Technical Reports

Massachusetts Division of Marine Fisheries
Technical Report TR-71

Random Stratified Ventless Trap Survey for American Lobster 2006–2016

T. L. Pugh and R. P. Glenn

Massachusetts Division of Marine Fisheries
Department of Fish and Game
Executive Office of Energy and Environmental Affairs
Commonwealth of Massachusetts

June 2020

Massachusetts Division of Marine Fisheries Technical Report Series

The Massachusetts Division of Marine Fisheries Technical Reports present information and data pertinent to the management, biology and commercial and recreational fisheries of anadromous, estuarine, and marine organisms of the Commonwealth of Massachusetts and adjacent waters. The series presents information in a timely fashion that is of limited scope or is useful to a smaller, specific audience and therefore may not be appropriate for national or international journals. Included in this series are data summaries, reports of monitoring programs, and results of studies that are directed at specific management problems.

All Reports in the series are available for download in PDF format at:
https://www.mass.gov/service-details/marine-fisheries-technical-reports.

Recent Publications in the Technical Series:

TR-70: Nelson, G. A. 2019. **Massachusetts striped bass monitoring report for 2018**.
TR-69: Whitmore, K. A., E. M. Moore, and E. J. Brewer. 2019. **Characterization of Fishing Activity and Trap Loss in the Massachusetts Recreational American Lobster Fishery**.
TR-68: Nelson, G. A. 2018. **Massachusetts striped bass monitoring report for 2017.**
TR-67: Chosid, D. M., M. Pol, B. P. Schondelmeier, and M. Griffin. 2019. **Early Opening Experimental Fishery for Silver Hake/ Whiting in Small Mesh Area 1 and the Western Raised Footrope Exemption Area.**.
TR-66: Nelson, G. A., S. H. Wilcox, R. Glenn, and T. L. Pugh. 2018. **A Stock Assessment of Channeled Whelk (*Busycotypus canaliculatus*) in Nantucket Sound, Massachusetts**.
TR-65: Nelson, G. A. 2017. **Massachusetts striped bass monitoring report for 2016**.
TR-64: Nelson, G. A. 2016. **Massachusetts striped bass monitoring report for 2015**.
TR-62 Nelson, G. A. 2015. **Massachusetts striped bass monitoring report for 2014**.
TR-61 Nelson, G. A., J. Boardman, and P. Caruso. 2015. **Massachusetts Striped Bass Tagging Programs 1991–2014**.
TR-60 Nelson, G. A. and J. Stritzel-Thomson. 2015. **Summary of Recreational Fishery Data for Striped Bass Collected by volunteer Anglers in Massachusetts**.
TR-59 Nelson, G. A. 2015. **Massachusetts Striped Bass Monitoring Report for 2013**.
TR-58 Elzey, S. P., K. J. Trull, and K. A. Rogers. 2015. **Massachusetts Division of Marine Fisheries Age and Growth Laboratory: Fish Aging Protocols**.
TR-57 Chase, B.C., K. Ferry, and Carl Pawlowski. 2015. **River herring spawning and nursery habitat assessment: Fore River Watershed 2008-2010.**
TR-56 Sheppard, J.J., S. Block, H.L. Becker, and D. Quinn. 2014. **The Acushnet River restoration project: Restoring diadromous populations to a Superfund site in southeastern Massachusetts**.
TR-55 Nelson, G. 2013. **Massachusetts striped bass monitoring report for 2012**.
TR-54 Chase, B.C., A. Mansfield, and P. duBois. 2013. **River herring spawning and nursery habitat assessment**.
TR-53 Nelson, G.A. 2012. **Massachusetts striped bass monitoring report for 2011**.
TR-52 Camisa, M. and A. Wilbur. 2012. Buzzards Bay Disposal Site Fisheries Trawl Survey Report March 2001-March 2002.
TR-51 Wood, C. H., C. Enterline, K. Mills, B. C. Chase, G. Verreault, J. Fischer, and M. H. Ayer (editors). 2012. **Fourth North American Workshop on Rainbow Smelt: Extended Abstract Proceedings**.
TR-50 Hoffman, W. S., S. J. Correia, and D. E. Pierce. 2012. **Results of an industry-based survey for Gulf of Maine cod, May 2006-December 2007**.
TR-49 Hoffman, W. S., S. J. Correia, and D. E. Pierce. 2012. **Results of an industry-based survey for Gulf of Maine cod, November 2003—May 2005**.
TR-48 Nelson, G. A. 2011. **Massachusetts striped bass monitoring report for 2010**.

Massachusetts Division of Marine Fisheries
Technical Report TR-71

Random Stratified Ventless Trap Survey for American Lobster 2006–2016

Tracy L. Pugh[1] and Robert P. Glenn[1]

[1]Massachusetts Division of Marine Fisheries
836 South Rodney French Blvd.
New Bedford, MA 02744

June 2020

Commonwealth of Massachusetts
Charles D. Baker, Governor
Executive Office of Energy and Environmental Affairs
Kathleen Theoharides, Secretary
Department of Fish and Game
Ronald S. Amidon, Commissioner
Massachusetts Division of Marine Fisheries
Daniel J. McKiernan, Director

Executive Summary: The Massachusetts lobster fleet landed roughly 17.7 million pounds in 2016, worth more than 82 million dollars. This accounted for approximately 11% of all US lobster landings, second only to Maine. The lobster fishery in the United States is managed cooperatively by the Atlantic States Marine Fisheries Commission (ASMFC) and the National Marine Fisheries Service (NMFS), and the stock is assessed via the ASMFC Lobster Stock Assess-ment. The stock assessment relies on accurate indices of relative abundance produced by surveys that must be based on a random sampling design, with the survey area stratified in such a way as to minimize the variance of parameter estimates. The ASMFC Lobster Technical Committee developed the Coastwide Ventless Trap Survey in 2006 to provide an additional fishery-independent index of abundance to complement the traditional trawl-based surveys used in the stock assessment. The survey stratification scheme is based on NMFS statistical area and depth (to account for habitat), and the survey design combines a random stratified sampling design with static fishing gear that can be deployed on any substrate type. There are two survey areas in Massachusetts waters, Gulf of Maine (GOM, NMFS Statistical Area 514) and Southern New England (SNE, Statistical Area 538), each of which is divided into three depth ranges 0 to 20 meters, 21 to 40 meters, and 41 to 60 meters. Stations are randomly selected annually within each depth range and sampled from June through September with a six-trap trawl consisting of al-ternating ventless and vented traps (three of each trap type). Sampling is conducted by the Massachusetts Division of Marine Fisheries (DMF) working cooperatively aboard contracted Massachusetts commercial lobster vessels. This report provides details on the results of the Massachusetts Ventless Trap Survey, including data describing the relative abundance of legal and sublegal-sized lobsters, size distribution, sex ratio, shell disease prevalence, as well as other characteristics of the catch and spatial patterns observed. The time series of relative abundance generated by this survey has been incorporated into the ASMFC Lobster Stock Assessment, complementing the existing trawl survey data. Additionally, the results from this survey have demonstrated that specific demographics (sex, size class, maturity status) within the lobster population are not distributed randomly. It has provided evi-dence that lobster distribution and abundance may be related to preferred thermal habitats, which vary based on depth and geographic location.

Introduction

The American lobster (*Homarus americanus*) represents the second most valuable commercial species landed in Massachusetts, with 17.7 million pounds landed in 2016 valued at more than 82 million dollars ([2016 DMF Annual Report]). In the United States, Massachusetts is second to Maine in lobster landings, bringing in approximately 11% of the country's total (Maine lands approx. 83%; http://www.accsp.org/data-warehouse, accessed 4/11/2017). The US fishery is managed cooperatively by ASMFC in state waters and NMFS in federal waters.

A vital component of a successful species management program is a reliable and accurate index of relative abundance to assess stock status. For an index of relative abundance to be useful for stock assessment purposes it must: 1) include a sampling frame which encompasses the species range within the specified stock unit, 2) incorporate a random sampling design so that all areas within the sampling frame have an equal probability of being sampled, and 3) preferably incorporate a stratification scheme based on meaningful habitat components to help minimize the variance of parameter estimates. We have designed a cooperative random stratified ventless trap survey that incorporates these elements. The intent of the ventless trap survey is to provide an additional fishery-independent index of abundance to complement the traditional trawl-based surveys used in the ASMFC Lobster Stock Assessment. An added benefit of the ventless trap survey is that it is not prone to some of the limitations that trawl surveys have with regards to structure-dwelling animals. Unlike otter-trawls, trap gear can be fished on all bottom types (rocky/hard bottom) and in areas where high densities of fixed gear (including commercial traps) are present. This attribute of a trap-based survey makes it very useful for monitoring species with a high affinity for complex bottom like American lobster.

DMF conducted pilot studies in Massachusetts Bay (2004–2006) and in Buzzards Bay (2005–2007) to develop a survey methodology and sampling protocols. The stratification scheme employed in these pilot studies included depth and bottom complexity. Results from these studies indicated that depth was the primary habitat variable driving catch rates and observed demographics in Massachusetts waters (Pugh and Glenn, in prep). Additionally, the pilot work indicated that recapture rates of tagged individuals, particularly in Buzzards Bay, necessitates accounting for recaptured individuals in subsequent trap hauls in order to avoid biasing abundance estimates (DMF unpublished data).

The trap design employed by the Coastwide Ventless Trap Survey was developed in consultation with industry partners during the pilot studies. The design was based on the traps used in the Canadian volunteer ventless trap surveys (MacDonald et al. 2001). There were concerns expressed by some industry participants that the 12.7 cm (5 inch) entrance heads were too small and would exclude larger individuals. However, a comparison of catch composition between the survey traps and traps with enlarged entrance heads 20.32 cm (8 inch), similar to those used in the offshore fishery, indicated no difference in the size distribution of lobsters caught in the traps with larger heads (DMF unpublished data). In order to account for potential trap saturation issues (crowding) in ventless traps that may negatively impact the catch of larger individuals, our survey methodology incorporates both ventless and vented traps into the sampling unit.

The Coastwide Ventless Trap Survey was developed by the ASMFC Lobster Technical Committee, including partner agencies Maine DMR, New Hampshire F&G, Rhode Island DEM, Connecticut DEEP, and New York F&G, based on the methods tested in the DMF pilot studies. The survey stratification scheme is based on NMFS statistical area (to account for the large geographic scale and to allow for good spatial alignment of catch and survey data) and depth (to account for habitat). This survey design combines the best aspects of both fishery-independent and dependent surveys; random stratified sampling design, and static fishing gear that can be deployed on any substrate type. The Coastwide Ventless Trap Survey is the first survey designed specifically to monitor American lobster using a standardized methodology throughout the inshore range of the commercially exploited US population.

Methods

Survey Design

The territorial waters of each participating state were stratified by NMFS Statistical Area and by three depth ranges; 0–20 meters, 21–40 meters, and 41–60 meters. There are two survey areas in Massachusetts territorial waters, GOM (NMFS Statistical Area 514) and SNE (Statistical Area 538). Depth strata and potential sampling cells were generated by overlaying the bathymetry of the study area with a one-minute latitude/longitude grid in ArcGIS (Figure 1). The two layers were then intersected, and the percent cover that each depth range occupied within a cell was calculated, relative to the total area of the cell. The grid cell was then assigned a final depth stratum based on which depth category comprised at least 75% of the cell's surface area. Any 'mixed' cells (all depth categories < 75% of the cell) were excluded from the selection process.

Each survey area was divided into zones for logistical purposes related to captain/port selection, and in GOM to spread the geographic distribution of the sampling locations over a broad area along the coast. New sampling stations were randomly selected each survey year (Figure 2). In each of the five geographic zones of GOM, four stations were randomly selected in each depth stratum, for a total of sixty stations. The study area in SNE included only the first two depth strata (0–20 m and 21–40 m), in each of which twelve stations were selected, for a total of twenty-four stations. The total number of sampling stations was increased to these numbers starting in 2007. During the first year of the survey (2006), only twenty-four stations in GOM and sixteen stations in SNE were sampled.

Starting in 2011 the SNE portion of the survey was expanded spatially into the federal portion of NMFS Statistical Area 538, and into the northern-most portion of NMFS Statistical Area 537. This expansion was intended to improve the overlap between the survey and the commercial fishing grounds. The majority of commercial effort had shifted progressively further from shore throughout the 2000's, presumably following a shift in lobster distribution, which due to the existing survey boundary (MA territorial waters) we could not monitor. This survey expansion added the third depth stratum (41–60 m) to the study area, and the number of stations per stratum was increased to 14 (for a total of 42 stations in the newly expanded SNE survey area). Hereafter the SNE survey area is broken into the "original survey area" and the "expanded survey area" based on

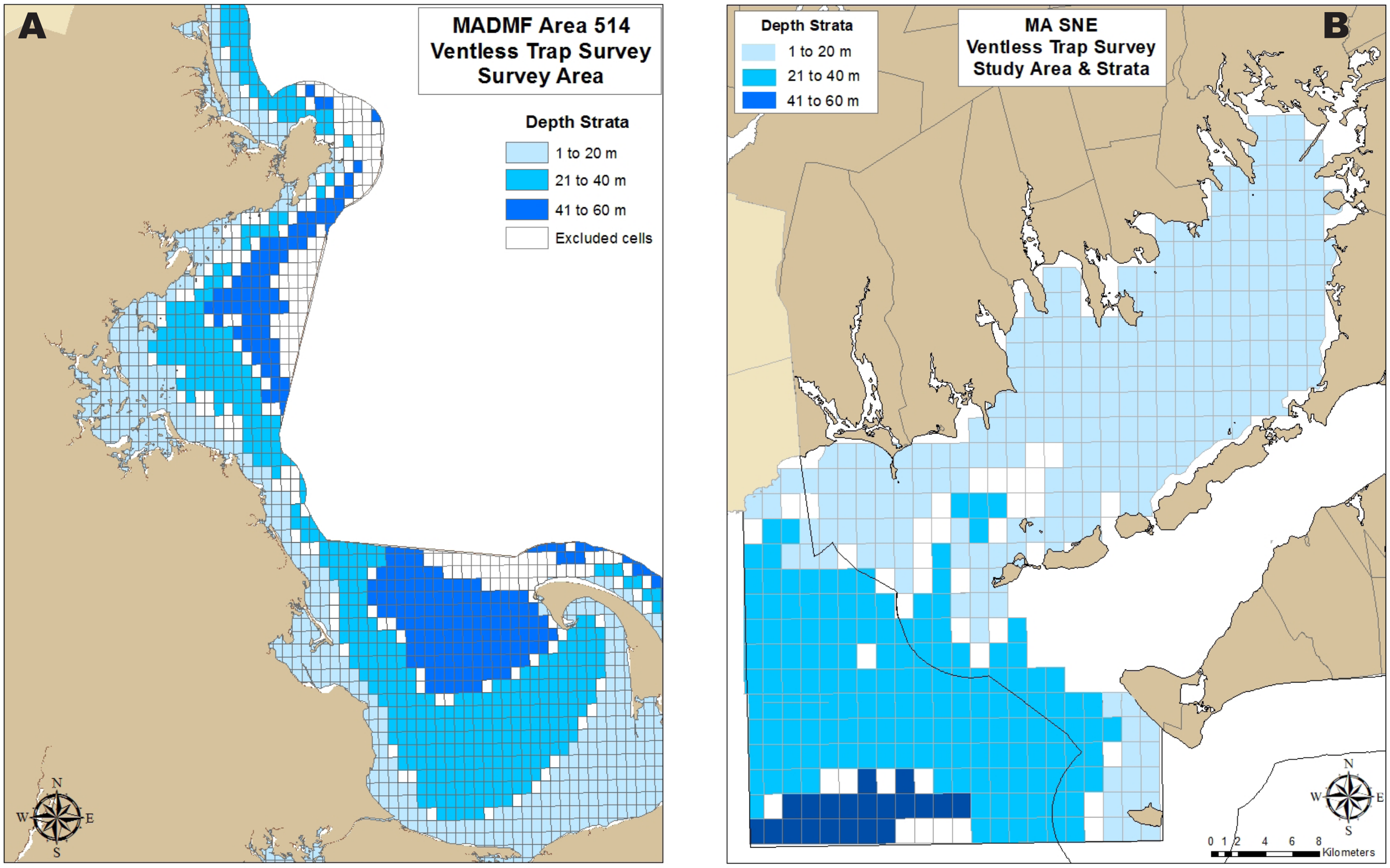


Figure 1. MA GOM (A) and SNE (B) survey areas (expanded area shown) with depth strata grid cells available for random selection of stations.

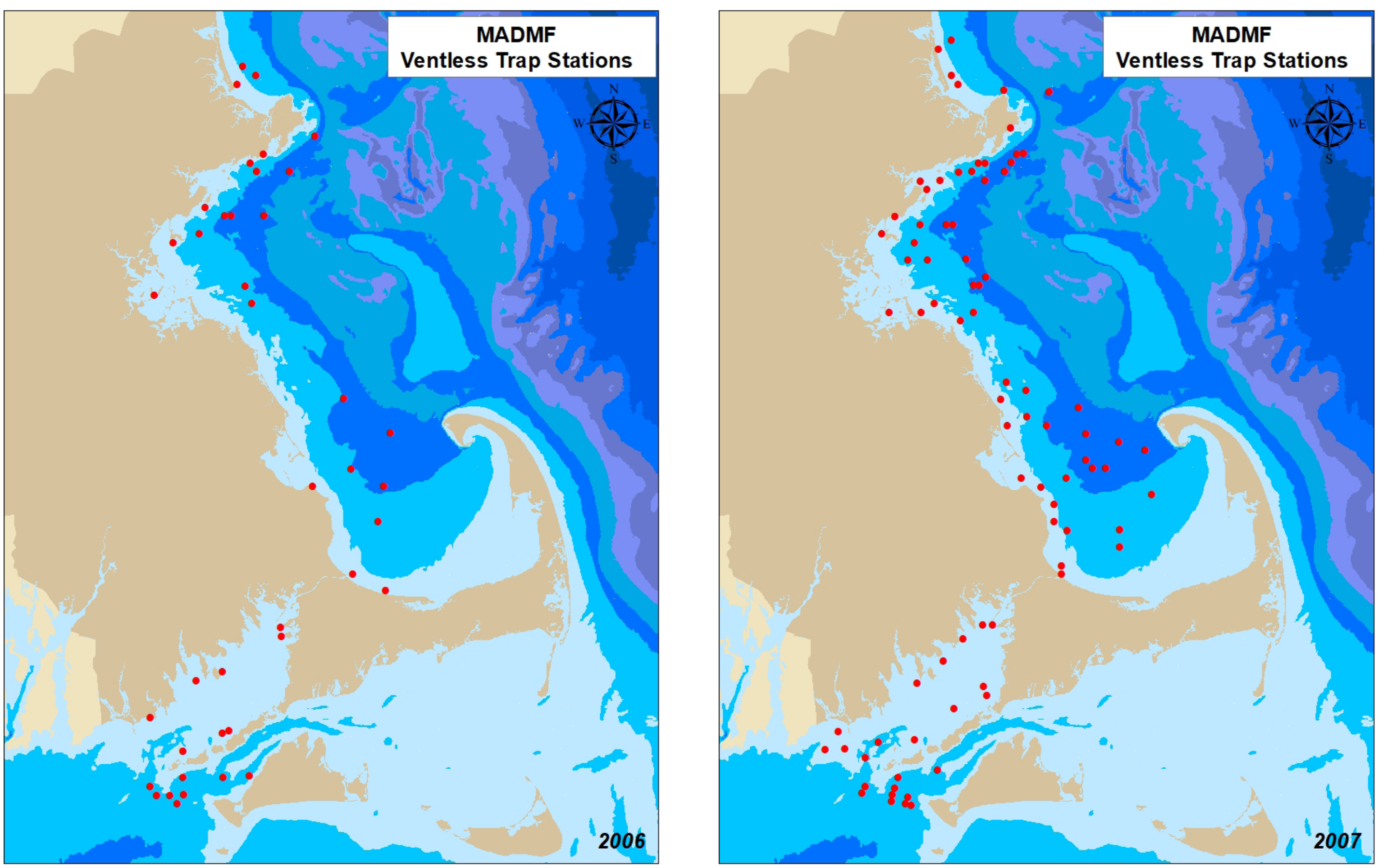


Figure 2. Sampling stations for the ventless trap survey in Massachusetts' waters, from 2006 and 2007. New sampling stations were randomly selected each year.

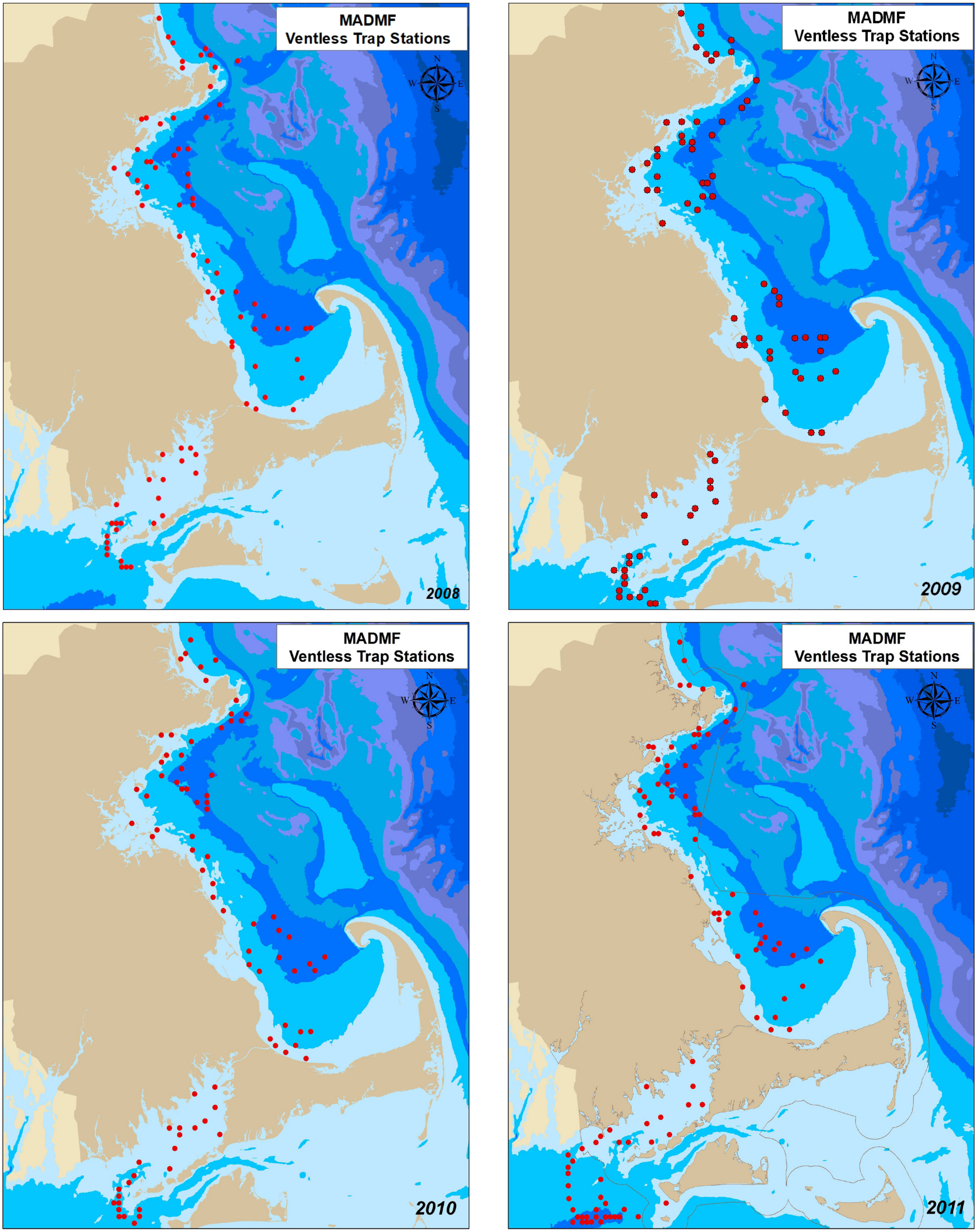


Figure 2 Continued. Sampling stations for the ventless trap survey in Massachusetts' waters, from 2008 through 2011. New sampling stations were randomly selected each year. Note the expanded survey area in the southern portion starting in 2011.

