot could vary in different sonar passes up to approximately 24 m.

<u>Phase 1</u>

Phase 1 field work was also conducted from the F/V *Andrea C*. Side scan sonar towfish deployment and towing procedures were the same as above. The side scan image was live-viewed by a sonar analyst.

Baseline Survey

In the selected survey area, a baseline survey was conducted to identify any existing derelict pot gear ("baseline pots") in the work area and to classify habitat types.

The area was imaged along transects, 75 m apart, at 100 m range using the side scan sonar. This distance and range provided 150% swath overlap of the imaged substrate; this overlapping coverage was selected based our lack of knowledge of the actual area required for detecting pots. Direction of transects was based on the wind direction; for vessel stability along transects, it was preferable to head into or with the wind rather than have effects from cross-winds. Transect lines for navigation were displayed using SonarPro (visible to the captain and not to the sonar analyst).

The sonar analyst was instructed to identify any targets that he thought were lobster pots, based on his experience and using the calibration photos as a guideline. Baseline pots were identified using the sonar imagery during the fieldwork. Targets were later reconfirmed in the more controlled lab setting using both raw data and processed data.

Substrate Classifications and Buffer Zones

The backscatter mosaic from the baseline survey was used to delineate areas of simple and complex habitat; simple substrate was identified as areas of uniform and lower backscatter values indicating flat sandy or mud habitats; complex substrate was identified by higher backscatter areas with larger acoustic shadows indicating rocky habitats (Figure 3). Delineations were done by hand at a scale of 1:5,000 and then were checked at 1:1,000. The minimum mapping unit was 45.7 x 45.7 m (150 x 150 ft); simple or complex areas smaller than that were not delineated.

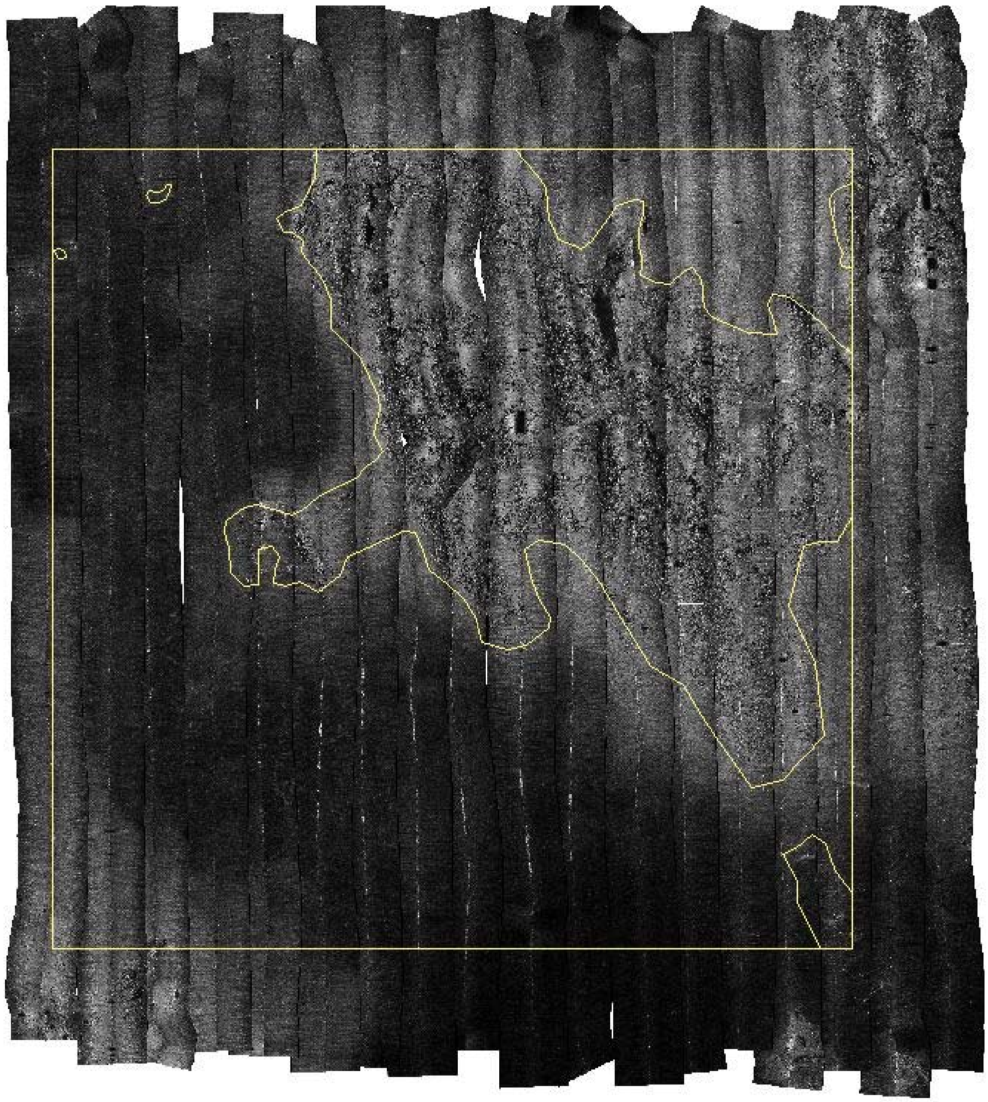


Figure 3: Sonar mosaic of Phase 1 work area showing areas of high and low backscatter (delineated by the yellow line). Lighter areas indicate complex habitat; darker areas indicate simple habitat. The yellow box is the baseline survey and pot detection trial area.

The buffer tool in ArcGIS was used to create a habitat “transition zone” of 45.7 m (150 ft) wide along the identified edges of both simple and complex habitats, resulting in a total transition zone between the habitats of 91.4 m (300 ft) wide. These transition zones were then excluded from classification as habitat areas. A 45.7 m (150 ft) buffer radius from each derelict baseline pot was also created (Figure 4). We selected this distance based on the calibration assessment when we imaged pots in different directions. We found the resulting targets that were the same pot clustered in a circle of approximately 24.4 m (80 ft) radius. To be conservative, we increased this radius to 45.7 m (150 ft). The habitat transition and baseline pot buffer zones were intended to ensure placed pots would be definitively set in either substrate type and they would not be too close to existing baseline pots.

