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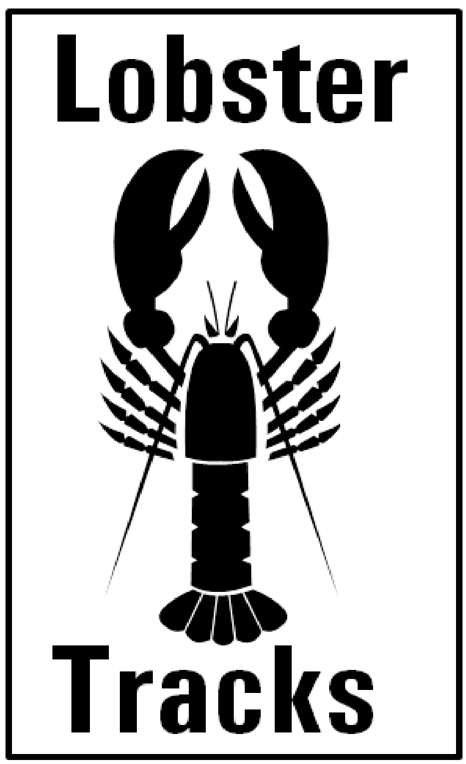
BOEM 2016-073

Spatial and Temporal Distributions of Lobsters and Crabs in the Rhode Island/Massachusetts Wind Energy Area



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Spatial and Temporal Distributions of Lobsters and Crabs in the Rhode Island Massachusetts Wind Energy Area

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Spatial and Temporal Distributions of Lobsters and Crabs in the Rhode Island Massachusetts Wind Energy Area

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Abbreviations and Acronyms

ASMFC	Atlantic States Marine Fisheries Commission
BOEM	Bureau of Ocean Energy Management
MADMF	Massachusetts Division of Marine Fisheries
OCS	Outer Continental Shelf
RIDEM	Rhode Island Department of Environmental Management
RIS	Rhode Island Sound
SNECVTS	Southern New England Cooperative Ventless Trap Survey
WEA	Wind Energy Area

1. Introduction

A goal of marine spatial planning is to aid in siting activities in areas that will minimize, to the extent possible, the cumulative impacts on resident species while maintaining the ecological and economic services derived from near-shore regions (Crowder & Norse 2008). A core challenge of developing a spatial management plan is the acquisition of knowledge concerning the distributions, population structures, interactions and trends of key species and communities (Foley et al. 2010). Some work addressing these knowledge gaps has been undertaken in the vicinity of the study area for this project, the Rhode Island/Massachusetts Wind Energy Area (RI/MA Lease Area) in Southern New England. Rhode Island's Ocean Special Area Management Plan compiled the available knowledge of finfish, shellfish and fisheries in the offshore waters of RI (Olsen et al. 2014). Trawl surveys throughout Rhode Island Sound and Block Island Sound have begun to characterize fish populations (Malek et al. 2014), but spatial coverage is limited by the presence of fixed fishing gear, such as gillnets and lobster trawls, and the inaccessibility of rocky bottom. Consequently, the distribution and dynamics of the American lobster (*Homarus americanus*), one of the most valuable species in New England, is poorly understood (ASMFC 2009). With the leasing of areas for offshore wind-energy development, it is essential to evaluate the baseline status of the lobster population in the RI/MA Lease Area, to inform the siting of wind turbines within the lease area and to monitor the potential impacts of wind turbine construction.

The American lobster fishery remains one of the most valuable fisheries in Southern New England, with 2013 landings of 3.3 million pounds worth $15 million in revenue (ASMFC 2015). Massachusetts and Rhode Island are the primary contributors to the Southern New England lobster fishery, supporting fleets of 1500 and 250 vessels, respectively (MADMF 2010, Hasbrouck et al. 2011). In addition to nearly 2000 commercial fishing jobs, the southern New England lobster fishery also sustains a variety of support businesses, such as trap-builders, gear suppliers, bait and ice dealers, shipyards, fuel companies, engine sales and repair businesses, and marine electronic retailers. Since peaking in the late 1990s, the Southern New England lobster stock has become severely depleted, especially the inshore component of the stock, where environmental conditions have remained unfavorable for lobsters (ASMFC 2015). Since 2008, a higher percentage of landings has come from the offshore stock component.

This report is a product of the Southern New England Cooperative Ventless Trap Survey (SNECVTS) which developed a baseline for measuring the cumulative effects of offshore development projects in the RI/MA Lease Area. In addition, the survey was designed to contribute to the assessment of the Southern New England lobster stock, which is currently at a low level of abundance (ASMFC 2010). The study was necessary to establish the pre-construction status of the lobster population, without which potential effects post construction would not be discernable from the effects of fishing and other population stressors (Schmitt & Osenberg 1998). To the extent possible, this project followed ASMFC survey protocols and adhered to the Atlantic Coastal Cooperative Statistics Program data requirements.

1.1 Project objectives

The objectives of this two-year study were as follows:

a. Establish a ventless trap survey protocol to assess the potential impacts of wind energy development in the RI/MA Lease Area and the northwestern portion of Massachusetts Lease Area.

b. Determine the seasonal and spatial patterns of lobster abundance within these development areas.

c. Conduct two years of pre-development monitoring that will allow Before-After and Control-Impact (BACI) comparisons to be made. This monitoring survey will establish pre-construction conditions. Continuation of monitoring during construction and post-construction will assess possible impacts in the context of a regional database.

2. Survey Design and Description

This survey was a cooperative project that included representatives of the Rhode Island lobster industry, the University of Rhode Island, and Roger Williams University. The vessel captains and their fishing vessels are:

Lanny Dellinger, F/V Megan and Kelsey, Newport, RI
Greg Mataronas, F/V Cailyn Grace, Sakonnet Point, RI
Brian Thibeault, F/V Ashley Ann, Point Judith, RI

Twenty-four lease blocks in the RI/MA Lease Area were selected for this study after discussions with BOEM and lobster industry representatives (black boxes Fig. 1). These blocks were selected based on their potential development for wind energy, and the practicality of conducting a monitoring survey with lobster boats. In consultation with the lobstermen, five aliquots (1/16 of a BOEM lease block) that would be suitable for the survey were selected from each lease block, given known fishing grounds and gear conflicts. One of these five aliquots from each lease block was randomly chosen for sampling, along with another aliquot as an alternate. A new set of sampling aliquots was randomly chosen each year (2014 and 2015), for a total of 48 aliquots (Fig. 2). This sampling design provided a broad coverage over the selected lease blocks with randomized placement within each lease block. This stratified random design allows the results from the selected stations to be generalized over the study area. The sampling density translates to one station per 9 square nautical miles. The coordinates of the selected aliquots are listed in Appendix 3.

The sampling design employed in this project is consistent with Atlantic States Marine Fisheries Commission (ASMFC 2010) ventless trap survey, in which stations are selected randomly at the start of the season and are then retained for the duration of the year. New stations are then randomly selected each year. Maintaining fixed locations approximates the operations of commercial lobstermen, keeps the locations occupied, and reduces the time spent moving gear.

2.1 Description of the sampling gear

Trap design

- 40” length × 21” width × 16” height
- Single parlor
- 5” entrance hoops
- 1” square rubber coated 12-gauge wire
- Standard shrimp mesh netting
- Wood runners with three “ergo” blocks
- 4” × 6” disabling door
- One rectangular vent with dimensions 5-3/4” length × 1-15/16” height

This trap design is consistent with ASMFC coastwide, ventless trap surveys (ASMFC 2010). Traps were deployed on ten-pot trawls with 100-ft separation between traps. Six ventless traps were alternated with four standard traps so that the data can be compared with commercial catch rates, resulting in a trap pattern of (V-S-V-S-V-V-S-V-S-V). Longer trawls are required offshore (than inshore) to provide more total weight and for ease of recovery in the event that buoys are lost.

3. Summary of Biological Sampling

Given the spatial extent of the study area, three commercial lobster boats were needed to conduct the survey. An additional vessel was on standby in case of mechanical problems with the primary vessels. Each boat was responsible for eight trawls (80 traps) in a particular segment of the overall study area (Fig. 2). Each boat sampled eight stations over four days each month. The first day was allocated to baiting the traps with skate and the remaining three days to sampling the lobsters. The target soak time (number of days between baiting and sampling) was five days, which differs from the three-day soak time used in state ventless trap surveys. A longer soak time was used because lower densities of lobsters were expected offshore compared with inshore areas of Maine and Massachusetts, and because of the logistics of sampling offshore. After the third sampling day, the traps were disabled for the remainder of the month. On-board data sampling was conducted by two qualified biologists. Data were collected on audio recorders and transcribed onto computer tablets. Over the course of two years, a total of 8640 trap hauls were sampled.

Table 1. Frequency of soak times by year.

Year	4 Days	5 Days	6 Days	7 Days	Totals
2014	1	343	56	24	432
2015	48	272	104	8	432

All trap hauls were made within the acceptable window of 3 to 7-day soak time (Table 1). The majority of soak times were 5 days; deviations from the target were due to adverse weather conditions.

3.1 Data parameters collected for individual lobsters:

- Carapace length (mm) measured with calipers
- Sex (determined by examining the first pair of swimmerets)
- Presence or absence of eggs
- Cull status (claws missing, buds, or regenerated)
- V-notch status (presence or absence)
- Mortality (alive or dead)
- Incidence of shell disease (none, moderate, severe)

Legal sized lobsters were not retained for sale. All lobsters were returned to the water in the area where they were caught before moving to the next station. The target species was lobster, but crabs and demersal fish species were also enumerated as "bycatch." Up to 10 Jonah crabs (*Cancer borealis*) per trap were measured and their sex recorded; if more than 10 Jonah crabs were caught, a subsample of 10 was measured. The physical variables collected at each station included latitude, longitude, depth, temperature, sea state, and wind direction and velocity. Bottom temperature was measured with data loggers, one of which was attached to each trawl. Wind direction and velocity were measured with a hand-held weather meter.

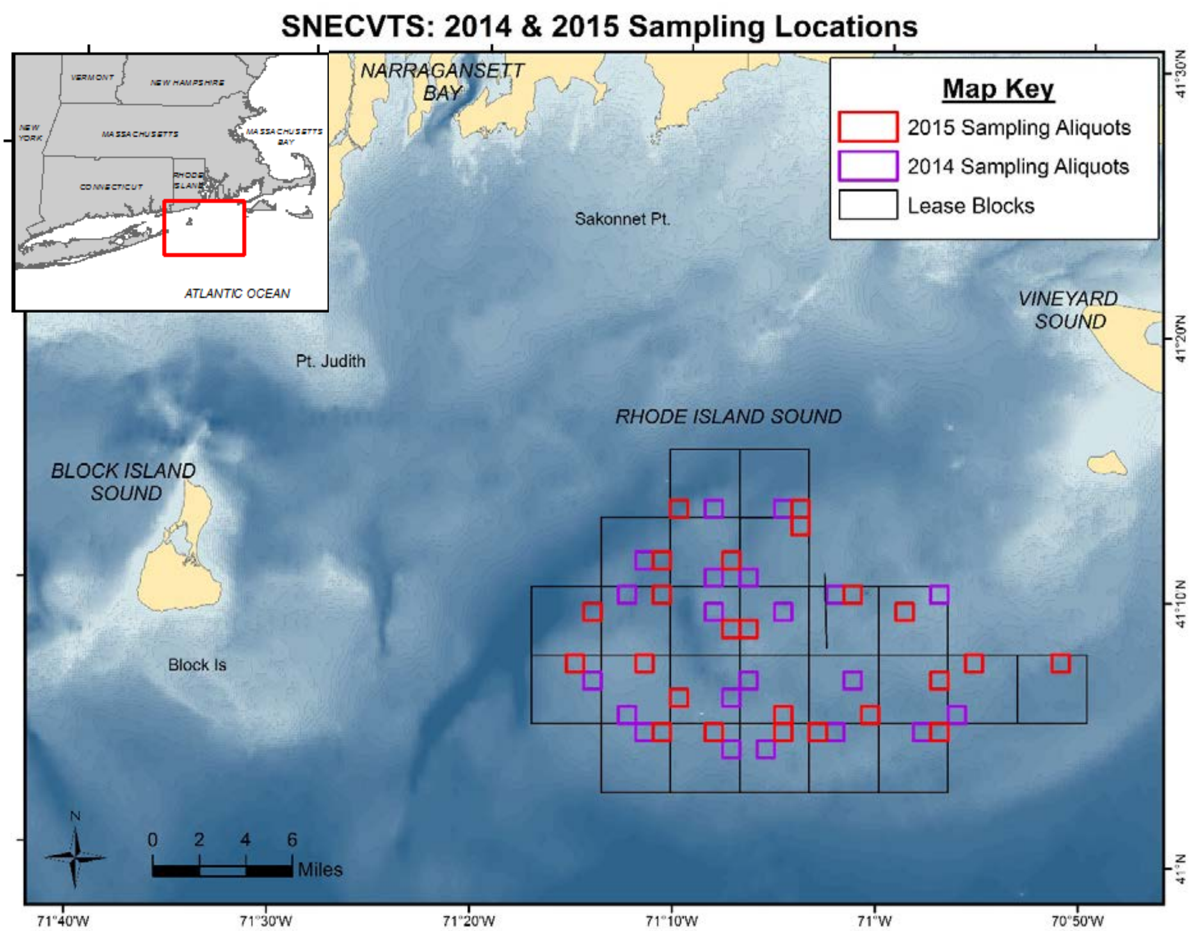

Figure 1. Study site in the Rhode Island/Massachusetts Lease Area. Coordinates and depths of the sampling locations are given in Appendix 3.

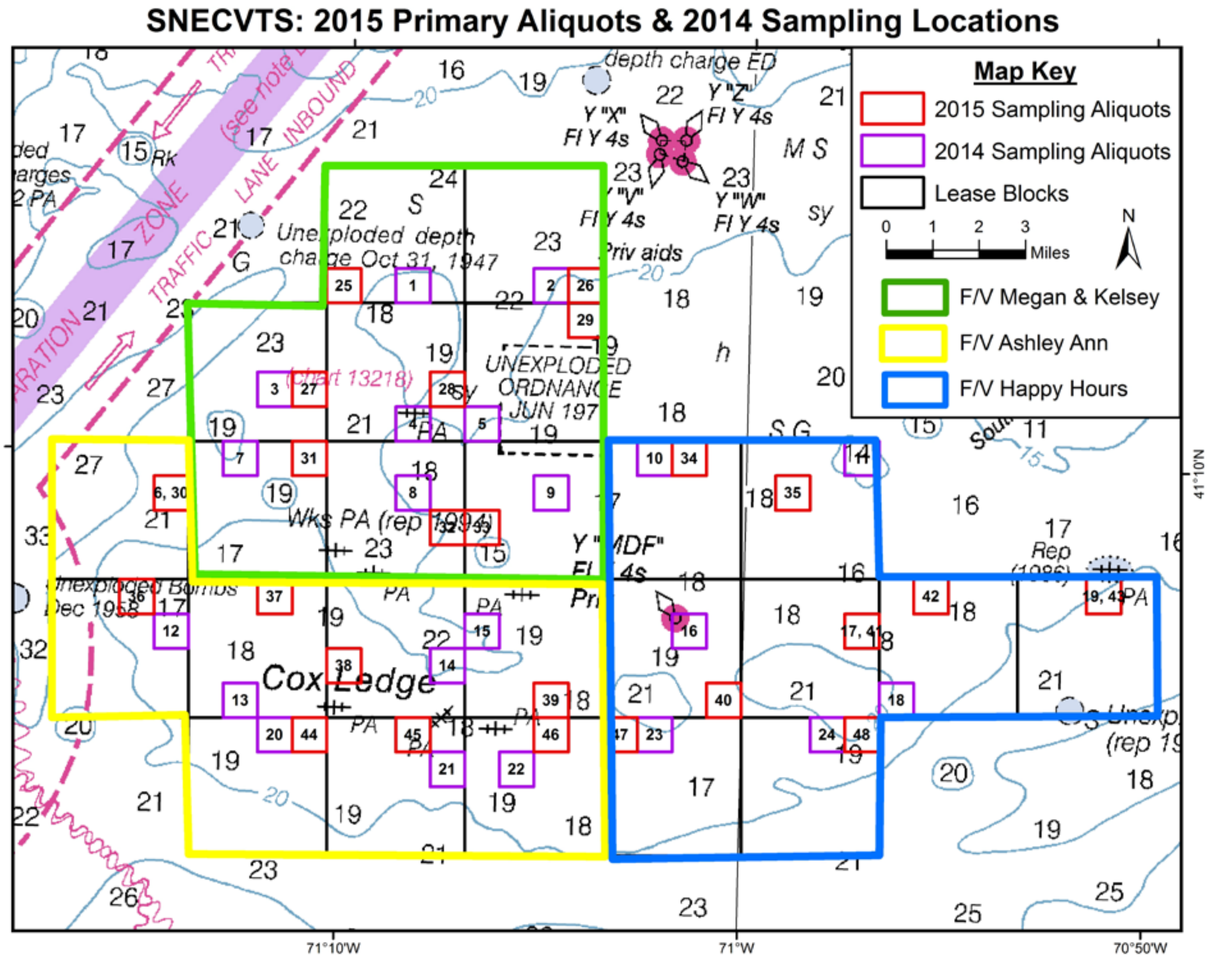

Figure 2. Detail of the study area showing the 24 lease blocks (black boxes), the 2014 aliquots (purple boxes), and the 2015 aliquots (red boxes). Note that three 2015 aliquots (30, 41, and 43) were repeats from 2014; all the other aliquots were distinct.

4. Habitat Studies and Classification

The sedimentary composition of each sampling site was characterized with sidescan sonar, followed by ground-truth data consisting of three grab samples taken along the transect where the traps were set. In addition, a video camera on the grab sampler provided visual confirmation of habitat type.

4.1 Mapping

The sidescan sonar survey was conducted with a Teledyne Benthos 200 kHz C3D interferometric sonar, pole-mounted along the starboard side of a 42-ft survey vessel. Data were collected with GeoDas software developed by Ocean Imaging Consultants (OIC) and monitored topside in real-time to ensure that adequate data quality and coverage were being achieved. The data were collected in association with an Applanix POS MV system to assure positional accuracy and to correct for vessel motion (pitch, roll, heave). The survey was designed to cover the lobster trap sites and some of the surrounding area within the aliquot sites for context. As such, the survey design at each of the 48 sites was composed of two parallel track lines approximately 600-800 m in length. Depending on survey conditions, line spacing was set to 100 m or 150 m and sonar swath range was set to 130 m or 200 m, respectively, to ensure overlap with adjacent lines for full-coverage data.

The raw sidescan records were processed with OIC CleanSweep software. The process followed standard techniques of bottom-tracking the data and then applying angle-varying gains (AVG) and look-up tables (LUT) as necessary to correct for water-column returns, arrival angle, and contrast to produce color-balanced sidescan sonar images. All of the data were examined manually to confirm quality and accuracy. The horizontal coordinate system was set to UTM Zone 19N and the data were exported at 1-m pixel resolution. The images are displayed as an inverse gold color scale, with pixel values ranging from zero (dark gold) to 255 (white). The lighter pixels indicate hard acoustic returns and represent the presence of hard surficial sediments (e.g. coarse sand, cobbles, and boulders), whereas darker pixels represent the presence of soft sediments, which tend to absorb sound to a greater degree.

4.2 Ground-truth

The ground-truth survey consisted of two components: grab samples and video. Surficial samples of the seafloor, or “grab samples” were collected with a Smith-McIntyre grab sampler (0.058 m^2 area). In addition, a GoPro camera was affixed to the grab sampler to simultaneously capture co-located high-definition video imagery. Ground-truth data were collected at three locations within each site, except when sites from 2014 and 2015 overlapped (this occurred three times), for a total of 135 samples at 45 sites. The locations were chosen by visual examination of the sidescan sonar imagery and positioned to capture all distinct geophysical bottom types at a site. If the bottom type was consistent throughout the site, then the ground-truth locations were about evenly spaced over the site.