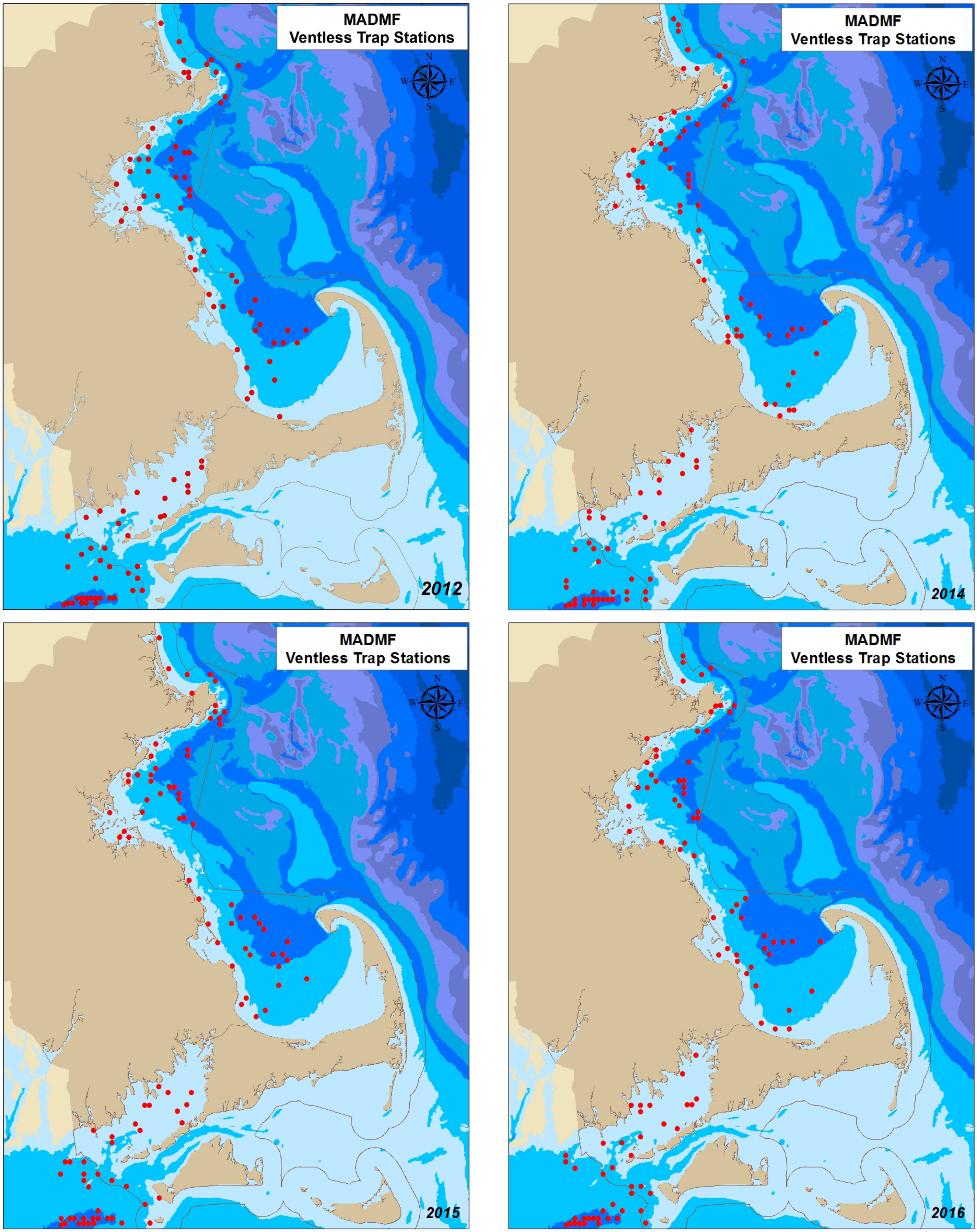


Figure 2 Continued. Sampling stations for the ventless trap survey in Massachusetts' waters, from 2012 through 2016. New sampling stations were randomly selected each year. Note the expanded survey area in the southern portion starting in 2011. There was no survey in 2013.

the location of the survey stations. Those stations that have always been available to the random selection process are included in the original survey area, while all survey stations from 2011 onwards are included in the expanded survey area. Thus from 2011–2016, the original survey area is a subset of the expanded survey area.

Each survey station was sampled with one six-trap trawl, in which vented and ventless lobster traps were alternated (three of each per trawl, see Figure 3). Traps were spaced 18.3 m apart, with each trap tied into the main groundline with a 1.8 m gangion. Survey traps were constructed of polyvinyl coated wire mesh (2.5 cm mesh) with a single parlor, overall trap dimensions were 101.6 cm x 53.3 cm x 35.6 cm and there was a single rectangular escape vent (14.6 cm x 4.9 cm) in the parlor of the vented traps. All survey gear conformed to Federal "whale-safe" regulations (see 322 CMR 12: Protected Species, https://www.mass.gov/regulations/322-CMR-1200-protected-species).

Data Collection

Stations were sampled twice per month from June through September in 2007–2012 and in 2014–2016. In 2006, sampling took place in GOM from July–August, and in SNE from June–August. There was no survey conducted in 2013 due to lack of funding. The bi-monthly sampling frequency of this design enhances the temporal resolution of the survey, making it more likely to capture seasonal aspects of lobster distribution and abundance.

Trap deployment, maintenance, and hauling were contracted to commercial lobstermen. To the degree possible, survey gear was hauled on a three to five-day soak time, in the attempt to standardize catchability among trips. All trawls were reset in the same assigned location after each haul. DMF staff accompanied the fishermen on each sampling trip to record catch per unit effort (CPUE) and biological data. Samplers used the standard DMF lobster trap sampling protocol, which records: catch in number of lobster, number of trap hauls, set-over-days, bait type, trap type (vented or ventless), and biological data for every lobster in the trap including carapace length (to the nearest mm), sex, shell hardness, culls and other shell damage, external gross pathology (including shell disease symptoms), mortality, and presence of extruded ova on females (ovigerous). Trawl location was confirmed with the station's assigned coordinates after each haul via GPS. Depth at mean low water for each trawl location was recorded from NOAA navigational charts as a coastwide standard to avoid variability from tidal fluctuations.

On the first haul of each month, each lobster was 'tagged' by placing a band on one chelae around the

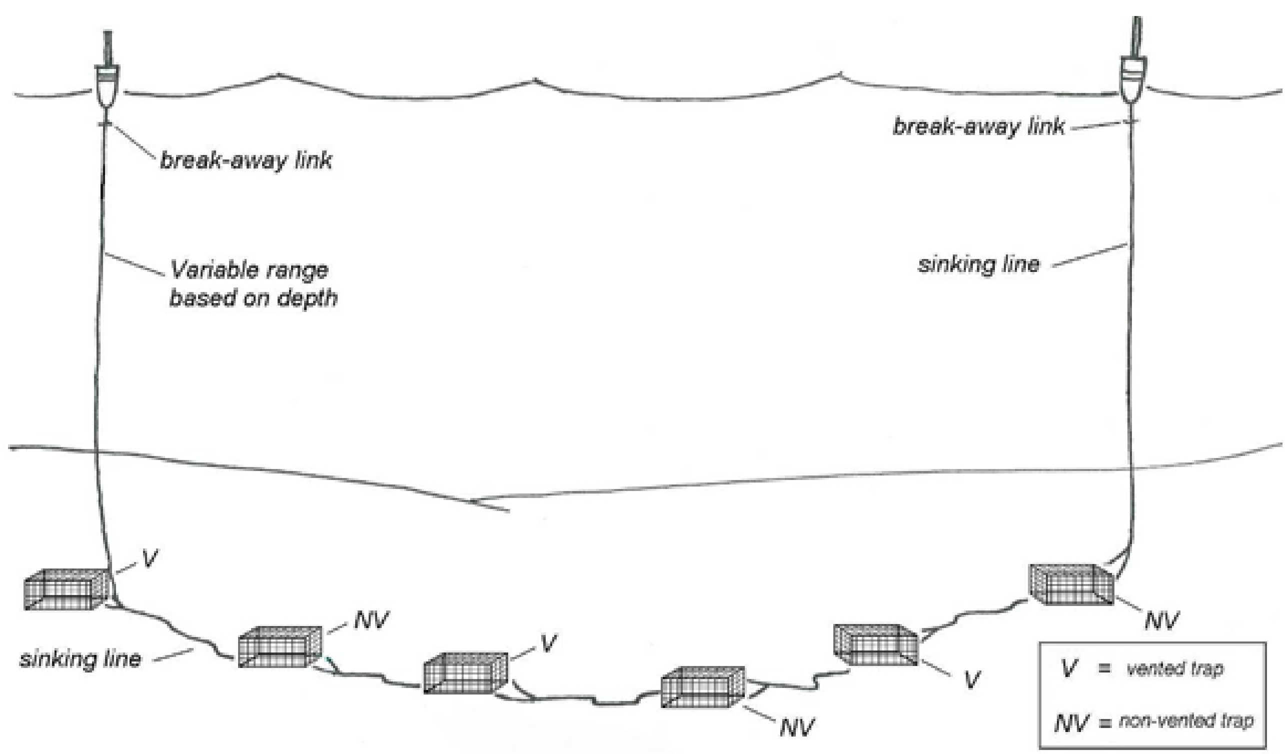


Figure 3. Diagram of the arrangement of a ventless survey trawl.

Figure 4. Applying a “knuckle band” to a lobster. Note the claw is not disabled.

‘knuckle,’ such that the claw was not disabled (Figure 4). Recaptures of tagged individuals were recorded on all subsequent trap hauls.

Data Analysis

The catch data from vented and non-vented traps within an individual trawl were pooled (the trawl was the sampling unit for each randomly selected station) and catch per trawl haul was standardized to three of each trap type (vented and non-vented) prior to calculations of mean CPUE. In order to account for repeated observations of the same individuals, the annual recapture rate (proportion of total) of tagged sublegal and legal lobsters was subtracted from the standardized catch per trawl for each size class, respectively. We then calculated the mean CPUE of each size class for each depth stratum.

The area-stratified mean (referred to as the “stratified mean” in the text) for each survey area (GOM and SNE) was calculated using the following formula:

$$U_A = \sum_r \frac{A_r}{A} U_r$$

where A_r is the area of each depth stratum, A is the total survey area, and U_r is the mean standardized catch per trawl (CPUE) for each depth stratum. The stratified mean was calculated separately for sublegal and legal-sized lobsters. The annual area-stratified mean represents the time series of relative abundance for each size class.

For reporting purposes, all CPUE data were reported as the standardized catch per trap haul, or “CTH_6”, which was calculated by dividing the standardized mean catch per trawl by six traps.

To monitor the abundance of females contributing to the current year’s larval production, a “spawning stock index” was developed. The spawning stock is comprised of late stage ovigerous females, including those females with brown eggs (will hatch in the current year) and recently hatched clutches (“spent”). The annual mean CTH_6 of the spawning stock (sizes combined) was calculated for each depth stratum, and a “spawning stock index” was calculated as the area stratified mean CTH_6 for each survey area.

Size distributions of lobsters observed in each depth stratum were compared using the two-sample Kolmogorov - Smirnov test for continuous data, accounting for cluster sampling, using the clus.lf script in the R package “fishmethods” (Nelson 2014, R Core Team 2016, Nelson 2017). Significance thresholds (α) were Bonferroni-adjusted to account for multiple comparisons when necessary (GOM 2006-2016, SNE expanded survey area 2011-2016). Comparisons were not made across years, only between strata within a year.

For the SNE survey area, results from the original survey area and the expanded survey area (see Survey Design Section) were analyzed separately.

Temperature Monitoring

Bottom water temperature data were collected bi-hourly with HOBO pendant data loggers (Onset Computer Corporation, model number UA-002-64). Temperature loggers were attached to one of the traps at each of ~12 haphazardly selected stations within GOM and SNE survey areas. Stations were selected in order to obtain temperature data from each depth stratum and from all portions of each survey area. In addition to these temperature loggers, DMF has eight permanent temperature monitoring stations located within the two survey areas. Daily mean temperature was calculated for each temperature monitoring station (ventless and permanent) from June 1 through September 30, then all stations within a stratum were averaged for each year. No stratum had fewer than two temperature monitoring stations, with the exception of the deep stratum in SNE in 2015 and 2016 for which no data are reported.

Results

GOM Survey Area

The annual number of trawls sampled by depth stratum are shown in Table 1. The total number of stations and the total number of trawl hauls increased from 2006 to 2007 when the resolution and time period of the survey were expanded (see Survey Design Section). Total trawl hauls varied slightly from year to year due to weather and occasional gear losses, but have averaged 468 annually since 2007 (Table 1). The mean number of lobsters sampled from 2007 through 2016 was 15,604 (Table 2). The number of lobsters caught peaked in 2012, related to large increases in lobsters caught in the 21–40 m and 41–60 m strata (Table 2).

Relative Abundance

The stratified mean CTH_6 of sublegal lobsters more than doubled between 2006 and 2012, and while CTH_6 declined in 2014, it returned to high levels in 2015 and 2016 (Figure 5). The stratified mean CTH_6 of legal lobsters varied slightly around the time series median of 0.51 per trap haul from 2006 to 2011 and exhibited a substantial increase to 0.8 legal lobsters per trap in 2012, with 2016 being similarly high (Figure 5). Sublegal-sized lobsters were on average nine times more abundant than legal-sized lobsters throughout the survey time period.

The average catch of sublegal lobsters has been consistently highest in the shallow stratum and declines with increasing depth; this pattern has persisted throughout the time series (Figure 6). Sublegal catch increased slightly over time in the shallow stratum, reaching a time series high in 2016. It increased more substantially in the mid and deep strata, particularly from 2007 through 2012 when it reached time series highs for both these strata.

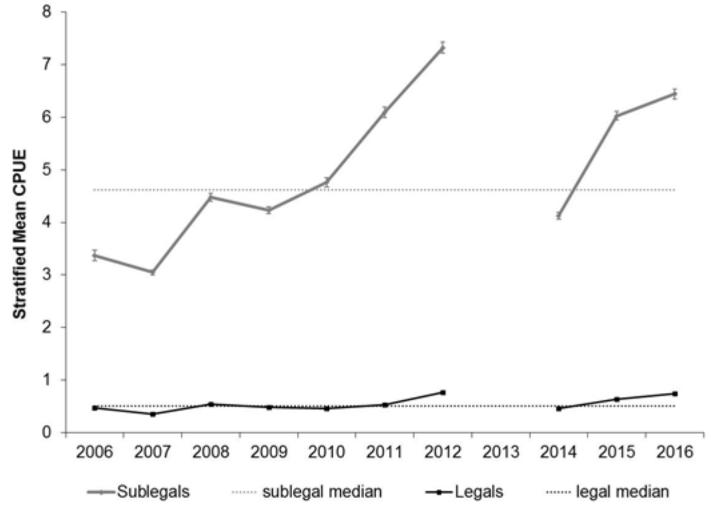


Figure 5. Relative abundance (stratified mean catch per trap haul (± S.E.)) of sublegal (< 83 mm CL) and legal-sized (≥83 mm CL) lobsters from 2006–2016. No data available for 2013. Horizontal dotted lines represent the time series median values.

The average catch of legal-sized lobsters in the shallow stratum increased from 2007 through 2012 and has remained relatively high through 2016 (Figure 7). Catch in the mid stratum followed a similar pattern as in the shallow stratum, increasing through 2012 and remaining relatively high although slightly more variable through 2016. The greatest changes in legal-sized catch were observed in the deep stratum, where after a period of low catches from 2007–2010, catch tripled by 2012, with 2012 being the only time abundance of

Table 1. Number of trawl hauls completed each year in each stratum. Note that in 2013 there was no survey (no data, “nd”).

Strata	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
0 to 20 m	36	158	151	158	153	160	156	nd	159	157	160
21 to 40 m	31	157	148	156	158	154	158	nd	160	156	159
41 to 60 m	30	157	147	149	152	156	158	nd	160	153	159
Total	97	472	446	463	463	470	472	nd	479	466	478

Table 2. Number of lobsters observed by depth stratum each year. Note that in 2013 there was no survey (no data, “nd”).

Strata	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
0 to 20 m	1,478	6,436	7,297	6,879	7,418	8,633	8,472	nd	6,607	8,467	9,858
21 to 40 m	543	2,119	3,673	3,703	4,076	5,512	7,865	nd	3,356	6,025	5,838
41 to 60 m	357	1,448	1,671	2,035	2,425	4,249	5,988	nd	2,947	3,239	4,200
Total	2,378	10,003	12,641	12,617	13,919	18,394	22,325	nd	12,910	17,731	19,896

lobsters was highest in the deep stratum. Legal catch dropped in 2014 and 2015 before again increasing substantially in 2016.

The consistent pattern seen in the sublegal catch related to depth compared to the lack of such a persistent pattern in the legal-sized catch may be related to the ontogeny of movement in lobsters. Smaller, sublegal lobsters have yet to develop the more extensive movement patterns that would take them away from the shallow waters in which they originally settled to the bottom, in contrast to the more mobile legal-sized lobsters (Lawton and Lavalli 1995).

Sublegal lobsters were not evenly distributed from north to south in GOM. Catch rates of sublegal-sized lobsters were generally lower in the southern portion of GOM (south of Boston) than in the northern portion. The highest catch rates of sublegal lobsters occurred consistently from the outer Boston Harbor area north along the shore to Salem Sound, generally in the shallow stratum (Figure 8). This pattern was consistent throughout the survey time period and increases in catch in the latter years of the survey were most evident at stations within the Boston to Salem region.

Catch of legal lobsters at each station was always much lower than the sublegal catch and did not necessarily follow the same geographic pattern within or across years (Figure 9). For example, the increased catch in 2012 was distributed throughout the GOM survey area, not concentrated in the Boston to Salem region as it was for the sublegal component. Comparing 2012 with 2016, the two years of highest legal-sized catch, several stations with the highest catch rates in 2012 were located to the south in Cape Cod Bay, while in 2016 those stations with the higher catch rates were distributed more to the north. Legal catch in the stations in the southern portion of GOM was not consistently lower than in the northern portion.

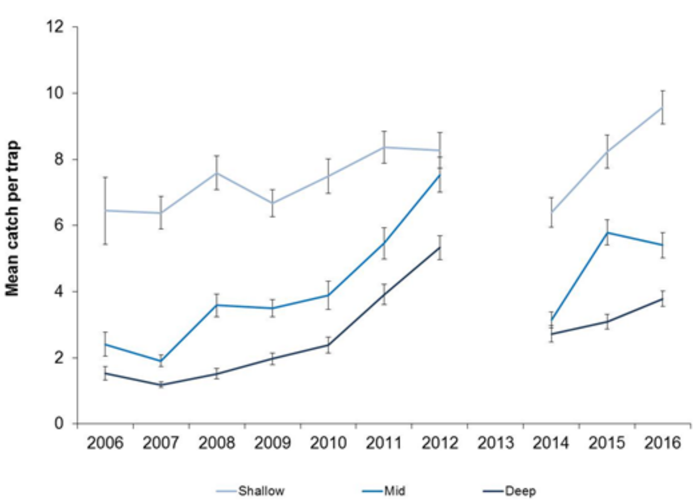


Figure 6. Mean CTH_6 (± S.E.) of sublegal lobsters in each depth stratum from 2006–2016 (no data for 2013).

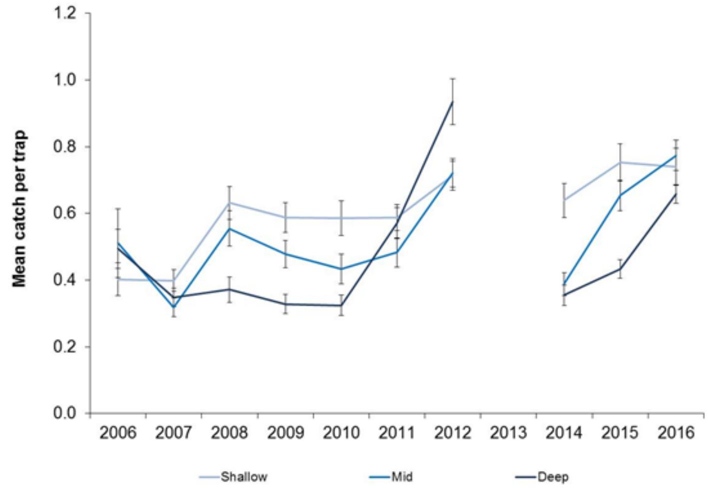


Figure 7. Mean CTH_6 (± S.E.) of legal lobsters in each stratum from 2006–2016 (no data for 2013).

The locations of sampling stations with higher catch rates of sublegal-sized lobsters correspond to regions along the coast of MA with concentrations of hard bottom (see http://maps.massgis.state.ma.us/map_ol/moris.php). This preferred lobster habitat may be more of an important driver for distribution of smaller lobsters than larger lobsters, since lobsters not only progressively outgrow their dependence on shelter-providing complex habitat, but also increase their propensity to make larger scale movements as they increase in size (see Lawton and Lavalli 1995). Larger legal-sized lobsters are less dependent on hard complex bottom and tend to be more broadly distributed.

Catch Characteristics

The size distribution of lobsters observed was truncated, with sublegal lobsters (< 83 mm) averaging 89.9% of the catch over the entire time series (Figure 10). Females generally made up a higher percentage of the catch than males from around 75 mm to about 83 mm.

Breaking down the catch data into 5 mm size class bins provides a more detailed look at changes in abundance over time (Figure 11). Substantial increases in the CPUE of 58–62 mm, 63–67 mm, 68–72 mm, 73–77 mm, and 78–82 mm lobsters were observed from 2006–2012, indicating that increased abundance in

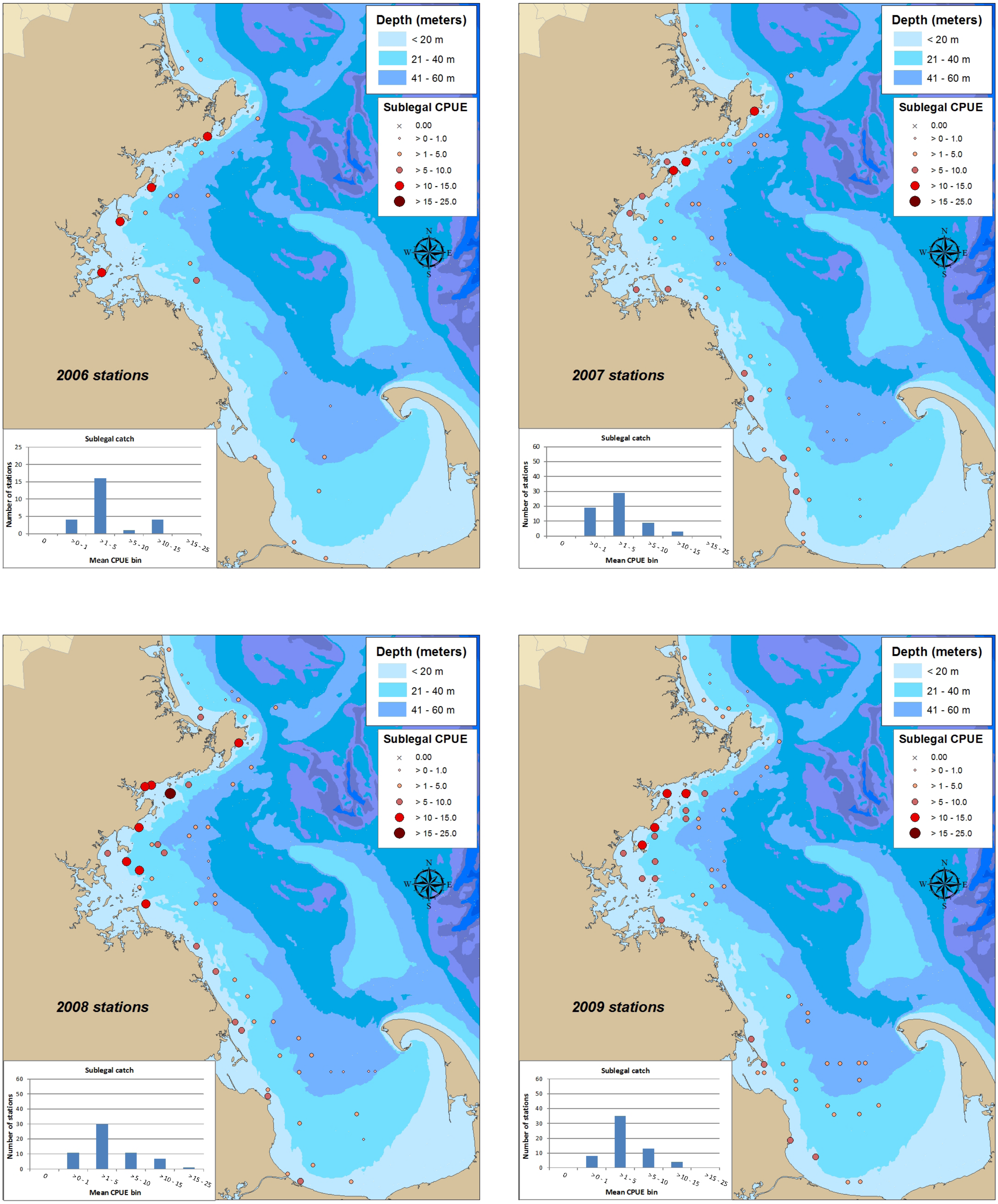
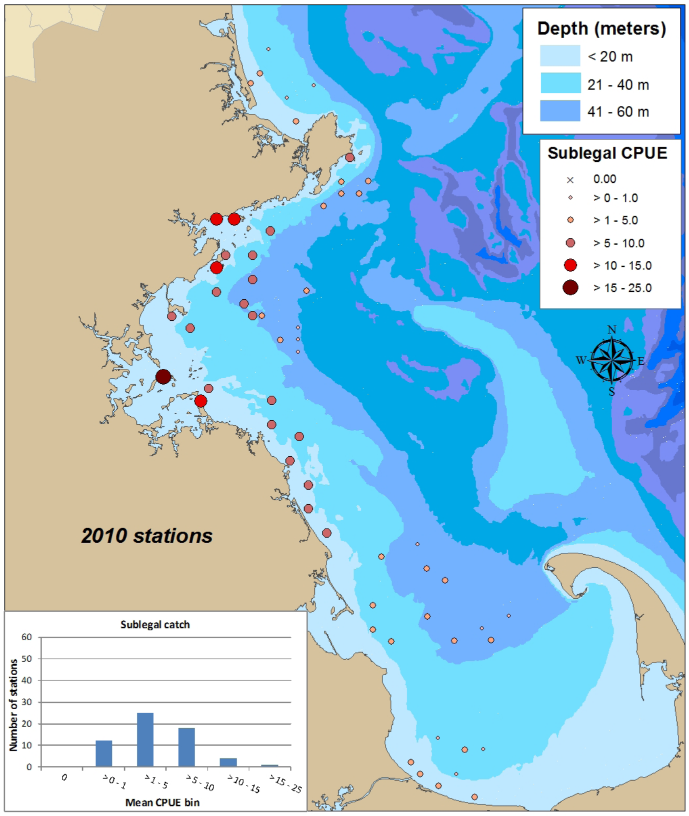
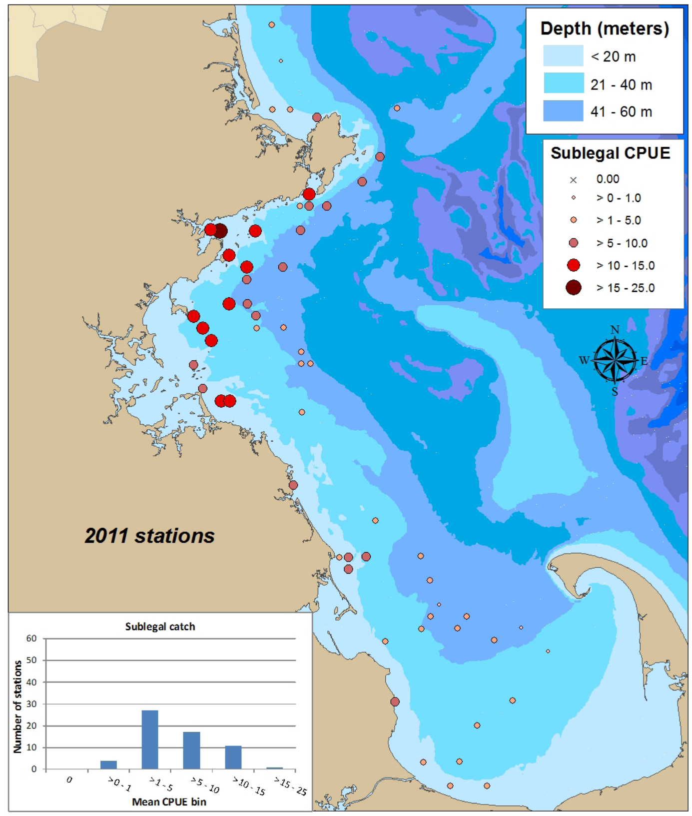
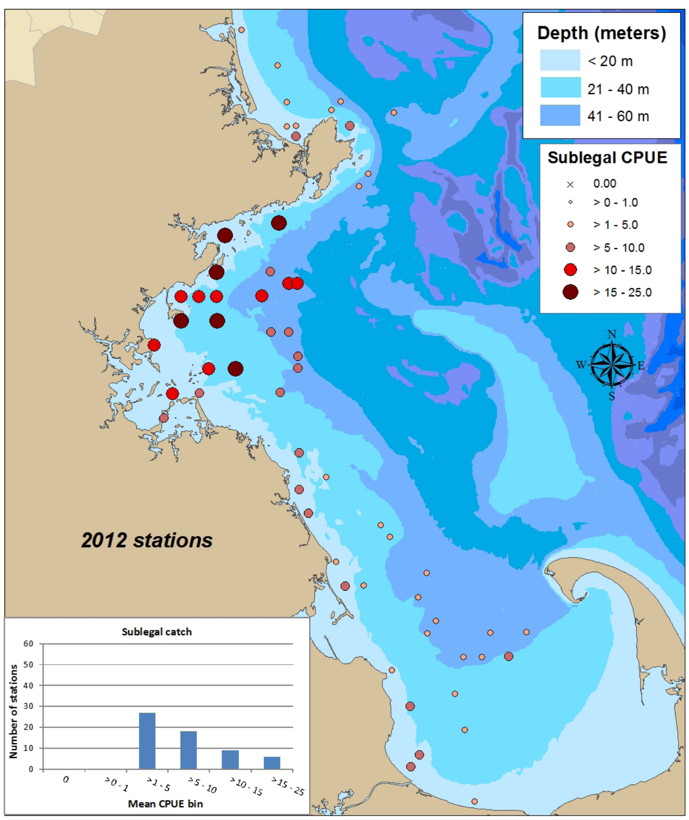


Figure 8. Mean catch per trap (CTH_6) of sublegal lobsters at each sampling station, 2006–2009. Histograms show the number of stations that fell within each catch bin.