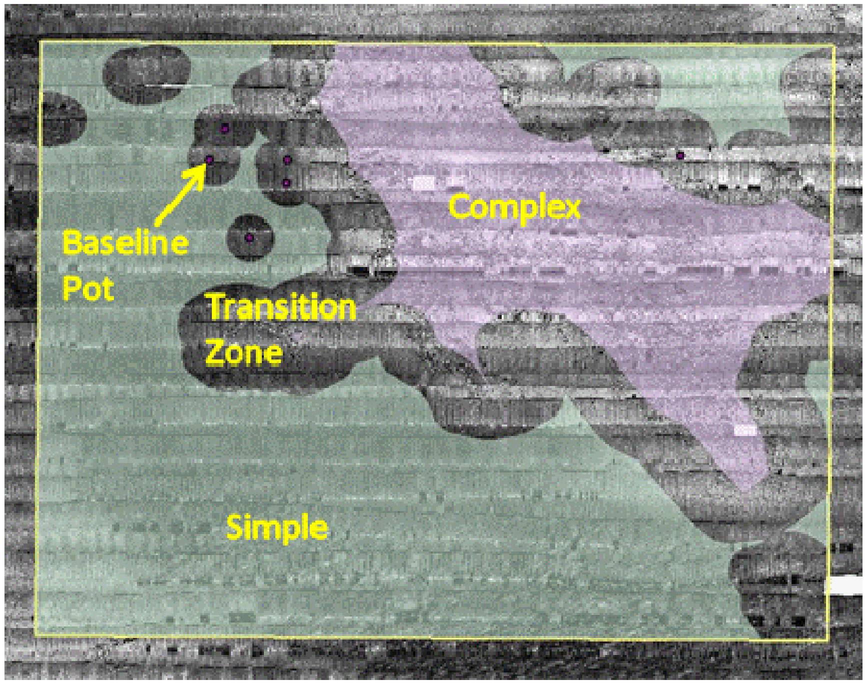


Figure 4: Sonar mosaic of Phase 1 baseline survey and pot detection trial area (yellow box) with overlaying simple habitats (green) and complex habitats (purple). Also shown are transition zones between habitats and buffer zones around identified baseline pots (red points).

Pot Detection Trials

We estimated a maximum of 20 pots could be deployed, imaged, and hauled in a single sea day, so we selected a base number of 10 pots for each habitat area. We then applied a chosen distribution to derive the actual number of pots to be deployed ("placed pots"). The distribution used was concealed from the sonar analyst to avoid any prior knowledge of the number of pots deployed, otherwise adding count bias. For this work, we used a ¾ binomial distribution to determine the number of placed pots in each habitat. The numbers of placed pots were adjusted by the deviation of the percent coverage of each habitat from the expected 50% coverage and rounded. The procedure to determine pot numbers was repeated for each sampling day. Six trial days were conducted, based on the minimum number of replicates required for statistical analyses and available funding.

Since lobster pots use a surface buoy to aid in retrieval, we ensured the sonar analyst remained unaware of the location of the pots so that sampling bias was not introduced from awareness of location; the sonar analyst was kept below deck during trials. The navigation output was only available in the wheelhouse, so the sonar analyst did not generally know at any given time which part of the work area was surveyed although bias from site familiarity (through review of sonar images) was possible over time.

Pot placement locations were randomly assigned within respective habitats (exclusive of transition zones for habitat edges and buffer zones around baseline pots) for each trial using the Create Random Points tool in ArcGIS. A minimum distance of 15.2 m (50 ft) was used between set locations, based on likely drift from surface set locations in 30 feet of water. The number of pots set on each habitat type and for each day and their assigned location was also concealed to the extent possible from the sonar analyst to prevent biasing pot detections. Also, to prevent bias of pot estimation, the same number of pots (20) was loaded on the boat each day. All pots were deployed; extra pots, not used in analyses, were deployed outside of the survey area so the analyst would not observe the remaining pots on deck and thus know the number of pots in the survey area.

Using the vessel GPS, the captain set the pots as close to the assigned coordinates as possible. Actual coordinates of the pots as they entered the water were also recorded.

After pots were placed, side scan sonar transects were conducted, 75 m apart with 100 m sonar swath resolution and 150% overlap. During the transects and in post-processing, the sonar analyst identified all possible pots in the sonar record. These identifications were called "targets" and were selected based on similarity to the calibration images. Additionally, the snapshot tool in SonarPro was used to confirm that the image dimensions were similar to a lobster pot.

We planned that no pot fishing would be occurring in our study site. However, we found buoys indicating actively fished pots in the survey area on each trial day. We confirmed with the fisherman that buoys indicated single lobster pots (not trawls/strings) and that these "active pots" were similar to our placed pots in size and materials, and therefore, likely indistinguishable from them in sonar images. The active pots were not distributed randomly (they were set to target lobsters), but when combined with the randomly placed pots, we judged their locations would adequately approximate randomness. Therefore, active pots are included as part of the dataset. Surface locations of the buoys marking the active pots were recorded relative to the vessel's position during the closest transect.

Data Analyses

All sonar data were reviewed by the analyst following completion of the fieldwork in the same order as it was collected. Initial target identifications, field notes, raw side scan data, and processed side scan mosaics were used to generate final identification of targets for each trial. The identified targets were plotted onto the study area map, along with placed, baseline, and active pot locations, and habitat zones.

The accuracy of the pot placement was assessed using the Near Tool in ArcGIS to calculate the distance between planned stations and placed pots using a search radius of 100 m.

Side Scan Sonar Pot Detection Rate

In order to account for positional errors associated with pot deployment and the sidescan sonar data collection, we also buffered the mapped locations associated with targets, placed pots, baseline pots, and active pots. Targets were buffered with a 24.4 m (80 ft) buffer, based on the calibration assessment. Placed pots were buffered by a 15.2 m (50 ft) radius, based on the surface set drift estimate described above. Baseline pots were also buffered by a 15.2 m (50 ft) radius on mapped locations although using the precision from the calibration assessment would have been more suitable but did not affect the final assessment since we ultimately compared the baseline pots individually in the trial mosaic images. Buoy position, along with the depth and length (21.9 m (72 ft), provided by the pot fisherman) of buoy line were used to approximate the likely locations of active pots. Active pot locations were plotted as an elliptical zone due to inconsistencies in recording which side of a transect the buoy was observed. The elliptical zone therefore took into account maximum distance from the vessel position to either side (37.5 m), minimum depth (21.5 m) over all trials, and buoy line scope. These buffers were also plotted onto the study area map, along with habitats and habitat transition zones.

Plots were scrutinized for overlap of targets and associated buffers with expected pots (baseline, placed, and active) and their associated buffers. Targets were categorized as true positives ("TP" – target buffers overlapping placed or active pot buffers (i.e., correct detections)); false positives ("FP" – target buffers not overlapping any placed or active pot buffers (incorrect detections)), and false negatives ("FN" - placed or active pot buffers not overlapping a target buffer (i.e., undetected). True negative ("TN") cases (no target identified and no pots present) were not verified and are therefore not reported. Targets whose buffer partially overlapped habitat zones were assigned to simple or complex habitat or neither, based on central substrate location. Targets centrally located in a transition zone were included in analyses for combined habitat evaluations only.

Only one pot could be associated with one target and vice versa. For instance, if the buffers of two different pots shared the buffer of a single target, then the centrally closest pot was classified as a TP while the other pot was classified as a FN.

A pot could be marked as a target more than once due to overlapping swaths. In these cases, two principal investigators (PIs), working together, identified these possible duplicate targets by their proximity to each other and overlapping buffer zones and by other near-by structures, used as points of reference, also captured in overlapping swaths. Sonar mosaics of suspected duplicate targets were examined more closely and validated, case-by-case.

Other decision rules were developed for unclear results such as a pot placement whose buffer partially overlapped the survey area. We attempted to be consistent regarding decisions. However, judgements were required for particular difficult but rare events.

Repeat FP results in the same location over multiple trials were also scrutinized to determine if persistent substrate features were being identified as pots.

TP, FP, and FN cases were populated into contingency tables (Figure 5) within each trial (Fawcett, T. 2006) and by habitat classification (simple, complex, or all habitats combined).

	Pot present	Pot not present
Target marked	TP	FP
Target not marked	FN	TN

Figure 5: Model contingency table.