A sub-sample of sediment from each grab sample was analyzed with a particle size analyzer (Malvern Mastersizer 2000E). The analyzer provided the percent composition of sediment grain size fractions (excluding gravel) according to the Wentworth scale (Wentworth 1922). Dominant grain sizes fell into the following categories: clay, silt, fine sand, medium sand and coarse sand. The remaining material from each sample was sieved on a 1-mm mesh sieve; the organisms retained were preserved in a solution of formalin and rose bengal and archived for future benthic biological community analysis.

4.3 Data Integration and Aliquot Bottom Type Classification

Habitat categories were chosen that are relevant to this lobster study and also consistent with the substrate component of the CMECS classification framework. The substrate component was the only component that could be applied to the datasets collected for this study (Table 2). Substrate component classifications from this study were cross-validated in areas within Rhode Island and Block Island Sounds where the CMECS classification framework had been applied in previous studies (LaFrance et al. 2010; LaFrance et al. 2014). This validation was done to confirm the interpretations from this project and to ensure consistency in the classification. Previous comparisons and analyses within the study area of this project have shown that the surface sediment typically falls into one of two categories: fine sediments (which includes clay, silt, very fine sand, and fine sand) and coarse sediments (which includes medium sand, coarse sand, and very coarse sand).

Still frames from the GoPro video footage were analyzed to visually determine a bottom-type description at each ground-truth site. Records of habitat characteristics included the following components when available: general surficial sediment type (e.g. sandy bottom), presence and extent of gravel cover from granule to boulder size, presence of shell hash, and observable macro-biota. In addition, qualitative descriptions of grab samples (Appendix 2) were used to supplement video analysis, particularly when visibility in video footage was limited. Sidescan sonar images were also used to differentiate between sample sites with and without large boulders. When possible, video footage was in turn used to corroborate these classifications; i.e. when boulders were evident in video footage, boulders were consistently present in corresponding sonar images.

Once analysis of the sidescan sonar, sediment grain size, and video data was completed, the various datasets were integrated and used to characterize the bottom type of each ground-truth sample site. The first step in this process was to confirm agreement between the data types at each site; once this confirmation was completed, sample sites were classified according to dominant sediment grain size and presence of boulders. The bottom type for each lobster sampling aliquot was determined by integrating habitat data from all three of its ground-truth sample sites.

Table 2. CMECS Substrate Component Classification for all bottom type categories defined in this study.

Component Code	Unit Code	Origin	Class	Subclass	Group	Subgroup
S	1.2.2	Geologic Substrate	Unconsolidated Mineral Substrate	Fine Unconsolidated Substrate	See below	See below

CMECS Substrate Component 'Group' and 'Subgroup' Classifications defining Bottom Type Categories

Bottom Type Category	Unit Code	Group	Subgroup	CMECS Modifier
Soft Sediment	1.2.2.2.4	Sand	Fine Sand	
	1.2.2.2.5	Sand	Very Fine Sand	
	1.2.2.3.1-3	Muddy Sand	Silty Sand, Silty-Clayey Sand	
	1.2.2.4.1-3	Sandy Mud	Sandy Silt, Sandy Silt-Clay, Sandy Clay	
	1.2.2.5.1-3	Mud	Silt, Silt-Clay, Clay	
Medium to Coarse Sand	1.2.2.2.1	Sand	Very Coarse Sand	
	1.2.2.2.2	Sand	Coarse Sand	
	1.2.2.2.3	Sand	Medium Sand	
Boulders on Sand	1.2.2.2.2	Sand	Very Coarse Sand	Boulders
	1.2.2.2.3	Sand	Coarse Sand	Boulders
Transition Zone*	Combination of above categories			

*Transition Zone indicates that the habitat encompasses more than one of the other habitat categories

The number of bottom-type categories was not pre-defined; instead, aliquots with similar characteristics were grouped together as appropriate. The bottom-type categories were given names believed to be meaningful to the end user. Four habitat categories were generated: soft sediments (comprising clay, silt, very fine sand, and fine sand), medium to coarse sand (comprising of medium, coarse, and very coarse sands), boulders on sand (boulders on medium to coarse sand), and transition zone (where a change in bottom type was evident within an aliquot). These categories along with their corresponding CMECS classifications are given in Table 2.

The habitat classification of each aliquot is listed in Appendix 3 and mapped in Fig. 3. Bottom types are patchily distributed throughout the lease area. Medium to coarse sand occurs throughout the study area. Soft sediments are confined to the northern, deeper aliquots. Boulders on sand occurred in the southwest and central aliquots. Finally, the transition zone habitat occurred in two central and two eastern aliquots. Figures 4 through 7 show representative examples of each habitat type.

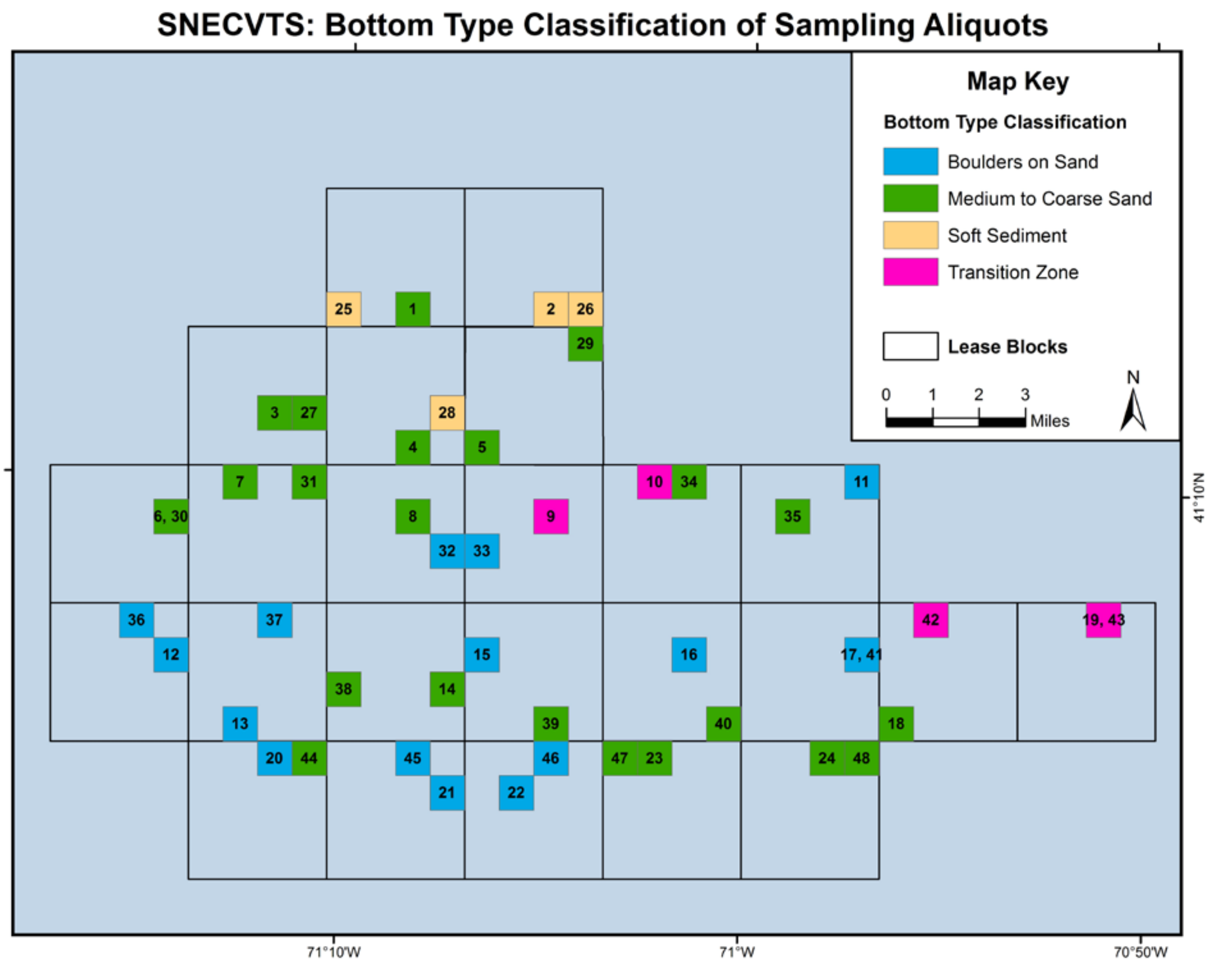

Figure 3. Bottom type classifications of aliquots sampled by SNECVTS.

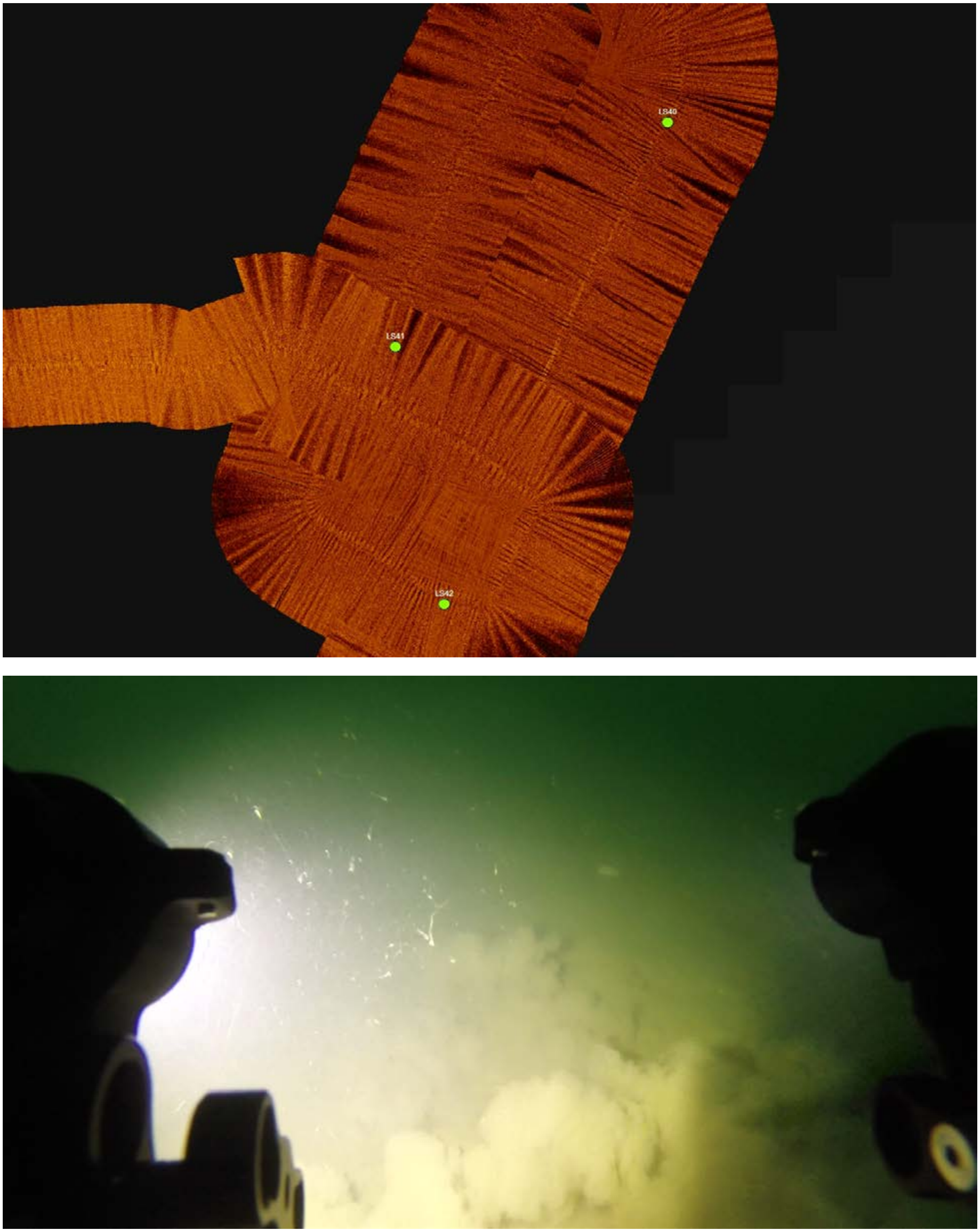

Figure 4. Sidescan sonar of Aliquot 2 and bottom photograph taken at grab-sample station 41, representing the “soft sediments” category.

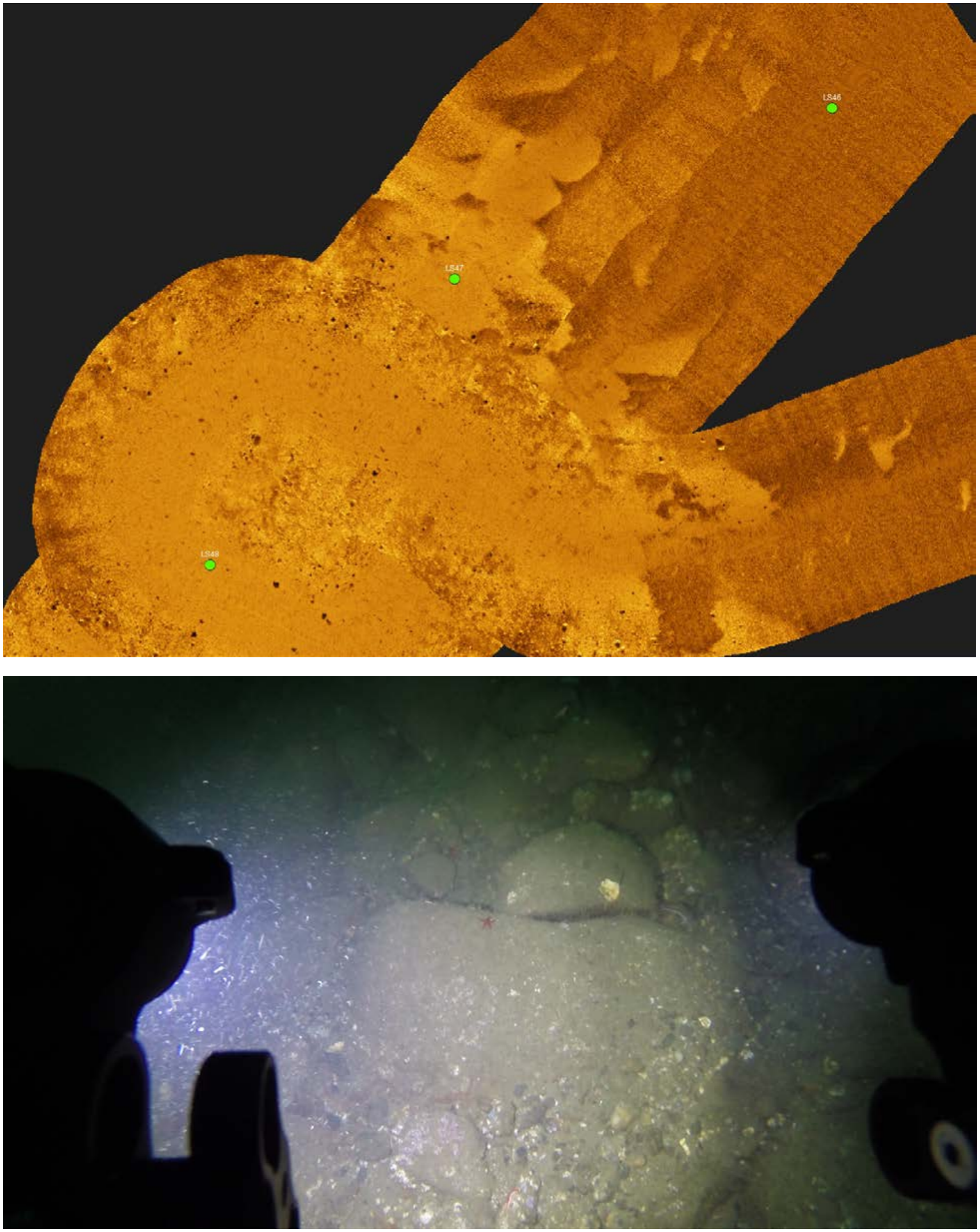

Figure 5. Sidescan sonar of Aliquot 9 showing the transition from sand to boulders and bottom photograph of the “boulder on sand” category taken at grab-sample station 48.

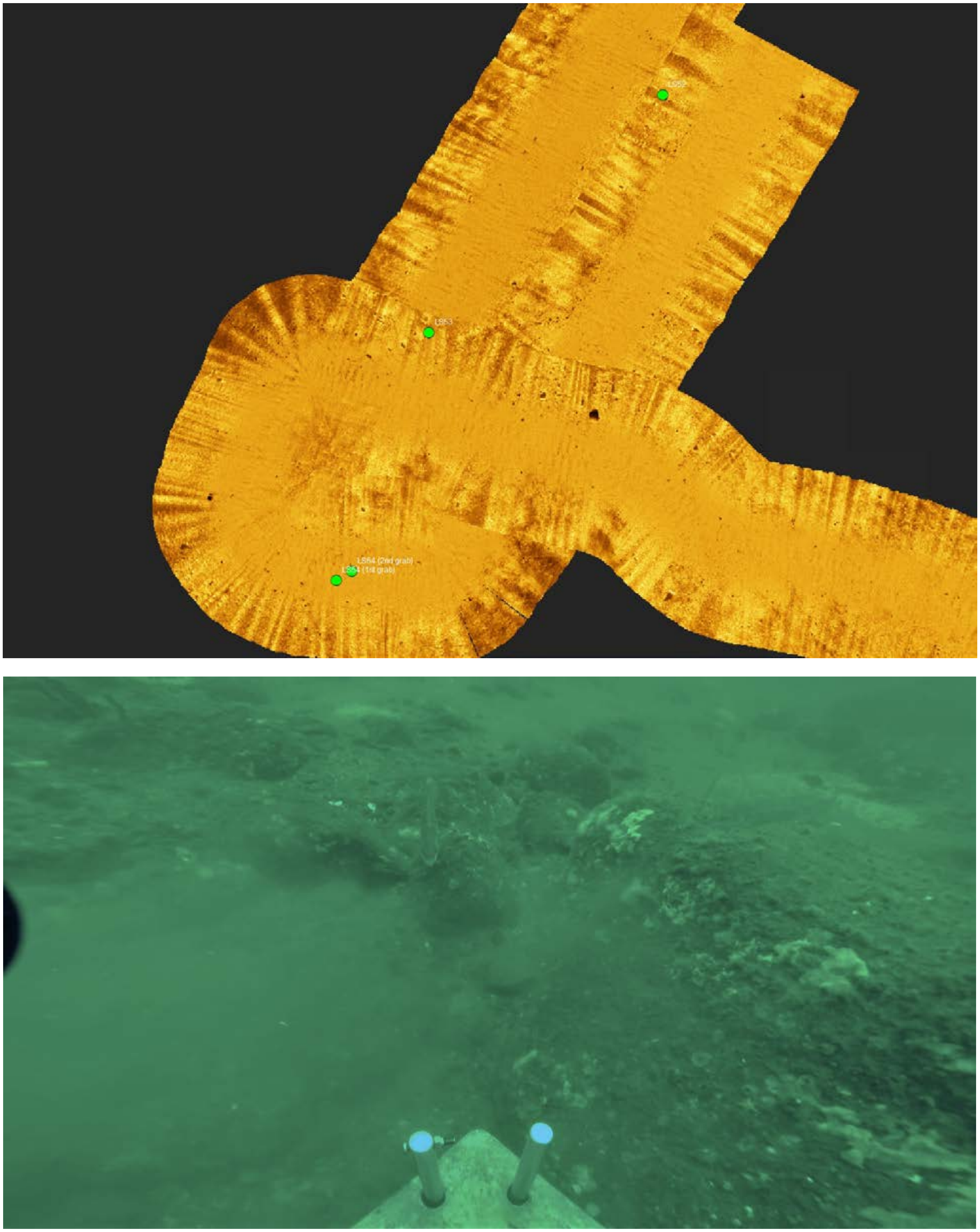

Figure 6. Sidescan sonar of Aliquot 11 and bottom photograph taken at grab-sample station 54, showing a boulder habitat.