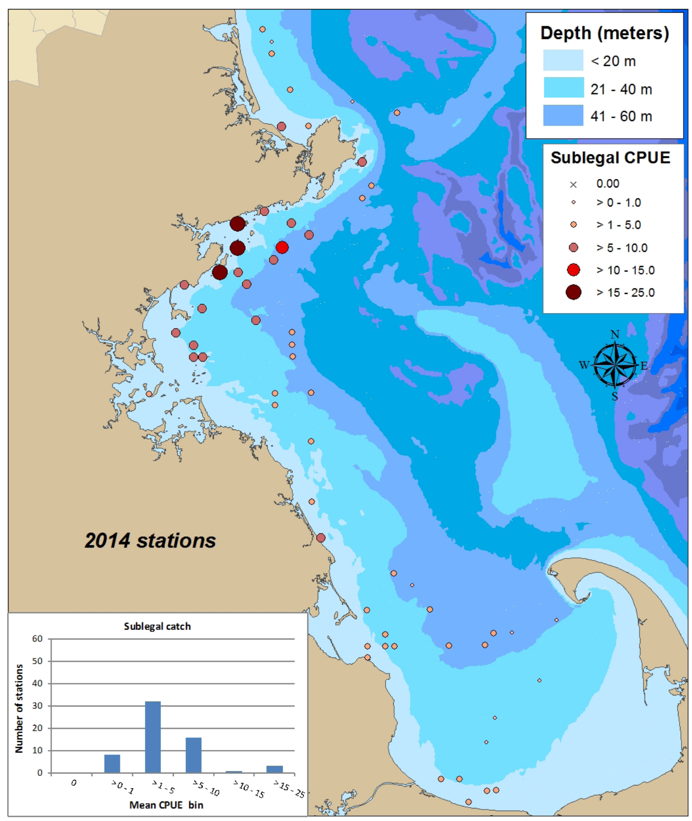


Figure 8 Continued. Mean catch per trap (CTH_6) of sublegal lobsters at each sampling station, 2010–2014. Histograms show the number of stations that fell within each catch bin.

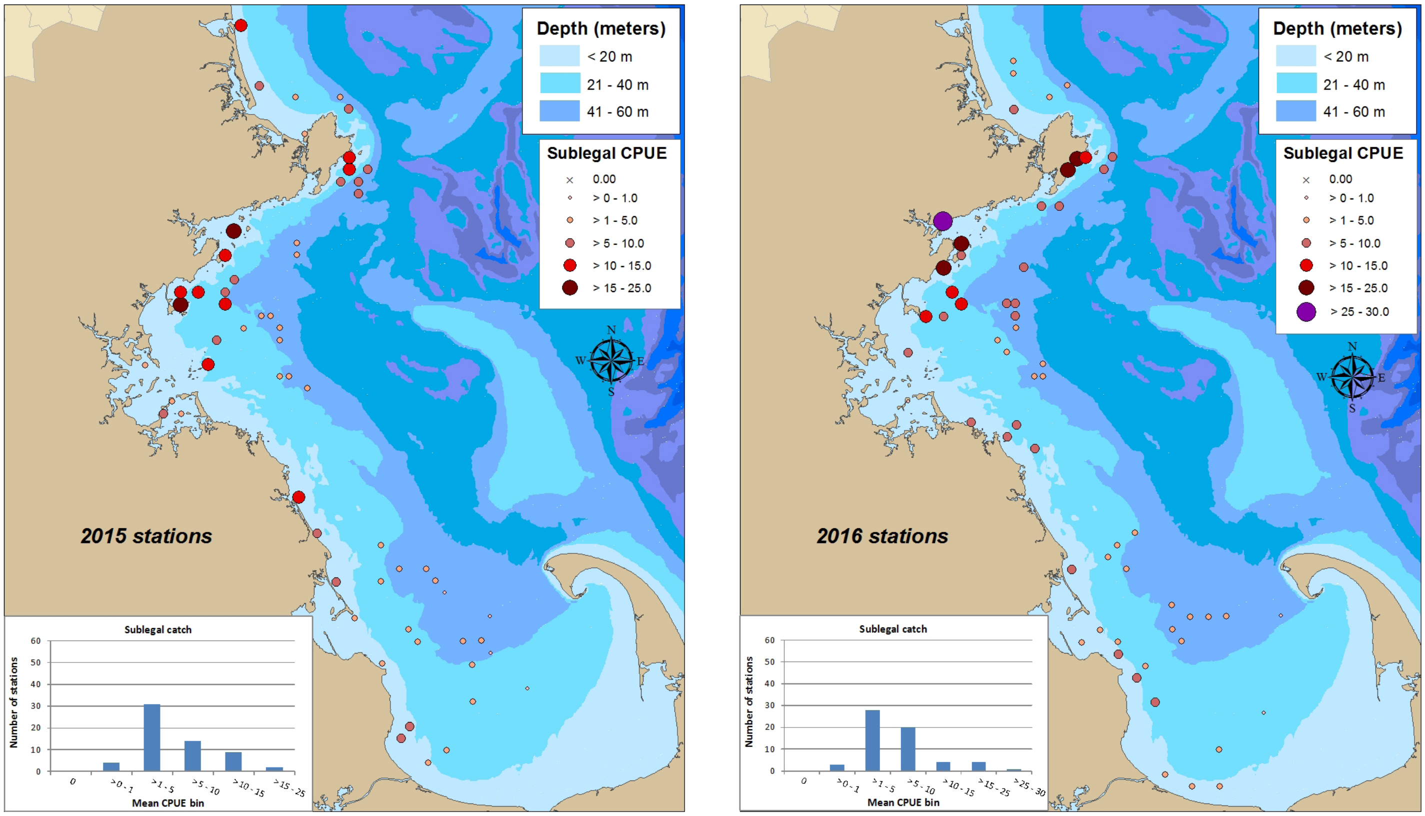


Figure 8 Continued. Mean catch per trap (CTH_6) of sublegal lobsters at each sampling station, 2015 and 2016. Histograms show the number of stations that fell within each catch bin.

the sublegal size category is not attributable to a single large recruitment event. To the contrary, increasing CPUE in such a wide range of size classes indicates positive recruitment conditions over a broad time frame. Some of the larger size bins had the highest relative increases in mean catch per trap; the largest three size bins (98–102 mm, 103–107 mm, >107 mm) had increased by more than 70% by the end of the time series compared to the first three years of the survey (93%, 72%, and 150% increase for each size bin respectively). These increases across all sizes are indicative of a widespread increase in recruitment that occurred over this time period, potentially influenced by favorable environmental conditions (see Temperature Monitoring Section).

Although the above data suggest a large recruitment event, the percent of marketable lobsters (≥ 83 mm, no eggs or v-notch) that were within one molt increment (10 mm CL) of minimum legal size remained high with little variation over the survey time period, from 90% to 95% (Table 3). These population characteristics indicate a heavily exploited, recruit-dependent fishery, and it seems as though the increased recruitment was mostly absorbed by subsequent increases in landings (DMF unpublished data, or see NMFS landings data https://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html). However, the increase in the larger size bins (>98 mm CL) suggests at least some broadening of the size distribution resulted from the increased recruitment.

Table 3. Annual percent of the marketable catch in each stratum that was within one molt increment (10 mm) of minimum legal size.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)	97.4	95.7	95.1	93.1	93.0	93.0	91.8	ND	89.9	90.8	91.1
Mid (21-40m)	93.8	92.3	93.7	87.9	93.4	88.9	92.6	ND	93.2	91.0	89.2
Deep (41-60m)	94.0	88.5	87.4	89.7	93.3	92.5	88.1	ND	92.2	89.7	88.7
TOTAL	95.1	92.4	92.8	90.7	93.2	91.6	90.6	ND	91.5	90.7	89.7

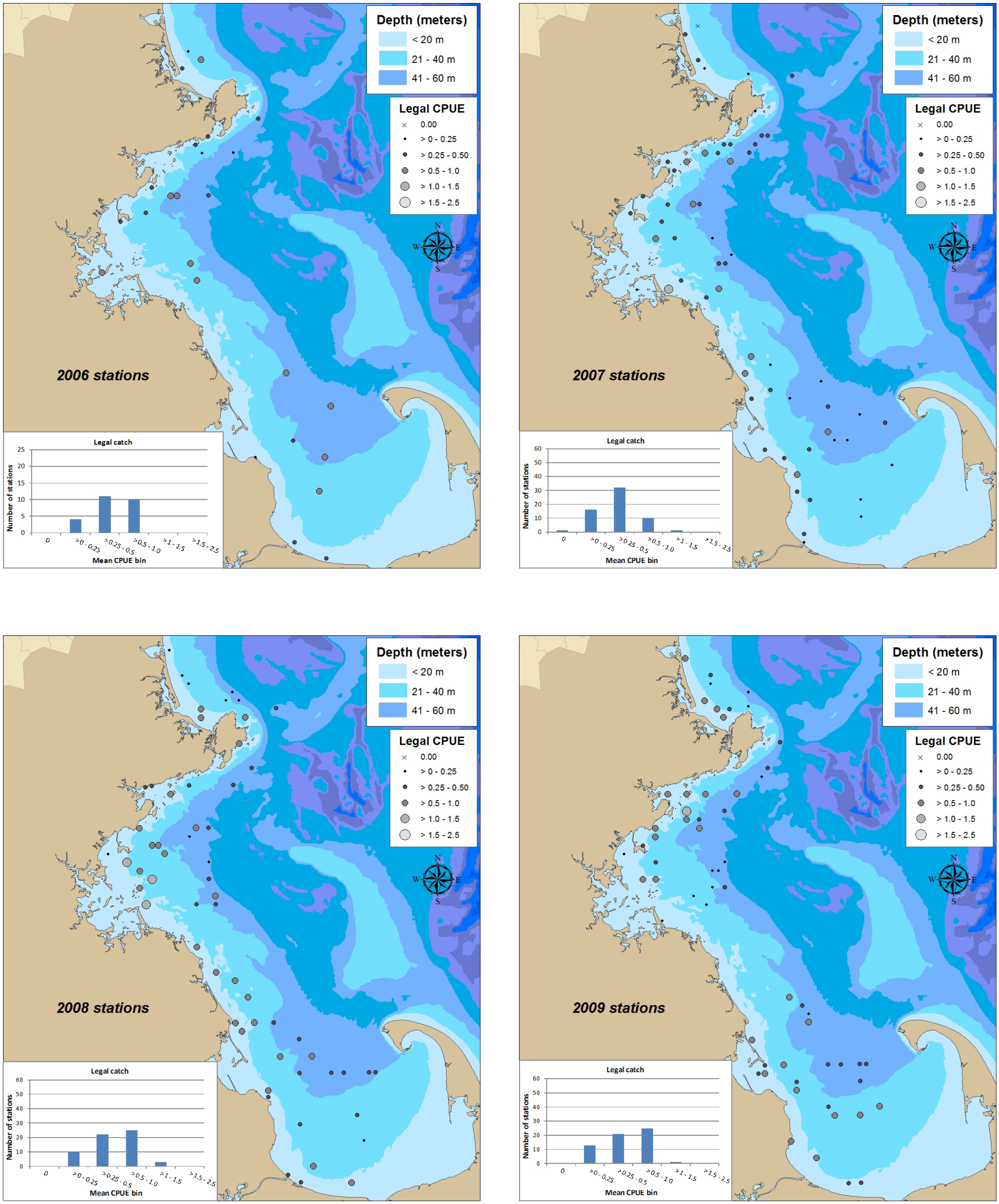


Figure 9. Mean catch per trap (CTH_6) of legal lobsters at each sampling station, 2006–2009. Histograms show the number of stations that fell within each catch bin.

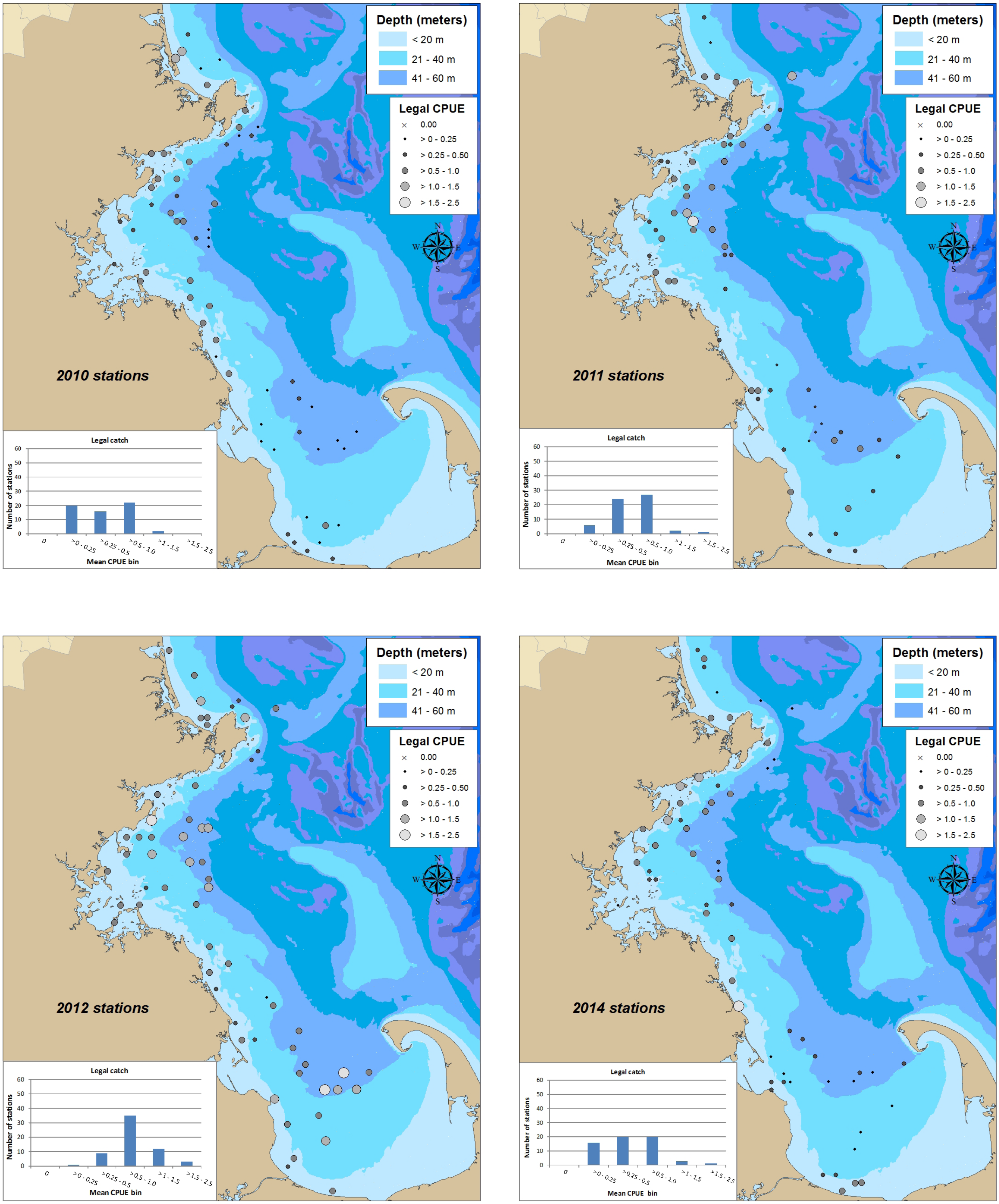


Figure 9 Continued. Mean catch per trap (CTH_6) of legal lobsters at each sampling station, 2010–2014. Histograms show the number of stations that fell within each catch bin.

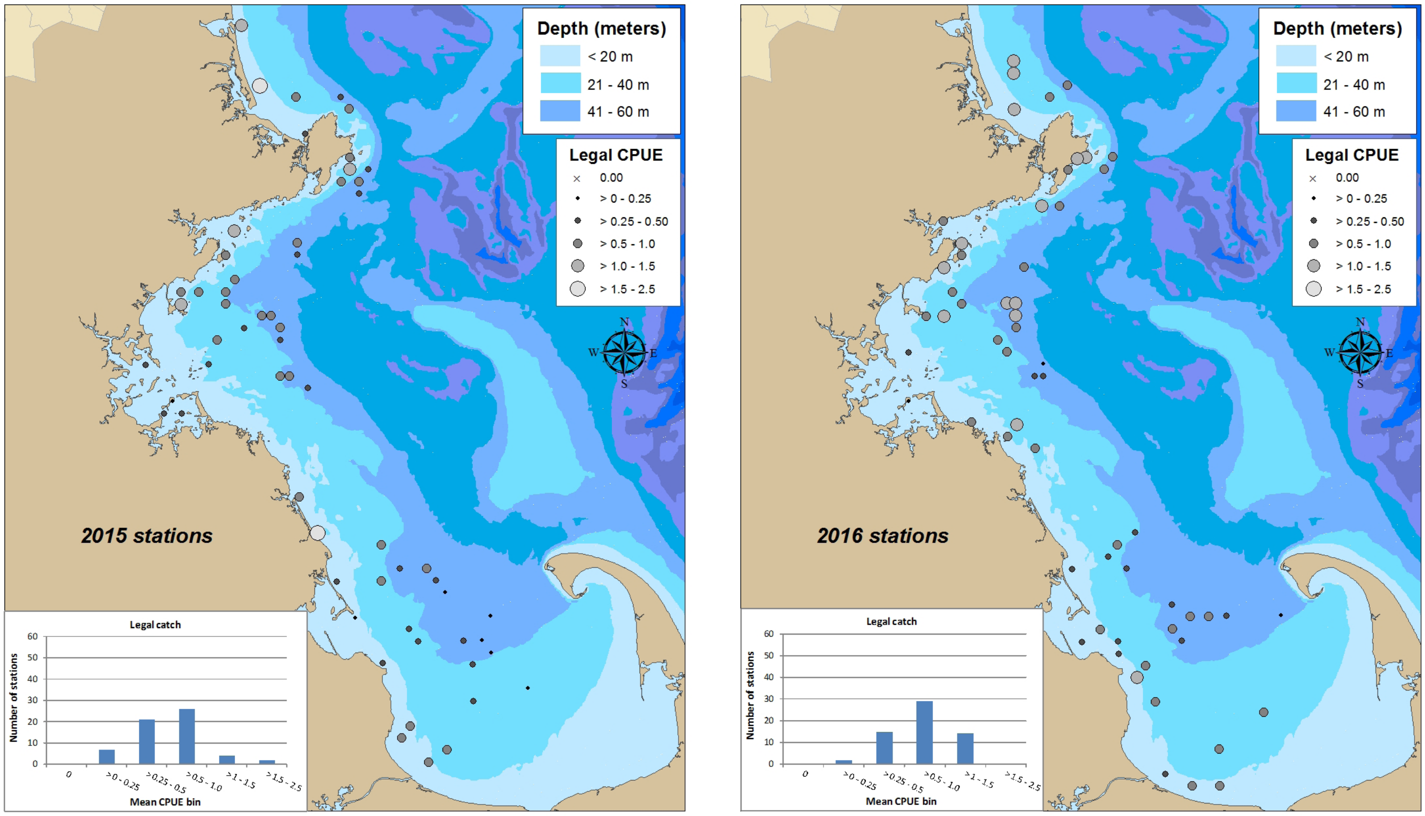


Figure 9 Continued. Mean catch per trap (CTH_6) of legal lobsters at each sampling station, 2015 and 2016. Histograms show the number of stations that fell within each catch bin.

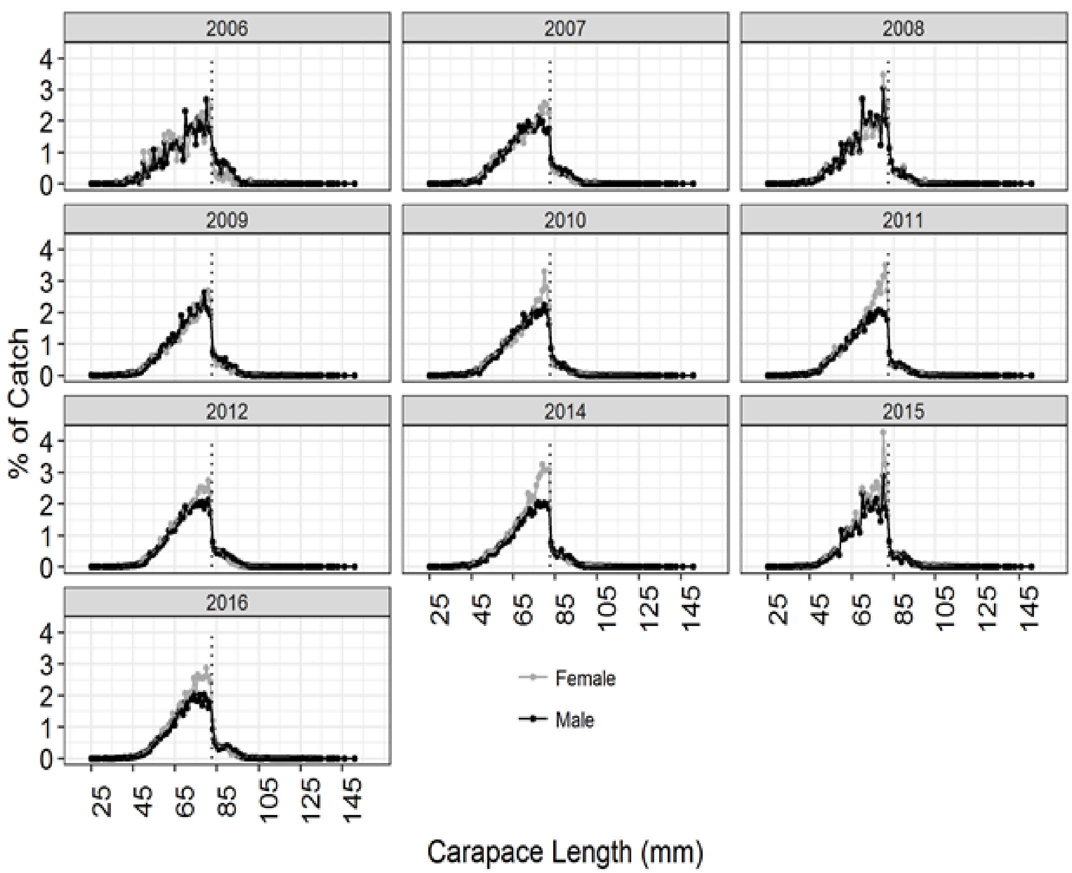


Figure 10. Annual percent of the total catch at-length comprised of each sex for each survey year (2006–2016). Vertical dotted line indicates minimum legal size (83 mm CL).

The size distributions of lobsters observed in each depth stratum were significantly distinct in 2007–2010, 2012, and 2016 (Bonferroni adjusted $\alpha = 0.025$ for k=3 comparisons) (Table 4). In 2006, 2011, 2014, and 2015 the size distributions of lobsters in the shallow stratum were different from the mid and deep strata, but the size distributions of lobsters in the mid and deep strata were similar. The lobsters caught in the shallow stratum (0 to 20 m) were consistently smaller than in the other two depth strata (21 to 40 m and 41 to 60 m), while the catch in the deep stratum (41 to 60 m) tended to have a higher proportion of larger lobsters (Figure 12).