The following contingency metrics were considered relevant (Fawcett, T. 2006):

- True positive rate (TPR) = $\frac{\mathrm{TP}}{\mathrm{TP+FN}}$ = the fraction of targets correctly marked over all pots present.
- Positive predictive value (PPV) = $\frac{\mathrm{TP}}{\mathrm{TP+FP}}$ = the fraction of targets correctly marked over the total of all targets.

Means and standard errors for trials were determined for the TPR and PPV. The mean TPR is the effective pot detection rate of the sonar analyst.

Baseline Target Verification

To confirm the validity of the baseline targets, their persistence throughout the six trial days was confirmed by reviewing the same areas on each trial's sonar imagery mosaics.

Phase 2

The Phase 2 pilot survey occurred in Cape Cod Bay since the Bay supports a strong lobster pot fishery and pot loss in this area is a known phenomenon. Existing bathymetric charts from NOAA were used to select a survey area that contained an approximately equal amount of simple and complex habitat types over an area with limited bathymetric relief for consistent side scan sonar imaging.

An approximate 1 $mile^2$ area was selected for the Phase 2 pilot survey in Western Cape Cod Bay (Figure 6). The size of the survey area was established based on the amount of sonar coverage that could be achieved at 150% coverage combined with transit time in an 8-hour day.

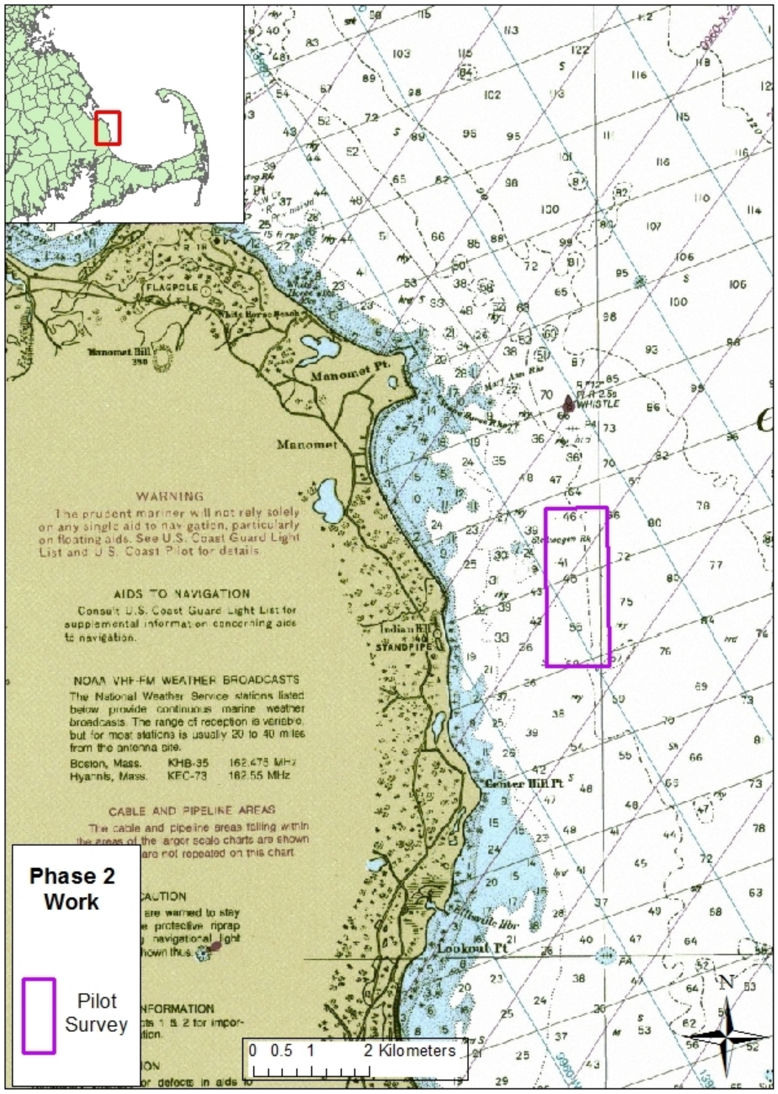


Figure 6: Phase 2 pilot survey area in Western Cape Cod Bay, MA. The inset map shows the greater Massachusetts area.

Fieldwork was conducted from the MADMF *R/V Mya*, a 9.4 m (31 ft), 355 HP Eastern lobster-style vessel. The side scan sonar towfish was deployed off the stern. Survey methods, target identification, sonar data processing, and final target assessment were conducted as in Phase 1. Transects were conducted using the SonarPro navigation display.

Heat maps of derelict pot densities were plotted using ArcGIS 10.3 to show a pot density estimate of the pilot survey area. A point density surface using the targets was generated with an output cell size of 80 m^2 and a neighborhood of 3 x 3 cells (selected through experimentation). The original output of the point density tool is targets per unit area, so this was converted to the total number of targets in a cell using the raster calculator to multiply the raster grid cell values by the neighborhood area. The raster to point tool was used to create a point surface for the purpose of creating a better looking heat map using a spline interpolation with a cell size of 55 m^2 (regularized spline type with a weight of 0.1 and search radius of 12).

The interpolation method was selected by testing several methods and selecting the best output for display of the data.

Results: Phase 1

Baseline Survey and Pot Detection Trials

The Phase 1 baseline survey and pot detection trials were completed in March-April, 2016. Weather during the field work was generally mild – bad weather days were avoided. The maximum wind speed was 15 kts, with a maximum of 1.5 m (5 ft) of wave height, which occurred during baseline scanning (Table 1). While winds were as high as 15 kts during detection trials, the wave heights remained below 0.5 m (1.5 ft).

Table 1: Weather and sea state conditions for the baseline field work, pot detection trials, and pilot survey. Transects were either conducted in a north-south direction (N-S) or east-west direction (E-W).

Trip Name	Wind Speed (knots)	Wind Direction	Wave Height (m)	Direction of Transects
Baseline	15	W	1.5	E-W
Trial 1	8	NE	0.3	N-S
Trial 2	15	E	0.5	E-W
Trial 3	6	NW	0.3	N-S
Trial 4	0	N	0.0	N-S
Trial 5	0	N	0.0	E-W
Trial 6	6	N	0.6	N-S
Pilot Survey	6	NE	0.8	N-S

The selected Phase 1 site consisted of 0.92 km^2 of designated habitat areas and 0.38 km^2 of designated transition zone areas (Figure 4). The habitat areas contained an estimated 69% simple (0.63 km^2) and 31% (0.29 km^2) complex bottom. Six baseline pots were identified using sonar in the final work area, five in simple habitat and one in complex habitat.

The habitat coverage modifiers to determine the corrected (rounded) number of placed pots selected using the sampling distribution were 0.19 for simple habitat and -0.19 for complex habitat.

Six days of pot detection trials were successfully completed as planned. Overall, 88 pots were placed within the work area; 67 active pots were also in the selected site during trials (Table 2).

Table 2: Realized numbers of placed and active pots for each pot detection trial by habitat type or transition zone.