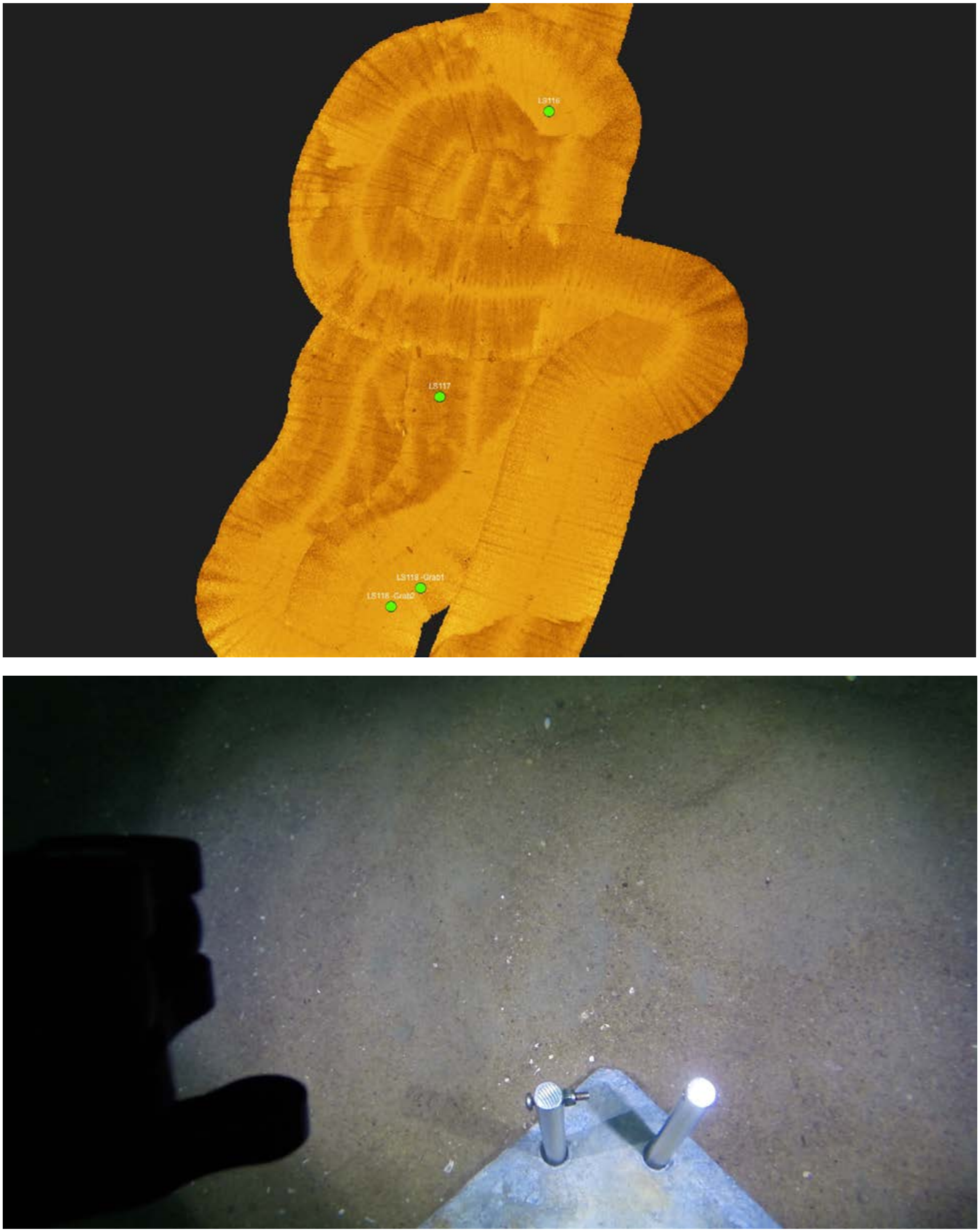

Figure 7. Sidescan sonar of Aliquot 38 and bottom photograph taken at grab-sample station 118, illustrating the “medium to course sand” category.

5. Bottom temperature

Continuous records of bottom temperature were made from May to October in each aliquot. The raw data were collected at 30-minute intervals. They have been averaged over daily intervals (Fig. 8) for comparison with the lobster catches and over monthly intervals for presentation (Fig. 9). In May the shallower, eastern aliquots warm more quickly than the western, deeper aliquots. This temperature gradient is maintained throughout the summer, until the bottom water begins to cool. In October, the shallower, eastern aliquots cool more rapidly than the deeper, western aliquots.

Following the cold winter of 2015, bottom-water temperatures were several degrees cooler in May 2015 than in May 2014 (Fig. 8). After rapid warming, bottom temperatures in June 2015 were equivalent to June 2014. The maximum temperature reached was lower in 2015 than in 2014, when bottom temperature exceeded 20° C in aliquots 23 and 24 at the end of September.

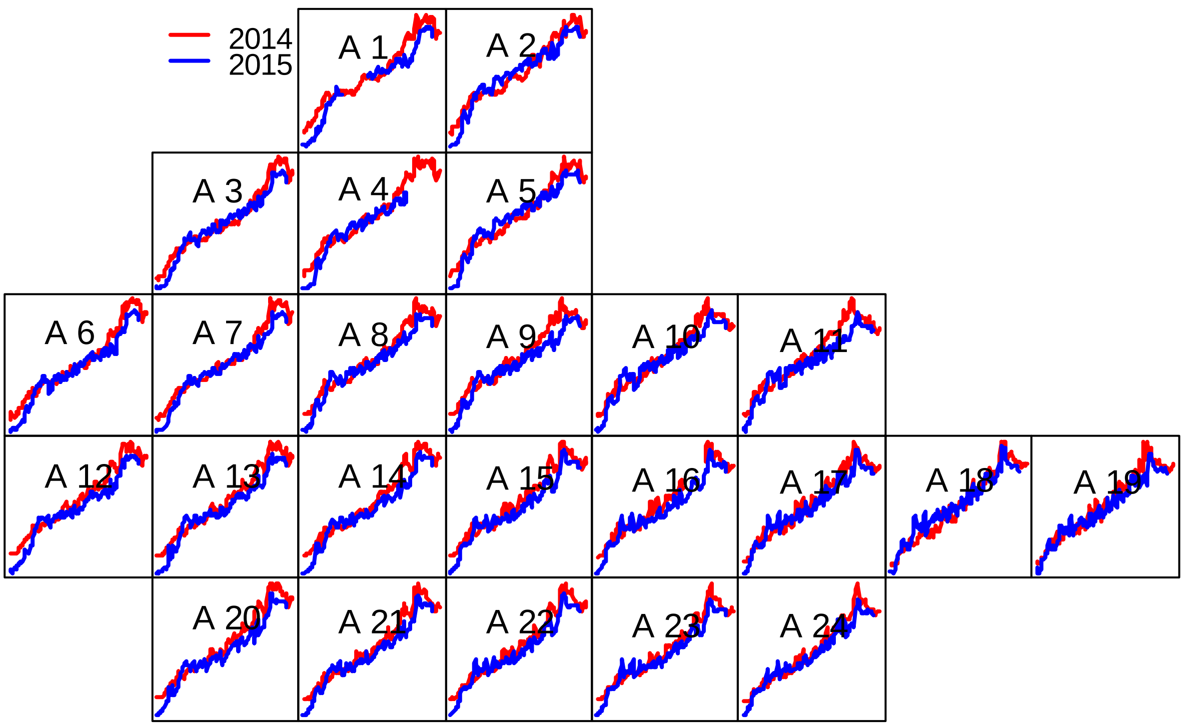

Figure 8. Daily bottom temperatures at each aliquot in 2014 and 2015. The boxes correspond with the lease blocks shown in Fig. 2.

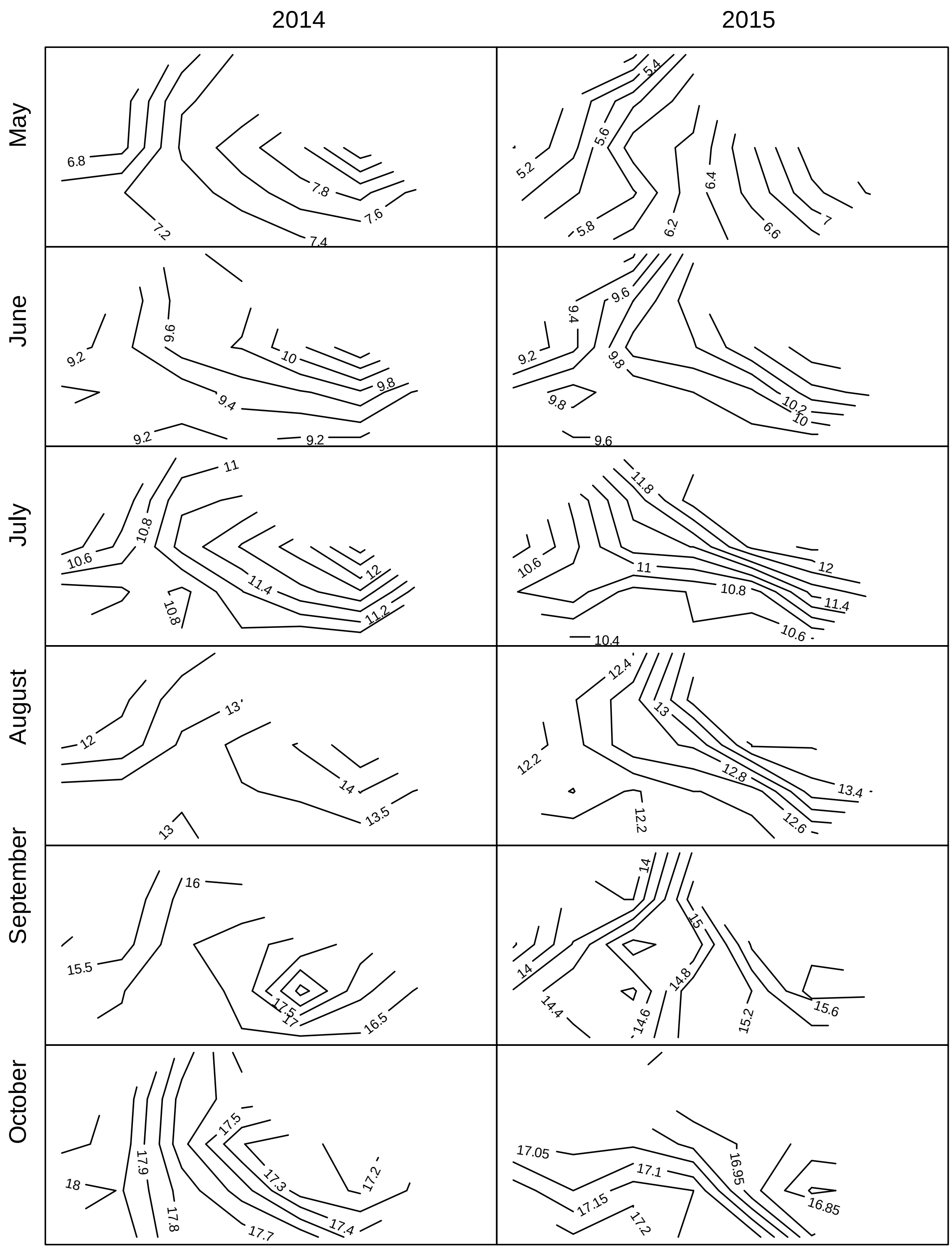

Figure 9. Bottom temperature by month and year. Each subplot corresponds with the study area shown in Fig. 2. The lines are contours of bottom temperature in degrees Celsius.

6. Lobster Statistics

In general, lobster catches were higher on the eastern side of the study area (Fig. 10). In 2014 the highest lobster catches were from aliquots 10 and 11 (Table 3), which are located in the northeast of the lease block area (refer to Fig. 2). High catches were also obtained from aliquots 2, 9, and 17, which are also on the northeast side of the lease block area. In 2015, the total lobster catch was slightly lower and the catches were distributed more evenly across aliquots. The highest catches were obtained in aliquots 41 and 42, which are on the east side of the study area. High catches were also obtained from aliquots 26, 30, 35, 40, and 43.

Table 3. Total catches of lobsters and Jonah crabs by year and aliquot. Note that aliquots in the same row are in the same lease blocks. Aliquots 6 and 30, 17 and 41, and 19 and 43 refer to the same aliquots in different years.

2014			2015		
Aliquot	Lobsters	Jonah Crabs	Aliquot	Lobsters	Jonah Crabs
1	495	1482	25	376	1342
2	663	1604	26	449	1167
3	444	1600	27	333	1049
4	304	1213	28	469	1157
5	529	1224	29	428	1318
6	424	2136	30	464	1138
7	241	1544	31	276	1068
8	245	1443	32	337	835
9	627	1257	33	299	932
10	1235	1246	34	284	1587
11	1140	1067	35	437	1014
12	340	531	36	354	325
13	221	725	37	158	660
14	309	3197	38	252	830
15	434	890	39	409	913
16	685	1390	40	430	496
17	801	740	41	594	431
18	374	655	42	889	396
19	197	1367	43	449	664
20	207	787	44	182	972
21	173	1749	45	385	913
22	180	1953	46	326	717
23	235	1091	47	206	960
24	253	583	48	288	349
Totals	10,756	31,474		9,074	21,233

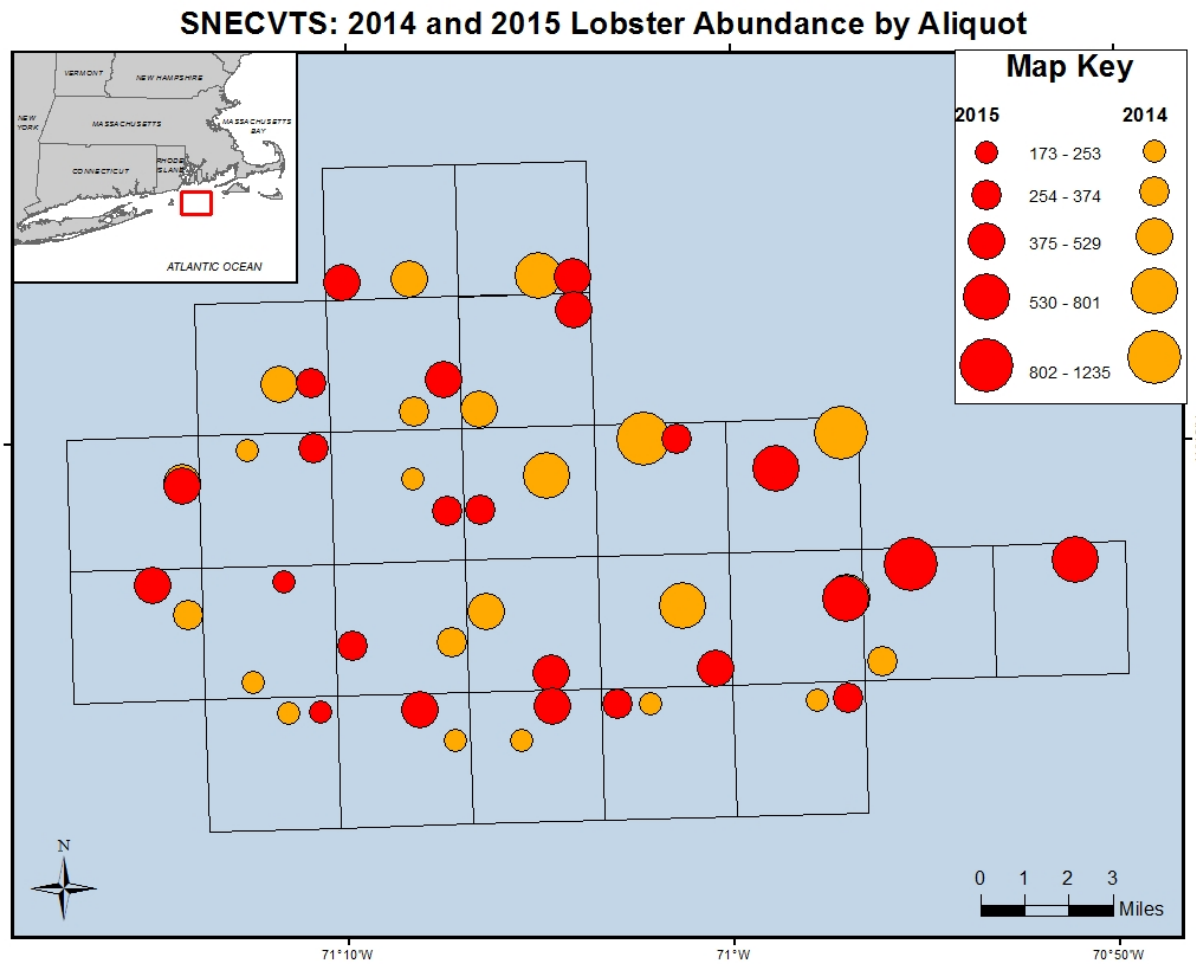

Figure 10. Lobster abundance in 2014 and 2015 by aliquot.

Table 4. Sex ratio and percent of female lobsters with eggs by year and month.

Year	Month	Female	Male	Percent female	Eggers	% females with eggs
2014	May	357	60	85.61	231	64.71
	June	668	120	84.77	231	34.58
	July	1336	936	58.80	93	6.96
	August	1772	1451	54.98	56	3.16
	September	1386	1177	54.08	176	12.70
	October	966	527	64.70	253	26.19
2015	May	199	36	84.68	132	66.33
	June	279	128	68.55	149	53.41
	July	535	554	49.13	44	8.22
	August	1329	1540	46.32	37	2.78
	September	1293	1515	46.04	112	8.66
	October	886	778	53.25	237	26.75

Lobster catches in the SNECVTS survey were dominated by females in spring and early summer (Table 4). In both years the percentage of females started at about 85% in May and decreased toward an equal sex ratio in July through September. The percentage of females increased again in October. In 2014, the percentage of females never decreased below 50%, whereas in 2015 it decreased to 46%. The percentage of females with eggs was highest in May when females dominated the catches. Females incubate their eggs until the larvae hatch from mid-May to mid-June (ASMFC 2015). The percent of females with eggs declined to a minimum in August and then increased to 26% in October of both years, as the next generation was incubated. The dominance of females in May and June can therefore largely be explained by the presence of egg-bearing females, which are protected from capture. Given the high exploitation rates of legal-sized lobsters, these females rapidly disappear from the population once they shed their eggs.