These patterns in size distribution by depth can likely be attributed to habitat characteristics and ontogenetic changes in lobster mobility. Lobsters become progressively less shelter-restricted as they increase in body size, which is particularly true for the early benthic phase (< 40 mm) (Wahle and Steneck 1992). As lobsters get larger and reach sexual maturity, movement tends to change from limited inshore movements to larger-scale offshore movements (see, for example Krouse 1977, Ennis 1984, Campbell and Stasko 1985, Campbell and Stasko 1986). The increasing propensity to move likely progresses gradually from adolescent through adult stages (see Lawton and Lavalli 1995) and may also be related to density and competition for space (Steneck 2006).

The sex ratio (reported as percent of the catch that was female) was balanced over most of the size range of lobsters observed, varying around 50% female for sublegal-sized lobsters, and ranging from 35% to 52% female in the legal-size class (Table 5). The catch of sublegal lobsters in the mid stratum tended to be slightly female-skewed (55–65% female in seven of ten years, Table 5), but otherwise there were no strong patterns in sex ratio by size and strata.

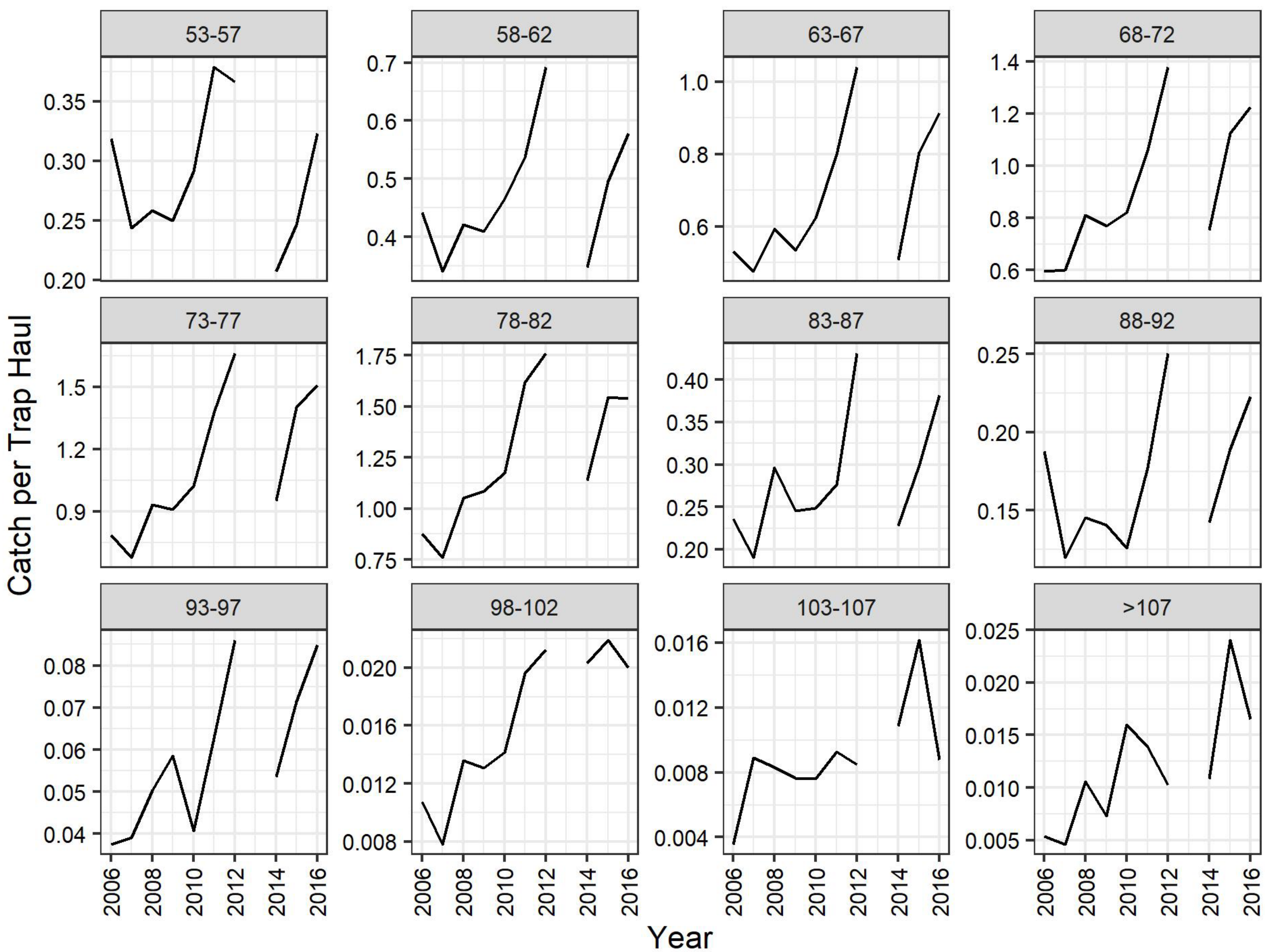


Figure 11. Time series of catch per trap haul (number lobsters/total traps hauled) by 5 mm size bins for lobsters > 52 mm CL. Note the y-axis varies.

Table 4. Annual results of K-S 2-sample test (D_{max} (p-value)) comparing size distributions between depth strata. Significant differences (α_{adj} = 0.025) shown in bold italic font.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow vs mid	***0.216 (0.00)***	***0.195 (0.00)***	***0.146 (0.00)***	***0.138 (0.00)***	***0.133 (0.00)***	***0.165 (0.00)***	***0.081 (0.00)***	nd	***0.104 (0.00)***	***0.105 (0.00)***	***0.161 (0.00)***
Mid vs deep	0.147 (0.04)	***0.086 (0.01)***	***0.098 (0.00)***	***0.055 (0.02)***	***0.075 (0.01)***	0.060 (0.03)	***0.144 (0.00)***	nd	0.020 (0.70)	0.056 (0.04)	***0.078 (0.00)***
Shallow vs deep	***0.354 (0.00)***	***0.259 (0.00)***	***0.225 (0.00)***	***0.190 (0.00)***	***0.199 (0.00)***	***0.191 (0.00)***	***0.219 (0.00)***	nd	***0.104 (0.00)***	***0.147 (0.00)***	***0.237 (0.00)***

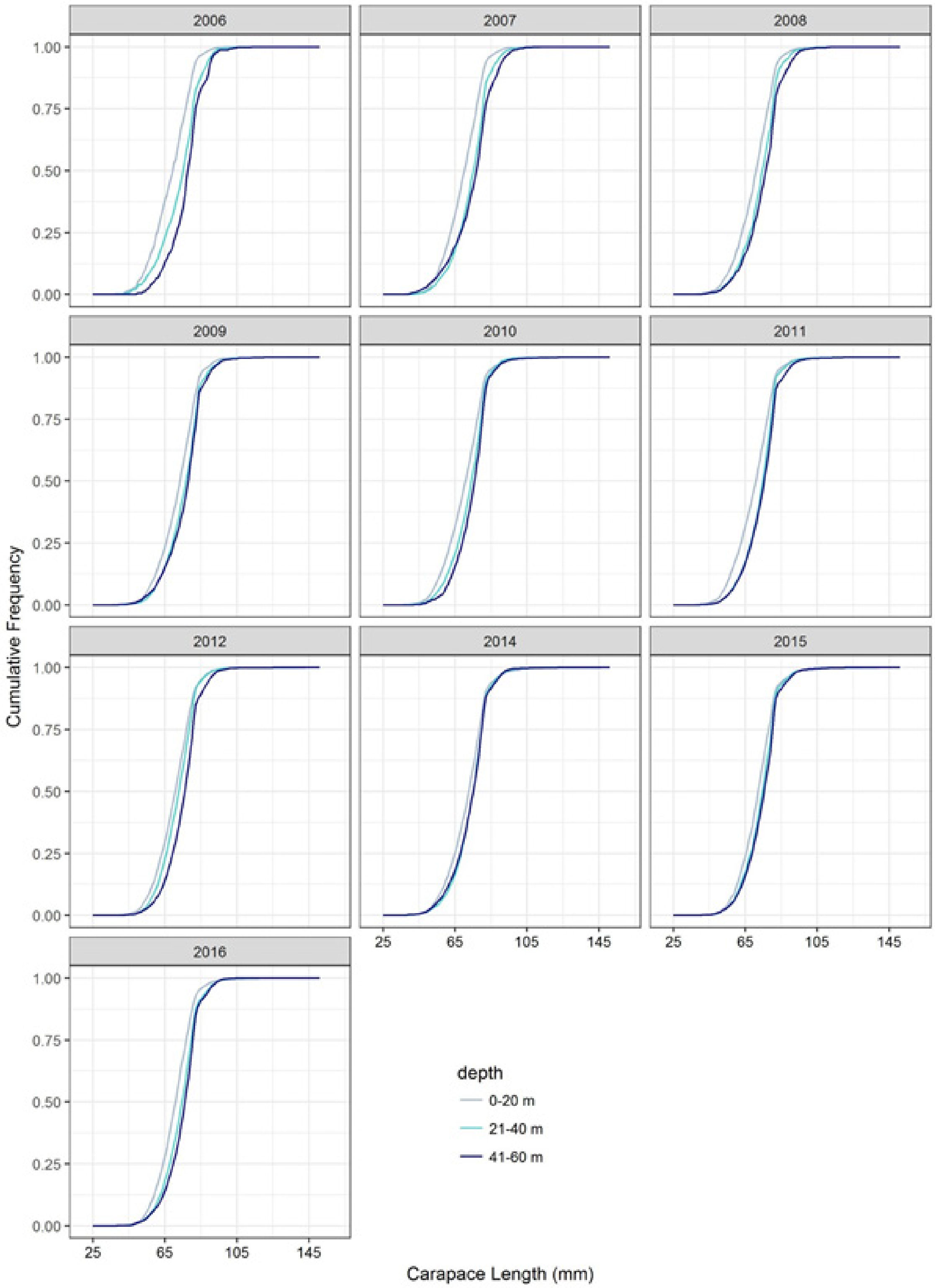


Figure 12. Cumulative length frequency distributions by depth stratum for each survey year, 2006–2016.

Table 5. Annual percentage of the sublegal and legal-sized catch that was female in each depth stratum 2006 - 2016. Color shading indicates male (green) or female (red) skew and follows the same gradient as in Figure 13.

Sublegal

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)	50.7	50.2	49.4	47.9	50.7	51.9	48.7	ND	53.2	48.8	48.6
Mid (21-40m)	52.9	56.9	53.5	53.8	56.6	61.0	56.5	ND	61.5	61.2	60.9
Deep (41-60m)	61.0	52.0	45.1	50.4	51.7	52.3	55.1	ND	57.7	60.9	64.6
TOTAL	52.5	51.8	50.0	50.0	52.6	54.7	53.1	ND	56.3	55.1	55.3

Legal

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)	36.8	57.3	53.8	42.3	55.1	53.5	47.1	ND	55.8	54.2	46.0
Mid (21-40m)	32.6	43.8	53.6	54.4	55.6	50.4	53.7	ND	49.6	57.7	56.0
Deep (41-60m)	36.4	37.9	46.0	45.0	45.5	50.5	40.7	ND	40.4	54.9	51.2
TOTAL	35.2	46.9	51.9	47.1	53.0	51.6	46.6	ND	50.1	55.6	51.1

Table 6. Annual percentage of the female catch that was egg-bearing (including recently hatched clutches) by size category and by depth stratum, 2006–2016.

Sublegal

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)	5.5	6.1	6.3	6.6	8.4	7.1	5.3	ND	10.2	7.4	5.3
Mid (21-40m)	21.9	13.7	10.5	15.8	12.4	17.2	8.2	ND	15.5	13.8	9.7
Deep (41-60m)	34.1	17.0	13.7	19.7	19.0	22.6	12.4	ND	25.1	21.7	14.9
TOTAL	13.3	9.1	8.3	11.5	11.4	13.7	8.3	ND	15.1	12.6	9.0

Legal

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)	6.3	19.1	26.0	29.0	44.3	34.3	18.5	ND	39.0	44.7	34.7
Mid (21-40m)	19.4	28.1	27.8	32.1	24.6	25.0	14.9	ND	36.4	28.3	20.0
Deep (41-60m)	37.5	28.3	34.7	38.2	34.8	35.6	19.6	ND	44.9	42.3	25.4
TOTAL	21.1	24.1	28.4	32.2	35.6	32.1	17.6	ND	39.5	38.0	26.2

Generally, many sampling locations had relatively balanced sex ratios throughout most of the survey area, ranging from 45% to 55% female (Figure 13). However, there appeared to be fine-scale spatial variation in the sex ratio of lobsters captured at stations in close proximity to one another, as well as variation from year to year. Each year there were a few stations with moderate to highly skewed sex ratios. While there was no apparent spatial pattern in stations with a female-skewed sex ratio, there appeared to be a tendency for male-skewed stations in the Cape Cod Bay area, particularly the eastern section.

A higher percentage of legal-sized females were ovigerous than sublegal-sized females (Table 6). There were some differences in the percentage of females with eggs by depth stratum, with the deepest stratum having the highest percentage of ovigerous females in all years for sublegal females but not legal-sized females. There has been an increase in the percentage of legal-sized females with eggs in the shallow stratum over time, while in the mid and deep stratum there was no consistent trend. The percent of females with eggs was lower in 2012 than in other survey years, particularly for legal-sized females.

The timing of spawning and egg development in the survey area varies annually, likely due to annual variations in water temperatures (see Waddy and Aiken 1995), but a typical cycle is apparent in the data (Figure 14). Spawning tends to begin in August in most years ("green" eggs), and eggs are incubated on the females' abdomens over the winter into spring, when most eggs are observed as "brown" (well-developed with visible eye spots and preparing to hatch). Hatching takes place starting in June in most years, and females with recently hatched clutches ("spent") are observed throughout the survey months, although more rarely in September. It is unclear how long after hatching the cementum remains on the female's pleopods, making her visibly identifiable as 'recently hatched,' although anecdotal information suggests this may be from two to three weeks (J. Carloni, NH Fish & Game, personal communication).

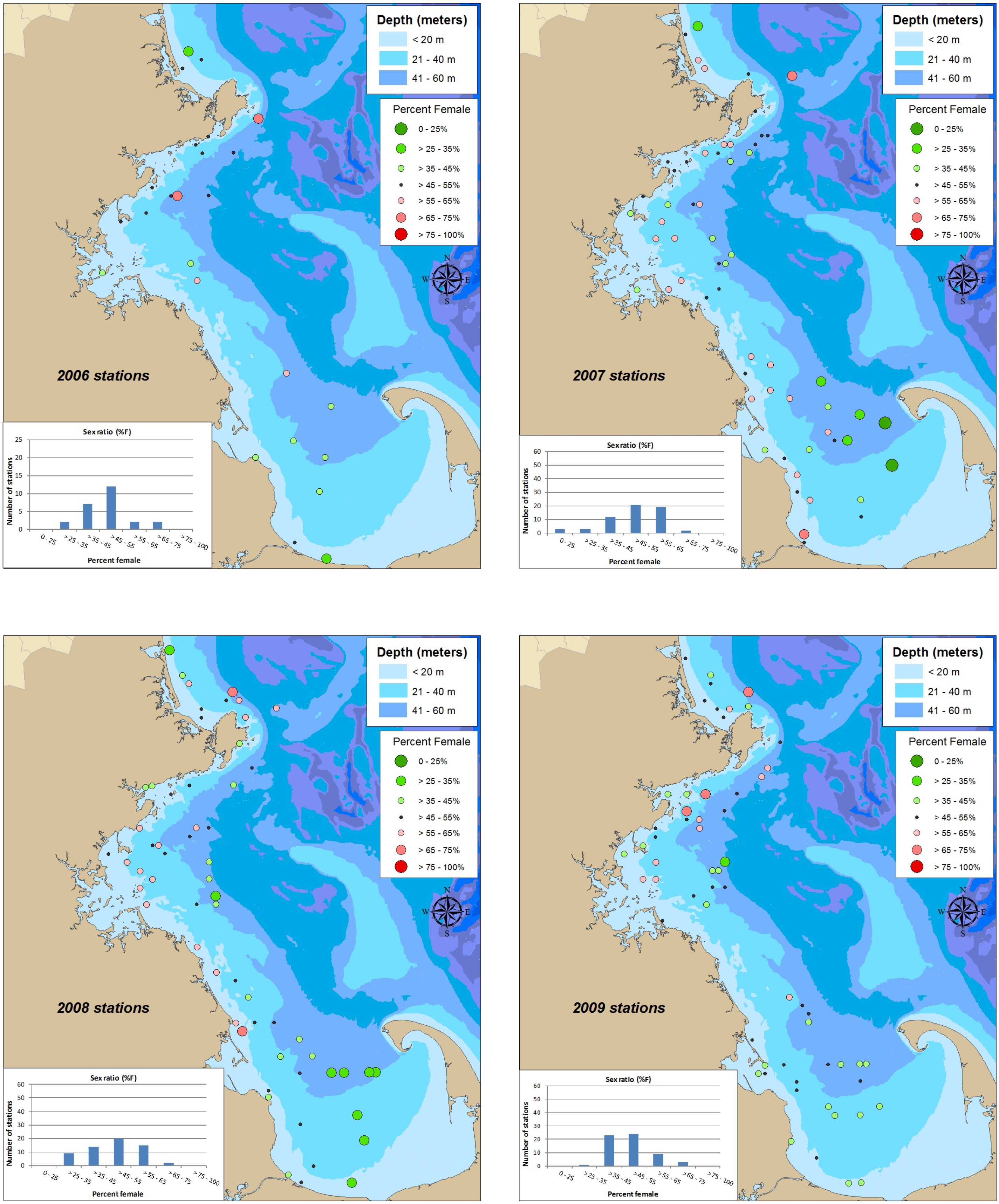


Figure 13. The sex ratio (shown as % female) at each sampling station 2006–2009. Larger, darker red dots indicate female skew, while larger, darker green dots indicate male skew. Histogram shows the number of stations that fell within each mapped sex ratio range.

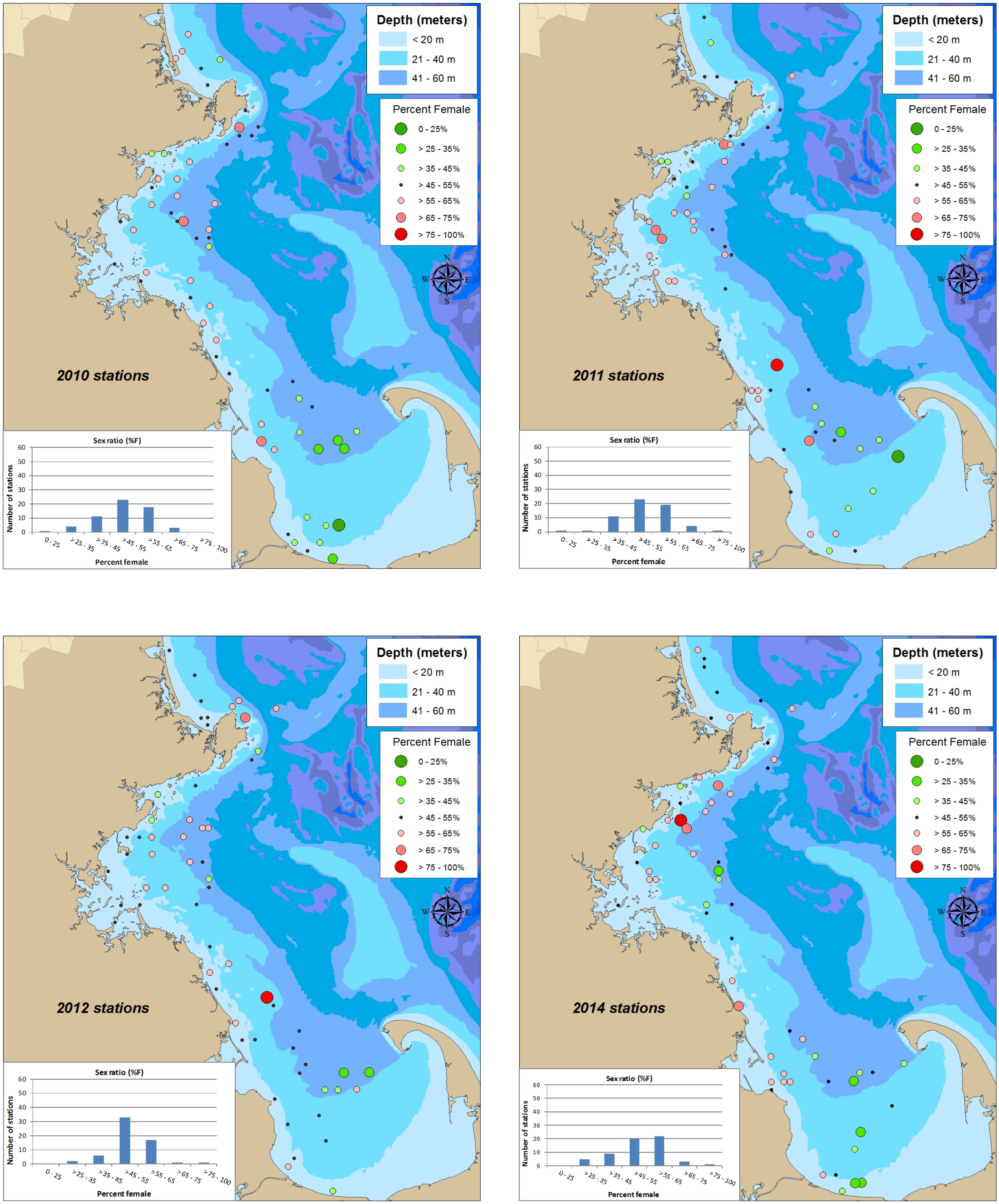


Figure 13 Continued. The sex ratio (shown as % female) at each sampling station 2010–2014. Larger, darker red dots indicate female skew, while larger, darker green dots indicate male skew. Histogram shows the number of stations that fell within each mapped sex ratio range.

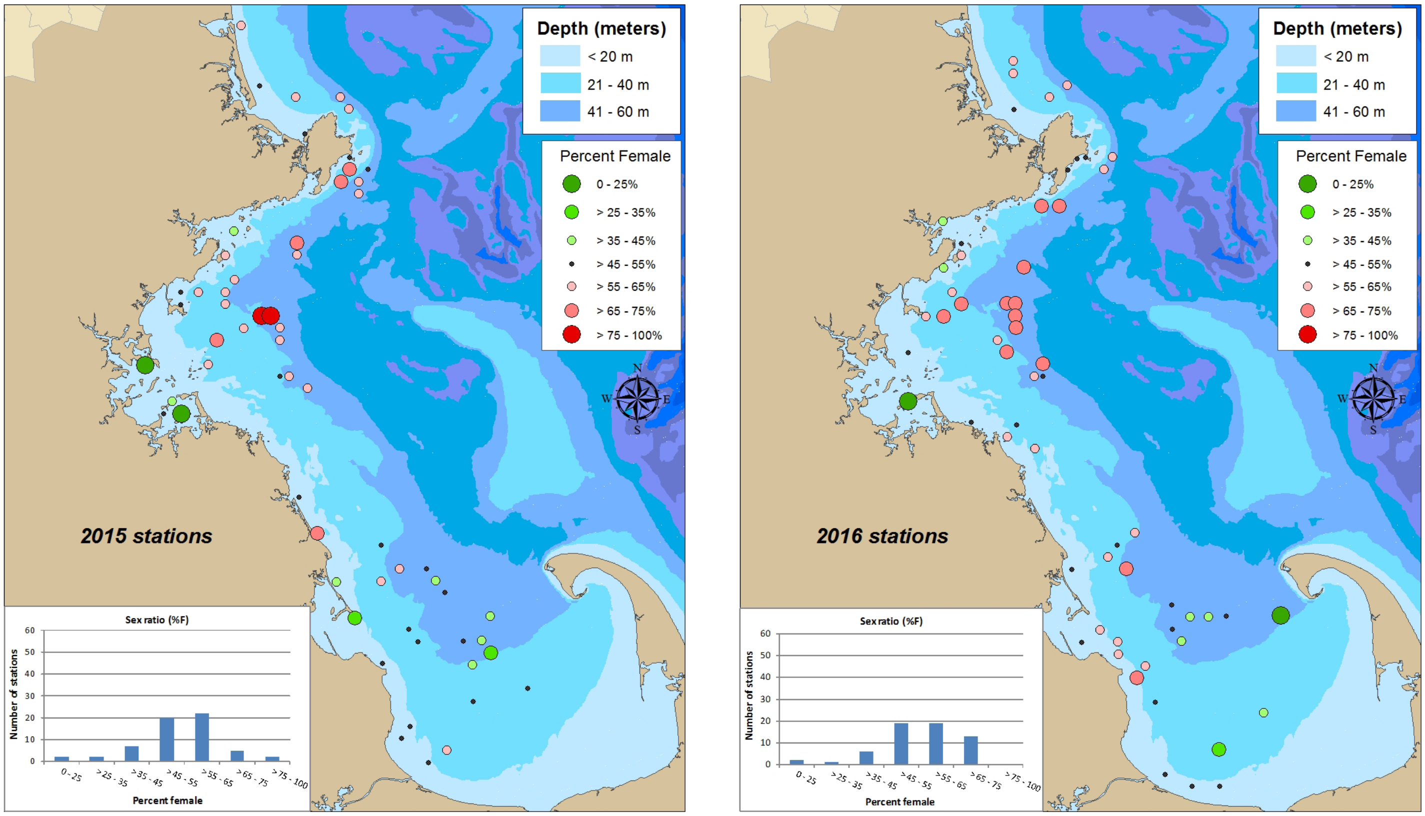


Figure 13. The sex ratio (shown as % female) at each sampling station 2015 and 2016. Larger, darker red dots indicate female skew, while larger, darker green dots indicate male skew. Histogram shows the number of stations that fell within each mapped sex ratio range.