	# of Pots Present Within Habitats					
	Placed Pots			Active Pots		
Trial #	Simple	Complex	Transition	Simple	Complex	Transition
1	7	5	0	2	4	3
2	10	3	1	3	6	1
3	8	8	0	1	6	3
4	11	5	0	2	8	3
5	9	6	1	2	9	3
6	7	7	0	1	6	4
Total:	52	34	2	11	39	17

Realized densities of placed and active pots within a km^2 area were calculated within each habitat and for all habitats combined (including transition zones) (Table 3).

Table 3: Densities of pots for all trials (including transition zones) and individual habitats.

	Placed and Active Pot Densities (pots/km^2)		
Trial	All	Simple	Complex
1	11.7	7.2	16.1
2	13.3	10.5	16.1
3	14.4	7.2	25.1
4	16.1	10.5	23.3
5	16.7	8.9	26.9
6	13.9	6.4	23.3

Only actual placed coordinates were used for analyses (as opposed to planned coordinates). Differences between placed and planned coordinates were generally smaller than the area of the pots' buffer zones. Deviations from the expected pot coordinates may have been caused by drift while setting or user error.

<u>Side Scan Sonar Pot Detection Rate</u>

Contingency tables of outcomes (Table 4) indicated that TP results were low overall. The most successful detection of pots was on the second trial day, when 6 TPs were recorded, compared to 18 FNs (Figure 7). A maximum of 6 TPs were identified on three different days. Examination of detections separately by substrate suggested that identification was low on complex habitat (maximum TP 2 out of 14 (on Trial 3)), and slightly higher on simple habitat (maximum TP 5 out of 13 (on Trials 2 and 4)).

Table 4: TP, FN, and FP results for all trials and habitats. Total true targets in the area = #TP+#FN.

	All			Complex			Simple		
Trial	TP	FN	FP	TP	FN	FP	TP	FN	FP
1	2	19	13	0	9	1	1	8	9
2	6	18	11	1	8	0	5	8	6
3	6	20	6	2	12	0	4	5	5
4	6	23	6	0	13	3	5	8	1
5	5	25	7	1	14	0	4	7	5
6	3	22	7	0	13	1	2	6	4

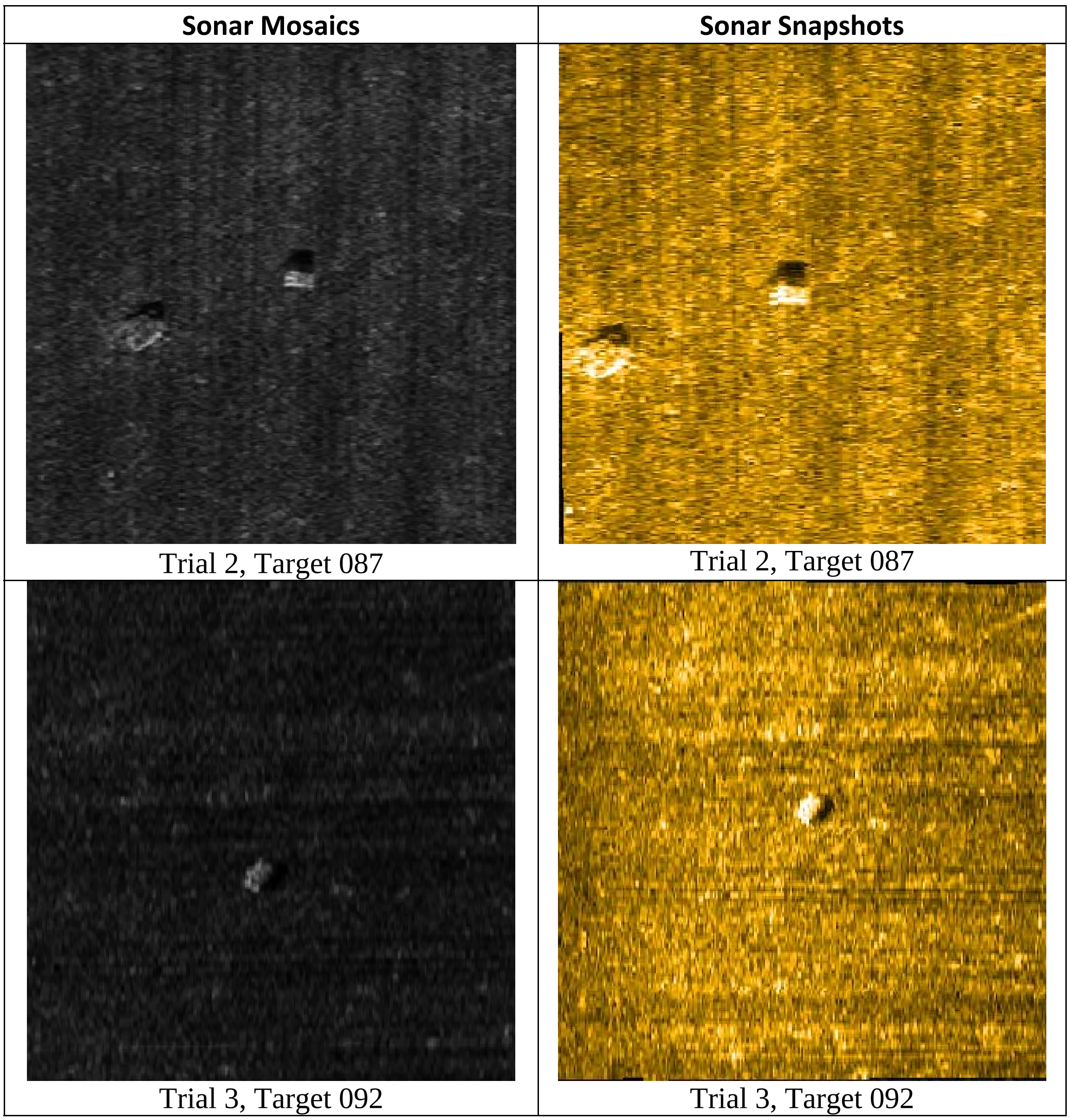


Figure 7: Two examples of true positive (TP) targets in the sonar mosaics (left) and respective SonarPro snapshots (right) from two trials.

FN results remained largely consistent over trials - most pots were not found (Table 4). As many as 25 of 30 (83.3%) placed were undetected in trial 5, with the fewest overlooked on the second trial (75%). The highest percent undetected occurred in trial 1 (90.5%). The percent undetected was greater in complex habitat compared to simple habitat, but was high in both.

The most false detections of pots (FPs) occurred in trial 1 followed by trial 2 (Table 4). FP targets on complex habitat were low.

In one case in trial 6, an active pot's buffer was partially located inside the research area; the central position was outside the work area and two targets' buffers overlapped that pot but were themselves outside the work area. In this particular case, the active pot and one of the targets were included in the analyses as a TP, despite that the active pot would otherwise be considered a FP without an associated target. The second associated target was determined to be a duplicate and therefore was removed from the analyses.