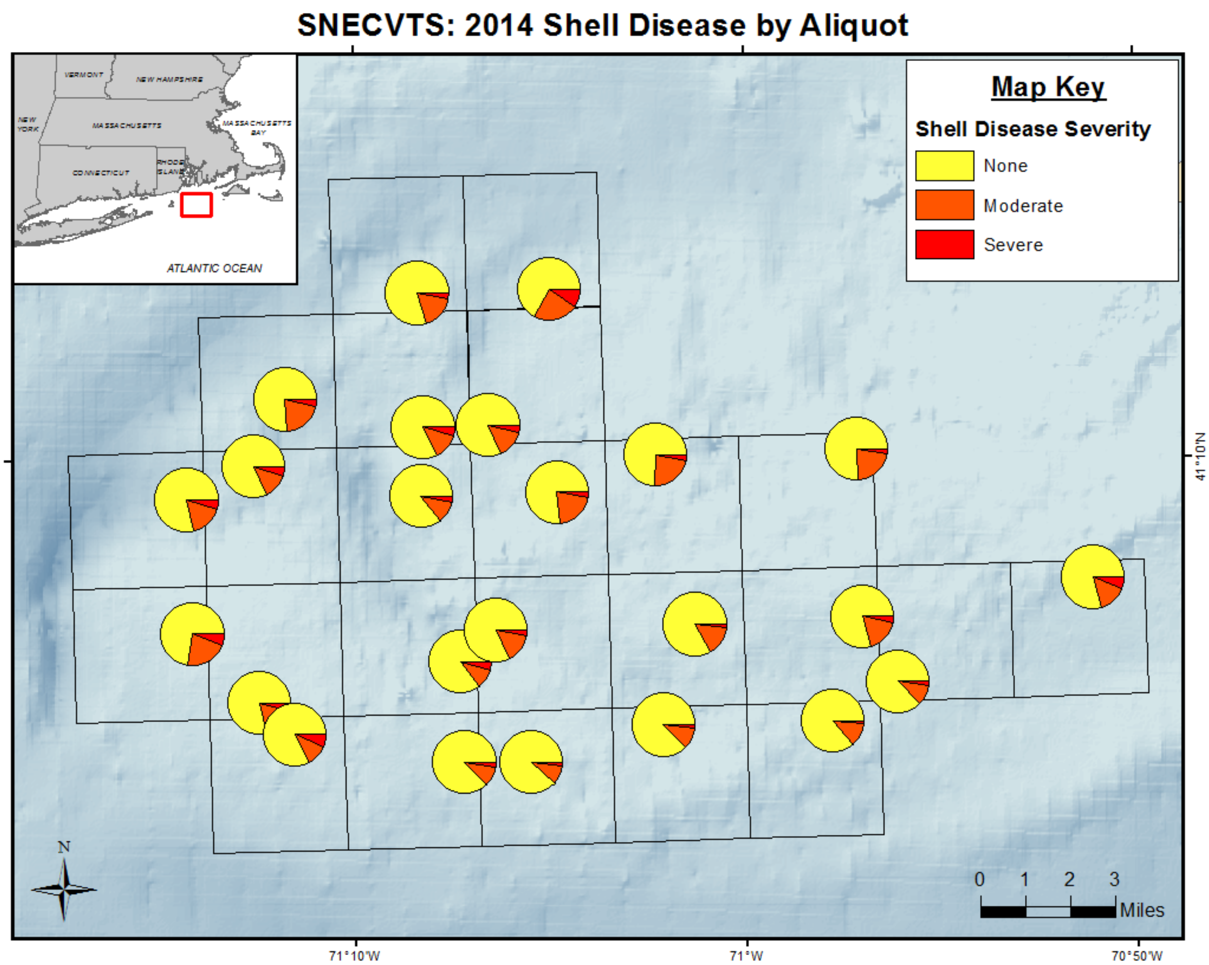

Figure 11. Incidence of shell disease by aliquot in 2014.

The incidence of shell disease was generally low in the SNECVTS survey. In 2014, shell disease incidence was lower in the offshore aliquots (Fig. 11). In 2015, shell disease incidence was lower overall, especially on the eastern side of the lease block area (Fig. 12). Lower incidence of shell disease in 2015 could be explained by lower bottom water temperature in spring 2015 (Figs. 8 and 9). The incidence of severe shell disease was higher in the near-shore lease blocks.

Shell disease incidence was highest in May to June, and then decreased below 10% in August and September as more of the lobsters had recently molted (Table 5). Following the molting period, shell disease incidence increased moderately in October. The incidence of shell disease therefore follows the annual molt cycle of lobsters (Castro and Angell 2000).

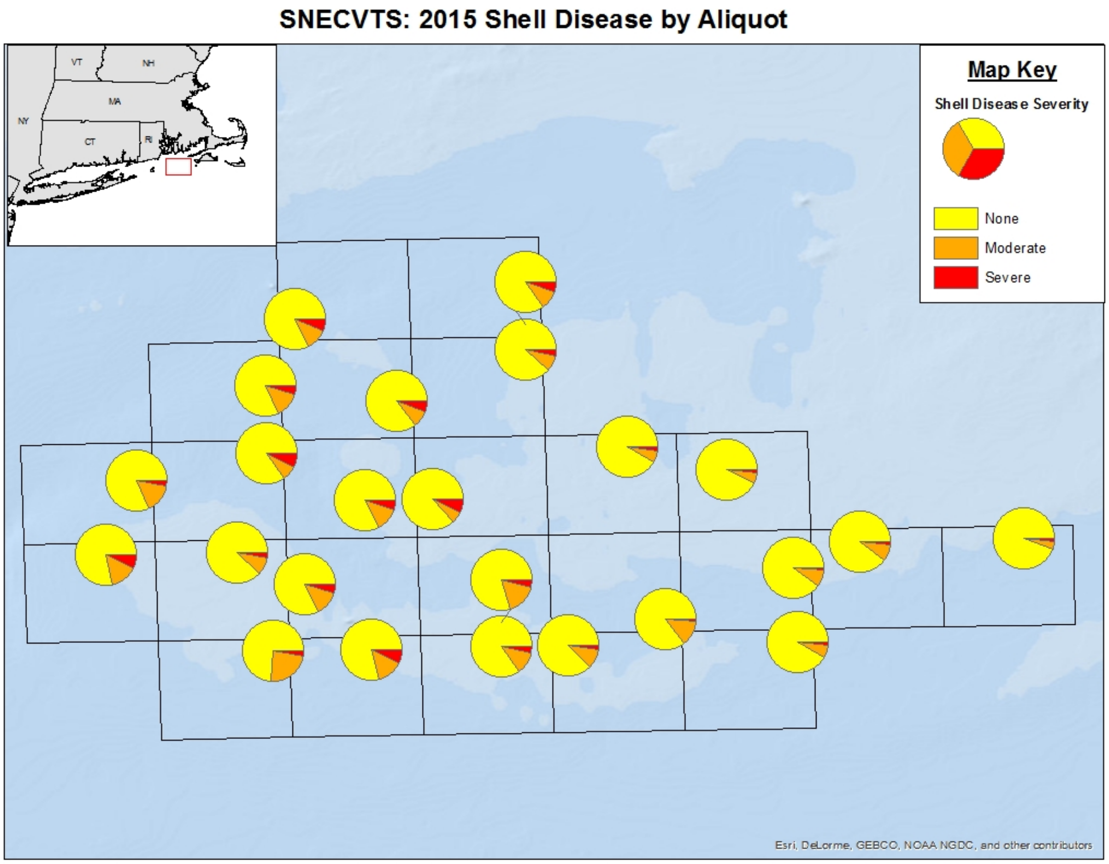

Figure 12. Incidence of shell disease by aliquot in 2015.

Table 5. Incidence of shell disease by year and month.

		Frequency			Percentage		
Year	Month	Moderate	None	Severe	Moderate	None	Severe
2014	May	220	158	39	52.76	37.89	9.35
	June	396	277	115	50.25	35.15	14.59
	July	469	1673	130	20.64	73.64	5.72
	August	236	2952	35	7.32	91.59	1.09
	September	153	2374	36	5.97	92.63	1.40
	October	391	1068	34	26.19	71.53	2.28
2015	May	89	106	40	37.87	45.11	17.02
	June	135	193	79	33.17	47.42	19.41
	July	186	811	92	17.08	74.48	8.45
	August	125	2689	56	4.36	93.69	1.95
	September	180	2584	45	6.41	91.99	1.60
	October	231	1394	39	13.88	83.77	2.34

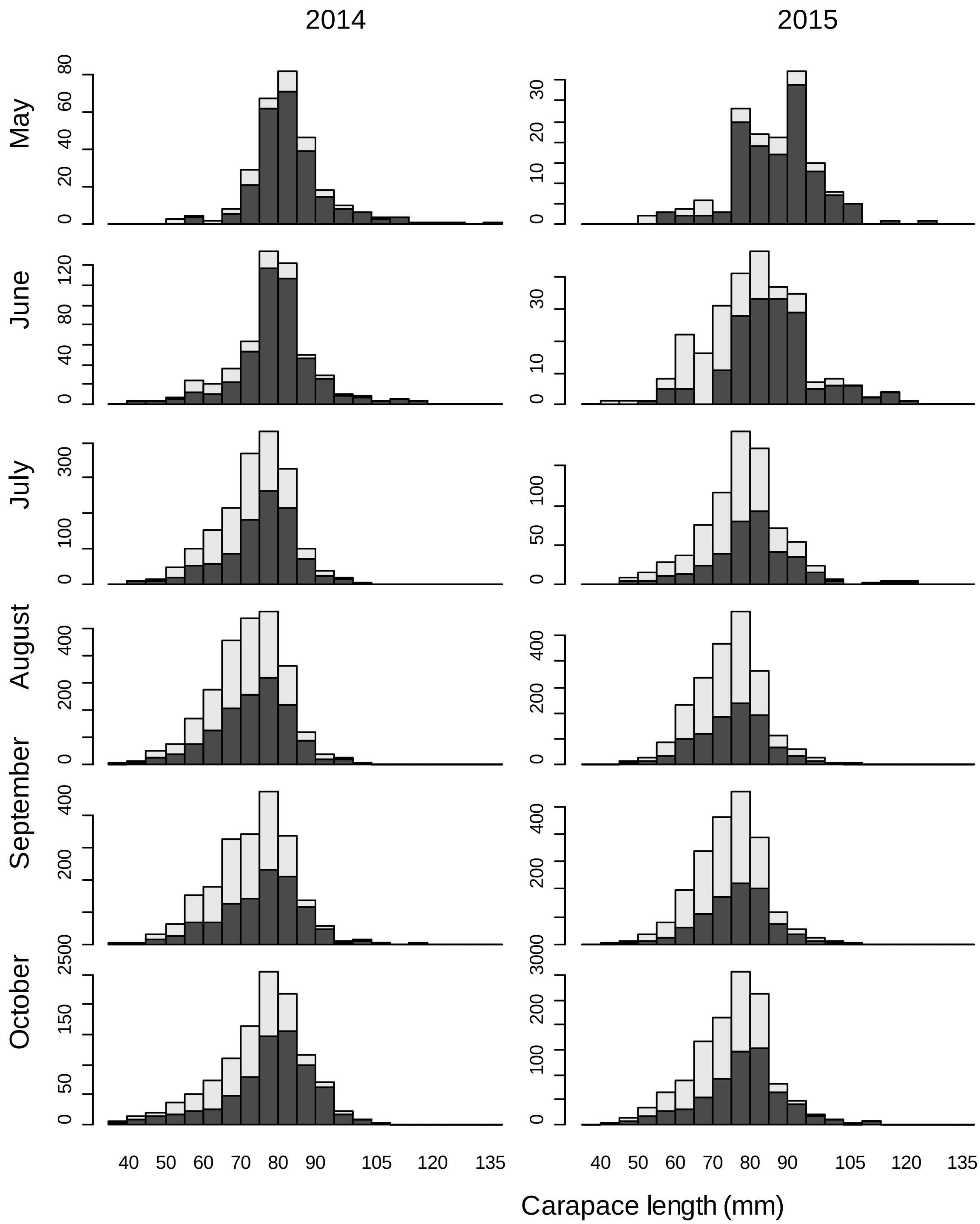

Figure 13. Length-frequency distributions of lobsters in ventless traps, by year and month. Dark bars are females and light bars are males.

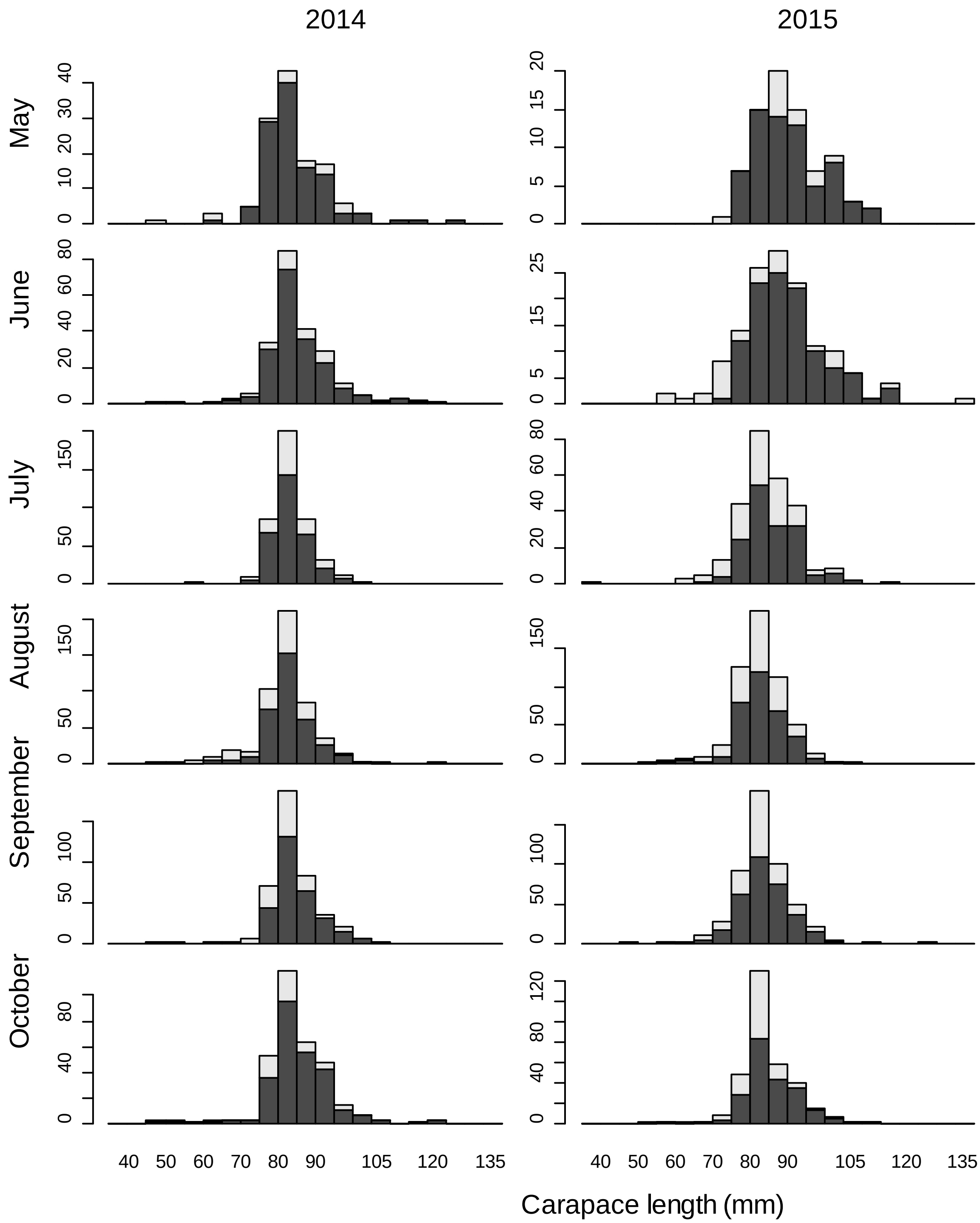

Figure 14. Length-frequency distributions of lobsters in standard traps, by year and month. Dark bars are females and light bars are males.

Lobsters ranged from 20 to 196 mm carapace length. However, the majority of lobsters were between 40 and 120 mm (Figs. 13 and 14). May and June catches contained large females, a high proportion of which carried eggs (Table 4) and were therefore protected from exploitation. Once the eggs are released these females are no longer protected from exploitation and the size distributions became more truncated beyond the legal size of 85.7 mm. Smaller lobsters were more numerous in the summer months, with a high proportion of males. These smaller lobsters may have just molted into the 60 to 80 mm length class and become vulnerable to capture. As expected, the standard traps caught few lobsters smaller than 80 mm (Fig. 13). An exception was June 2015, when numerous male lobsters between 60 and 80 mm were caught in standard traps.

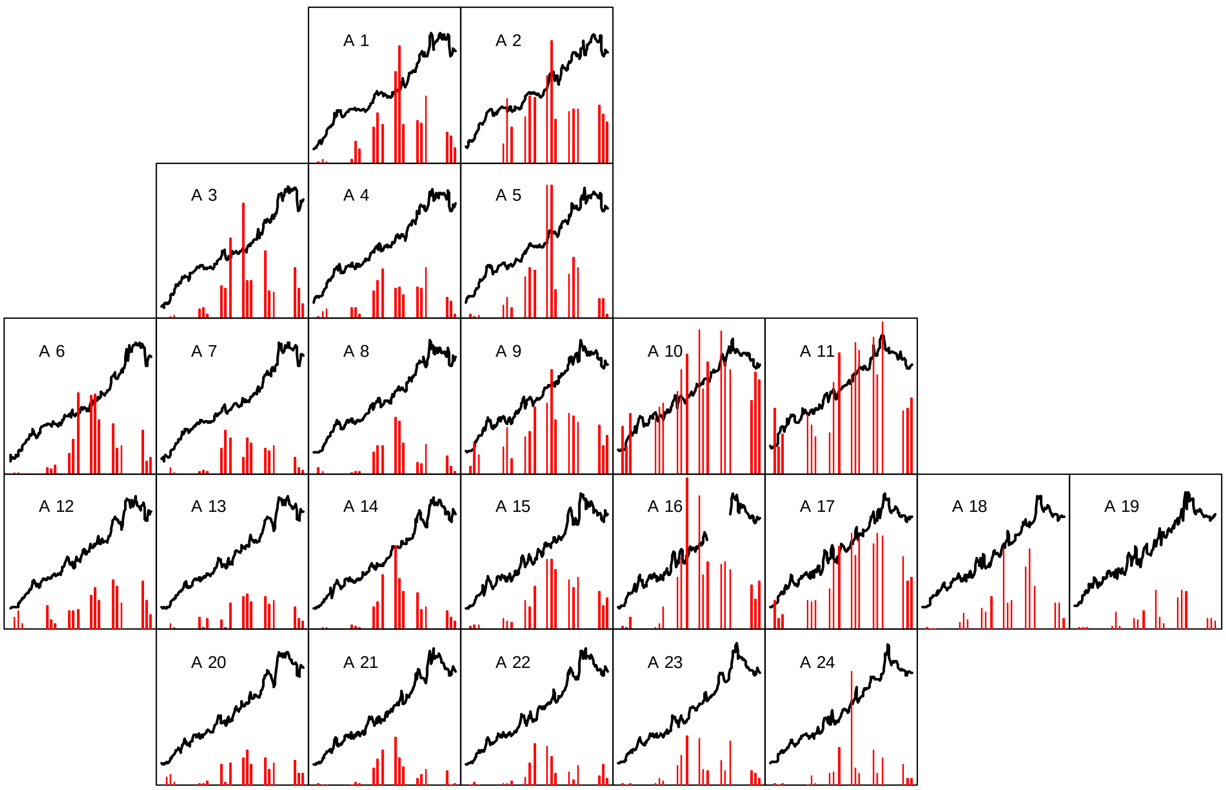

Figure 15. Distribution of lobster catches (red bars) in relation to bottom temperature (black lines) in 2014. The boxes correspond with the lease blocks shown in Fig. 2.

In 2014, lobster catches were consistently higher in aliquots 10 and 11 (Table 3, Fig. 15). These high catches are partially explained by the warmer water temperatures in the northeast of the lease block area; this temperature gradient persisted through September, after which catch rates decreased. In 2015, lobster catches were low in May and June in most aliquots, owing to low bottom temperatures (Fig. 16). With warming temperatures, the highest catches were obtained in August, September, and early October.