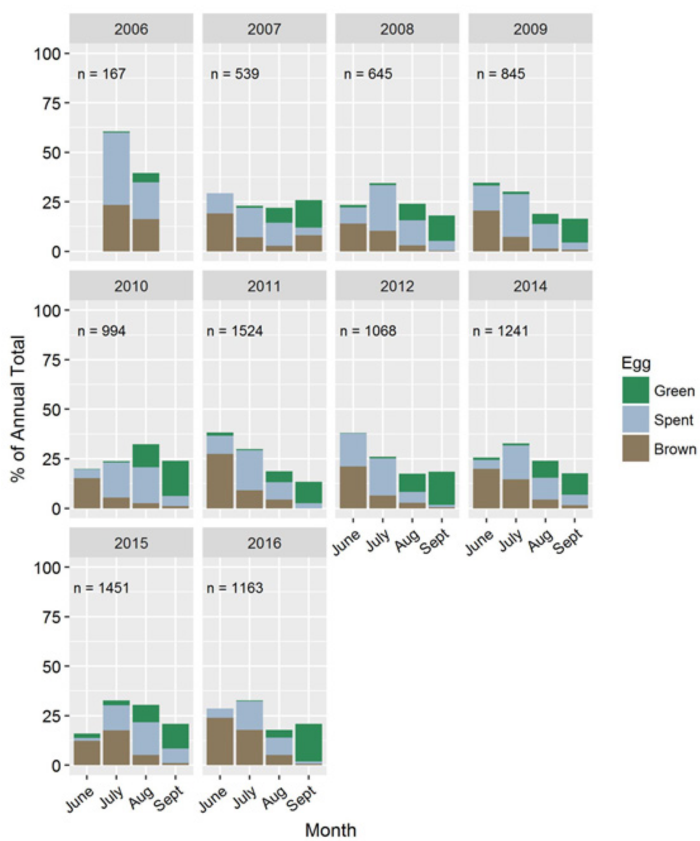


Figure 14. Annual timing of gross egg developmental stages for ovigerous females. Green = recently spawned, brown = well-developed and will hatch this year, spent = recently hatched.

The spawning stock index increased over time, peaking in 2011 (Figure 15). It has remained above the time series median (0.27) since 2014. The strata-specific mean spawning stock CTH_6 was higher in the mid and deep strata than the shallow stratum in most years, and the overall increase in spawning stock was more dramatic in the mid and deep strata.

The station-specific catch rates also illustrate the increased abundance of ovigerous females over time; after 2010 there were more stations with higher average catch rates, and fewer stations with zero ovigerous females. The largest increases occurred in the same general area as the increases in overall catch, at stations within the Massachusetts Bay region (south of Cape Ann and north of Cohasett, Figure 16).

The percent of legal-sized females with a v-notch averaged 31% over the survey time period, while an average of 2% of sublegal-sized females were v-notched (Table 7). The percentage of legal-sized females that were v-notched generally increased with increasing depth.

Shell disease is relatively uncommon in GOM, with an average of only 2.2% of the total catch exhibiting symptoms over the survey time period. However, there has been an increasing trend in prevalence over the time period of the survey, with peak prevalence observed in all depth strata in 2014 (Figure 17). In general, disease was slightly more prevalent in lobsters caught in the deeper stratum than in shallow stratum (Figure 17), a pattern which may in part be related to the size distributions of lobsters found in each stratum (smaller lobsters in shallower strata, see Figure 12). Disease prevalence follows some general size and sex-related patterns (Table 8). Legal-sized lobsters are more likely than sublegal lobsters to have disease. Females are more likely than males to have disease, and ovigerous females or those females that recently hatched a clutch are more likely than non-ovigerous females to have disease. These patterns are likely reflective of intermolt duration and the accumulation of shell disease symptoms over time, as larger lobsters, particularly reproductive females, are more likely to have gone longer between molts (Glenn and Pugh 2006).

For the first several years of the survey, the catch at most sampling stations had less than 5% shell disease prevalence, and at many stations there was no disease observed (Figure 18). Starting in 2011, there was an increase in the number of stations where the catch had more than 5% prevalence, and a decrease in the number of stations with less than 1% disease prevalence. In most years, those stations with observations of higher disease rates (5% or higher) were relatively scattered throughout the mid and deep strata of the survey area. However, in 2012 and 2015 stations with higher disease rates appeared more clustered in the Massachusetts Bay area than other years.

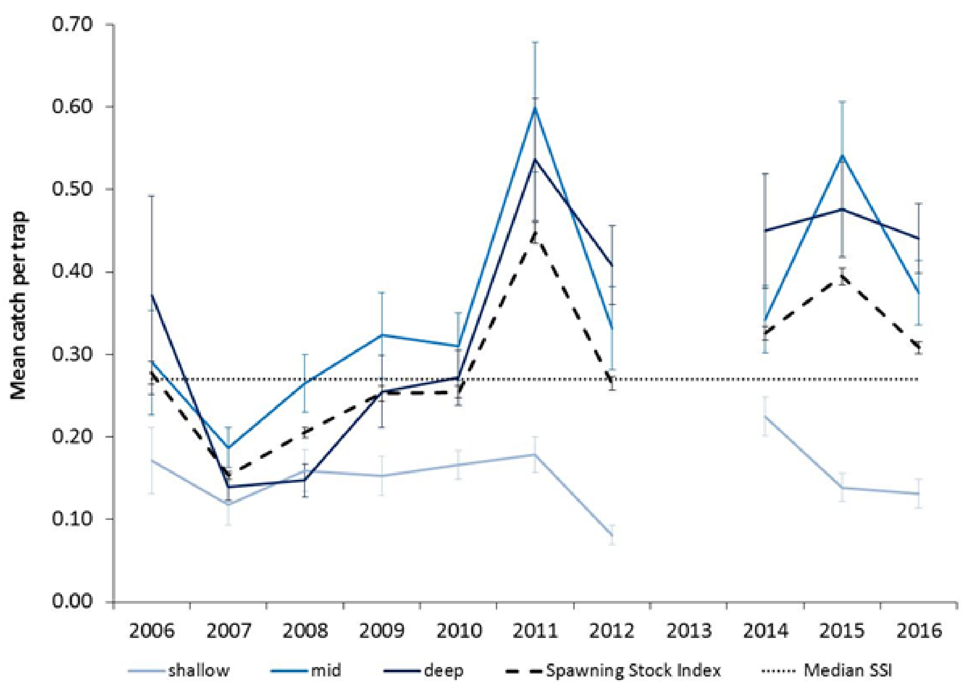


Figure 15. Annual spawning stock mean CTH_6 ± S.E. in each depth stratum and the spawning stock index (± S.E.; black dashed line). Horizontal dotted line represents the spawning stock index (SSI) time series median.

Table 7. Percentage of the sublegal and legal-sized female catch with a v-notch (zero-tolerance definition), and percentage of legal-sized females with a v-notch in each depth stratum, 2006–2016.

Percent with v-notch	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Sublegal	8.05	1.34	0.46	0.74	1.13	2.18	1.05	ND	1.01	1.70	2.02
Legal	34.74	30.71	23.58	30.39	32.07	38.57	26.65	ND	32.73	38.57	26.36

Legal-sized only	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)	31.3	24.1	20.8	22.3	33.9	33.0	19.4	ND	31.4	35.1	19.6
Mid (21-40m)	35.5	33.3	22.6	28.8	28.1	39.0	24.3	ND	28.9	39.8	26.2
Deep (41-60m)	37.5	39.4	31.3	48.1	34.8	44.4	35.3	ND	41.3	42.7	33.4

Table 8. Percentage of sublegal and legal-sized lobsters with disease, percentage of female and male lobsters with disease, percentage of ovigerous (females with eggs and females with recently hatched clutches) and non-ovigerous females with disease.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Sublegal	0.8	0.8	0.7	1.3	1.0	2.3	2.5		4.9	2.7	3.1
Legal	0.8	2.2	2.3	2.6	1.4	4.3	3.3		6.8	5.4	6.4
Female	1.0	1.7	1.5	2.2	1.7	4.0	4.4		8.3	5.1	6.0
Male	0.6	0.3	0.4	0.7	0.3	0.8	0.6		1.3	0.7	0.6
Female ovig & recently hatched	3.6	12.8	11.9	14.0	9.0	19.3	31.1		37.3	23.5	32.2
Female non-ovig.	1.0	1.2	0.9	1.5	0.5	1.3	1.7		2.2	1.8	2.8

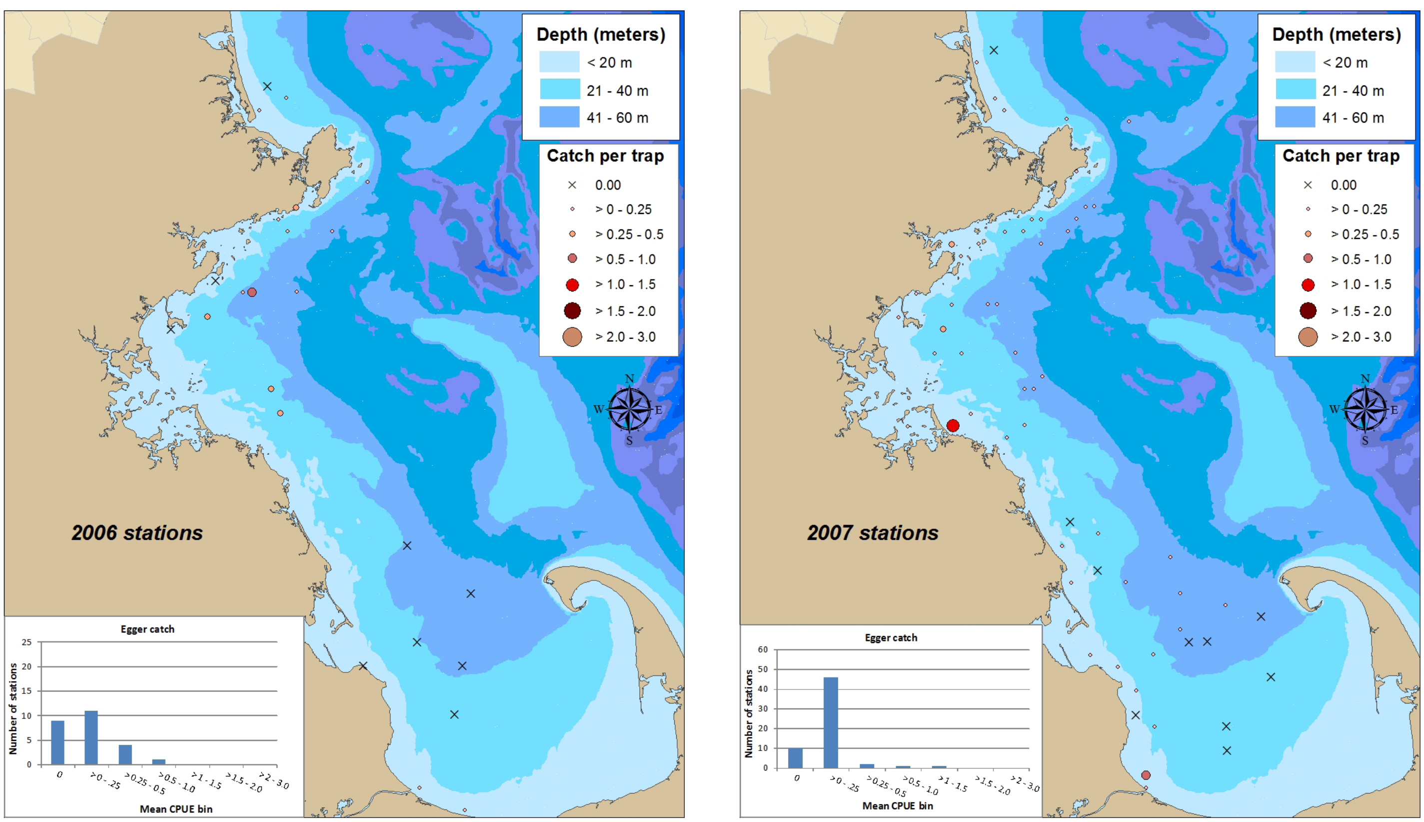


Figure 16. Mean catch per trap haul of ovigerous females (green and brown eggs) at each sampling station, 2006–2007. Histogram shows the number of stations that fell within each mapped catch bin.

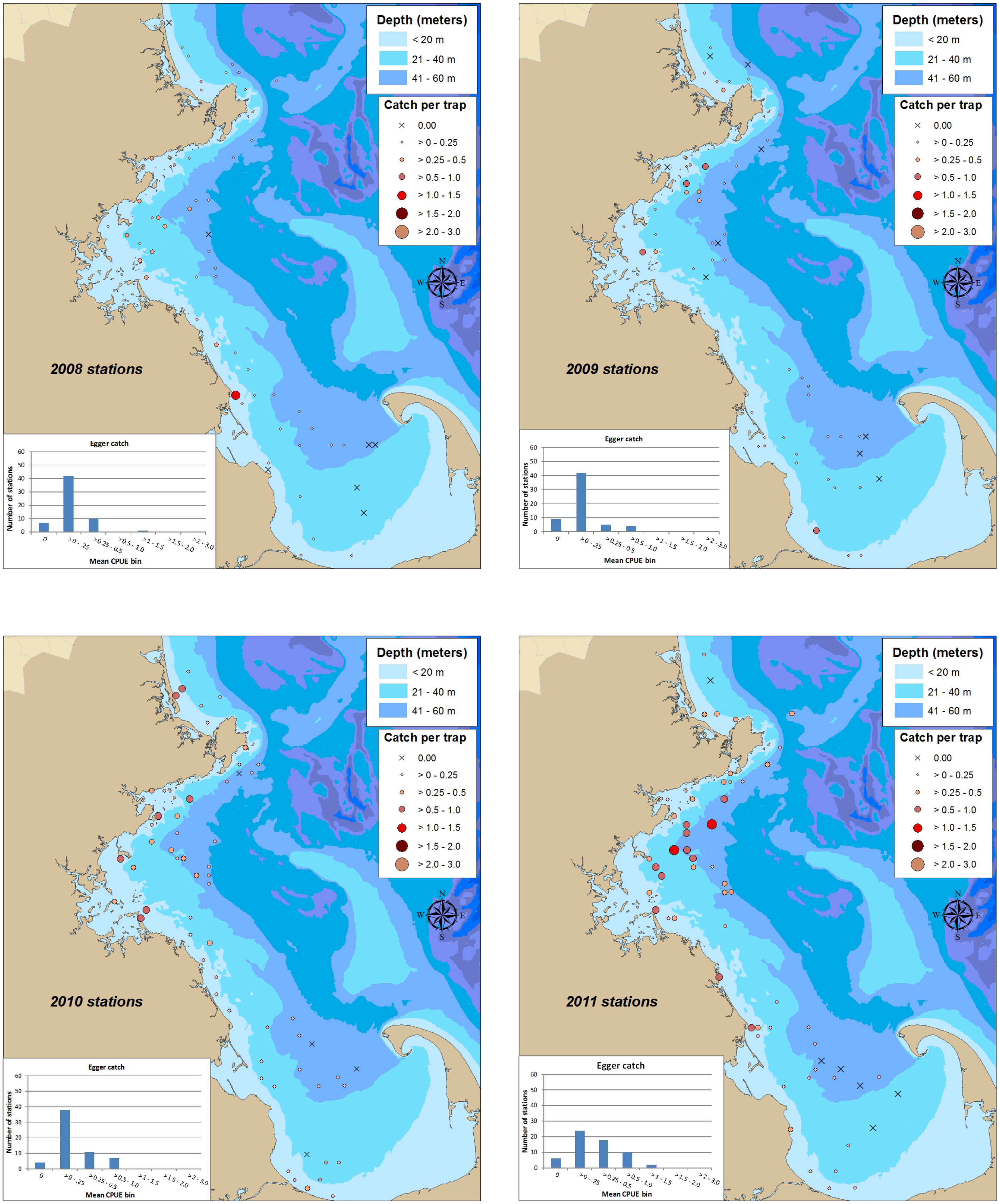


Figure 16 Continued. Mean catch per trap haul of ovigerous females (green and brown eggs) at each sampling station, 2008–2011. Histogram shows the number of stations that fell within each mapped catch bin.

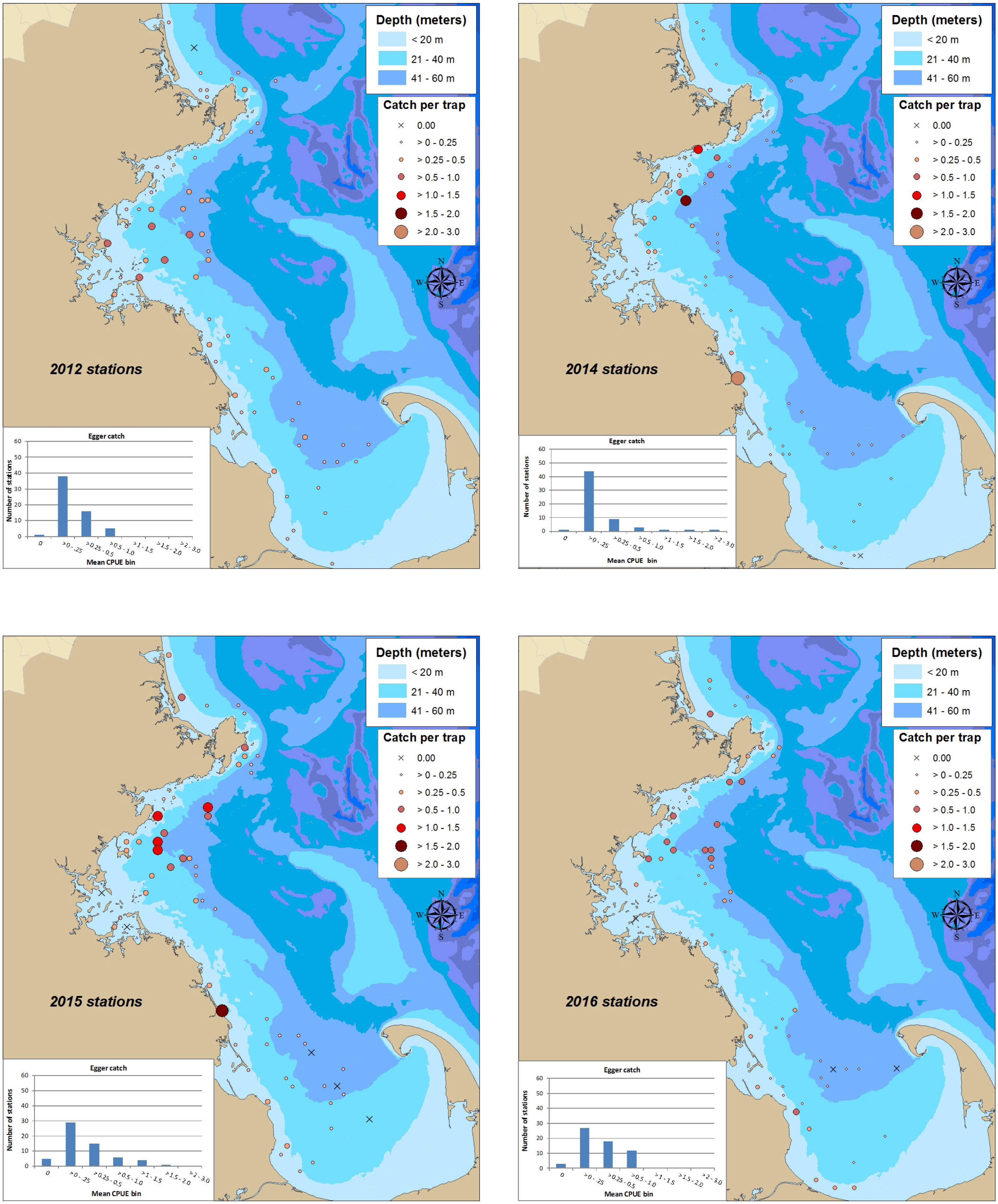


Figure 16 Continued. Mean catch per trap haul of ovigerous females (green and brown eggs) at each sampling station, 2012–2016. Histogram shows the number of stations that fell within each mapped catch bin.

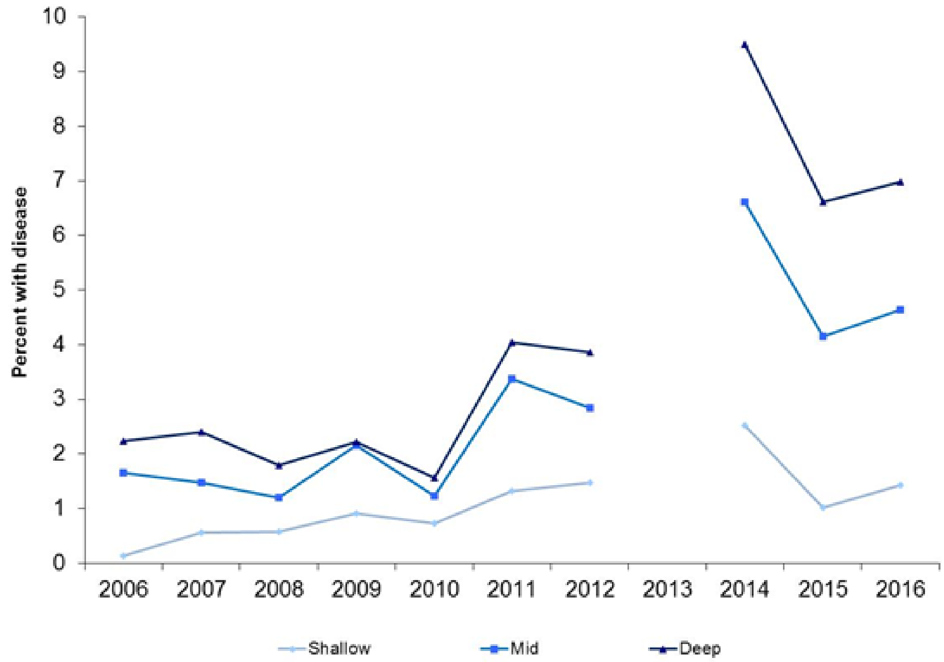
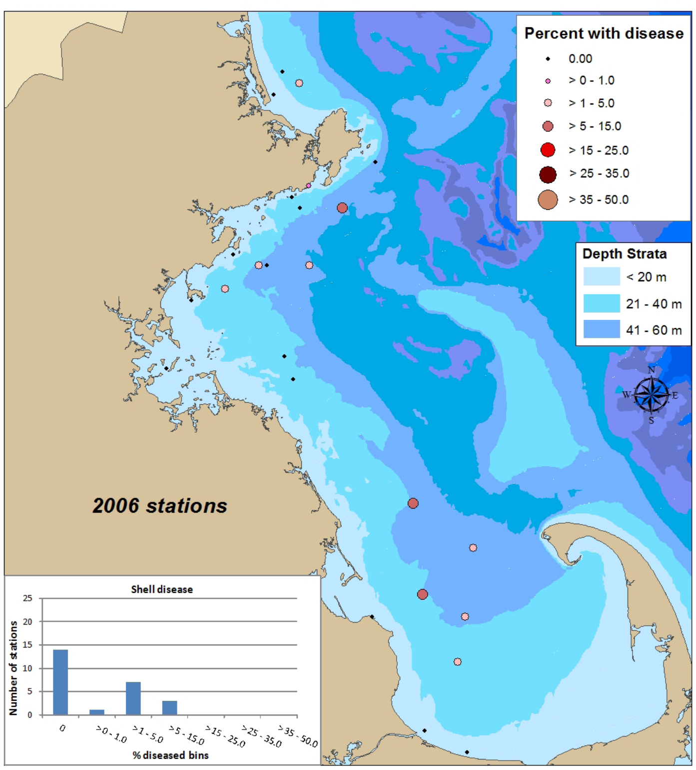


Figure 17. Percentage of the catch with shell disease by depth stratum from 2006–2016.



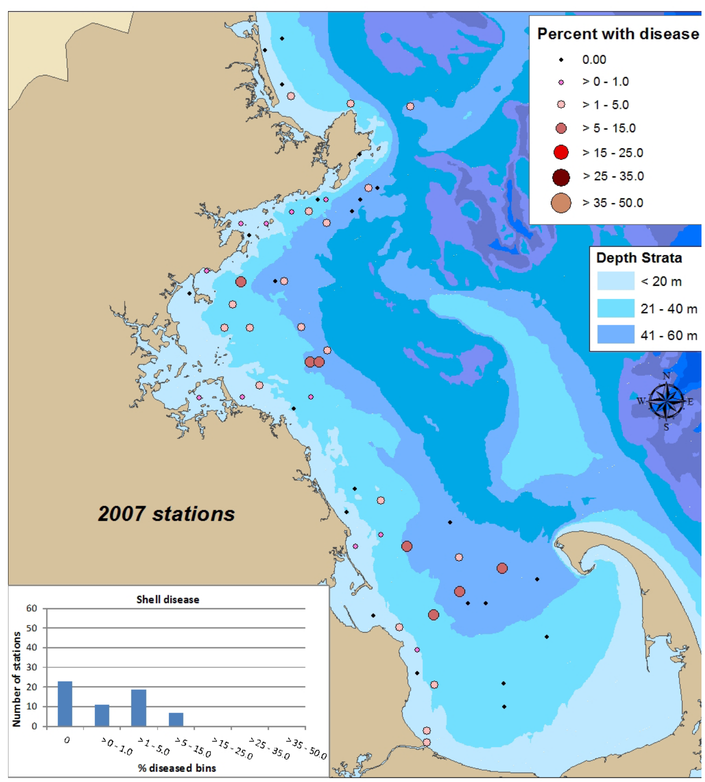


Figure 18. Percentage of the catch with shell disease at each sampling station, 2006–2007. Histogram shows the number of stations that fell within each disease percentile range.