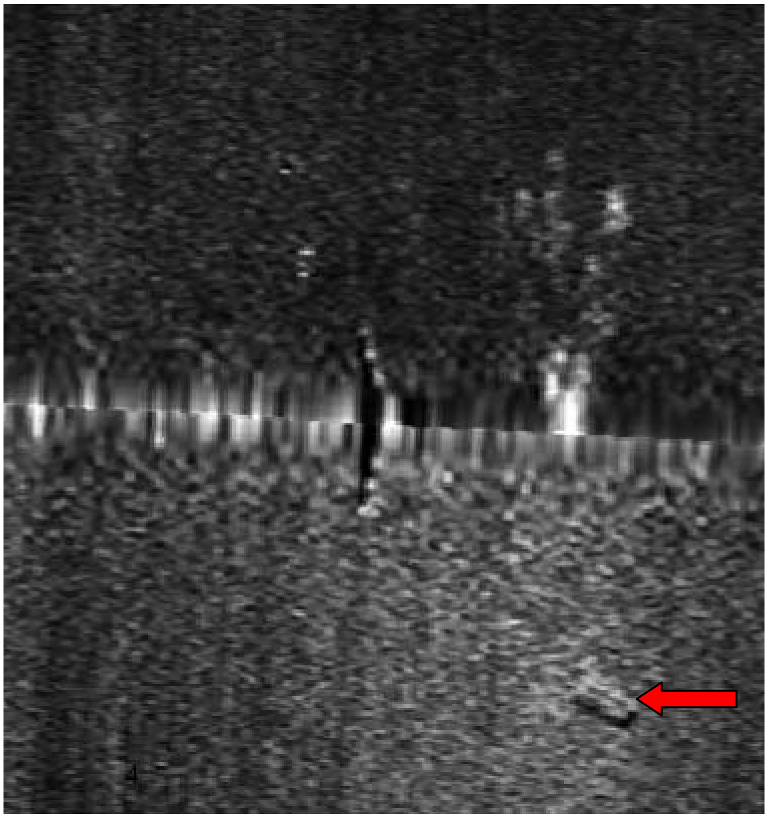
FP targets were identified more than once at the same location 31.8% (22.7% + 9.1%) of the time (the number of possible repeat targets = 44) (Table 5); FP targets were identified three times 9.1% of the time.

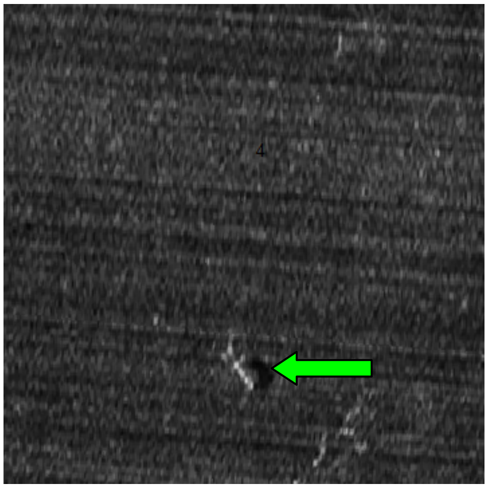
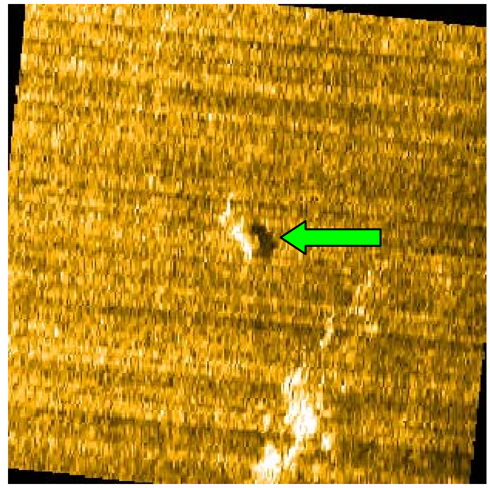
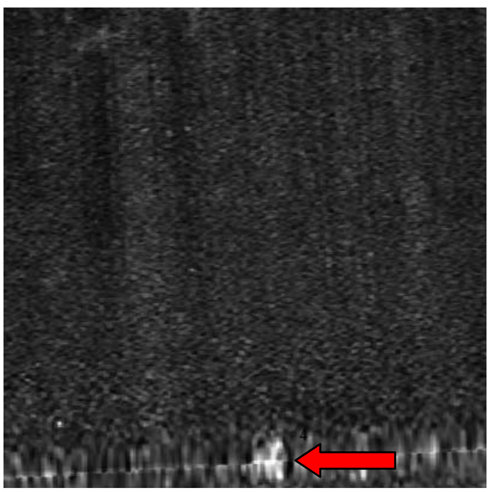
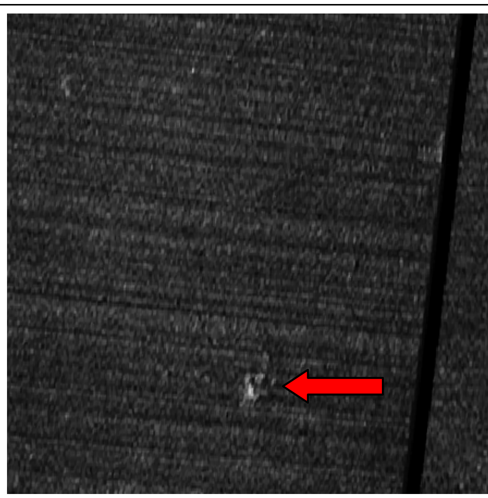
Table 5: Counts of overlapping FP targets between trials.

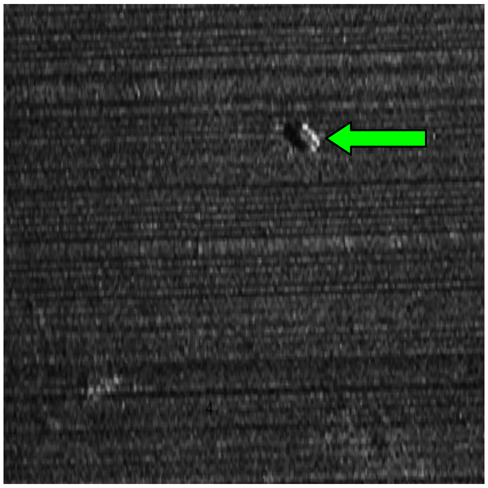
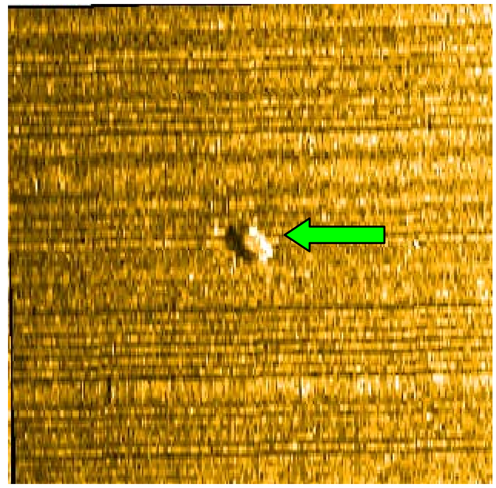
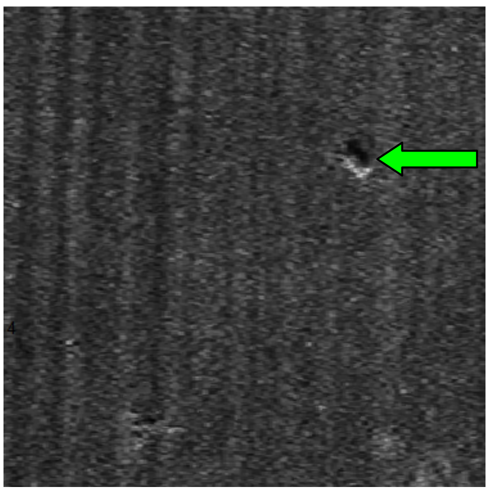
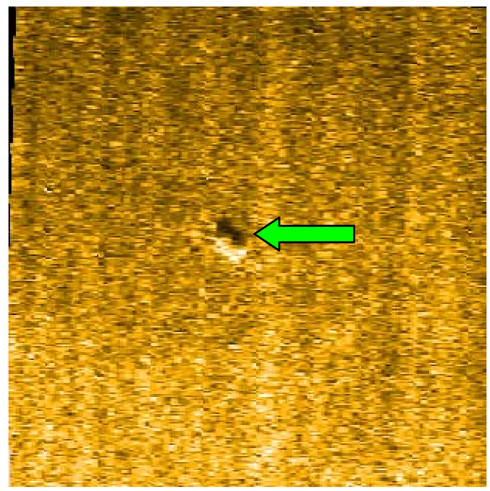
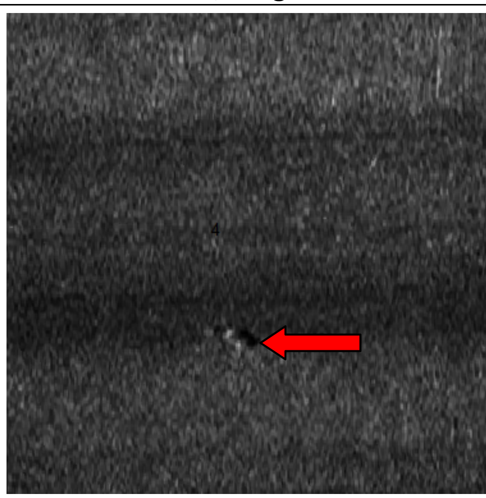
FP Repeats	FP Counts	%
0	30	68.2%
1	10	22.7%
2	4	9.1%
3	0	0.0%