The seasonal onshore-offshore migrations of American lobster are understood as a strategy to maintain high local ambient temperatures to maximize the degree days needed for molting, growth, gonad development, egg extrusion (Cooper and Uzman 1986) and egg development (Campbell 1986). As bottom temperature warms in the spring, lobsters migrate onshore to shallower depth. As water in shallower depths cools more rapidly in fall, lobsters return to deeper offshore water. This strategy can explain the increasing catches in the SNECVTS survey from May through August, followed by declines in October.

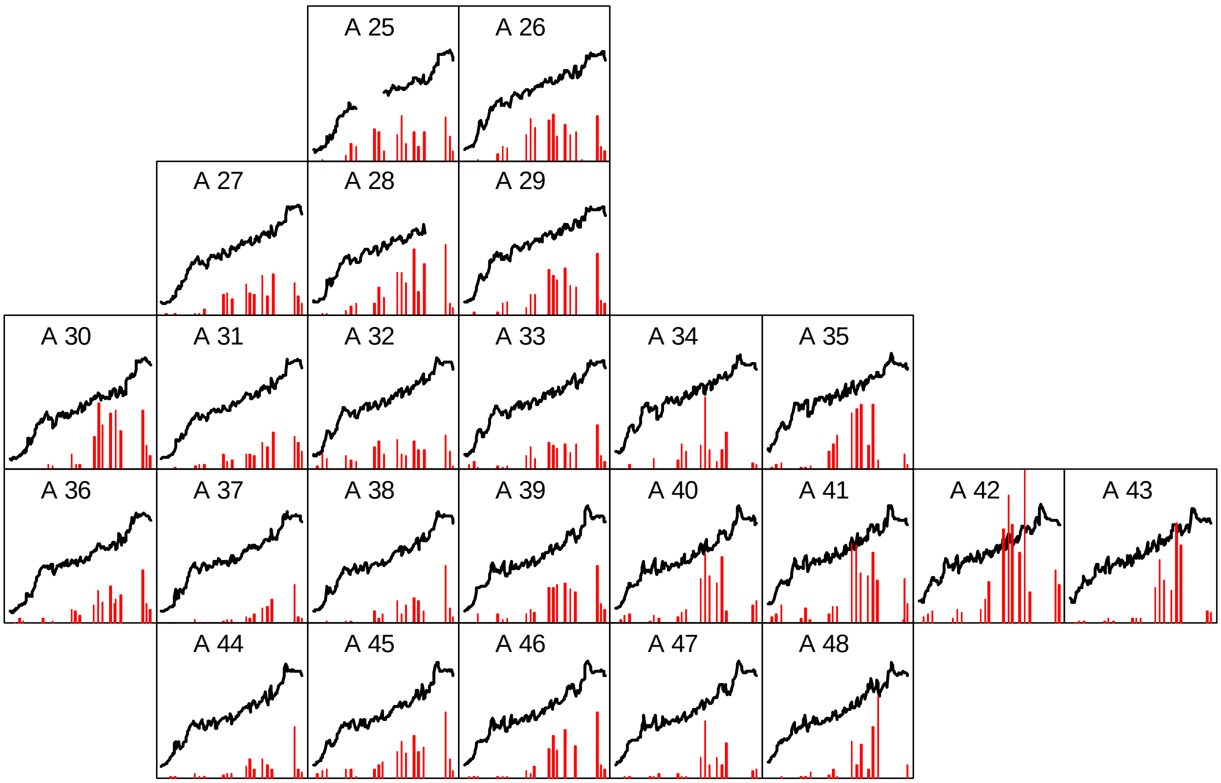

Figure 16. Distribution of lobster catches (red bars) in relation to bottom temperature (black lines) in 2015. The boxes correspond with the lease blocks shown in Fig. 2.

A series of generalized additive models (GAMs) was fit to explain the spatio-temporal variability of lobster abundance as smooth functions of predictor variables. The dependent variable was the sum of lobster catches by aliquot and date. Year and habitat type (Appendix 3) were entered as factors. Bottom temperature and depth were fit with spline functions. Day of year was not included as an independent variable because it is highly correlated (0.96) with temperature. The interaction between longitude and latitude was included to explain any residual geographic variation not explained by the other predictor variables. For this interaction term, the number of knots was constrained to k=12 to avoid over-fitting the data.

All the independent variables were nominally significant except for year, which was removed. The final model explained 61.8% of the deviance in lobster counts (Table 6). The habitat coefficients are measured relative to Boulders with sand, which is assigned a value of 0. Therefore, the habitat types, ranked by lobster abundance are Transition zone, Boulders with sand, Medium to course sand, and Soft Sediment. Lobster abundance increased rapidly with temperature up to a peak at ~14 ºC (Fig. 17). The temperature effect appears to increase again above 17 ºC but there are fewer observations at high temperature. At higher temperatures, lobsters may begin to migrate south to deeper, cooler water (see Section 8). Depth had a smaller effect on lobster abundance, partly because of the limited depth range of the aliquots. Since there were no aliquots between 25 and 32 m, the decline seen in this interval could be confounded with some other variable. Beyond 32 m, lobster abundance increased to a maximum around 42 m. The interaction between longitude and latitude shows a pattern of high abundance in the northeast and lower abundance in the southwest corners of the lease-block area.

Table 6. Generalized additive model fit to the abundance of lobsters in 2014 and 2015. A Poisson model with a log link was specified because the data are counts per trawl. Significance codes: *** < 0.001, ** < 0.01, * < 0.05.

```
Formula: lobs ~ s(temp_c) + bottom_type + s(depth_m) + s(lon, lat, k = 12)

Parametric coefficients:
                                   Estimate Std. Error z value   Pr(>|z|)
(Intercept)                         2.92273    0.02069 141.234   <2e-16 ***
bottom_type: Medium to coarse sand -0.42173    0.02901 -14.538   <2e-16 ***
bottom_type: Soft sediment         -0.56414    0.06212  -9.081   <2e-16 ***
bottom_type: Transition zone        0.62576    0.03403  18.386   <2e-16 ***

Approximate significance of smooth terms:
              edf Ref.df Chi.sq p-value
s(temp_c)   8.719  8.965   5196  <2e-16 ***
s(depth_m)  8.957  8.999    591  <2e-16 ***
s(lon,lat) 10.671 10.979   1375  <2e-16 ***
---

R-sq.(adj) =  0.556   Deviance explained = 61.8%
UBRE = 7.6194  Scale est. = 1         n = 857
```

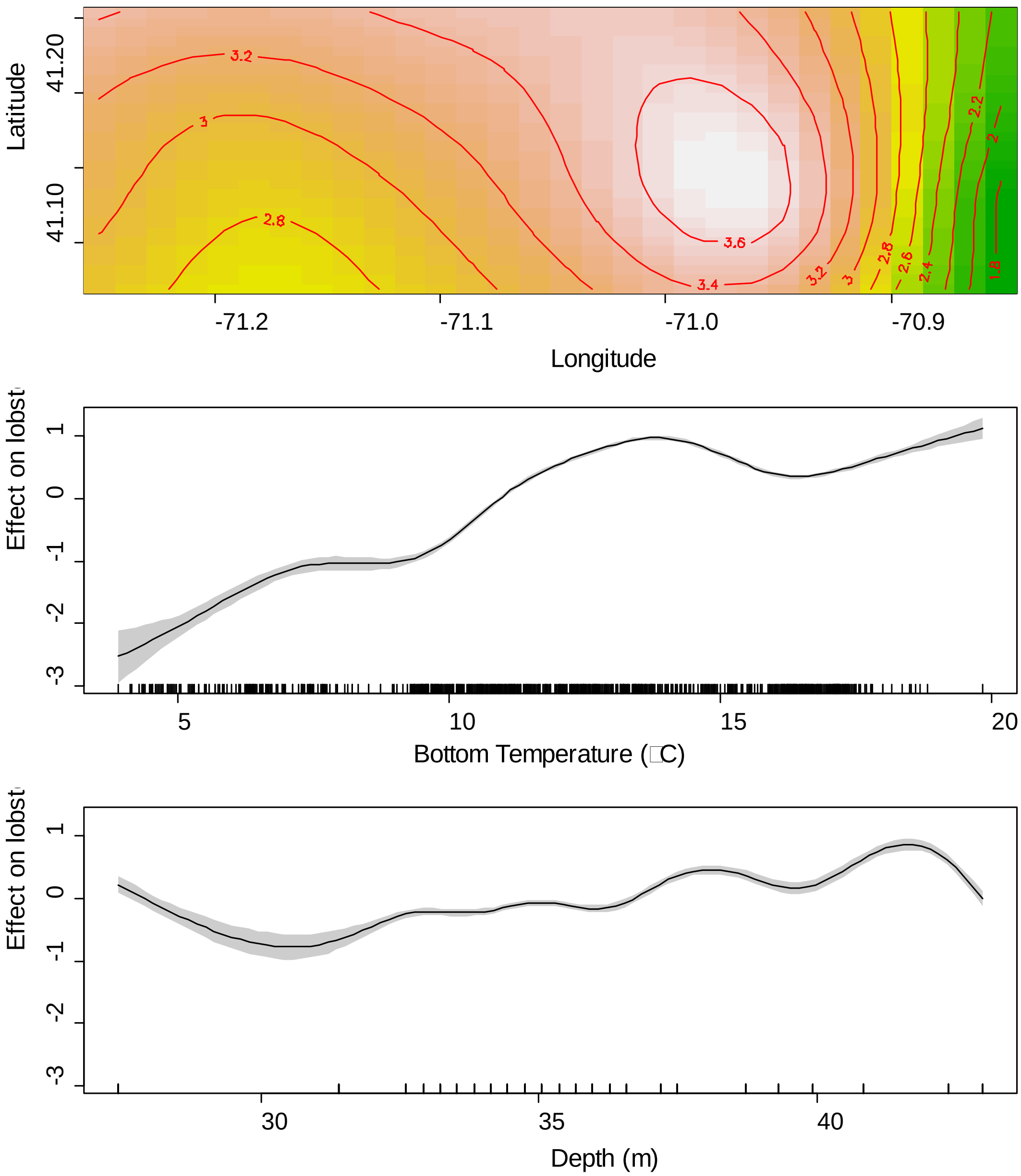

Figure 17. Results of the Generalized Additive Model fit to lobster abundance per trawl in 2014 and 2015. The subplots show the linear predictors (partial effects) of bottom temperature (ºC), depth (m), latitude (N) and longitude (E). The rug plots at the bottom of each subplot show the values of the predictor variables.

7. Bycatch Species

A total of 39 different species were caught in the SNECVTS survey (Table 7). Besides the target species, lobster, the most numerous bycatch species were Jonah crab, rock crab, red hake, and black seabass. The spatial distributions of these species are plotted in Figs. 18-21. The Jonah crab data were analyzed separately because it was the most numerous bycatch species and because of the developing Jonah crab fishery.

Table 7. Total numbers of species other than lobsters caught in the SNECVTS survey.

		Total Abundance	
Common Name	**Scientific Name**	**2014**	**2015**
Jonah crab	*Cancer borealis*	31,474	21,223
Rock crab	*Cancer irroratus*	15,405	18,765
Red hake	*Urophycis chuss*	3,133	1,795
Black seabass	*Centropristis striata*	1,914	1,109
Cunner	*Tautogolabrus adspersus*	779	359
Ocean pout	*Macrozoarces americanus*	288	376
Conger eel	*Conger oceanicus*	294	289
Scup	*Stenotomus chrysops*	264	115
Sea raven	*Hemitripterus americanus*	48	165
Longhon sculpin	*Myoxocephalus octodecemspinosus*	60	63
Hermit crab	*Pagurus spp.*	71	23
Moon snail	*Polinices heros*	57	12
Atlantic cod	*Gadus morhua*	20	23
Spotted hake	*Urophycis regia*	6	2
Waved welk	*Buccinum undatum*	4	4
Spider crab	*Libinia emarginata*	5	2
Sea scallop	*Placopecten magellanicus*	2	4
Starfish	*Asterias spp.*	5	0
Skate (egg case)	*Leucoraja spp.*	3	1
Spiny dogfish	*Squalus acanthias*	2	2
Haddock	*Melanogrammus aeglefinus*	3	0
Filefish	*Monacanthidae*	2	1
Lions mane jellyfish	*Cyanea capillata*	1	2
Smooth dogfish	*Mustelus canis*	1	2
Butterfish	*Peprilus triacanthus*	2	0
Sea robin	*Prionotus spp.*	2	0
Yellowtail flounder	*Pleuronectes ferruginea*	2	0
Ameican eel	*Anguilla rostrata*	1	1
Pollock	*Pollachius virens*	1	0
Snowy grouper	*Epinephelus niveatus*	1	0
Speckled barrelfish	*Hyperoglyphe perciformis*	1	0
Surfclam	*Spisula solidissima*	1	0
Tilefish	*Lopholatililus chamaeleonticeps*	1	0
Winter flounder	*Pseudopleuronectes americanus*	1	0
American shad	*Alosa sapidissima*	0	1
Mahogany clam	*Arctica islandica*	0	1
Toadfish	*Opsanus tau*	0	1
Triggerfish	*Balistes capriscus*	0	1

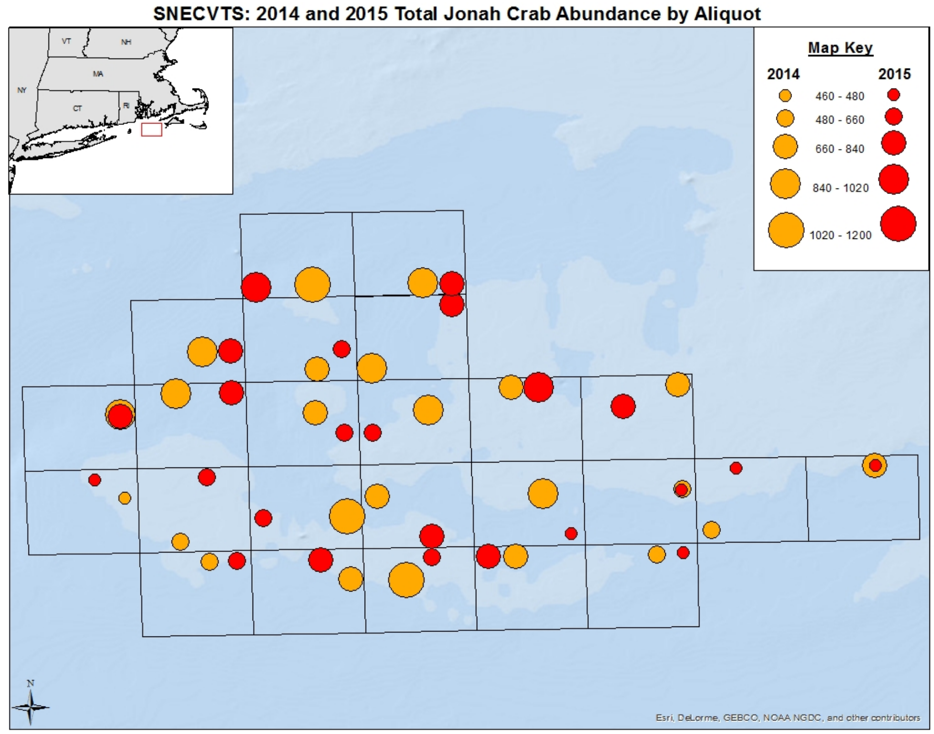

Figure 18. Jonah crab, *Cancer borealis*, abundance was highest in the central blocks of the lease area. This abundance pattern was consistent between 2014 and 2015.

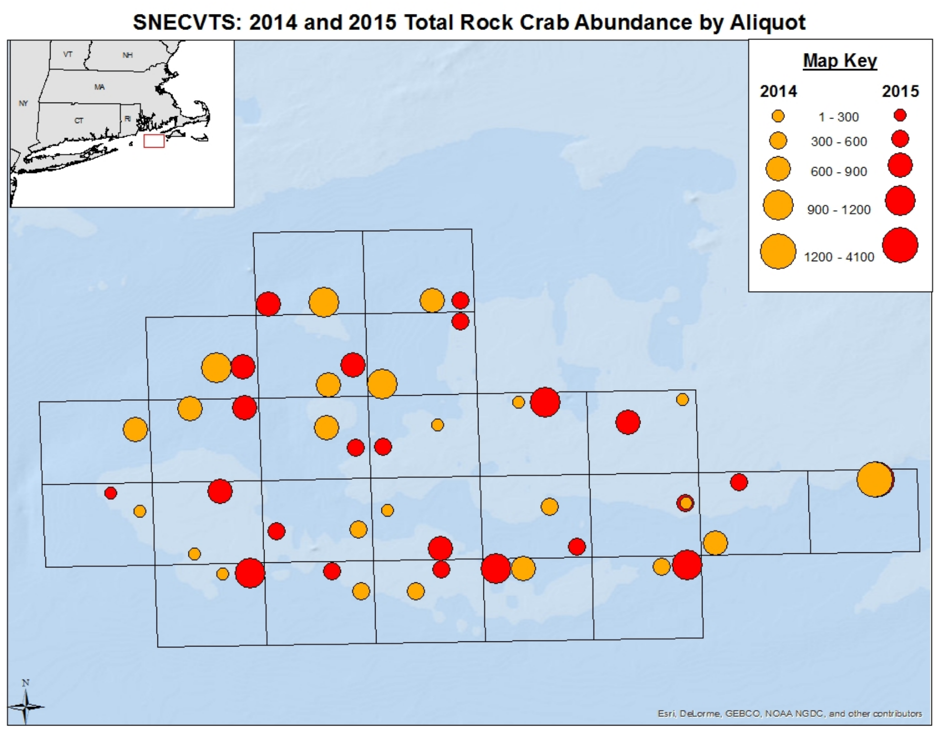

Figure 19. Rock crabs *Cancer irroratus*, were generally abundant throughout the lease-block area, with no clear spatial pattern or differences in abundance between 2014 and 2015.

SNECVTS: 2014 and 2015 Total Red Hake Abundance by Aliquot

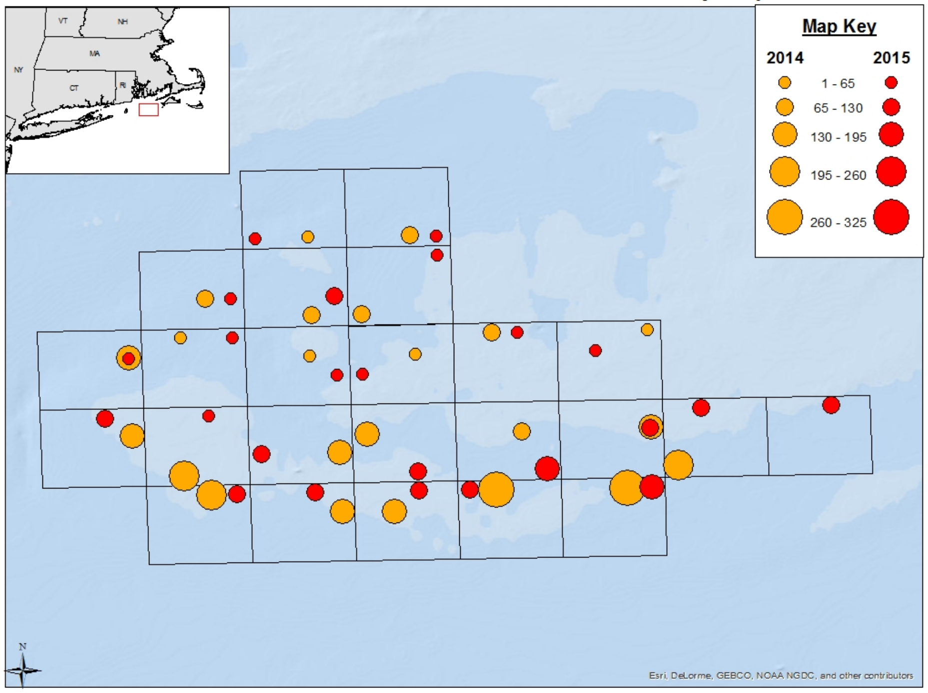

Figure 20. Red hake, *Urophysis chuss*, was more abundant in the southern blocks of the lease area (aliquots 12-24). Ovearall abundance was lower in 2015 than in 2014.