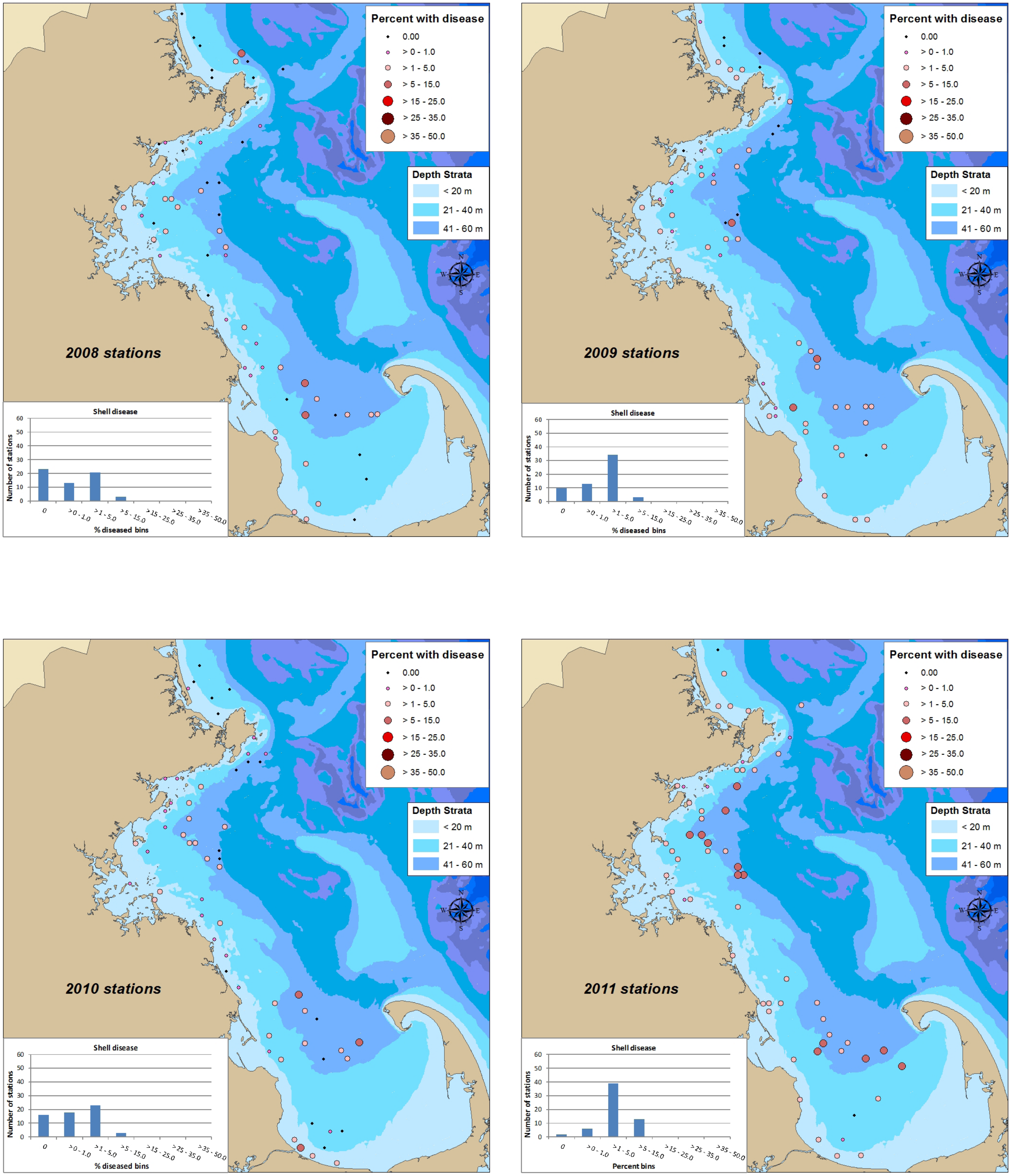


Figure 18 Continued. Percentage of the catch with shell disease at each sampling station, 2008–2011 Histogram shows the number of stations that fell within each disease percentile range.

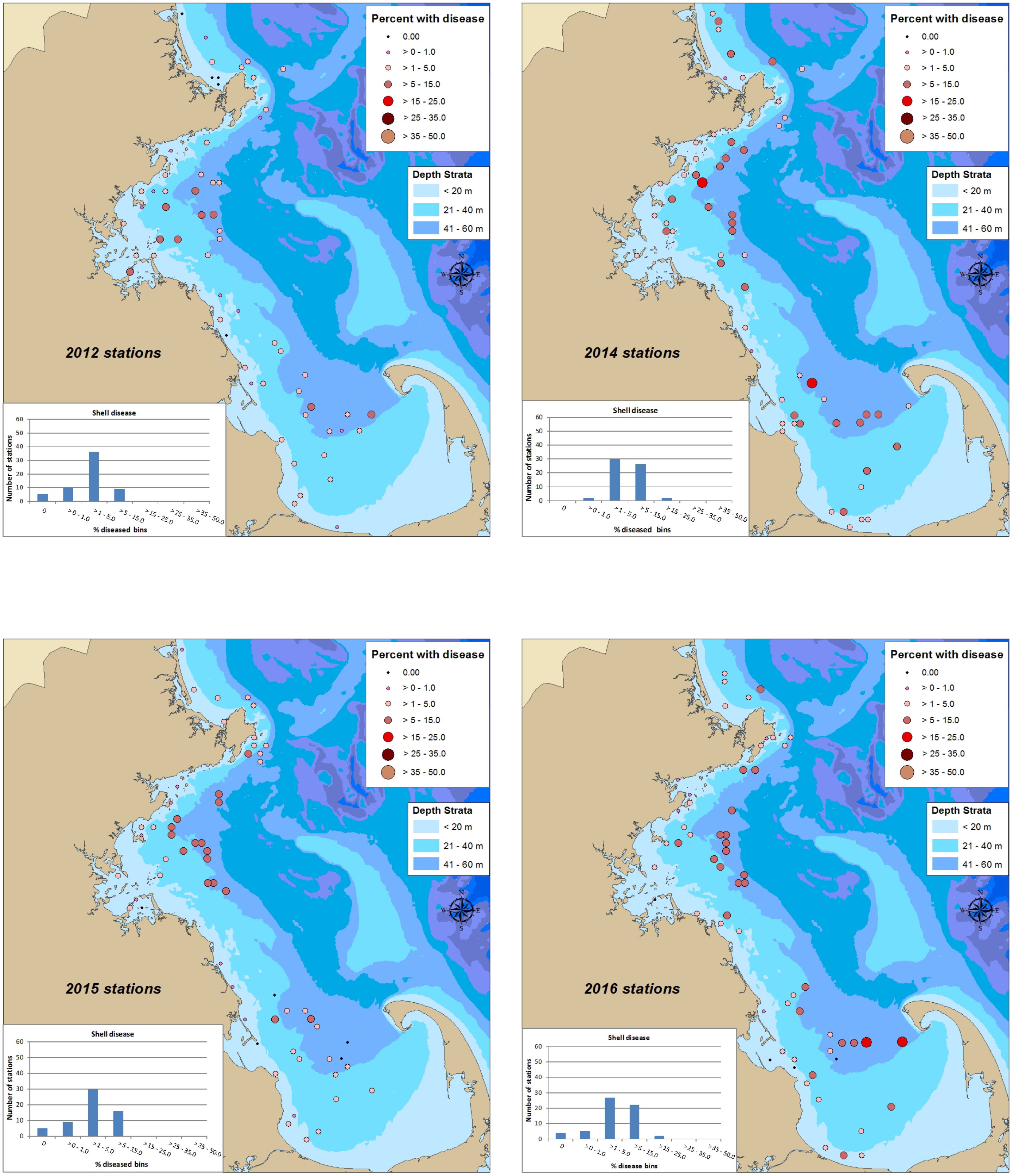


Figure 18 Continued. Percentage of the catch with shell disease at each sampling station, 2012–2016. Histogram shows the number of stations that fell within each disease percentile range.

SNE Survey Area

The total number of stations and the total number of trawl hauls in the southern portion of the DMF ventless trap survey increased from 2006 to 2007 when the resolution and time period of the survey was expanded (Table 9). Starting in 2011, the survey area was increased to include the federal waters portion of SA 538, as well as the northern-most portion of SA 537. This was done to ensure better spatial overlap between the survey and the bulk of the commercial effort in the area, and added sampling stations in the deep (41–60 m) stratum as well as increasing the available area of the shallow (1–20 m) and mid (21–40 m) stratum. The expansion also increased the total number of stations from 24 to 42 annually, resulting in a corresponding increase in the number of trawl hauls (Table 9). Total catch of lobsters also increased with the additional sampling stations in the expanded survey (Table 10).

Results for the SNE survey area are presented as two separate surveys. Results for the original survey area include only data from stations that were always a part of the survey area and represent a time series from 2006–2016. Results for the expanded area include data from both original survey area stations and those stations within the expanded survey areal extent, and represent a shorter time series, from 2011–2016.

Relative Abundance

The stratified mean CTH_6 for sublegal lobsters in the original survey decreased after 2006 and varied without trend through 2012 (Figure 19A). In 2014 and 2015 CTH_6 was extremely low, but in 2016 increased to slightly above the time series median (1.59 lobsters per trap). The stratified mean for legal-sized lobsters in the original survey area varied around the time series median CTH_6 of 0.18 lobsters per trap. Similar to the sublegal index the legal index declined to a low point in 2014, but in 2016 was the highest value for the time series (Figure 19A).

In the expanded survey area, the stratified mean CTH_6 of sublegal lobsters varied without trend from 2011–2016, with 2016 having the highest value in the time series (Figure 19B). The stratified mean CTH_6 of legal-sized lobsters increased over this time period to a time series high in 2016 (Figure 19B). This short time series precludes a meaningful interpretation of changes over time.

The mean CTH_6 of sublegal-sized lobsters in the original survey area was higher in the mid (21–40 m) depth

Table 9. The number of trawl hauls completed each year in each stratum in the original survey area and in the expanded survey area. There were no deep stratum stations in the original survey area. There was no survey conducted in 2013.

		0 to 20 m	21 to 40 m	41 to 60 m	Total
2006	original	48	47		95
	expanded	--	--	--	--
2007	original	94	96	--	190
	expanded	--	--	--	--
2008	original	93	91	--	184
	expanded	--	--	--	--
2009	original	96	92	--	188
	expanded	--	--	--	--
2010	original	96	95	--	191
	expanded	--	--	--	--
2011	original	104	16	--	120
	expanded	112	111	112	335
2012	original	112	24	--	136
	expanded	112	111	112	335
2013	original	0	0	0	0
	expanded	0	0	0	0
2014	original	111	7	--	118
	expanded	111	110	110	331
2015	original	95	32	--	127
	expanded	111	112	110	333
2016	original	111	40	--	151
	expanded	111	112	109	332

Table 10. The number of lobsters observed by stratum each year in the original survey area and in the expanded survey area. There were no deep stratum stations in the original survey area. There was no survey conducted in 2013.

		0 to 20 m	21 to 40 m	41 to 60 m	Total
2006	original	692	1,651	--	2,343
	expanded	--	--	--	--
2007	original	678	3,037	--	3,715
	expanded	--	--	--	--
2008	original	357	3,974	--	4,331
	expanded	--	--	--	--
2009	original	740	3,689	--	4,429
	expanded	--	--	--	--
2010	original	374	3,121	--	3,495
	expanded	--	--	--	--
2011	original	1,144	898	--	2,042
	expanded	1,298	2,657	1,941	5,896
2012	original	1,154	612	--	1,766
	expanded	1,154	3,364	3,113	7,631
2013	original	--	--	--	--
	expanded	--	--	--	--
2014	original	301	23	--	324
	expanded	301	3,425	2,324	6,050
2015	original	128	1,273	--	1,401
	expanded	281	3,060	1,743	5,084
2016	original	1,386	1,311	--	2,697
	expanded	1,386	4,104	2,683	8,173

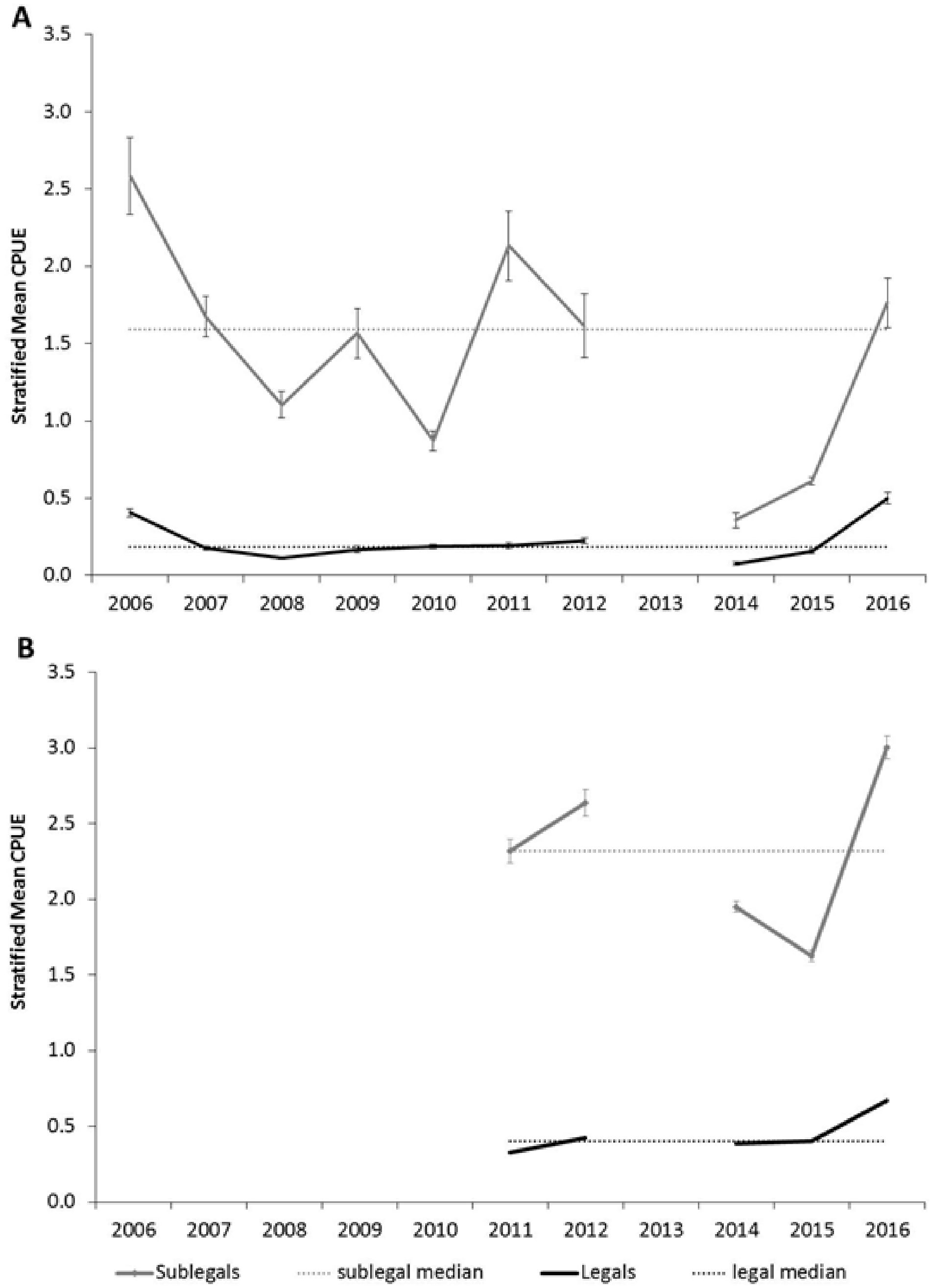


Figure 19. Stratified mean CTH_6 (±S.E.) for sublegal (grey) and legal-sized (black) lobsters for the original survey area (A) and the expanded survey area (B). Horizontal dotted lines represent the time series median values.

stratum than in the shallow (0–20 m) stratum in nine of the ten survey years (Figure 20A). In the expanded survey area, the mean catch of sublegal-sized lobsters was also higher in the mid than deep (41–60 m) stratum, with CTH_6 consistently lower in the shallow stratum than the mid and deep (Figure 20B).

For legal-sized lobsters, mean CTH_6 in both the original and expanded survey areas was higher in the mid than the shallow stratum (Figure 21A and B). In the expanded survey area, mean CTH_6 in the deep stratum was slightly higher than the mid stratum in 2011–2012, but from 2014–2016 was lower than the mid stratum (Figure 21B). Catch of legal-sized lobsters was higher in 2016 than most other years, particularly in the shallow stratum.

Average CTH_6 of sublegal lobsters was consistently lower at sampling stations inside Buzzards Bay (Figure 22). Early in the time series (2006–2009) there was at least one station each year with average catch rates of more than 10 lobsters per trap. However, after 2009

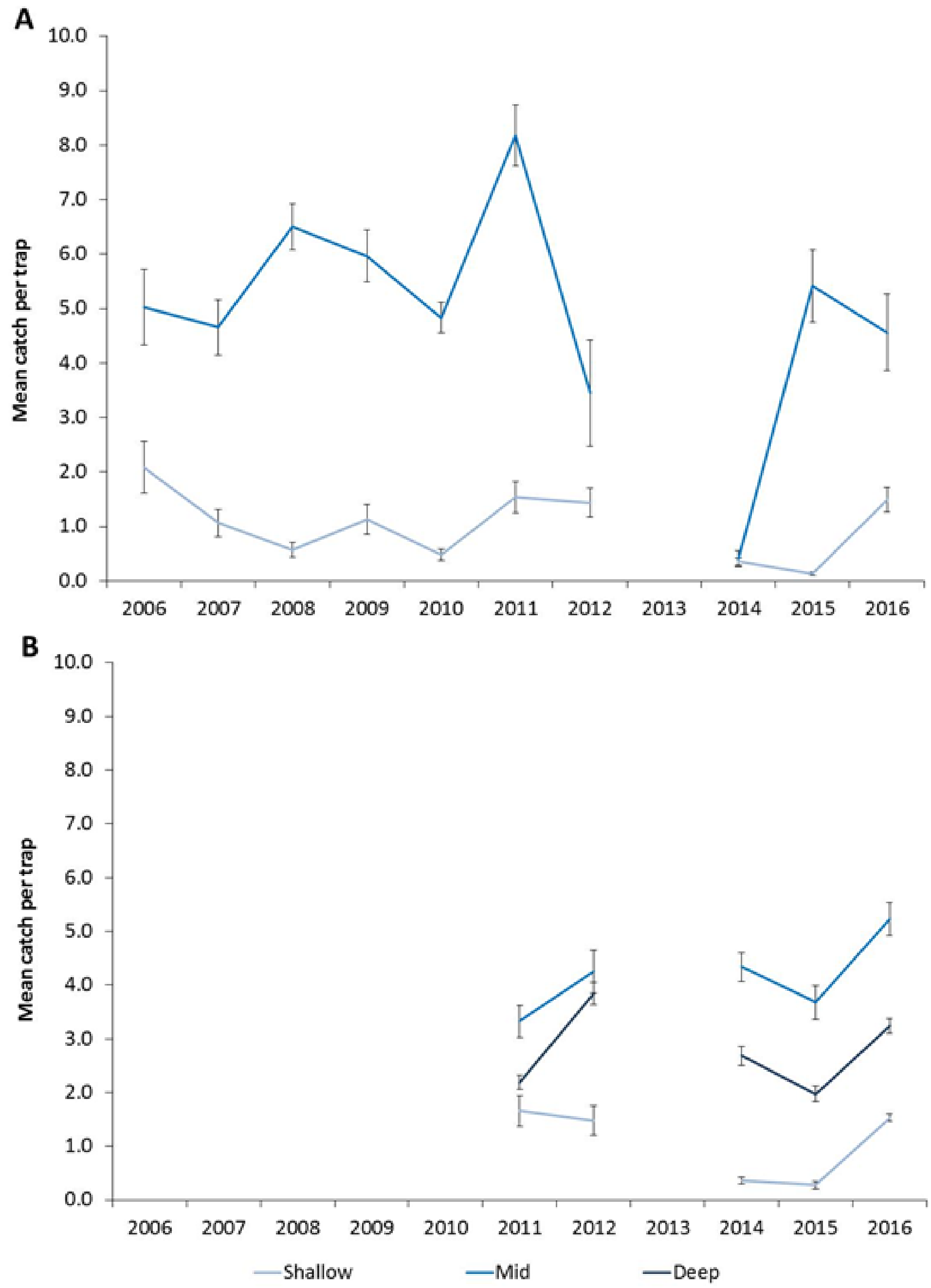


Figure 20. Mean CTH_6 (± S.E.) of sublegal (<86 mm CL) lobsters in each stratum from 2006–2016 in the original survey area (A) and the expanded survey area (B).

average catch rates this high became rare, occurring only once more at a single station in 2011. Higher catch rates generally occurred at stations near the mouth of Buzzards Bay and the mouth of Vineyard Sound in the mid depth stratum.

There was a similar pattern in the distribution of station-specific mean CTH_6 for legal-sized lobsters as there was for sublegal lobsters. Those stations farther from the interior of the Bay and into the mid and deep strata had higher average catch rates (Figure 23). The only year in which more than one station inside Buzzards Bay had average catch rates of 0.5 lobsters per trap or higher was 2016. There were also more stations in 2016 with average catch rates of more than one lobster per trap than any other survey year. Interestingly, stations in close proximity to each other did not necessarily have similar catch rates within a year, suggesting that there are fine-scale habitat features interacting with depth that may determine lobster presence and abundance.

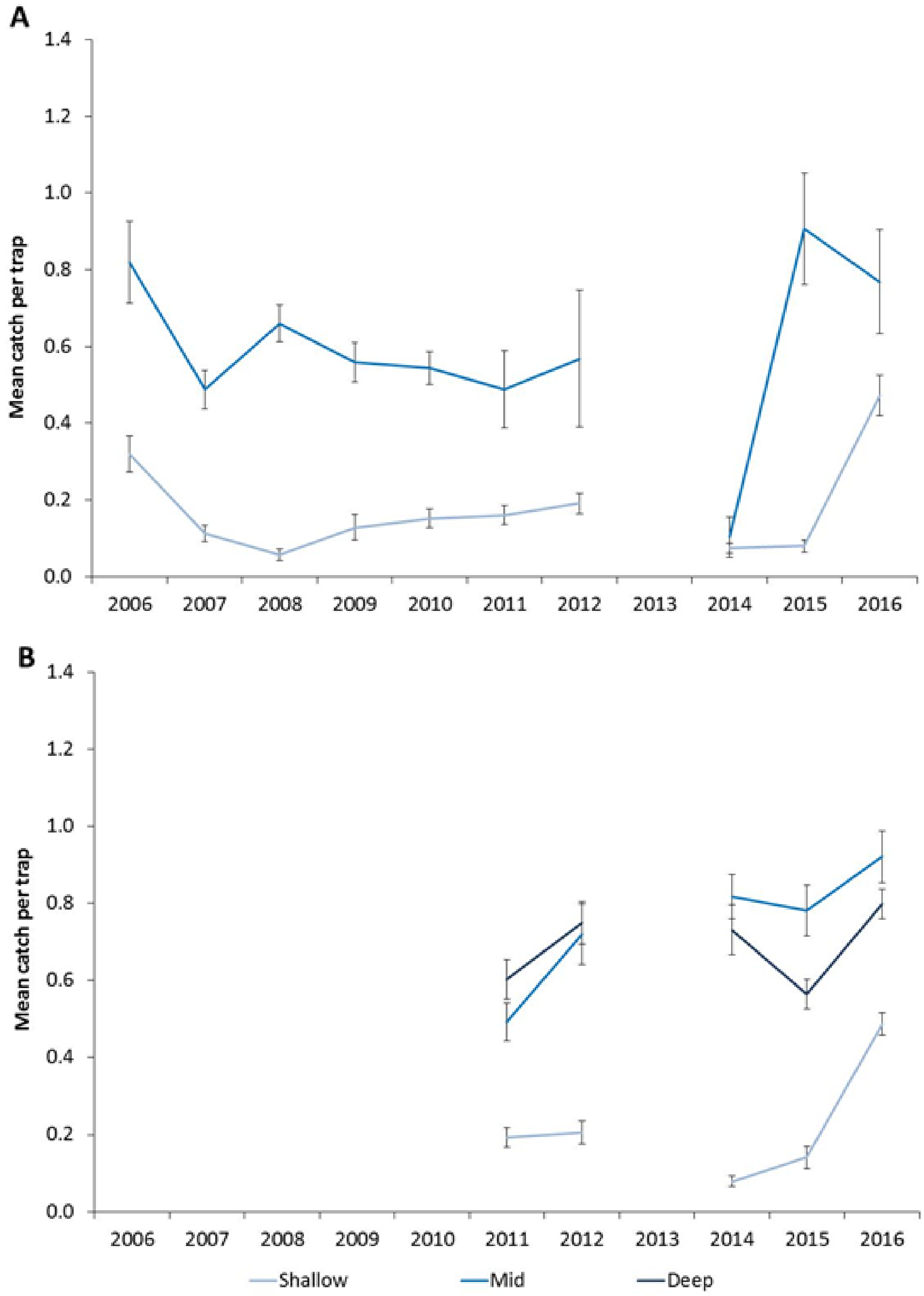


Figure 21. Mean CTH_6 (± S.E.) of legal lobsters in each stratum from 2006–2016 in the original survey area (A) and the expanded survey area (B).