The side scan sonar mosaics from the relevant trials were compared for all repeat FPs. Some type of object was typically present but in no cases was clearly a derelict pot. Therefore, it was assumed that no additional derelict pots were present in the work site beyond those identified in the baseline and, therefore, these targets were verified to the extent possible as FPs. An example of a repeated FP target is shown in Figure 8. On the baseline survey day (top), an object is visible but the image is too large (approx. 3.0 m (10 ft)) to be a lobster pot. During subsequent trials, an object is clearly visible, except for Trial 2, where it was lost in the nadir. Its apparent size and shape varied over trials, but it was judged to not be an overlooked derelict baseline pot.

Figure 8: Top image is a baseline survey sonar mosaic with a possible derelict pot. Subsequent trial (1-6) sonar mosaics (left) and respective SonarPro snapshots (right) of the same area as in the baseline survey (on following pages). Green arrows indicate targets identified by the sonar analyst; red arrows indicate possible targets identified later by two PIs. Snapshots were not taken when no target was identified by the analyst.



Sonar Mosaics	**Sonar snapshots**
 Trial 1, Target 117.	 Trial 1, Target 117.
 Trial 2	No detections.
 Trial 3.	No detections.

 Trial 4, target 36.	 Trial 4, target 36.
 Trial 5, Target 99.	 Trial 5, Target 99.
 Trial 6.	No detections.

The TPR was significantly higher in simple habitat (Table 6). There was no significant difference between the PPV values for habitat type. Over combined habitats, PPV greatly improved after the first trial but did not continue improving through the final trial. Targets were less commonly placed over complex substrate.

Table 6: True Positive Rate (TPR) and Positive Predictor Value (PPV) for all trials and habitats, with summary statistics. Numbers in parentheses are counts of pots in the TPR and counts of targets in the PPV respectively. PPV results assume that no derelict pots are on bottom aside from those identified in the baseline. SE= standard error.

	True Positive Rate (TPR), n= # of pots				Positive Predictor Value (PPV), n= # of targets		
Trial	**All**	**Complex**	**Simple**	**Trial**	**All**	**Complex**	**Simple**
1	0.10 (21)	0.00 (9)	0.11 (9)	1	0.13 (15)	0.00 (1)	0.10 (10)
2	0.25 (24)	0.11 (9)	0.38 (13)	2	0.35 (17)	1.00 (1)	0.45 (11)
3	0.23 (26)	0.14 (14)	0.44 (9)	3	0.50 (12)	1.00 (2)	0.44 (9)
4	0.21 (29)	0.00 (13)	0.38 (13)	4	0.50 (12)	0.00 (3)	0.83 (6)
5	0.17 (30)	0.07 (15)	0.36 (11)	5	0.42 (12)	1.00 (1)	0.44 (9)
6	0.12 (25)	0.00 (13)	0.25 (8)	6	0.30 (10)	0.00 (1)	0.33 (6)
mean	0.18	0.05	0.32	**mean**	0.37	0.50	0.44
SE	0.03	0.03	0.05	**SE**	0.06	0.22	0.10

Towfish setting and operation was easiest in calm weather and sea state conditions. Choppy seas distorted the sonar images, especially when traveling into the waves. However, TPR and PPV results are not clearly associated with the sea state (Tables 1 and 6). The greatest wave heights during pot detection trials occurred during trial 6 but weakest TPR and PPV results occurred in trial 1 which had low to moderate wave heights. Likewise, wind speed was highest during trial 2 for pot detection trials. Vessel transects were generally run parallel in the direction of the wind, except in trial 5 where transects were conducted perpendicular to the wind. Again, no clear effect is evident from transects running perpendicular to wind direction based on the mid-range trial 5 TPR and PPV values.

Baseline Target Verification

Baseline targets were not marked by the sonar analyst in each trial. The side scan sonar mosaic from the baseline survey was compared to the mosaics for each trial survey. Seafloor features were persistently found at the baseline target locations on subsequent pot detection trials, but the shape and clarity varied in the mosaics. In other words, a structure at a baseline target's location might appear very "pot-like" on one day but not the next.

Results: Phase 2

The Phase 2 area was surveyed on 4/28/16. The maximum wind speed was 6 kts, with a maximum 0.8 m (2.5 ft) wave height (Table 1). The pilot survey area was 2.91 km^2 (2.72 km x 1.07 km) in total, with 1.27 km^2 of simple substrate (43.6%) and 1.64 km^2 (56.4%) of complex substrate (Figure 9). Extrapolation was used for a transect that was partially imaged due to equipment or user error and habitats within this area were manually delineated as simple or complex.

Figure 9: Side scan sonar mosaic of the pilot survey area (within the yellow box). Lighter shaded regions indicate high backscatter (complex habitat); darker shaded regions indicate low backscatter (simple habitat). Yellow dots are identified derelict pots.

Fourteen derelict pots (targets) were identified in the pilot survey, four on complex habitat and 10 on simple habitat (Figure 9). The detections were clustered primarily in two areas (Figure 10). The heat map indicated two regions of the survey area with higher concentrations of pot targets.