SNECVTS: 2014 and 2015 Total Black Seabass Abundance by Aliquot

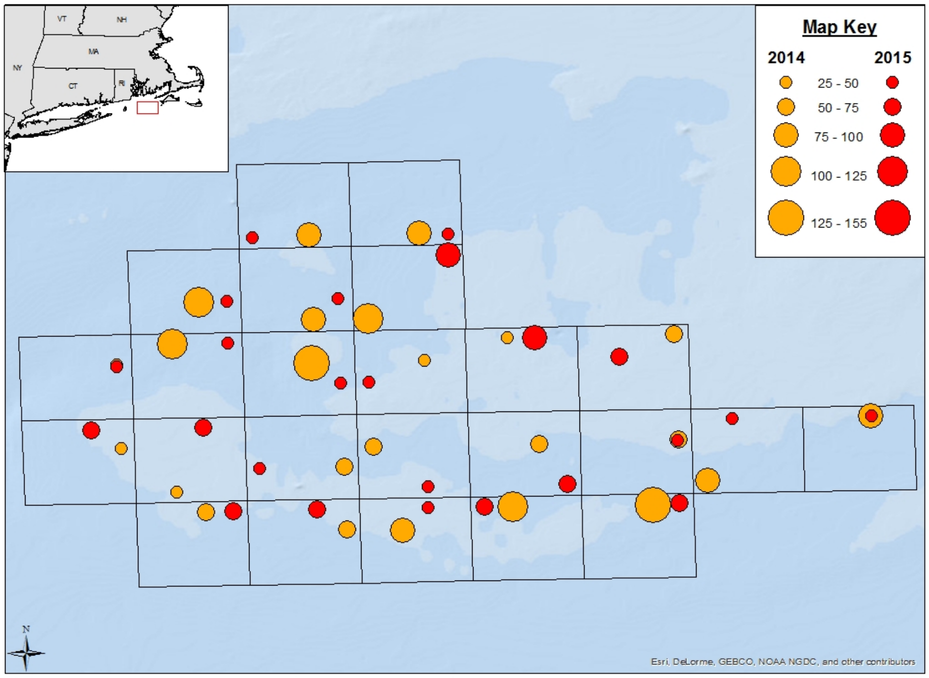

Figure 21. Black seabass, *Centropristis striata*, abundance was highest in the most northern and most southern aliquots, with lower abundance in between. Overall abundance was lower in 2015 than in 2014.

7.1 Jonah crabs

Jonah crab catches were generally higher toward central longitudes of the lease block area (Fig. 18). In 2014 the highest catches came from aliquots 6 and 14, which are located in the eastern and south-central regions of the lease block area, respectively (Table 3). High catches for 2014 also came from aliquots 2, 21 and 22. In 2015 the highest Jonah crab catches were in aliquots 25, 29 and 33. Aliquots 25 and 29 are located in the north-central region of the lease block area, and aliquot 33 is located centrally. High catches for 2015 also came from aliquots 26, 28, 30 and 34.

Jonah crab catches were highest in the month of September in both study years, followed by October (Table 8). Overall, Jonah crab catches were lowest in the months of May and June. The proportion of females was highest in catches in September and October and lowest in the months of June and July. Variations in total catch after May appear to be due largely to the variation in catches of females throughout the sampling season; catches of males were relatively consistent between months when compared to catches of females from May through October. Male Jonah crabs ranged in size from 40 mm to 191 mm, and females were between 49.1 mm and 188.8 mm. The mean carapace width of females (104 mm) was lower than for males (117 mm), which is consistent with the biology of the species (Fig. 22).

Table 8. Total catch, and proportional catch by sex of Jonah crabs in 2014 and 2015. Total numbers of males and females by month were calculated by multiplying the total catch by sex proportion in the subset of measured crabs.

	2014				2015			
Month	Total Catch	Proportion Females	Females	Males	Total Catch	Proportion Females	Females	Males
May	1255	0.29	364	891	410	0.35	144	267
June	3816	0.10	382	3434	1847	0.16	304	1551
July	4371	0.08	350	4021	2897	0.08	232	2665
August	5194	0.44	2285	2909	2844	0.40	1138	1706
September	11091	0.56	6211	4880	8455	0.71	6003	2452
October	5747	0.54	3103	2644	4780	0.64	3059	1721
Total	31,474		12,695	18,779	21233		10,871	10,362

The fluctuations in female catches may be due to a change in behavioral patterns throughout the reproductive cycle. Observations of ovigerous females in this study found the highest proportion of females with eggs in May, with progressively decreasing proportions through October. This may be a cause for the reduced catches of females in spring and early summer months; sex-specific migration and behavioral changes associated with the reproductive cycle have been postulated as causes for differential catches of male and female Jonah crabs (Wenner et al. 1992). Aggregating and burying behavior by ovigerous females has been observed in a related Cancer crab species (Rasmuson 2013), and low catchability of ovigerous females has been well documented in *Cancer borealis* and other cogeneric crabs (Krouse 1980, Ungfors 2007).

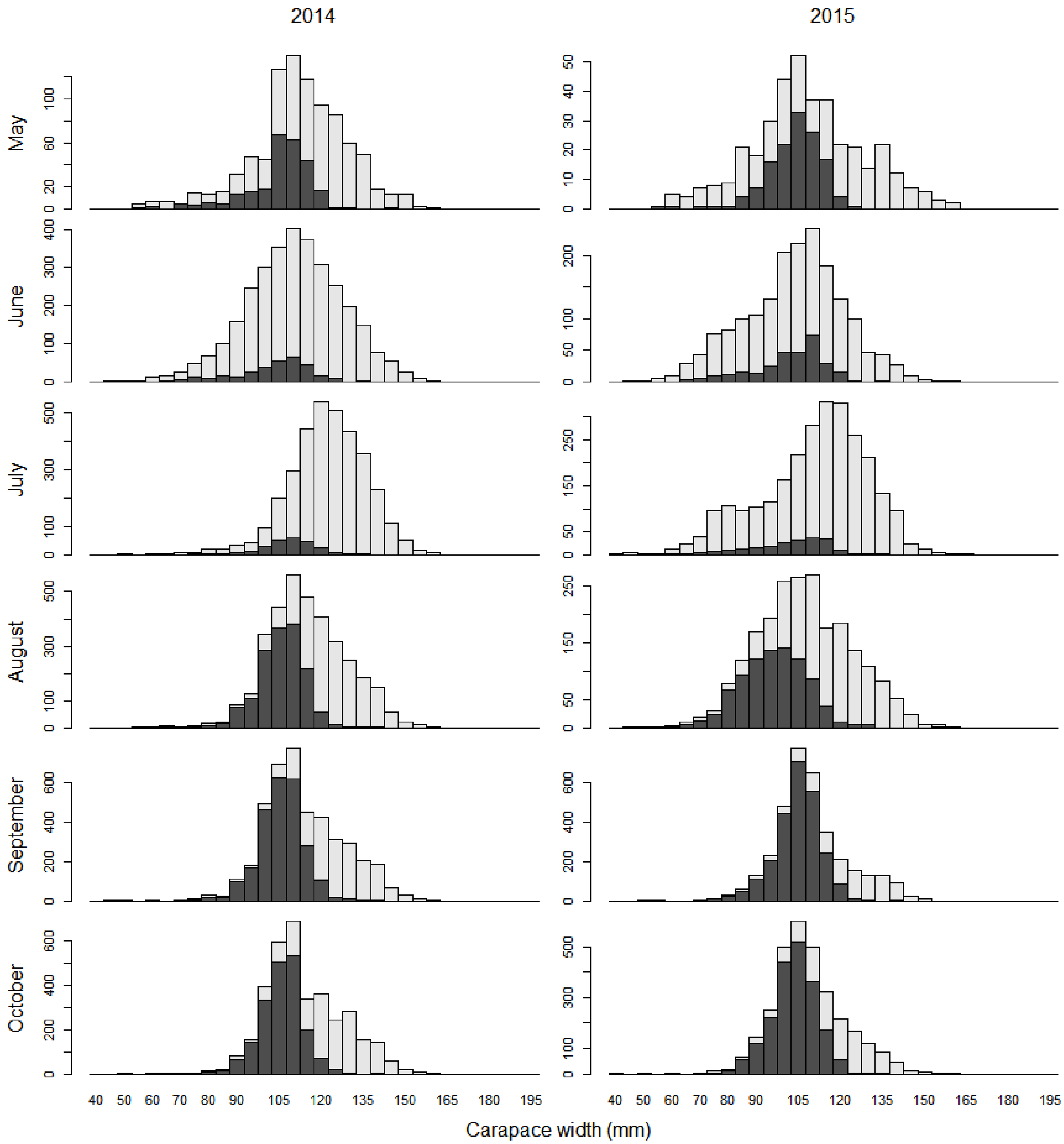

Figure 22. Length-frequency distributions of Jonah crabs by year and month. Dark bars are females and light bars are males.

A generalized additive model was fitted to Jonah crab abundance, using smooth functions of predictor variables to predict Jonah crab catches by aliquot and date. Year and bottom type were entered as factors. The following variables were fitted with spline functions: temperature, depth, latitude, and longitude. Latitude and longitude were explored as interactive variables to explain geographic variation not explained by the other available predictor variables; in the interactive term between latitude and longitude, the number of knots was constrained to 12.

All independent variables were found to be significant in the chosen model, which explained 57.5% of the variance in Jonah crab counts (Table 9). The year coefficient for 2015 is measured relative to 2014, and all habitat coefficients are measured relative to boulders on sand. Thus, Jonah crab abundance per trawl is ranked from highest to lowest according to the following bottom types, respectively: soft sediment, medium to coarse sand, boulders on sand, and transition zone. Interaction between latitude and longitude indicates a higher abundance of Jonah crabs in the northwest, northeast and south-central regions of the lease area, with lowest abundances in the southeast and southwest corners of the lease area (Fig. 23). Jonah crab abundance exhibits an increasing trend with temperature until ~ 15 °C, after which it appears to decline with increasing temperature. Catches were generally higher in 2014 than in 2015. Jonah crab catch increases with depth, though this relationship is not as strong as that of other variables. This may be due to the relatively small range of aliquot depths, or the depth to abundance relationship may be confounded by variables not investigated in this study.

Table 9. Generalized additive model fit to the abundance of Jonah crabs in 2014 and 2015. A poisson model with a log link function was specified because the data are counts per trawl.
Significance codes: *** < 0.001, ** < 0.01, * < 0.05.

```
Formula:
jonah_crab ~ s(lon, lat, k = 12) + bottom_type + s(temp) + s(depth) + year

Parametric coefficients:
                                  Estimate Std. Error z value Pr(>|z|)    
(Intercept)                      847.25967   23.17032  36.567  < 2e-16 ***
bottom_typeMedium to coarse sand   0.24176    0.01725  14.014  < 2e-16 ***
bottom_typeSoft sediment           0.35454    0.03502  10.123  < 2e-16 ***
bottom_typeTransition zone        -0.18024    0.02945  -6.119  9.4e-10 ***
year                              -0.41877    0.01150 -36.405  < 2e-16 ***
---

Approximate significance of smooth terms:
              edf Ref.df Chi.sq p-value    
s(lon,lat) 10.966 11.000   3404  <2e-16 ***
s(temp)     8.596  8.936  13226  <2e-16 ***
s(depth)    8.976  9.000   1312  <2e-16 ***
---

R-sq.(adj) =  0.469   Deviance explained = 57.5%
UBRE = 23.228  Scale est. = 1         n = 857
```

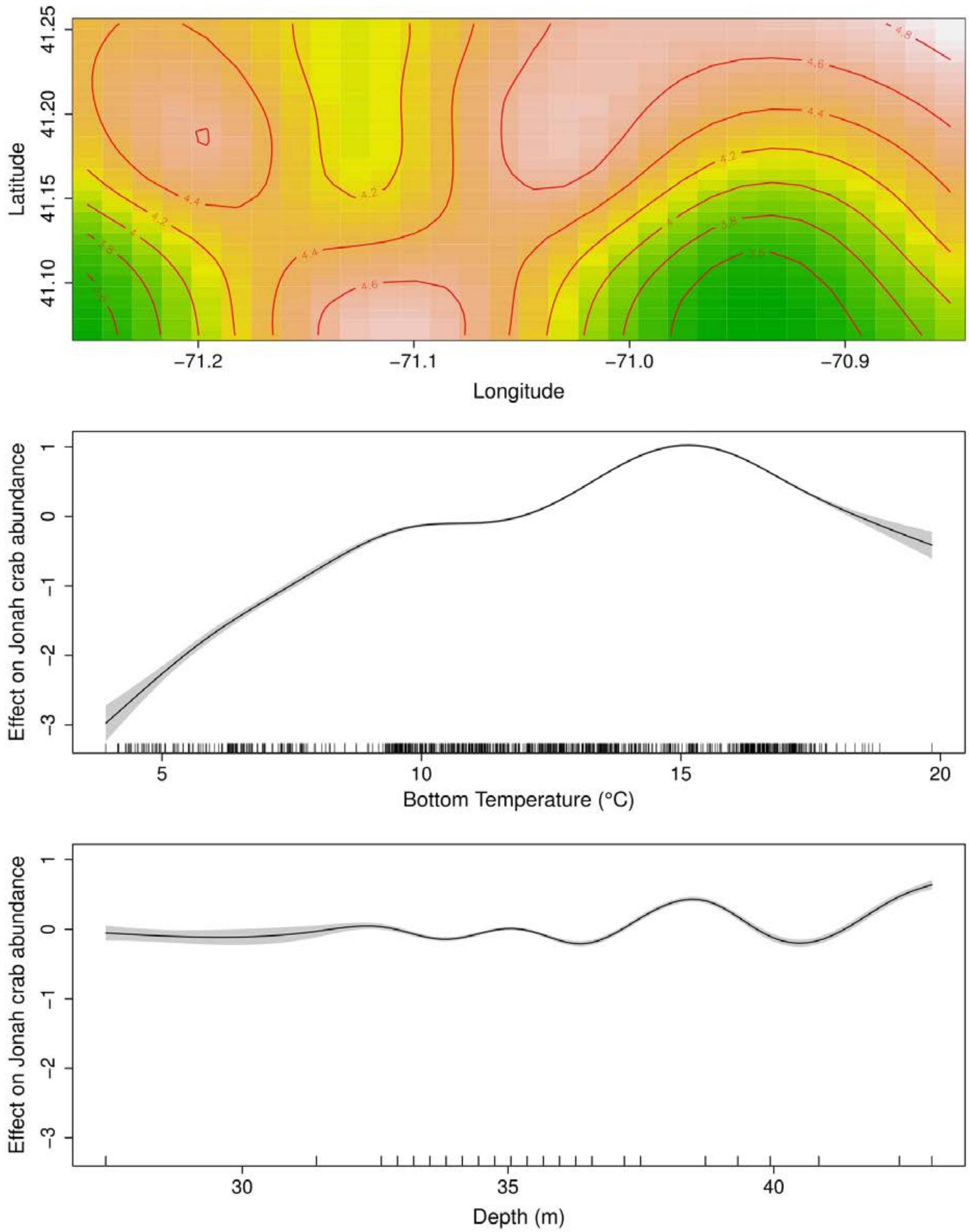

Figure 23. Results of the Generalized Additive Model fit to Jonah crab abundance per trawl in 2014 and 2015. The subplots show the linear predictors (partial effects) of bottom temperature (°C), depth (m), latitude (N), and longitude (E). The rug plots at the bottom of each subplot show the values of the predictor variables.

8. Pilot Tagging Study

A pilot tagging study was initiated in 2015, to begin to evaluate the movement of lobsters in and around the RI/MA lease area and the probability that the same lobsters are captured multiple times. Lobsters were tagged with individually numbered cable ties, attached around the “elbow” of the claw (Fig. 24). The tag is expected to remain on the lobster until it molts. We chose to tag on 14 August 2015 because by this date many lobsters have just molted. A total of 300 lobsters were tagged—100 on each vessel, distributed more-or-less evenly among aliquots (e.g. 12 per aliquot, depending on numbers caught). All sizes of lobsters were tagged. Lobsters with shell disease were not tagged, as these old-shell lobsters are more likely to molt and shed the tag.

Figure 24. Lobster tagged on 14 August 2015.

Thirty-nine recaptures have been reported, both by SNECVTS samplers and by other lobstermen (Appendix 4). Three of these 39 were double recaptures. This 13% recapture rate is encouraging, considering there was no advertising or incentive for reporting tags—just a phone number on the tag. Most of the recaptures occurred within two months of tagging (Fig. 25). These results are consistent with previous tagging studies, in which most recaptures occurred in the first few months near where the lobsters were tagged (Campbell & Stasko 1985). Four tagged lobsters were caught in November/December and three in June/July 2016. The most recent tag recaptures was on 17 August 2016, showing that the tags can remain on lobster for over a year.

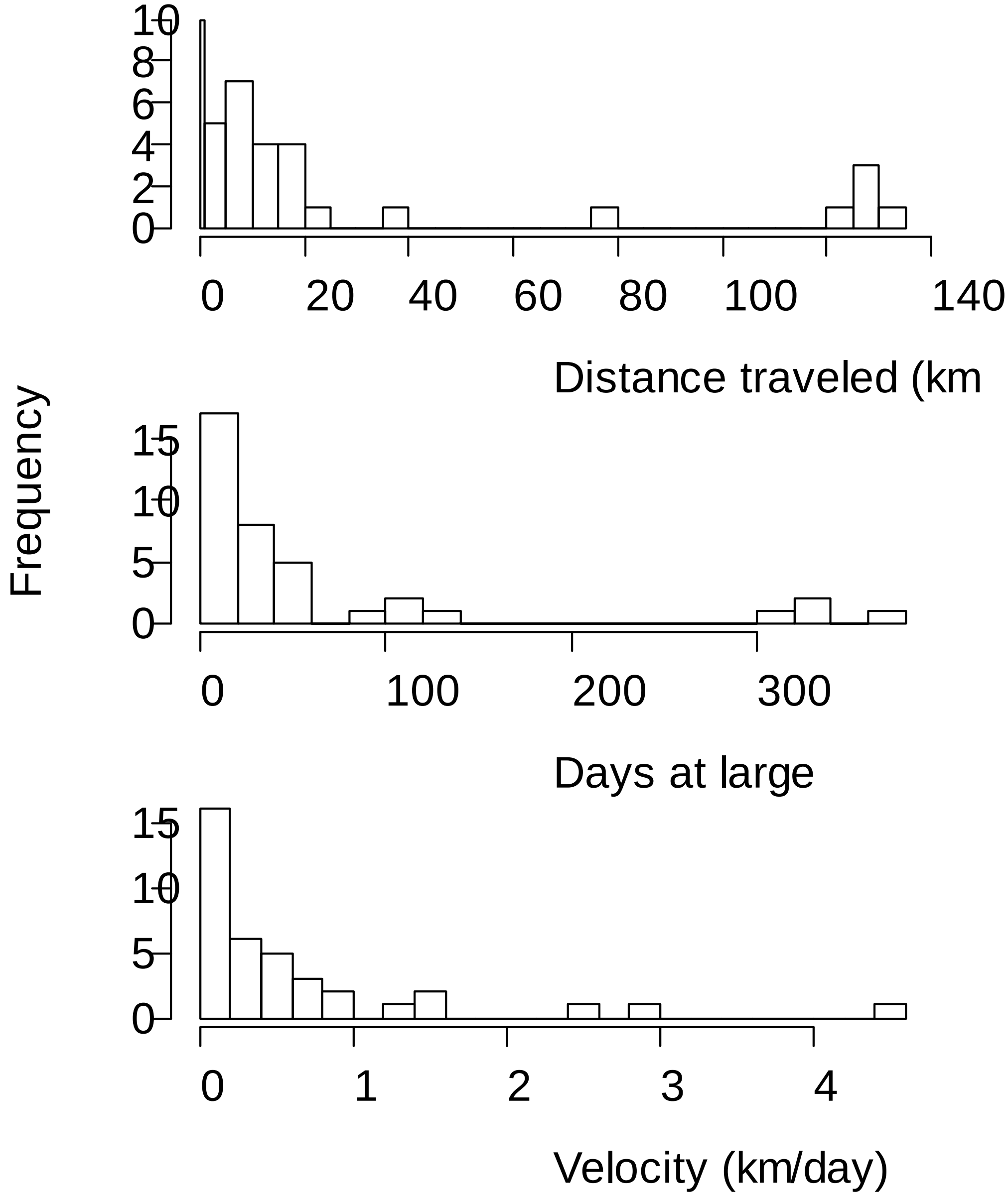

Figure 25. Distance traveled by lobsters from the point of tagging to the point of recapture, days between tagging and recapture and estimated velocity.