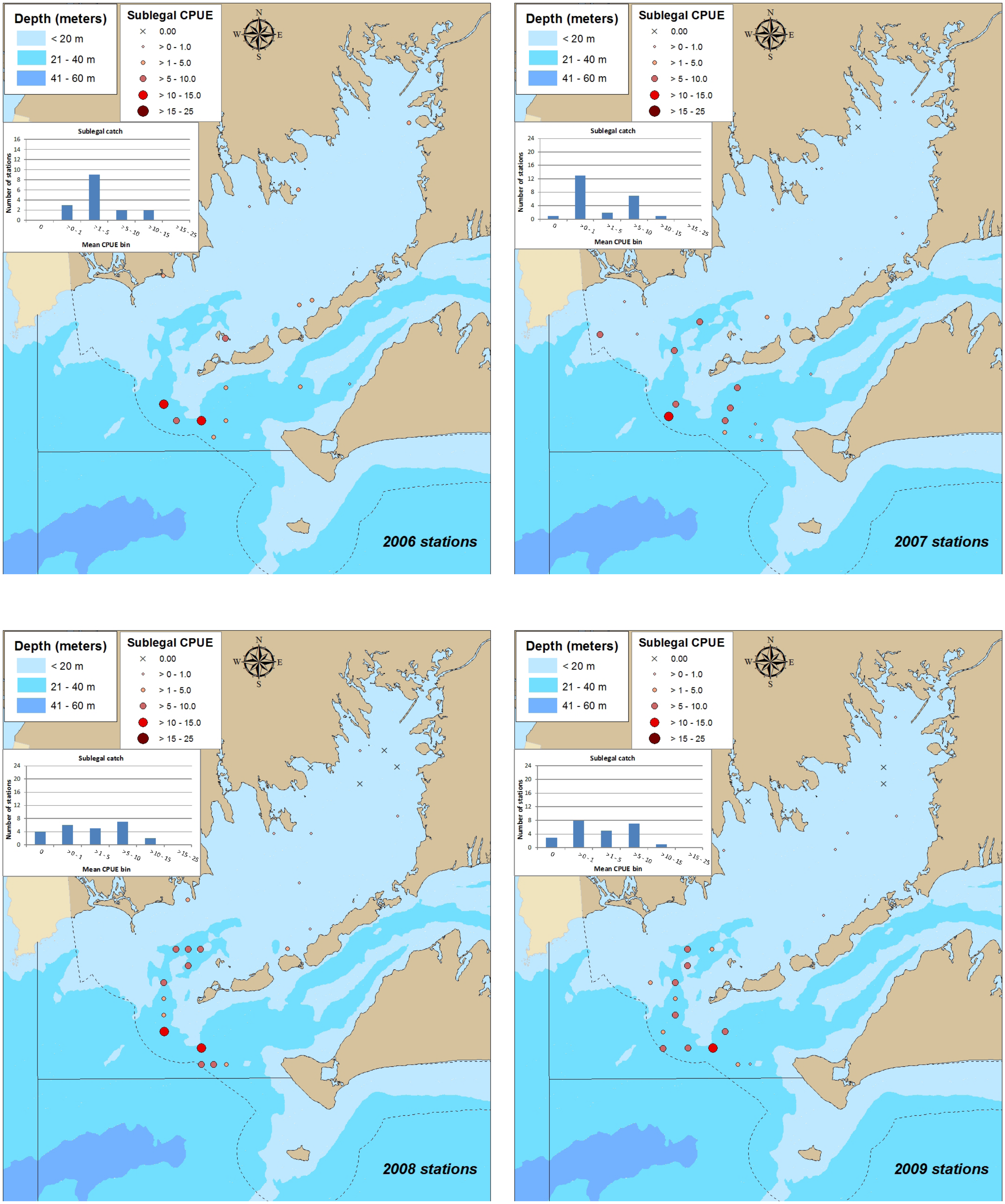


Figure 22. Mean catch per trap (CTH_6) of sublegal lobsters at each sampling station, 2006–2009. The solid lines represent NMFS statistical area boundaries, the dashed line represents MA territorial boundary. Histograms show the number of stations that fell within each catch bin.

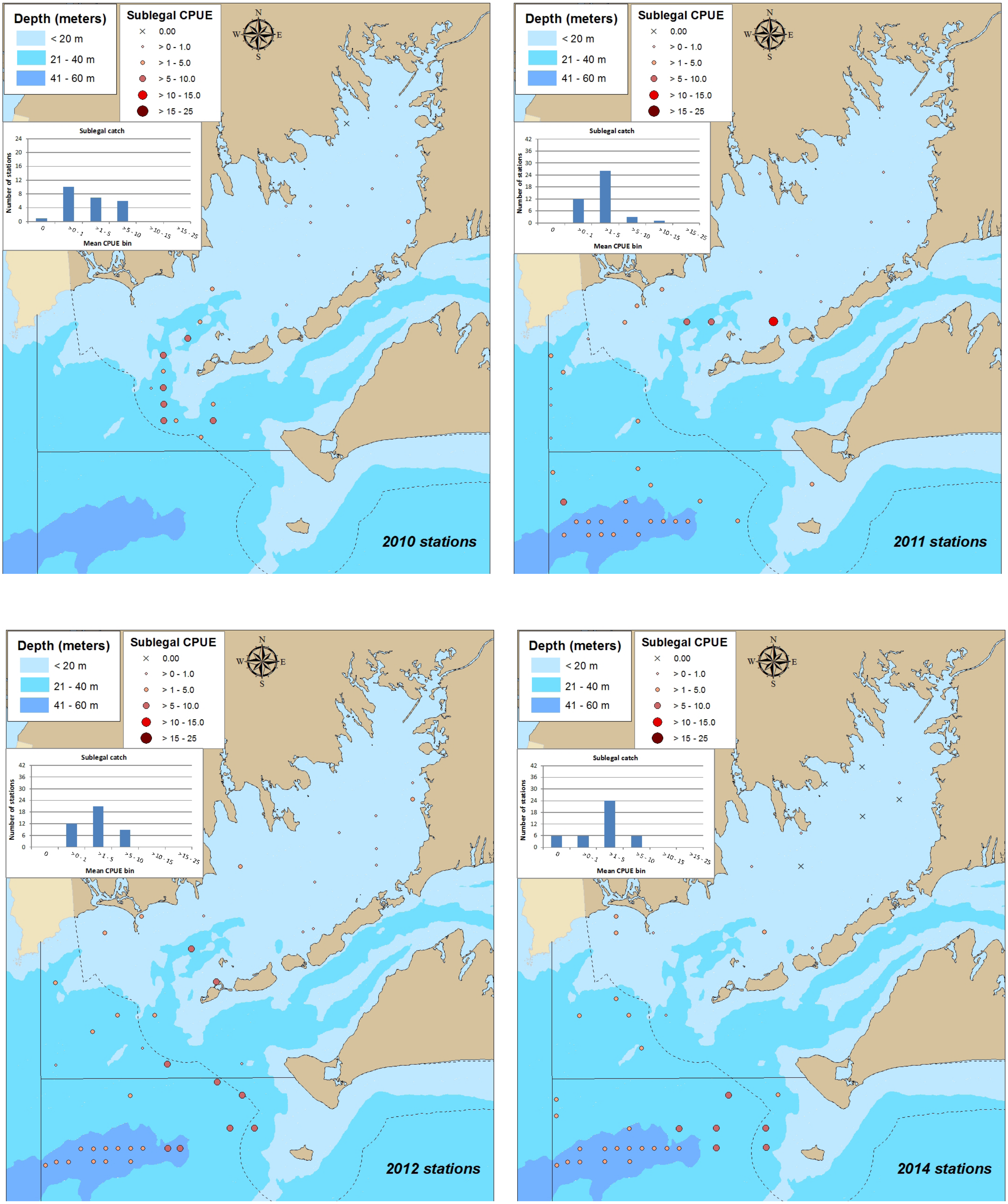


Figure 22 Continued. Mean catch per trap (CTH_6) of sublegal lobsters at each sampling station, 2010–2014. No survey was conducted in 2013. Note the expanded survey area starting in 2011. The solid lines represent NMFS statistical area boundaries, the dashed line represents MA territorial boundary. Histograms show the number of stations that fell within each catch bin.

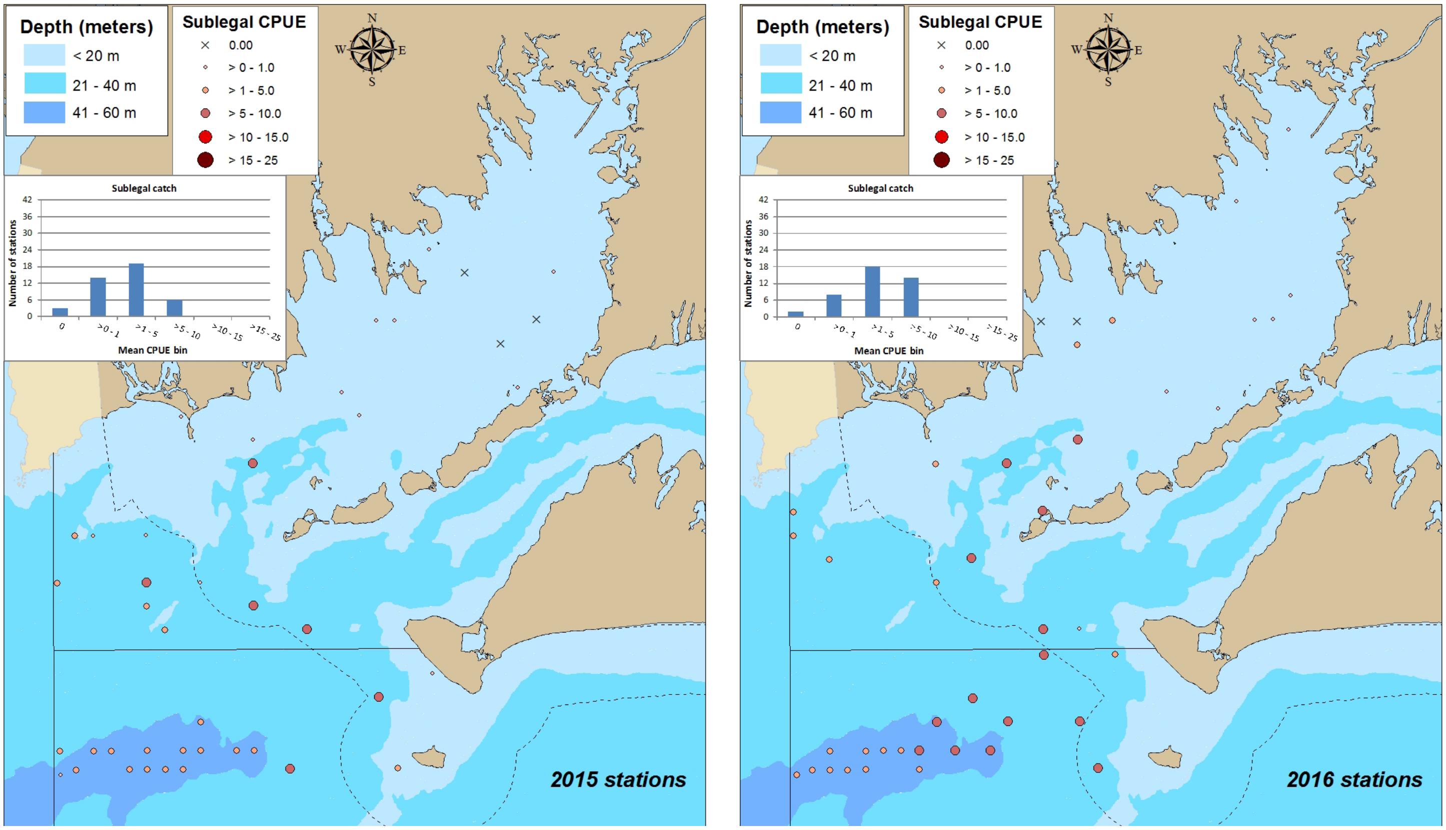


Figure 22 Continued. Mean catch per trap (CTH_6) of sublegal lobsters at each sampling station, 2015 and 2016. The solid lines represent NMFS statistical area boundaries, the dashed line represents MA territorial boundary. Histograms show the number of stations that fell within each catch bin.

Catch Characteristics

The size distribution of lobsters observed was truncated in both SNE survey areas (Figure 24), although not as drastically as that observed in GOM (see GOM Survey Area, Catch Characteristics Section). In the original survey area, an average of 18% of the catch over the last three years was legal-sized (≥ 86 mm CL), and an average of 19% was legal-sized in the expanded survey area. The percent of marketable lobsters (≥ 86 mm, no eggs or v-notch) that were within one molt increment of minimum legal size varied from 89% to 99% in the original survey area, and from 92% to 96% in the expanded survey area (Table 11), indicative of a recruit-dependent fishery.

Data from the original survey area indicate that catch in nearly every 5 mm size bin declined from 2007 to 2014 (Figure 25). Values in 2015 remained below average in most size bins, but in 2016 values were above the time series average for sizes 76 mm and larger. Based on the five years of data for the expanded survey area, catch rates tended to vary around the mean without a clear trend in most size bins (Figure 26). Catch in 2016 was above average for all size bins from 66–70 mm to 106–110 mm.

In the original survey area, the size distribution of lobsters in the shallow stratum was significantly different than the distribution of lobsters in the mid stratum from 2006–2010 and from 2015–2016 ($\alpha = 0.05$, Table 11, Figure 27A). In the expanded survey area, the size distributions of lobsters in each stratum were significantly distinct (Bonferroni adjusted $\alpha = 0.025$, Table 12, Figure 27B). The size distribution of lobsters in the shallow stratum is generally composed of more small individuals, while lobsters in the deeper stratum were larger than those in the shallow or mid stratum.

The percentage of sublegal-sized lobsters that were female in the original survey area varied from 38% to 60% over the survey period and ranged from 25% to 69% female in the legal-size class (Table 13, strata combined). In the expanded survey area, the percentage of sublegal-sized lobsters that were female ranged from 54% to 65%, and from 59% to 71% in the legal-size class. Females began to outnumber males in the catch at roughly 76 mm (see Figure 24), which

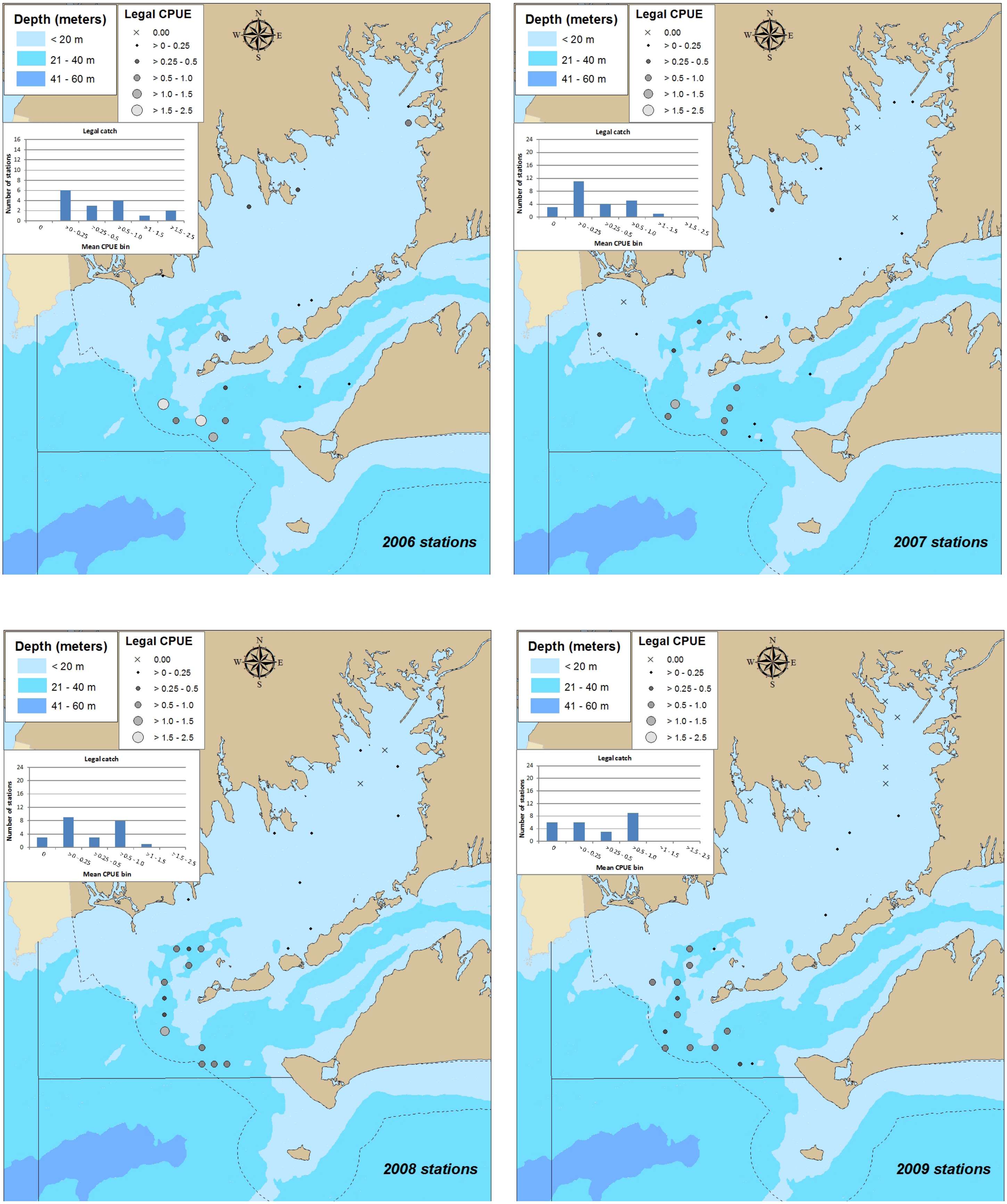


Figure 23. Mean catch per trap (CTH_6) of legal lobsters at each sampling station, 2006–2009. The solid lines represent NMFS statistical area boundaries, the dashed line represents MA territorial boundary. Histograms show the number of stations that fell within each catch bin.

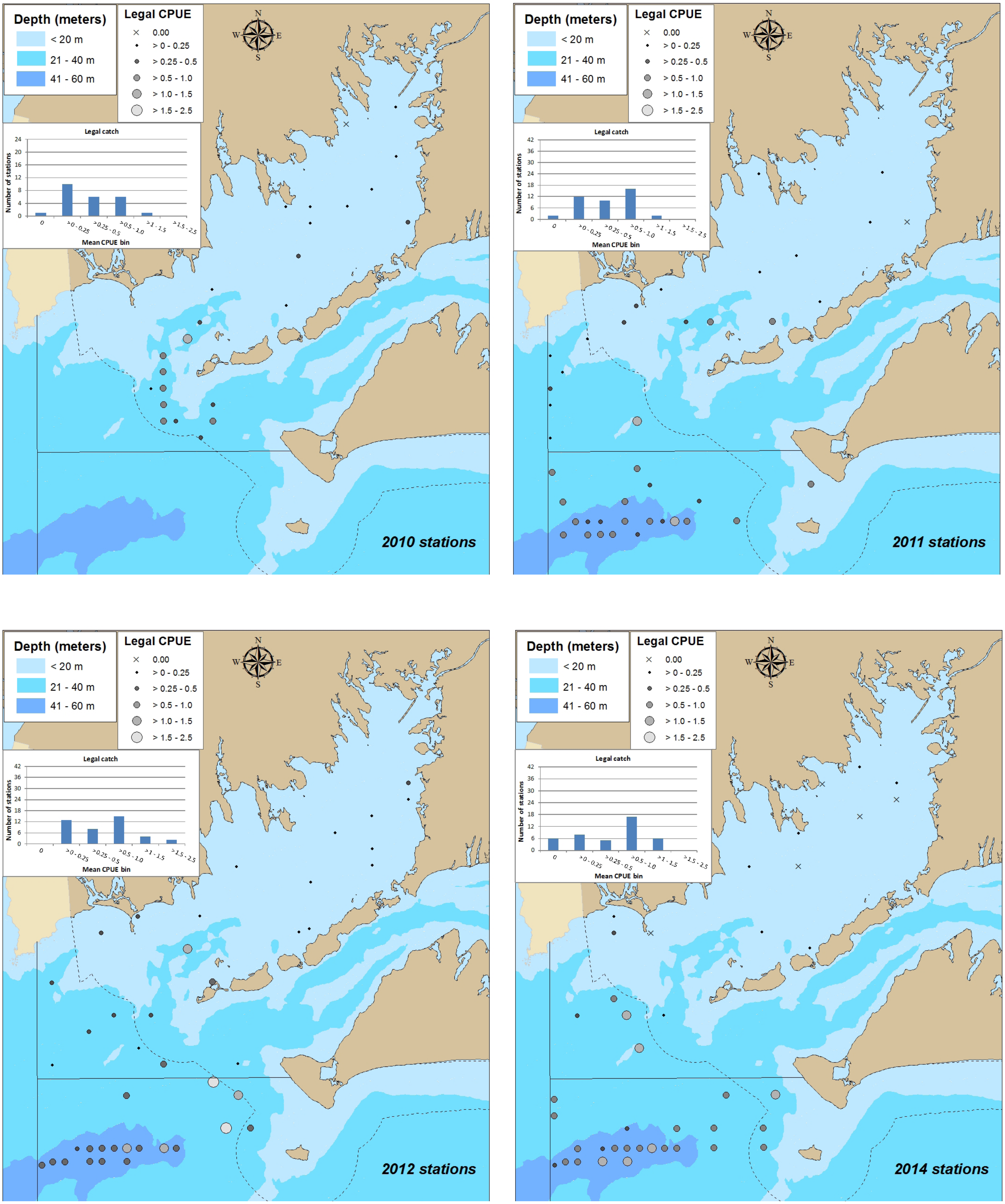


Figure 23 Continued. Mean catch per trap (CTH_6) of legal lobsters at each sampling station, 2010–2014. Note the expanded survey area starting in 2011. No survey was conducted in 2013 The solid lines represent NMFS statistical area boundaries, the dashed line represents MA territorial boundary. Histograms show the number of stations that fell within each catch bin.

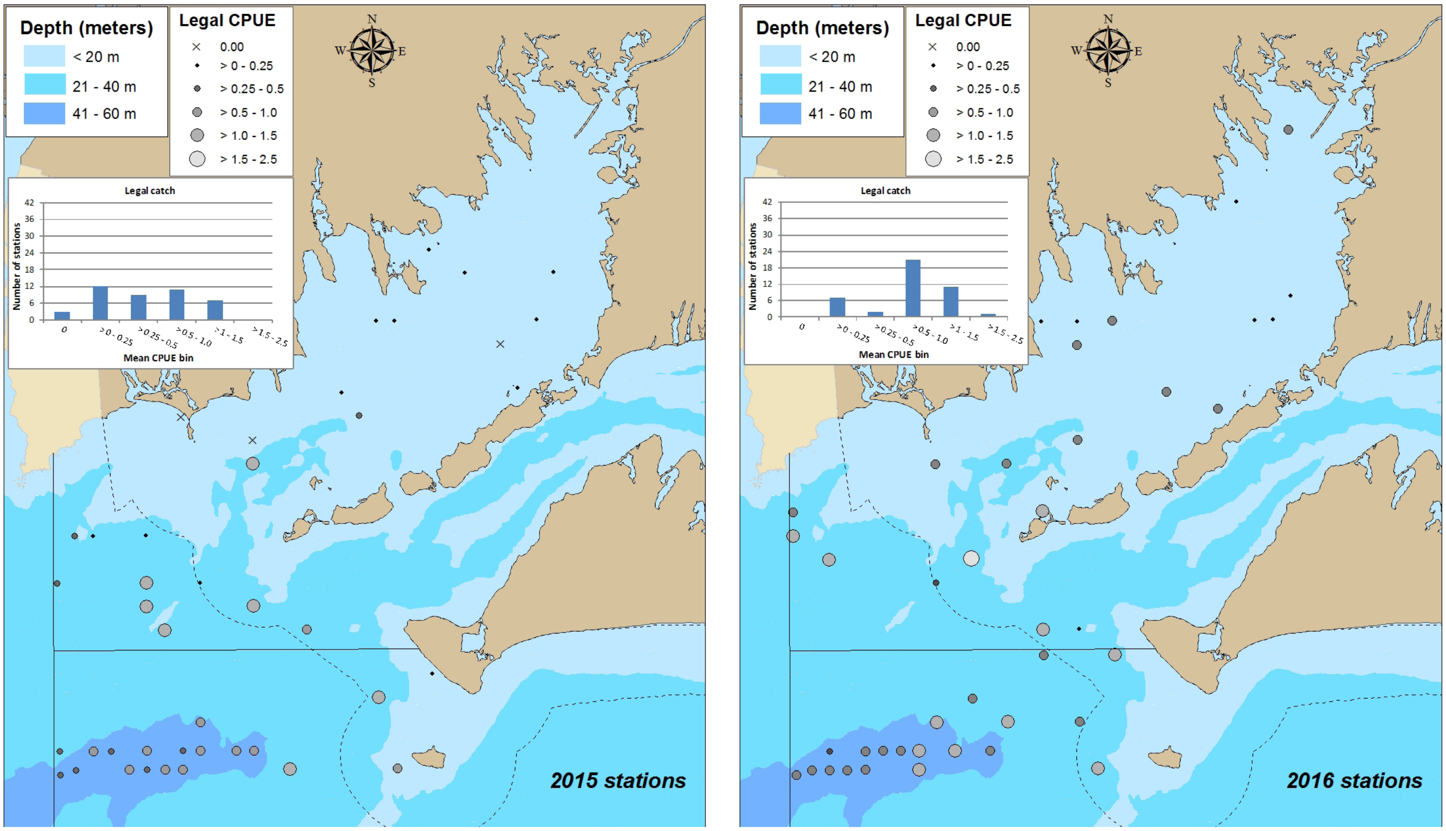


Figure 23 Continued. Mean catch per trap (CTH_6) of legal lobsters at each sampling station, 2015 and 2016. The solid lines represent NMFS statistical area boundaries, the dashed line represents MA territorial boundary. Histograms show the number of stations that fell within each catch bin.

Table 11. Annual percent of the marketable catch that was within 1 molt increment of minimum legal size in the original survey area (top) and the expanded survey (bottom).

Original area	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow (0-20m)	94.2	90.9	90.3	95.7	83.3	93.3	92.9	ND	94.5	75.6	85.0
Mid (21-40m)	97.0	97.3	99.4	97.8	97.2	97.8	93.0	ND	100.0	97.2	94.7
Deep (41-60m)								ND			
TOTAL	96.1	96.0	98.6	97.4	93.8	94.7	93.0	ND	94.9	92.9	88.5

Expanded area	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow (0-20m)						93.5	92.9	ND	94.5	81.4	85.0
Mid (21-40m)						96.8	94.0	ND	93.8	95.2	96.6
Deep (41-60m)						95.9	91.5	ND	93.2	91.5	91.8
TOTAL						95.8	92.8	ND	93.5	92.5	92.2

Table 12. Annual results of K-S 2 sample test (D_{max} (p-value)) comparing size distributions between depth strata for the original survey area and the expanded survey area. Significant differences (α = 0.05 for original area, α_{adj} = 0.025 for expanded area) shown in bold italic font.