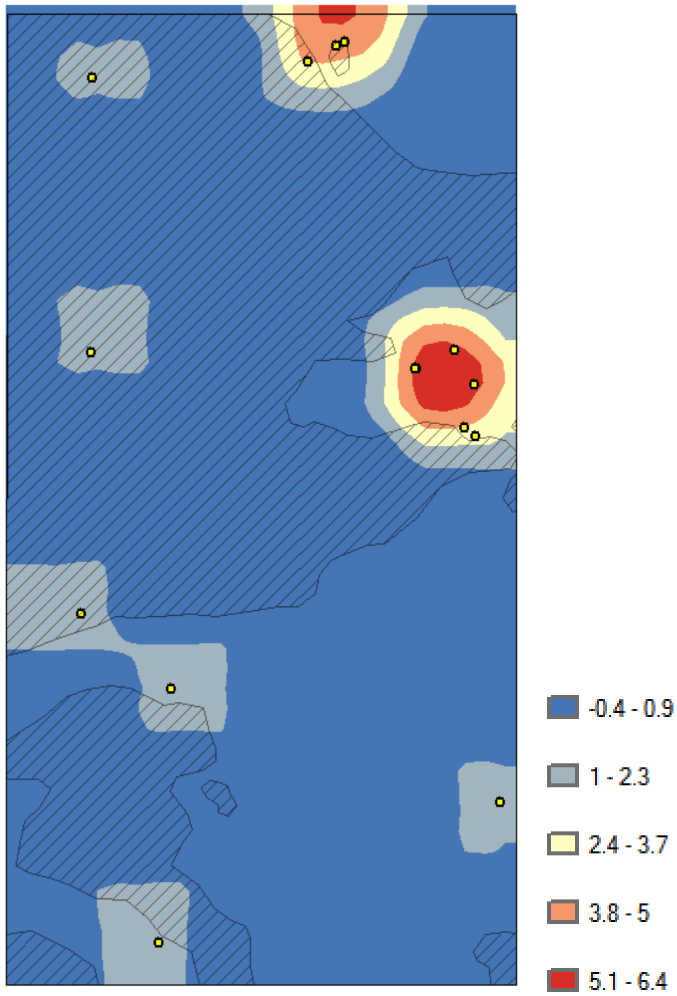


Figure 10: Pot density heat map of the pilot survey area. Yellow dots are targets. Colors indicate number of pots/80m^2. The hashed area is high backscatter; solid area is low backscatter.

An estimate for the total number of pots in the survey area was not calculated due to the low TPRs from Phase 1. Additionally, an estimate of the percent coverage required for a future survey was not determined, as the coverage would have to exceed that which was used in this study (150%), which would be impractical for conducting surveys.

Discussion

This project attempted to determine a lobster pot detection rate using side scan sonar to apply towards estimations of pot abundance in a pilot survey. Our detection efficiency was very low and therefore, not sufficient to use for pot abundance estimation or determination of the imaged area required for larger sonar surveys. This finding illustrates the importance of determining the detection rate when using sonar to survey for derelict fishing gear. Past projects have used sonar to find derelict pots and assist pot recovery efforts (Mcfadyen et al., 2009; SeaDoc Society, 2009; Center for Coastal Studies, 2014). However, in order to quantify overall abundance of derelict pots (and ultimately mortality associated with pots) using side scan sonar to count pots requires the sonar detection rate. Since side scan sonar has different detection capacity in simple and complex bottom, detection rates should be established for different habitat types. Research by Clark et al. (eds., 2012) used a side-scan sonar system to conduct 40 m width swaths (as compared to our 100 m width swaths) and identify placed pots in a flat (simple) habitat and coral reef (complex) habitat; detection rates were developed over each habitat type. Their results found high rates of detection over simple bottom and weaker rates of detections over complex bottom but these results were based on a small number of placed lobster pots over a single trial and using a very high resolution (duel frequency 900/1800 kHZ) side-scan sonar system. Additionally, most of the targets were identified with low confidence as being actual lobster pots and some pots were not detected; high FP results (the number of targets without a placed pot present) were identified during later surveys.

Our research also found better pot detection in simple bottom than complex bottom. The fraction of targets correctly marked compared to all pots present (TPR) was lower in complex bottom (Table 6), confirming previous conclusions about the difficulty of identifying pots in complex bottom (Clark et al. (eds.), 2012; Center for Coastal Studies, 2014). However, we found the TPR to be generally quite low, regardless of habitat type. We identified several potential factors explaining the TPR results:

1. Sonar limitations:

   Along with the low detection rate of placed pots, baseline and FP targets could not be consistently re-identified in trials and in the same location over multiple trials respectively illustrating the difficulty of using sonar to reliably detect pots (Table 5). While derelict pots were not verified visually, we are convinced they were indeed present, since a target was clear in multiple later trial mosaics. Likewise, when multiple FPs were marked in the same area on different trials, the sonar images did consistently have possible targets. However, the baseline targets and repeat FPs did not have consistent shapes and sizes in the sonar imagery trial to trial. These inconsistent dimensions between sonar imagery results are due to the angle that the target is captured and the sonar image distortion caused by poor sea state.

2. Inadequate data collection methods:

   Method improvements to detecting pots may be possible through increased sonar resolution and different standard operating protocols. We used a sonar frequency of 355 kHz which was adequate for identifying pots during the calibration work in simple habitat (Figure 2). In these optimal cases, the sonar analyst had awareness that the pots were present and we selected an area with flat bottom (no competing seafloor structures that might be identified as pots). However, for a blind pot survey (pot detection trials) conducted in a more complex habitat, the sonar imagery was inadequate to reliably differentiate pots from other targets. Placed pots were also sometimes identified in one direction but not in an overlapping swath from another direction, often due to image distortions (Figure 8). Likewise, baseline pots were not consistently identified over pot detection trials. Future use of side scan sonar to detect derelict pots may necessitate further assessment of the proper sonar resolution to get the best TPR. Instruments with higher sonar frequencies (on the e.g. 800 kHz) have higher imaging resolution. Higher resolution imagery should improve the likelihood of correctly identifying pots. Using higher frequency instruments typically requires more passes to cover the same area.

Increased sonar coverage may improve pot detections. More passes in different directions could increase the likelihood of identifying pots that may be obscured by the target being too close to the sonar's nadir and acoustic shadows cast in particular directions, especially in complex habitats. Increased passes require more surveying time and expense.

Some of the distortion in the sonar image was a result of the instrument pitching or rolling. Stricter work standards for acceptable sea state conditions may also improve the TPR. However, the frequency of suitable environmental conditions will limit the availability of side scan sonar work.

3. Sonar analyst capability:

We examined the evidence for learning in order to assess if the sonar analyst's experience was a factor. First, we observed that the TPR did not increase over time (as neither component of the TPR, TPs or FNs, seemed to improve over time) (Tables 4 and 6). We concluded that the analyst did not improve at correctly identifying placed pots from trial to trial. Sonar records were re-examined to determine why placed pots were often unidentified. This analysis is incomplete, but preliminary results show many examples where the sonar imagery distorts the target or misses it entirely when it is too close to or too far from the nadir. Images of objects scanned multiple times were frequently quite dissimilar in apparent size and shape, and sometimes absent (Figures 2 and 8). Additionally, the analyst seemed to exhibit bias towards a FN outcome in complex habitats where high densities of rocks appear similar to pots (Figure 11).

Figure 11: Example of an area that was a high risk for a FN result. The mosaic image is from trial 5 and shows an area of complex habitat. The yellow circle is the location buffer for placed pot #14 (a pot is present within the yellow circle).No active or baseline pots were present. No target was identified by the sonar analyst (FN).