Most recaptures were in the vicinity of the lease block area (Figs. 25 and 26). The majority of lobsters traveled less than 25 km; 10 of these traveled less than 1km. There was no obvious direction of travel, except that few lobsters moved in a northerly direction. Four lobsters traveled over 120 km to the edge of the continental shelf where they were caught by offshore lobstermen (Figs. 25 and 27). Four of these lobsters were large females (>85 mm) and one was male (78 mm). One of these four lobsters travelled 123 km in 28 days, which implies a velocity over 4 km per day.

Previous tagging studies indicate that mature lobsters travel considerably farther than juveniles (Campbell & Stasko 1985, Campbell 1986). Long-distance migration (>100km) has been reported, including lobsters that make excursions of 10-400 km, returning to the area of initial tagging after 10 to 14 months (Pezzack & Duggan 1986). These long excursions are thought to be part of the temperature-mediated, seasonal migration of American lobster.

This pilot tagging study demonstrated the feasibility of using numbered cable ties to mark lobsters. The 13% recapture rate is high compared with other tagging studies and could be increased with publicity and incentives for reporting. About two thirds of the recaptures were made inside the lease block area. Although these recaptures are not corrected for sampling effort, they do indicate a residence time of months within the lease block area.

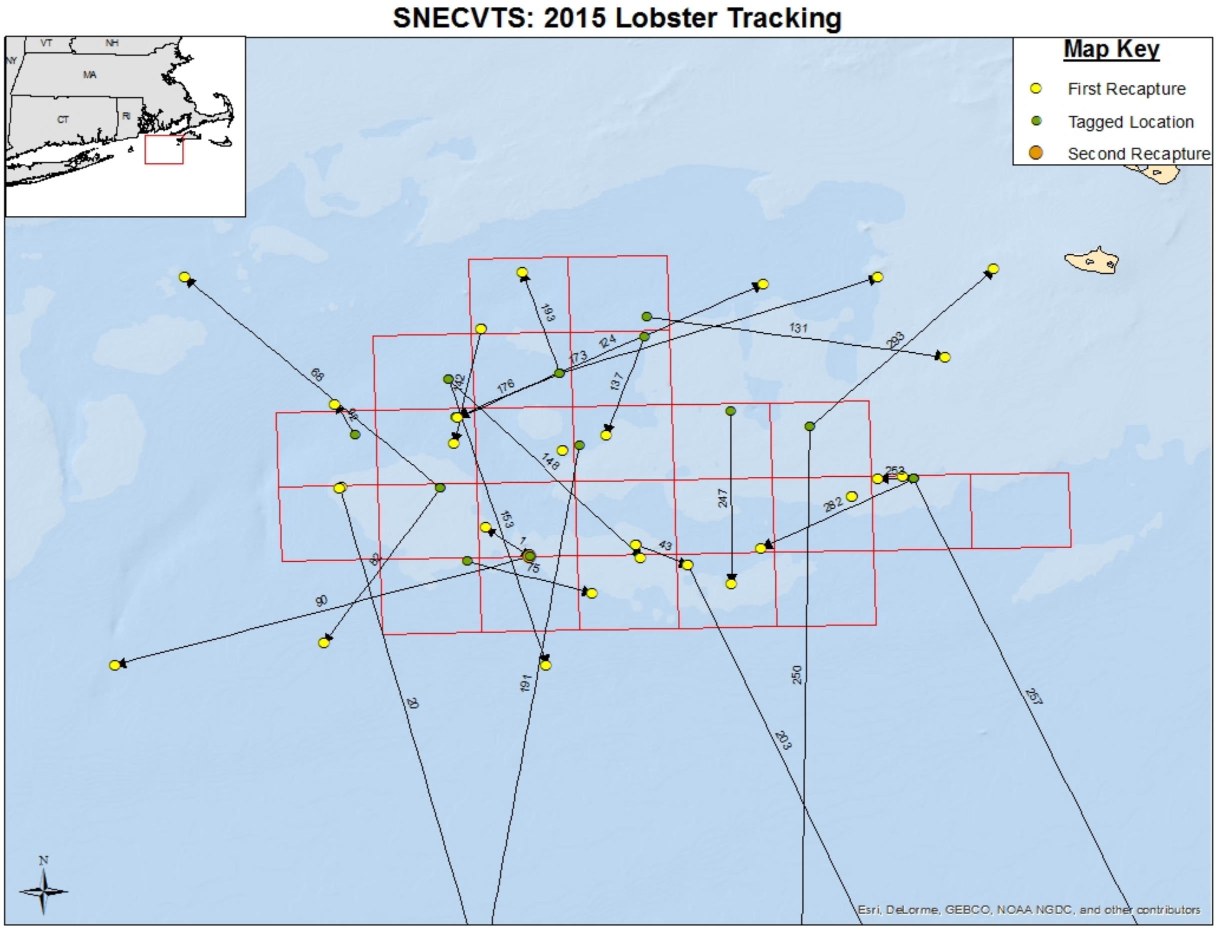

Figure 26. Tagging and recapture locations of lobsters tagged on 14 August 2015 and recaptured in the vicinity of the RI/MA Lease Area.

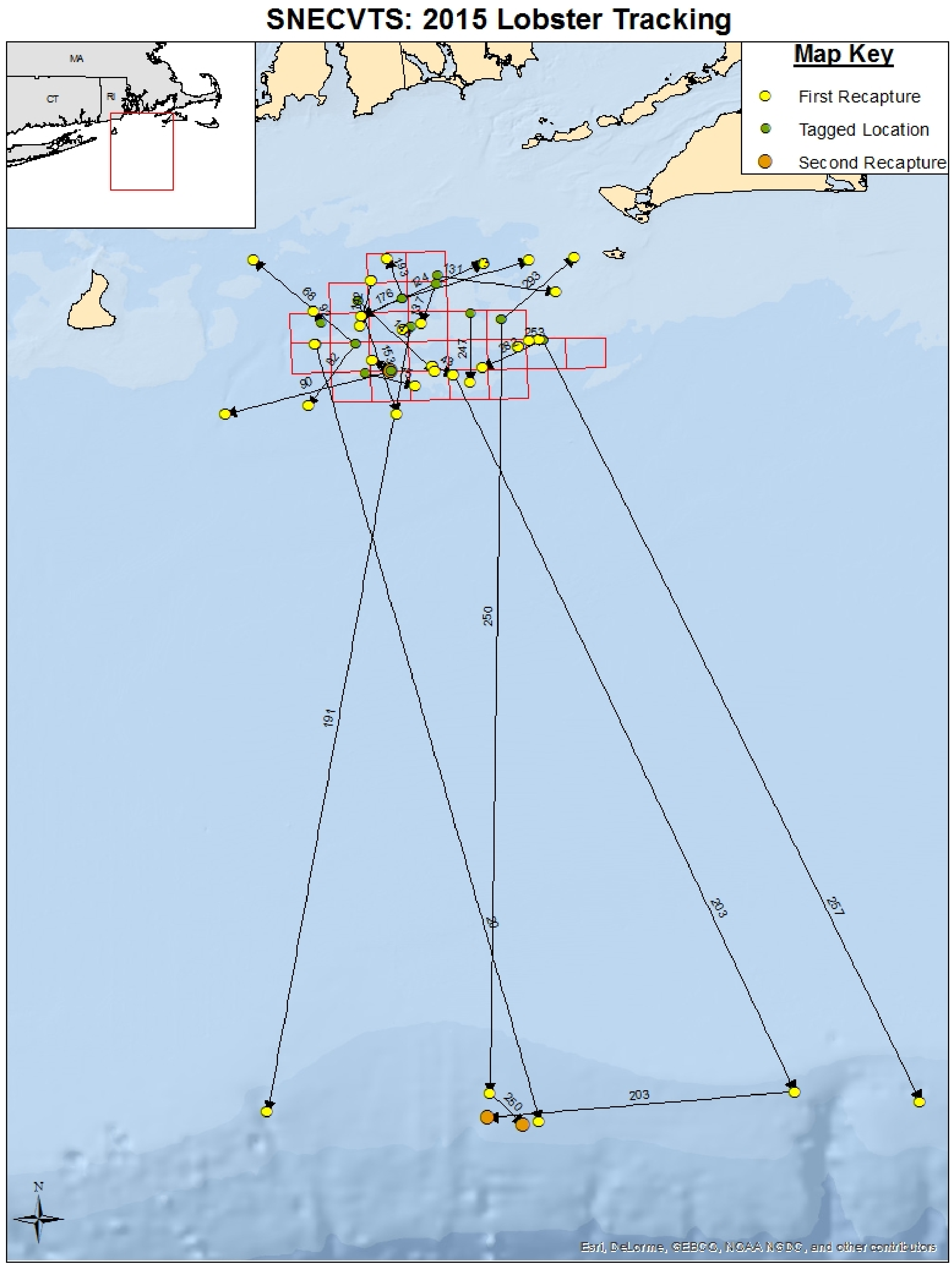

Figure 27. Tagging and recapture locations of all lobsters tagged on 14 August 2015.

9. Conclusions

9.1 Implications for siting and monitoring impacts of offshore wind energy development

This project documented a healthy population of American lobster on Cox Ledge in the RI/MA wind energy area. A broad size range of lobsters was sampled, from 40-mm juveniles to large, ovigerous females. The occurrence of small lobsters indicates recruitment to this area. The incidence of shell disease was low compared with shallower, estuarine areas. Given the adverse environmental conditions (high summer temperature, low dissolved oxygen) in estuaries, protection of the offshore component is needed to conserve the SNE lobster population (Wahle et al. 2015).

Survey results were consistent between the two years of the survey. Lobster abundance was consistently higher on the eastern side of the lease area. High density areas included aliquots 9,10,11, and 35 and aliquots 16-19 and 40-43. In general, these sites are relatively shallow with a bottom type consisting of boulders or a transition from boulders to medium sand. These aliquots are found in BOEM lease blocks 6918, 6919, and 6968-6971. High lobster densities were also measured at aliquots 2 and 26 at the northern edge of the lease area. These two aliquots were deeper (37-40 m) with soft sediments. They are in BOEM lease block 6817.

Table 10. Comparison of catch per trap between SNECVTS and the RI DEM ventless trap survey, which is conducted in RI state waters. State data courtesy of Michael McManus, RI DEM.

RIDEM	Standard trap				Ventless trap			
Year	June	July	August	September	June	July	August	September
2006	NA	1.56	1.40	1.12	NA	10.03	9.76	8.39
2007	2.18	3.18	1.90	NA	6.56	14.34	10.00	NA
2008	2.77	3.06	2.01	NA	10.22	14.58	9.85	NA
2009	NA	2.06	1.28	1.05	NA	13.12	7.19	5.27
2010	NA	1.99	1.65	0.86	NA	7.49	7.46	4.05
2011	NA	1.82	1.71	2.17	NA	7.69	6.74	7.01
2012	2.09	1.50	1.08	NA	9.12	7.59	6.34	NA
2013	1.38	1.32	1.11	NA	4.63	4.93	3.69	NA
2014	0.62	1.11	1.20	NA	3.07	5.02	5.58	NA
2015	0.91	1.62	1.43	NA	3.96	6.36	5.55	NA
SNECVTS	Standard trap				Ventless trap			
2014	0.78	1.49	1.78	1.49	1.31	4.27	6.28	4.94
2015	0.48	0.94	1.90	1.78	0.62	1.89	5.38	5.32

Lobster catch rates were consistent with those from the corresponding months and years in the RI DEM ventless trap survey. This comparison confirms the importance of the RI/MA Lease Area as lobster habitat, compared with inshore areas.

Despite the patchy habitat and sampling variability, a generalized additive model explained 62% of the deviance in lobster catches. On average, lobsters prefer boulder habitat and the transition from boulders to sand, compared with uniform sand and soft sediments (Cooper and Uzmann 1980). These preferred habitat types are available throughout the study area. Lobster abundance increased with depth, but this was a weak effect given the limited depth range of the study area.

Bottom temperature was the strongest predictor of lobster catches, which increased up to about 14 ºC and were fairly constant above this threshold. Summer bottom-water temperatures are within the optimal temperature range of 12-18 ºC. Temperatures above 20 ºF, which are known to stress lobsters, occurred only in aliquots 23 and 24 at the end of September 2014. Lobster catches increased throughout the summer, peaking in August and September, before declining in October. This pattern is consistent with the paradigm of a temperature-mediated, seasonal, onshore-offshore migration. The pilot tagging study demonstrated that most lobsters remained in the lease block area for several months. A few undertook long migrations to the edge of the continental shelf, which is consistent with known seasonal migration patterns of the American lobster.

Jonah crab, *Cancer borealis*, was the most numerous species caught in the survey. Jonah crabs ranged in size from 40 to 190 mm carapace with, with most falling between 60 and 160 mm. Jonah crabs were most abundant in central longitudes of the lease blocks. Apart from aliquots 2 and 26 in the north, the preferred habitat of Jonah crabs did not intersect with that of lobsters. According to the generalized additive model, Jonah crabs prefer soft and sand substrates compared with boulders. As with lobsters, there was a strong effect of temperature on Jonah crab catch rates. Jonah crab abundance increased throughout the summer, peaking in September. This seasonal pattern was driven mostly by females, which were rare in spring and dominant in early fall.

9.2 Recommendations for Future Research

Continuing efforts to evaluate the distribution and habitat use of lobsters and Jonah crabs in areas of wind energy development are essential (Petruny-Parker et al. 2015). The SNECVTS project established a cooperative survey protocol for monitoring the effects of offshore wind-energy development on lobster and crab populations. The study established a pre-construction baseline for lobster and Jonah crab populations to enable assessment of possible impacts of development. This survey should be continued, in some form, to provide a continuous time series of abundance, as development progresses. The survey design could be streamlined to provide cost efficiencies. Variables to consider include the number of months sampled and the number of sampling trips per month. For example, by reducing the number of sampling trips per month from three to two, sampling could be extended to include April and November. The number and identity of lease blocks to be surveyed could also be modified, based on offshore wind construction plans for the lease area, to focus on those lease blocks where development is most likely to occur and to identify appropriate control stations. The scope of coverage could also possibly be expanded to include portions of the areas leased offshore Massachusetts (leases OCS-A 0500 and OCS-A 0501), but this would require cooperation with larger fishing vessels.

As part of the ventless trap survey, a more intensive tagging study should be conducted to determine the seasonal movement patterns and habitat use by lobsters. Lobsters are thought to migrate offshore in the fall and onshore in spring (Fogarty 1995), but recent observations challenge this paradigm. With the last lobster tagging study in the Southern New England region conducted over 20 years ago (focused on the North Cape oil spill), there is an urgent need to assess current lobster movement patterns and the potential impacts of wind energy development in this region. An intensive tagging study would involve monthly tagging of 500 lobsters across the study site. Recoveries would be made by the sea samplers and reported by commercial lobstermen. Outreach and incentive programs will need to be developed to encourage tag reporting.

Encouraging results were obtained using individually numbered zip ties as tags, which are inexpensive, easy to apply, and remain on the lobster until it molts. Other types of tags could be considered, including spherion tags, which are retained when a lobster molts and have been used in previous lobster tagging studies (Campbell & Stasko 1985, Campbell 1986, Pezzak and Duggan 1986). Conventional tagging provides only the release and recapture locations, between which movement is inferred. In addition to conventional tagging, acoustic telemetry could provide more fine-scale data on lobster movement. Acoustic tagging studies have been performed on American lobster in Canadian waters, as well as spiny lobsters, the European lobster, and the Norway lobster. This work would involve affixing ~100 acoustic tags to new-shell lobsters captured within the study area. Fixed receivers could be deployed on lobster sampling gear in areas of high lobster density to track onshore-offshore movements.

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Appendix 1. List of project personnel

Name	Affiliation	Role
Jeremy Collie	URI/Graduate School of Oceanography	Principal Investigator
John King	URI/Graduate School of Oceanography	Co-principal Investigator
Lanny Dellinger	Captain, F/V Megan & Kelsey	Vessel 1
Greg Mataronas	Captain, F/V Cailyn Grace	Vessel 3
Brian Thibeault	Captain, F/V Ashley Ann	Vessel 2
Bill McElroy	Captain, F/V Ellen June	Backup fishing vessel
Anna Malek	URI/Graduate School of Oceanography	Field Coordinator
Monique LaFrance Bartley	URI/Graduate School of Oceanography	Benthic habitat analysis
Corinne Truesdale	URI/Graduate School of Oceanography	Lobster and Jonah crab data analysis
David Taylor	Roger Williams University	Supervisor of RWU undergraduates
Saroj Mohanty	URI Engineering student	Designed Lobster Tracks software
Alyssa Gavlik	URI Graduate	Assistant Sea Sampler
Chip Heil	URI Research Associate	Lead Sea Sampler
Dan Denaro	URI Gradaute	Lead Sea Sampler
Matthew Griffin	Roger Williams University	Lead Sea Sampler
Nathan Andrews	URI Graduate	Assistant Sea Sampler
Nick Calabrase	Roger Williams University	Assistant Sea Sampler
Oliver Bender	URI Graduate	Assistant Sea Sampler

Appendix 2. Grab samples collected for ground-truthing the acoustic mapping of lobster sampling sites. Locations of the grab samples are listed by Aliquot. The final column is a visual description of the grab sample from the field notes.

Aliquot	Latitude	Longitude	Grab Sample #	Date	Description
1	-71.146	41.226	LS43	11/18/15	Full, fine-medium sand, shells, amphipod
1	-71.148	41.223	LS44	11/18/15	Fine-medium tan sand, some shell hash, tubes
1	-71.149	41.221	LS45	11/18/15	fine-medium sand tan, tubes
2	-71.088	41.229	LS40	11/18/15	Medium sand, some amphipods, tubes
2	-71.093	41.226	LS41	11/18/15	very fine sand, mud, tubes
2	-71.092	41.222	LS42	11/18/15	Fine-medium sand, large 4-5 inch quahog clams, full
3	-71.203	41.195	LS1	8/19/2015	Full grab; medium sand, tubes, shrimp
3	-71.204	41.193	LS2	8/19/2015	1/2 grab, medium brown sand, tubes
3	-71.205	41.191	LS3	8/19/2015	Medium sand, brown, tubes, shells
4	-71.140	41.184	LS34	8/19/2015	Full, piece of sand dollar, medium sand, amphipod tubes
4	-71.144	41.182	LS35	8/19/2015	Full, tan medium sand, tubesm amph. Shell hash
4	-71.145	41.180	LS36	8/19/2015	Tan, medium sand, tubes, amph. Shell hash
5	-71.119	41.186	LS37	8/19/2015	full, medium sand, tubes, amph
5	-71.120	41.184	LS38	8/19/2015	full tan medium-fione sand, amph tubes
5	-71.121	41.181	LS39	8/19/2015	Full coarse sand, reddish quahog (3 inches), shell hash
7	-71.217	41.172	LS4	8/19/2015	Coarse brown sand, some tubes, shall hash, full grab
7	-71.218	41.170	LS5	8/19/2015	Medium to coarse brown sand; sand dollar, shell hash
7	-71.219	41.168	LS6	8/19/2015	Medium to coarse brown sand; sand dollar, shell hash
8	-71.145	41.161	LS31	8/19/2015	Full, finer sand w/ tubes + amph. Shell hash
8	-71.146	41.159	LS32	8/19/2015	3/4 full, slightly coarser sand, tubes, shell hash, amph.
8	-71.146	41.157	LS33	8/19/2015	Full, medium coarse sand, tubes, shell hash
9	-71.085	41.163	LS46	8/19/2015	Full, fine-med sand, tubes, amph. Small shell hash
9	-71.089	41.162	LS47	8/19/2015	1/2 full, coarser sand-pebbles, shell hash
9	-71.091	41.160	LS48	8/19/2015	Very little sample, recovered boulders
10	-71.044	41.173	LS49	6/27/2016	Full grab, sand, shells, pebbles
10	-71.044	41.170	LS50	6/27/2016	Full grab, sand, silty, shells, cobbles
10	-71.046	41.168	LS51	6/27/2016	Full grab, sand, shells, pebbles
11	-70.957	41.176	LS52	6/27/2016	1/2 full, sand, rocks, shell hash
11	-70.960	41.174	LS53	6/27/2016	mostly rocks, very little sediment
11	-70.960	41.171	LS54	6/27/2016	1/4 full
12	-71.240	41.117	LS10	6/27/2016	1/3 grab, very coarse sand, gravel, some cobbles
12	-71.240	41.115	LS11	6/27/2016	Coarse to very coarse sand, some gravel; few shells
12	-71.238	41.113	LS12	6/27/2016	Coarse to very coarse brown sand, 1/4 full grab
13	-71.217	41.100	LS13	1/7/2016	Full, fine sand, tubes
13	-71.215	41.096	LS14	1/7/2016	1/4 Full of rocks; lots of rocks, 5 inch rocks
13	-71.215	41.098	LS15	1/7/2016	3/4 Full, tubes, brown fine sand
14	-71.125	41.108	LS25	1/7/2016	full extrafine silt/clay material, amph. Shell hash

14	-71.126	41.105	LS26	1/7/2016	3/4 full, lots of tubes/amph, fine sand
14	-71.124	41.103	LS27	1/7/2016	Full, medium sand, brown tubes, amph
15	-71.112	41.119	LS28	6/28/2016	Full, coarse sand, pebbles, shell hash
15	-71.112	41.116	LS29	6/28/2016	1/2 full, sand, pebbles, shell hash
15	-71.112	41.114	LS30	1/7/2016	1/8-1/4 full, gravel, sand-gravel
15	-71.113	41.114	LS30	6/28/2016	1/4 full, rocks, shells
16	-71.026	41.123	LS64	6/28/2016	1/4 full, sand, rocks, cobbles
16	-71.029	41.122	LS65	6/28/2016	Full grab, sand
16	-71.031	41.118	LS66	6/28/2016	1/2 full, sand
18	-70.941	41.101	LS55	6/28/2016	Full grab, sand
18	-70.940	41.097	LS56	6/28/2015	3/4 full, sand, few shells
18	-70.943	41.099	LS57	6/28/2016	Full grab, sand
20	-71.200	41.086	LS16	1/7/2016	1/4 full, coarse sand, cobbles. 1 lg rock
20	-71.198	41.082	LS17	1/7/2016	Full, lots of rocks, med sand-coarse sand, shell hash
20	-71.197	41.080	LS18	1/7/2016	Rocks, 3/4 full, variation in grain size, gravel, coarse sand
21	-71.123	41.065	LS19	1/7/2016	Full, fine sand, tubesm, some shell hash
21	-71.122	41.068	LS20	1/7/2016	rocks in jaws, 1/8 full, shell frag, coarse sand, rocks
21	-71.120	41.074	LS21	1/7/2016	3/4 full, medium sand, rocks, pebbles, gravel
22	-71.095	41.075	LS22	1/7/2016	1/4 full, rocks, medium sand, coarse, large cobbles
22	-71.101	41.079	LS23	1/7/2016	coarse sand w/ small cobbles, pebbles, shell hash
22	-71.099	41.077	LS24	1/7/2016	1/8 full, fine sand, worms, some cobbles (pebbles)
23	-71.040	41.082	LS61	6/28/2016	Full grab, sand
23	-71.039	41.085	LS62	6/28/2016	Full grab, sand
23	-71.038	41.088	LS63	6/28/2016	3/4 full, sand, some shell hash
24	-70.969	41.087	LS58	6/28/2016	Full grab, sand, some shell hash
24	-70.971	41.089	LS59	6/28/2016	3/4 full, sand, some shell hash
24	-70.970	41.091	LS60	6/28/2016	3/4 full, sand, some shell hash, big quahog
25	-71.170	41.218	LS101	11/18/2015	Fine sand, medium tubes
25	-71.170	41.216	LS102	11/18/2015	medium brown sand, with tubes, full grab
25	-71.172	41.214	LS103	11/18/2015	mud - fine sand, tubes (tan-brown), full grab
26	-71.074	41.228	LS143	11/18/2015	Fine-medium sand, tubes, amph. Shell hash
26	-71.075	41.226	LS144	11/18/2015	Fine sands, amph shell hash
26	-71.075	41.224	LS145	11/18/2015	Lots of amph, fine sand, shell hash, tan sand
27	-71.188	41.190	LS104	8/19/2015	Coarse to very coarse sand, brown, snails
27	-71.190	41.188	LS105	8/19/2015	Full grab; coarse sand, brown
27	-71.191	41.186	LS106	8/19/2015	Medium to coarse sand, brown to dark brown
28	-71.123	41.194	LS140	8/19/2015	Full, worms, little tubes, (not a lot) amph, fine-med sand
28	-71.124	41.192	LS141	8/19/2015	Full, fine-medium sand, tubes, worms, some shell hash
28	-71.126	41.191	LS142	8/19/2015	Full, fine-med sand tan, small hash, amph. tubes
29	-71.076	41.216	LS146	8/19/2015	3/4 full, medium sand, shell hash, amph
29	-71.075	41.215	LS147	8/19/2015	Full, fine-medium sand, amph shells hash, tubes
29	-71.077	41.213	LS148	8/19/2015	Shell hash, fine-medium sand, some amph tubes
31	-71.183	41.170	LS107	8/19/2015	Brown to dark brown, medium sandy; shell hash, shrimp

31	-71.185	41.168	LS108	8/19/2015	Brown medium sand; shell hash, quahog
31	-71.187	41.167	LS109	8/19/2015	Brown medium sand; shell hash
32	-71.122	41.151	LS134	8/19/2015	1/4 very little samplke, cobbles/pebbles, coarse sand
32	-71.123	41.149	LS135	8/19/2015	3/4 full, gravel, coarse sand, amph.
32	-71.123	41.148	LS136	8/19/2015	3/4 full, medium sand, worms, shell hash, amph.
33	-71.116	41.153	LS137	8/19/2015	Full grab, med sand, shell hash, sand dollar
33	-71.115	41.149	LS138	8/19/2015	Full, med sand, sand dollars, worms (large)
33	-71.114	41.152	LS139	8/19/2015	Full, fine-med sand, amph, tubes, shell hash
34	-71.027	41.171	LS149	6/27/2016	Full grab, sand
34	-71.029	41.170	LS150	6/27/2016	Full grab, sand
34	-71.031	41.168	LS151	6/27/2016	Full grab, sand
35	-70.984	41.161	LS152	6/27/2016	3/4 full, sand, shell hash
35	-70.986	41.160	LS153	6/27/2016	Full grab, sand
35	-70.987	41.158	LS154	6/27/2016	Full grab, sand
36	-71.251	41.126	LS110	6/27/2016	1/2 grab, very coarse sand to gravel, brown
36	-71.253	41.124	LS111	6/27/2016	Coarse brown sand, some shells and tubes, some cobble
36	-71.252	41.122	LS112	6/27/2016	Coarse sand & gravel up to ~5cm, not as coarse as LS111
37	-71.195	41.121	LS113	1/7/2016	Fine sand,w/ cobble, 1/4 full
37	-71.196	41.123	LS114	1/7/2016	3/4 full, sand -fine, tan, tubes
37	-71.193	41.125	LS115	1/7/2016	1/2 full, coarse sand, small gravel
38	-71.168	41.104	LS116	1/7/2016	3/4 full, tubes, coarse sand, gravel, worms
38	-71.169	41.102	LS117	1/7/2016	3/4 full, fine sand with tubes, some shell hash
38	-71.170	41.100	LS118	1/7/2016	1/2 full, small cobbles and very coarse sand
39	-71.081	41.092	LS125	1/7/2016	1/4 full, medium sand, shells, rocks, pebbles ~3inches
39	-71.080	41.090	LS126	1/7/2016	full, fine sand, with tubes and amph
39	-71.082	41.094	LS127	1/7/2016	4in rock, fine sand w/ tubes amph. Very small pebbles
40	-71.010	41.098	LS167	6/28/2016	1/2 full, sand, pebbles, few cobbles
40	-71.012	41.097	LS168	6/28/2016	1/2 full, sand, pebbles
40	-71.012	41.096	LS169	6/28/2016	3/4 full, sand
42	-70.930	41.129	LS158	6/28/2016	Full grab, sand, pebbles, shells
42	-70.930	41.128	LS159	6/28/2016	Full grab, sand
42	-70.928	41.131	LS160	6/28/2016	1/4 full, sand, rocks
44	-71.178	41.083	LS119	1/7/2016	1/4 full of pebbles, tan sand
44	-71.179	41.080	LS120	1/7/2016	rocks in jaws, 3/4 full, coarse sand, gravel/small cobbles
44	-71.181	41.080	LS121	1/7/2016	3/4 Full, fine-medium brown sand, w/ tubes/amphipods
45	-71.141	41.086	LS122	1/7/2016	1/8 full, large rock, large shell
45	-71.144	41.083	LS123	1/7/2016	1/2 full, fine sand, gravel, shells, rocks
45	-71.144	41.081	LS124	1/7/2016	3/4 full, fine sand, shell hash, 3cm rock
46	-71.080	41.083	LS128	1/7/2016	rocks in jaws, medium sand w/ small pebbles
46	-71.079	41.084	LS129	1/7/2016	Full, medium sand, small pebbles, worm, 1-5in rock
46	-71.078	41.086	LS130	1/7/2016	1/2 full, medium sand, shell hash
47	-71.054	41.086	LS131	6/28/2016	Full grab, sand, some shell hash
47	-71.055	41.084	LS132	6/28/2016	1/2 full, sand

47	-71.056	41.083	LS133	6/28/2016	2/3 full, sand
48	-70.955	41.088	LS164	6/28/2016	Full grab, sand
48	-70.955	41.086	LS165	6/28/2016	Full grab, sand
48	-70.956	41.085	LS166	6/28/2016	Full grab, sand, few pebbles
17, 41	-70.950	41.117	LS161	6/28/2016	rock caught in jaws, very small sample
17, 41	-70.958	41.119	LS162	6/28/2016	3/4 full, sand, pebbles
17, 41	-70.956	41.120	LS163	6/28/2016	1/4 full, cobbles, pebbles, sand
19, 43	-70.858	41.129	LS155	6/27/2016	Full grab, sand
19, 43	-70.859	41.127	LS156	6/27/2016	Full grab, sand
19, 43	-70.860	41.124	LS157	6/27/2016	Full grab, sand
6, 30	-71.244	41.157	LS7	6/27/2016	Coarse brown to dark brown sand; shell hash
6, 30	-71.246	41.155	LS8	6/27/2016	Coarse, brown sand; some shell hash, tubes
6, 30	-71.247	41.153	LS9	6/27/2016	Coarse brown sand; some shells and tubes

Appendix 3. Coordinates of sampling locations, depth, and habitat classification

Year	Aliquot	Habitat	Depth (m)	N latitude	W longitude
2014	1	Medium to coarse sand	37.5	41.221	71.140
2014	2	Soft sediment	40.8	41.222	71.083
2014	3	Medium to coarse sand	40.8	41.187	71.196
2014	4	Medium to coarse sand	37.2	41.177	71.137
2014	5	Medium to coarse sand	37.2	41.178	71.110
2014	6	Medium to coarse sand	42.4	41.154	71.238
2014	7	Medium to coarse sand	36.3	41.165	71.210
2014	8	Medium to coarse sand	35.1	41.155	71.138
2014	9	Transition zone	34.1	41.156	71.080
2014	10	Transition zone	34.1	41.168	71.038
2014	11	Boulders on sand	27.4	41.170	70.953
2014	12	Boulders on sand	33.2	41.111	71.236
2014	13	Boulders on sand	33.2	41.089	71.208
2014	14	Medium to coarse sand	38.7	41.102	71.122
2014	15	Boulders on sand	34.7	41.112	71.107
2014	16	Boulders on sand	34.7	41.114	71.022
2014	17	Boulders on sand	32.6	41.116	70.950
2014	18	Medium to coarse sand	36.0	41.095	70.936
2014	19	Transition zone	37.5	41.128	70.852
2014	20	Boulders on sand	33.5	41.079	71.193
2014	21	Boulders on sand	34.7	41.069	71.120
2014	22	Boulders on sand	33.5	41.069	71.092
2014	23	Medium to coarse sand	36.0	41.081	71.036
2014	24	Medium to coarse sand	35.4	41.082	70.963

2015	25	Soft sediment	43.0	41.242	71.127
2015	26	Soft sediment	37.2	41.253	71.098
2015	27	Medium to coarse sand	39.9	41.187	71.182
2015	28	Soft sediment	38.7	41.188	71.125
2015	29	Medium to coarse sand	35.7	41.211	71.068
2015	30	Medium to coarse sand	42.4	41.153	71.238
2015	31	Medium to coarse sand	39.3	41.165	71.181
2015	32	Boulders on sand	35.7	41.145	71.124
2015	33	Boulders on sand	34.4	41.145	71.109
2015	34	Medium to coarse sand	32.9	41.168	71.024
2015	35	Medium to coarse sand	34.1	41.158	70.981
2015	36	Boulders on sand	33.8	41.121	71.251
2015	37	Boulders on sand	31.4	41.122	71.194
2015	38	Medium to coarse sand	35.1	41.101	71.165
2015	39	Medium to coarse sand	33.8	41.092	71.079
2015	40	Medium to coarse sand	36.0	41.093	71.008
2015	41	Boulders on sand	32.6	41.115	70.951
2015	42	Transition zone	32.9	41.127	70.923
2015	43	Medium to coarse sand	37.5	41.128	70.851
2015	44	Medium to coarse sand	34.1	41.079	71.179
2015	45	Boulders on sand	34.7	41.080	71.136
2015	46	Boulders on sand	33.8	41.081	71.079
2015	47	Medium to coarse sand	35.7	41.081	71.050
2015	48	Medium to coarse sand	36.6	41.083	70.950

Appendix 4. Data from tagged and recaptured lobsters

Tag number	Tagged latitude	Tagged longitude	Recapture latitude	Recapture longitude	Distance Traveled (km)	Days at large	Bearing	Travel rate (km/day)
1	41.0848	-71.1418	41.1017	-71.1674	2.857	26	-49	0.110
20	41.1245	-71.2519	39.9917	-70.9250	128.688	302	167	0.426
33	41.1245	-71.2519	41.1250	-71.2507	0.117	32	63	0.004
39	41.0921	-71.0807	41.0921	-71.0807	0.000	10	NA	0.000
43	41.0921	-71.0807	41.0800	-71.0500	2.908	6	118	0.485
58	41.1245	-71.2519	41.1245	-71.2519	0.000	5	NA	0.000
68	41.1246	-71.1936	41.2467	-71.3417	18.378	27	-42	0.681
69	41.1245	-71.2519	41.1245	-71.2519	0.000	10	NA	0.000
75	41.0822	-71.1784	41.0638	-71.1055	6.457	14	108	0.461
82	41.1246	-71.1936	41.0348	-71.2612	11.464	8	-150	1.433
90	41.0848	-71.1418	41.0224	-71.3817	21.320	123	-109	0.173
92	41.1555	-71.2432	41.1733	-71.2545	2.193	7	-26	0.313
105	41.2169	-71.1702	41.2169	-71.1702	0.000	35	NA	0.000
124	41.1656	-71.1847	41.2430	-71.0065	17.237	21	60	0.821
131	41.2236	-71.0741	41.2006	-70.9013	14.717	20	100	0.736
137	41.2123	-71.0757	41.1553	-71.0977	6.584	14	-164	0.470
142	41.2169	-71.1702	41.1508	-71.1858	7.448	9	-170	0.828
148	41.1873	-71.1888	41.0844	-71.0773	14.764	5	141	2.953
153	41.1873	-71.1888	41.0224	-71.1324	18.899	43	165	0.440
173	41.1912	-71.1248	41.2467	-70.9400	16.674	53	68	0.315
176	41.1912	-71.1248	41.1656	-71.1834	5.679	26	-120	0.218
191	41.1490	-71.1133	40.0055	-71.3208	128.070	53	-172	2.416
192	41.1466	-71.1228	41.1466	-71.1228	0.000	32	NA	0.000
193	41.1912	-71.1248	41.2499	-71.1463	6.758	339	-15	0.020
203	41.0800	-71.0500	40.0350	-70.5533	123.326	28	160	4.404
235	41.1300	-70.9200	41.1316	-70.9258	0.520	11	-70	0.047
247	41.1690	-71.0260	41.0690	-71.0248	11.096	14	179	0.793
257	41.1300	-70.9200	40.0200	-70.3700	131.653	369	159	0.357
250	41.1600	-70.9800	40.0327	-70.9971	125.074	96	-179	1.303
253	41.1300	-70.9200	41.1300	-70.9400	1.679	45	-90	0.037
282	41.1300	-70.9200	41.0900	-71.0080	8.622	6	-121	1.437
286	41.1200	-70.9550	41.1200	-70.9550	0.000	6	NA	0.000
293	41.1600	-70.9800	41.2517	-71.8733	75.610	339	-82	0.223
297	41.1200	-70.9550	41.1200	-70.9550	0.000	6	NA	0.000
298	41.1200	-70.9550	41.1200	-70.9550	0.000	6	NA	0.000
1	41.1017	-71.1674	41.0850	-71.1419	2.839	59	131	0.048

203	40.0350	-70.5533	40.0000	-71.0002	38.344	119	-96	0.322
250	40.0327	-70.9971	39.9861	-70.9481	6.652	118	141	0.056

Appendix 5. Description and disposition of the database

These digital files are provided on the accompanying CDROM.

Folder or filename	Description of contents
SideScan	Side-scan sonar images of each sampling site
GoPro	Still photographs from GoPro camera mounted on the grab sampler
Lobster_Survey_Grain_Size.xls	Sediment grain size composition of each grab sample
temps2014.txt, temps2015.txt	Tidbit bottom temperature data
SNECVTS_database_2014.accdb	Access database of 2014 lobster and bycatch data
SNECVTS_database_2015.accdb	Access database of 2015 lobster and bycatch data
LobsterTag&RecaptureData_SNECVTS2015.xlsx	Data from 2015 pilot tagging study
Report_Figures	Digital files for each figure in the report

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

The Bureau of Ocean Energy Management

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.