Second, we observed that in the simple habitat, the sonar analyst's FP results did generally improve (decline) over time (Table 4), which is evidence that the sonar analyst improved at ignoring or not detecting possible pots that were not present in simple habitat. Targets in simple habitats are more conspicuous than in complex habitats (Figures 11 and 12) and the analyst may have improved at discerning pots from other structures in multiple passes over the same area.

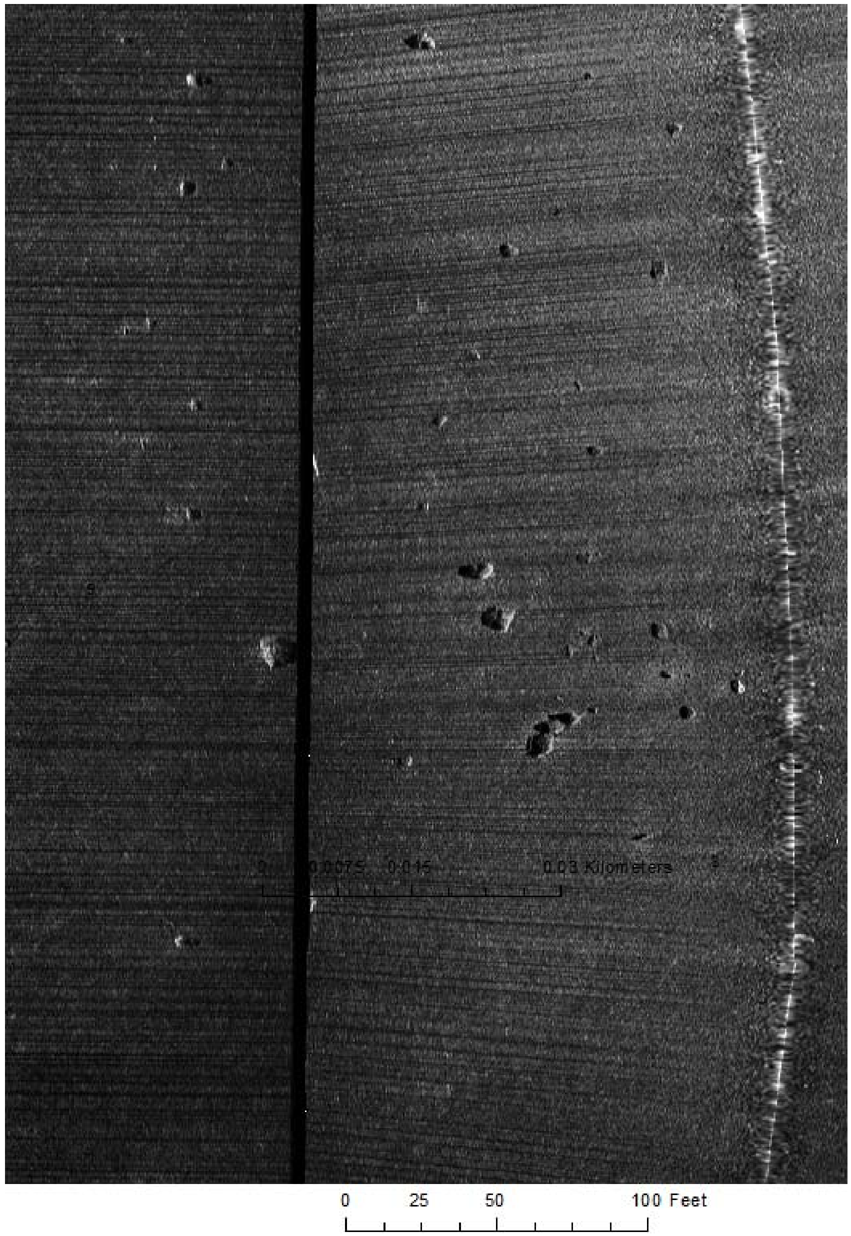


Figure 12: Example of an area that was a high risk for FP results. The mosaic image is from trial 3 and shows an area of simple habitat with some seafloor structures. Two targets were identified (on trials 1 and 6) even though no placed, active, or baseline pots were present (FPs).

Another way to more fully explore the impact of the sonar analyst's capability is to compare a more experienced analyst with a less experienced analyst, which was beyond the scope of this project. An analyst comparison is possible with the dataset collected from this study, as the raw data can replayed in SonarPro.

A total abundance of lobster pots was not estimated for the Phase 2 pilot survey as we felt that the TPR, the fraction of all placed pots that were correctly identified, was too low to create a weighting factor; any estimates of total abundance of derelict pots would be too misleading or inaccurate. Also, PPV, the fraction of correct targets over all targets, was low over both habitats (Table 6). Fewer targets were marked in complex substrate. The complexity of the bottom structure (e.g. increased reflective surfaces of rocks, cobble, etc.) made it difficult to distinguish between pots and other structures including rocks. Also, some pots were likely within large acoustic shadows of boulders and rocks on the seafloor, concealing them from detection.

Ideally, the false positive rate, or the fraction of targets incorrectly marked over all targets ($\frac{\mathrm{FP}}{\mathrm{FP+TN}}$), would be determined to measure the reliability of the sonar analyst (Carl Zeiss Meditec, Inc., 2012). This determination would require measuring the true negatives (TN), cases where no target is identified and no pots are present. To get TNs, a visually confirmation of the type of each target (pot, rock, etc.) could be made to confirm the absence of targets throughout the area. Visual surveys are time consuming and expensive. A reduced work area size could accommodate the time requirements for a verification survey but would also result in lower confidence when detection rates are applied towards pot quantity estimations in a larger area. Nevertheless, a smaller work area may be a realistic compromise to determine the actual TN numbers as well as confirming FPs.

Our results have demonstrated that in order to obtain a reliable detection rate we first need to improve our identification of derelict pots in the sonar record. In mixed and complex bottoms, we found that targets of similar shape and size as lobster pots were commonplace, and acoustic shadows inhibited detection by acoustic instruments. Even with methodological improvements, using sonar to identify pots may have limited utility in all but the most simple bottom types. Future work using side scan sonar to detect pots should carefully consider its efficacy and utility, not only for the success of the project but also for its applicability towards pot abundance estimation.

Outreach

Completed outreach consisted of a publication and two presentations at industry and scientist forums as listed below:

Chosid, D.M., M. Pol, K. Ford, S. Voss, R. Glenn. 2016. [presentation] ScanPot: Development of Side scan Sonar Methodology to Survey Derelict Lobster Pots in Simple and Complex Habitats. World Fisheries Congress. Session: Advances in fishing technology in support of sustainable fisheries. Busan, South Korea. Presented on 5/25/16.

Chosid, D.M. DMF News. Using Side scan Sonar to Find Lobster Pots. 1st and 2nd Quarters 2016, p. 12.

Glenn, R. [presentation] ScanPot: Development of Side scan Sonar Methodology to Survey Derelict Lobster Pots in Simple and Complex Habitats. Massachusetts Lobstermen's Association Annual Trade Show. Falmouth, MA. Presented 1/20/17.

We are also considering a methodology publication within a peer-reviewed journal, which would occur after the submission date of this final report.

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