Original area

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow vs mid	***0.12 (0.01)***	***0.205 (0.00)***	***0.277 (0.00)***	***0.11 (0.00)***	***0.141 (0.00)***	0.086 (0.21)	0.166 (0.06)	ND	0.219 (0.09)	***0.241 (0.00)***	***0.101 (0.01)***

Expanded area

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow vs mid						***0.114 (0.02)***	***0.215 (0.00)***	ND	***0.143 (0.00)***	***0.176 (0.00)***	***0.097 (0.00)***
Mid vs deep						***0.220 (0.00)***	***0.048 (0.00)***	ND	***0.177 (0.00)***	***0.185 (0.00)***	***0.142 (0.00)***
Shallow vs deep						***0.327 (0.00)***	***0.240 (0.00)***	ND	***0.321 (0.00)***	***0.145 (0.00)***	***0.132 (0.00)***

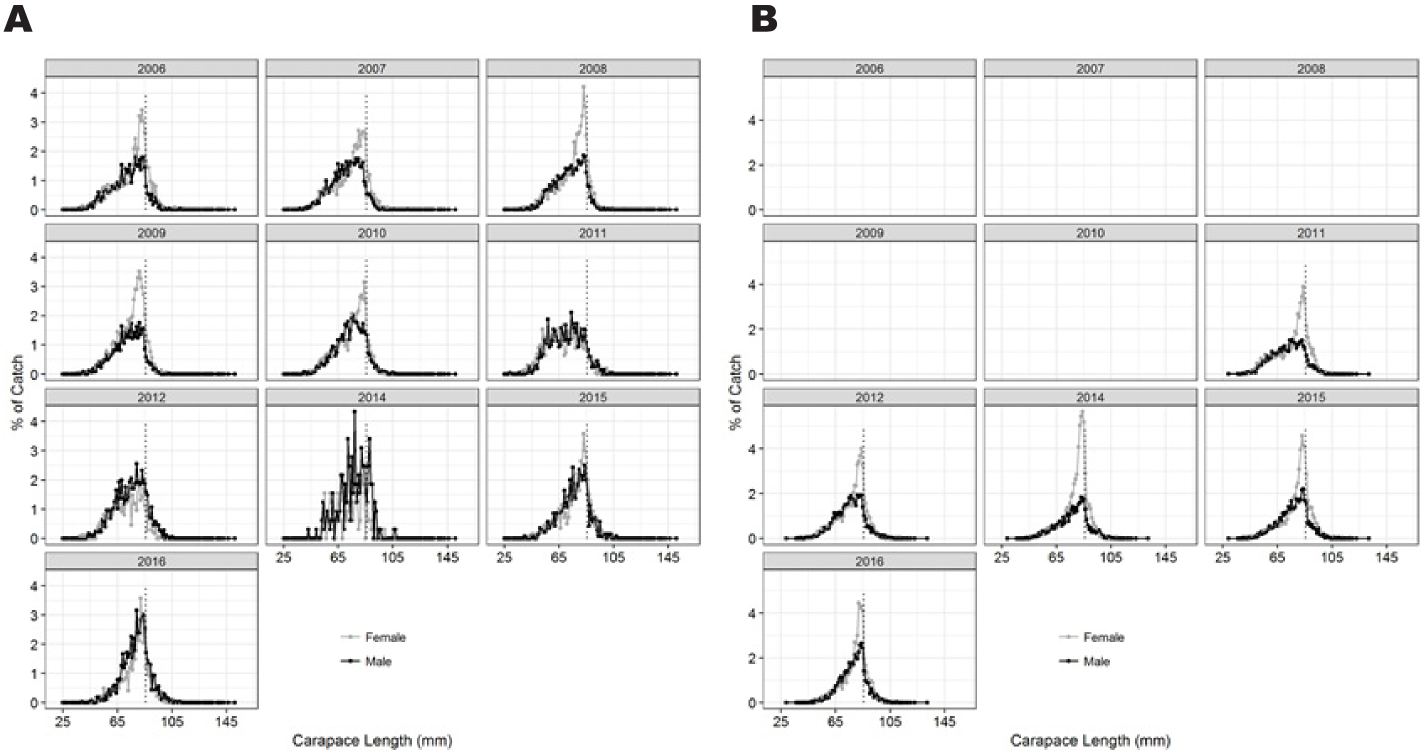


Figure 24. Percentage of the catch at length for male and female lobsters in the original survey area (A) and expanded survey area (B). Vertical dashed line represents minimum legal size (86 mm). Refer to Table 9 for total number of lobsters sampled each year.

Table 13. Percent female by size class (sublegal and legal) and by depth strata for the original survey area and the expanded survey area, 2006–2016. Color shading indicates male (green) or female (red) skew, and follows the same gradient as in Figure 28.

Original area

Sublegal	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow (0-20m)	45.1	41.2	32.4	52.6	41.3	45.5	40.2	ND	36.9	52.5	46.2
Mid (21-40m)	59.8	54.6	57.9	61.2	54.5	55.0	50.4	ND	61.1	50.0	44.1
Deep (41-60m)											
TOTAL	55.4	52.1	55.8	59.8	53.3	49.8	43.7	ND	38.5	50.2	45.1

Legal	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow (0-20m)	57.6	48.5	39.4	57.0	27.5	32.4	23.8	ND	19.6	45.8	38.0
Mid (21-40m)	74.0	71.7	66.1	69.8	61.4	73.1	43.5	ND	80.0	58.6	52.3
Deep (41-60m)											
TOTAL	69.3	67.4	64.0	67.3	53.9	45.4	31.5	ND	24.6	56.0	43.3

Expanded area

Sublegal	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow (0-20m)						47.2	40.2	ND	36.9	52.5	46.2
Mid (21-40m)						58.6	57.6	ND	66.3	56.0	52.1
Deep (41-60m)						61.7	57.2	ND	66.5	58.7	61.8
TOTAL						56.9	54.7	ND	64.9	56.7	54.3

Legal	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow (0-20m)						41.3	23.8	ND	19.6	61.2	38.0
Mid (21-40m)						77.1	61.4	ND	67.7	68.5	61.3
Deep (41-60m)						75.6	73.6	ND	70.8	62.5	68.7
TOTAL						71.0	62.2	ND	66.8	65.5	58.8

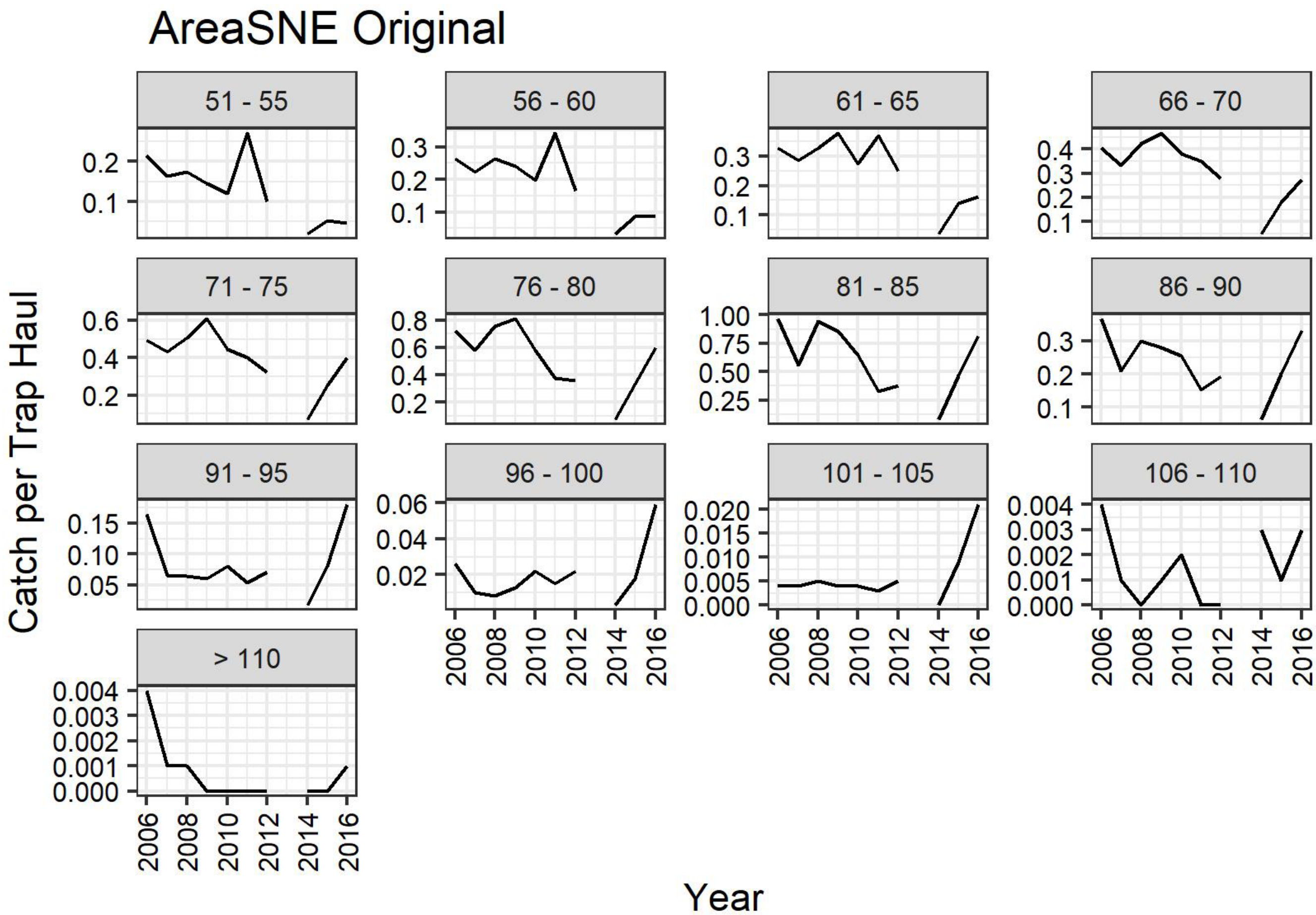


Figure 25. Annual catch per trap haul (number of lobsters/total traps hauled) by 5 mm size bin for lobsters > 50 mm CL for the original SNE survey area. Note the y-axis varies.

is the size at which 50% of females mature in the Buzzards Bay area (Estrella and McKiernan 1989). This accumulation of females results from the decrease in molt frequency in female lobsters that have reached maturity, when they switch from an annual molt to a biennial molt in order to accommodate reproduction.

There were patterns in sex ratio skew by depth stratum, in both the original survey area and the expanded survey. In the original area, catch of sublegal lobsters in the shallow stratum tended to be relatively balanced between the sexes or slightly male-skewed (less than 45% female), while balanced to slightly female-skewed (> 55% female) in the mid stratum (Table 13). This pattern was similar in the expanded survey area, but even more strongly female-skewed in the mid and deep strata.

The catch of legal-sized lobsters tended to show stronger sex ratio skews than sublegal-sized catches (Table 13). In the original survey area, legal-sized lobsters in the shallow stratum tended to be males in six of the ten survey years, with very strong male-skews (< 25% female) in 2012 and 2014. In the mid stratum, catch was female-skewed in eight of ten survey years, moderately (>65% – 75% female) to strongly (> 75% female) so in six of those years. In the expanded survey area, the pattern in sex ratio skew was similar, with male-skewed legal-sized catch in the shallow stratum and female skews in the mid and deep strata.

Catch appeared to be slightly to highly male-skewed at shallow stations in the interior of Buzzards Bay, while there was more of a tendency towards female-skew at the mouth of the Bay and Vineyard Sound (Figure 28). While this general pattern was persistent throughout the survey time period, there were differences in sex ratio between stations in close proximity, suggesting fine-scale habitat features that may have influenced the sex ratio of lobsters present.

From 2006–2016 an average of 8.9% of sublegal-sized females in the original survey area were ovigerous, and an average of 13% of legal-sized were ovigerous

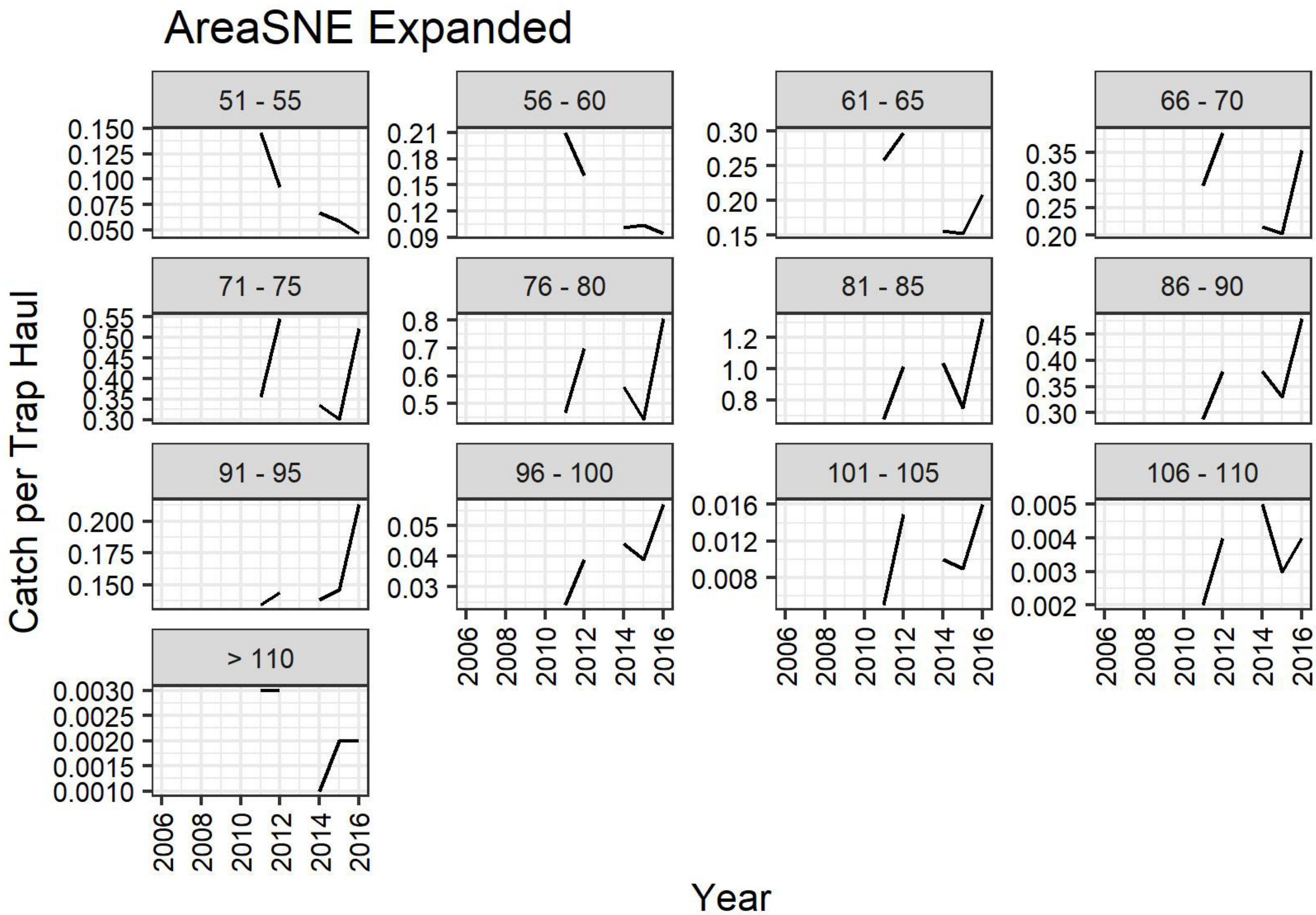


Figure 26. Annual catch per trap haul (number of lobsters/total traps hauled) by 5 mm size bin for lobsters > 50 mm CL for the SNE expanded survey area. Note the y-axis varies.

(Table 14). In the expanded survey area, an average of 9.8% of sub-legal females and 10.8% of legal females were ovigerous (Table 14). A slightly higher percentage of legal-sized females were ovigerous than sub-legal-sized females in both survey areas, although the differences were not as large between the size classes as those observed in GOM. Size at maturity in the southern survey area is much smaller than in GOM (Estrella and McKiernan 1989), such that about 93% of females are mature by the time they reach minimum legal size (86 mm CL) in this area.

In the expanded survey area, there was no clear trend in percent ovigerous by depth or over time (2011–2016). However, in the original survey area there was a tendency for a higher percentage of females to have eggs in the mid stratum than the shallow stratum in most years, for both size classes.

Most of the ovigerous females in the SNE survey area were observed during June and September, with July and August tending to be the time period when females were generally not carrying eggs (Figure 29). Well-developed eggs and recently hatched ("spent") clutches occurred in June and July, with very few spent clutches occurring in August in some years. These data illustrate a typical reproductive cycle for the region, with spawning taking place in late summer (August and September), egg development proceeding throughout the fall and winter so that eggs in the late spring and early summer are well-developed and ready to hatch.

The spawning stock index in the original survey area has declined from 2006 through 2012 when it reached a time series low but has since been relatively stable (Figure 30A). While an overall decline in mean spawning stock CTH_6 is clear in both depth strata, it is more dramatic in the mid stratum from 2006 through 2011 (Figure 30A). Increases in the mid stratum in 2015 and 2016 have allowed the stratified mean to remain low but stable since 2012. The mean CTH_6 was higher in the mid stratum than the shallow stratum throughout the time series in the original survey area.

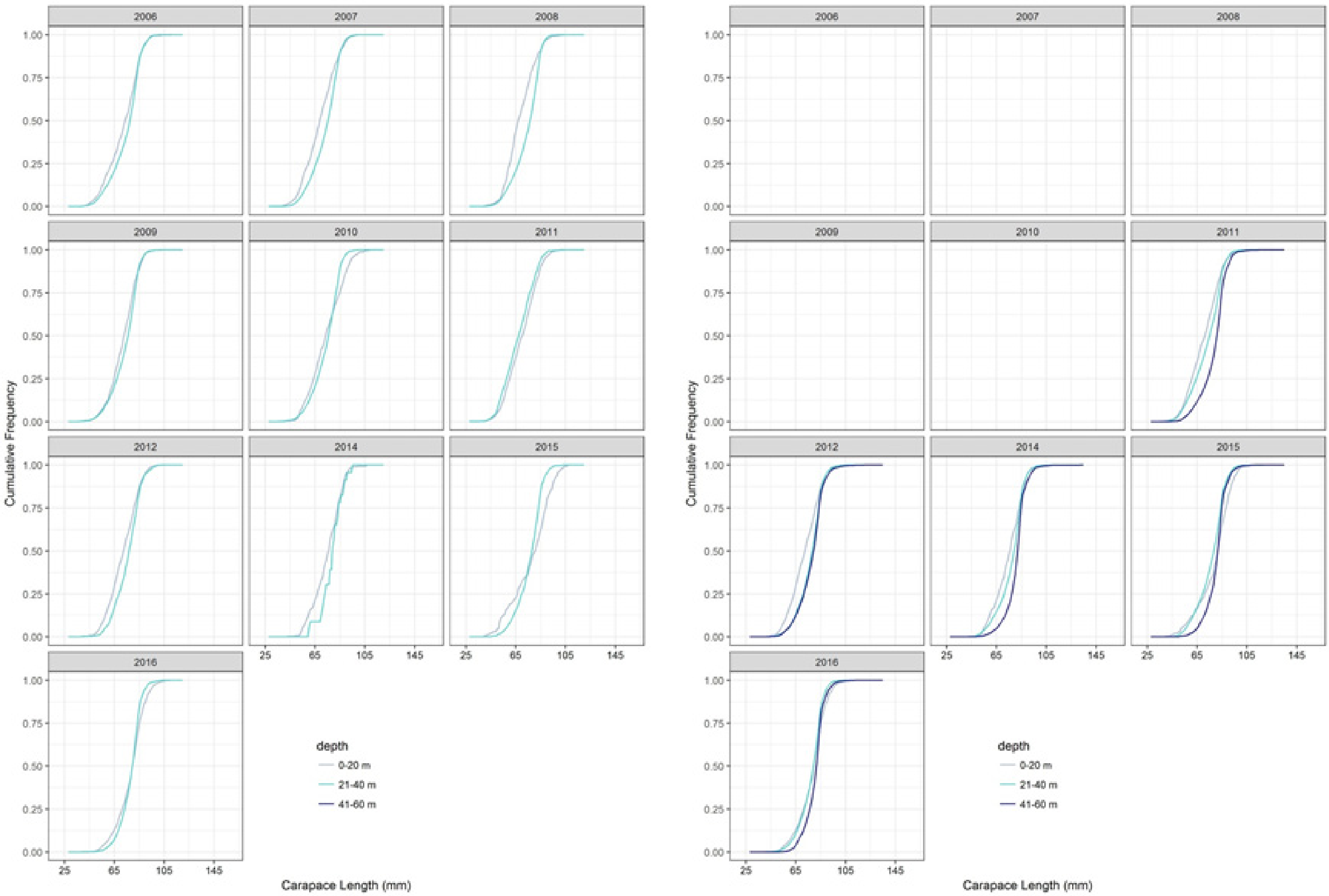


Figure 27. Annual cumulative length frequency distributions by stratum for the original survey area (A) and the expanded survey area (B).

In the expanded survey area, mean spawning stock CTH_6 in each depth stratum was distinct in 2011 and 2012, with highest catch rates observed in the deep stratum (Figure 30B). From 2014 through 2016 the mean CTH_6 in the mid stratum increased and was similar to that in the deep, while mean CTH_6 remained lowest in the shallow stratum. The spawning stock index was thus slightly higher from 2014–2016 than it was in the earlier two years. Note that the spawning stock index was at a time series high in the expanded survey area in 2014 but was the second lowest value in the time series in the original survey area.

There were clear spatial patterns in the average catch of ovigerous females. Most sampling stations in the interior of Buzzards Bay caught no ovigerous females (Figure 31). Catch averaged less than 0.5 ovigerous females per trap haul annually at most of the sampling stations. Those stations with higher catch rates were always located in the mid or deep strata. Stations in the deep stratum, added in 2011, did not produce higher catch rates of ovigerous females than the mid stratum; average catch each year remained highest at those stations located in the mid stratum.

The percentage of female lobsters with v-notches was relatively low in both the original and expanded SNE survey areas (Table 15) and a higher percentage of legal-sized females were v-notched than sublegal females (Table 15). Looking at only legal-sized females, the percentage with a v-notch was relatively high in 2006 in the original survey area, then declined and varied from zero to nine percent for the rest of the survey period, with no clear trend by depth. The decline in the percentage of females that were v-notched after 2006 was likely related to the end of the RI Cape North oil spill restoration program (2006, S. Olszewski, RIDEM, personal communication) and females notched during that program subsequently molting out of the v-notch. In the expanded survey area, the percentage of legal-sized females with a v-notch varied from zero to ten percent, with slightly higher percentages observed in the deep stratum than the shallow or mid strata.

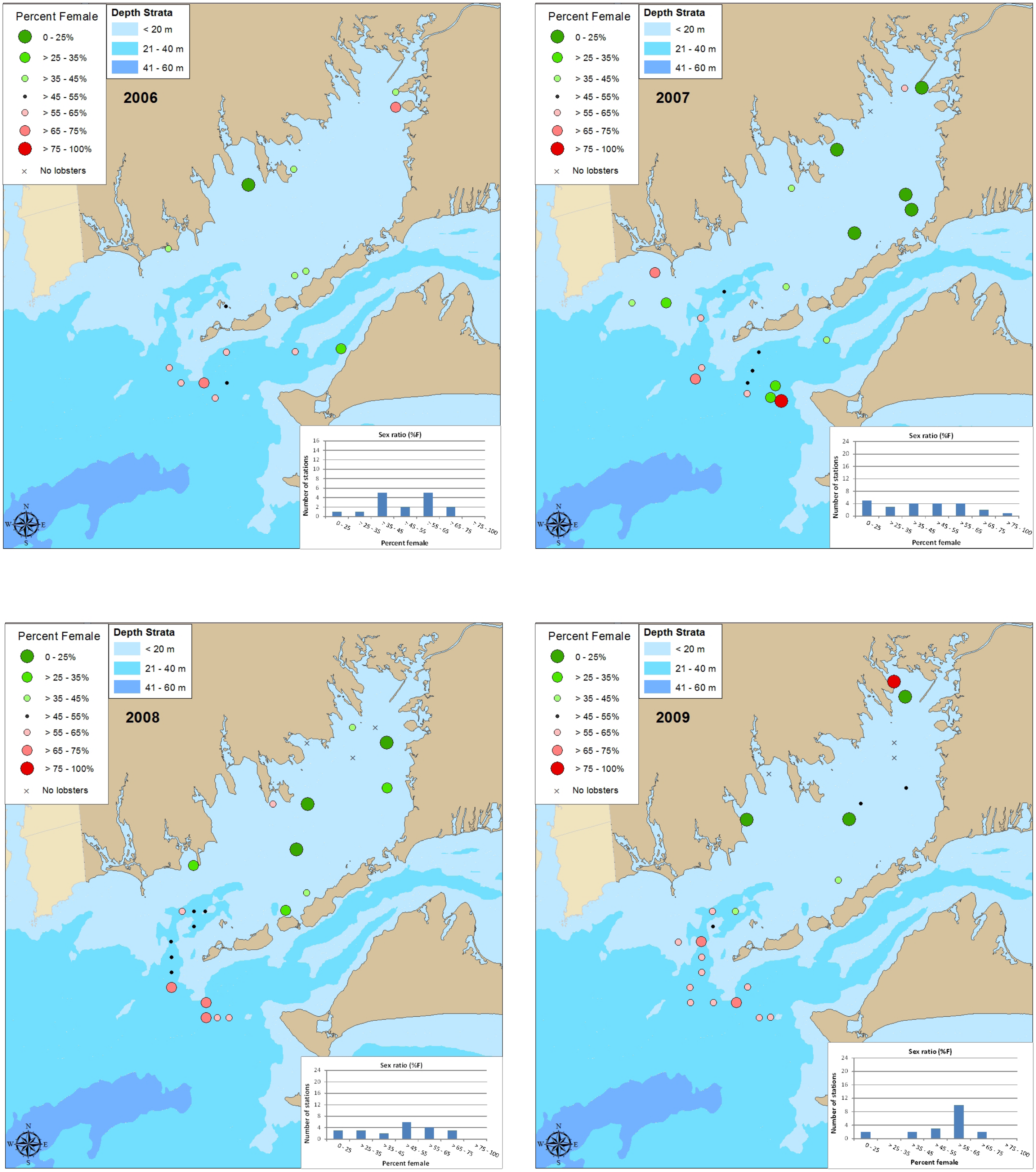


Figure 28. Percent of the catch that was female at each sampling station each year, 2006–2009. Larger, darker red dots indicate female skew, while larger, darker green dots indicate male skew. Histogram shows the number of stations that fell within each mapped sex ratio range (stations with no lobsters are not included in histogram).

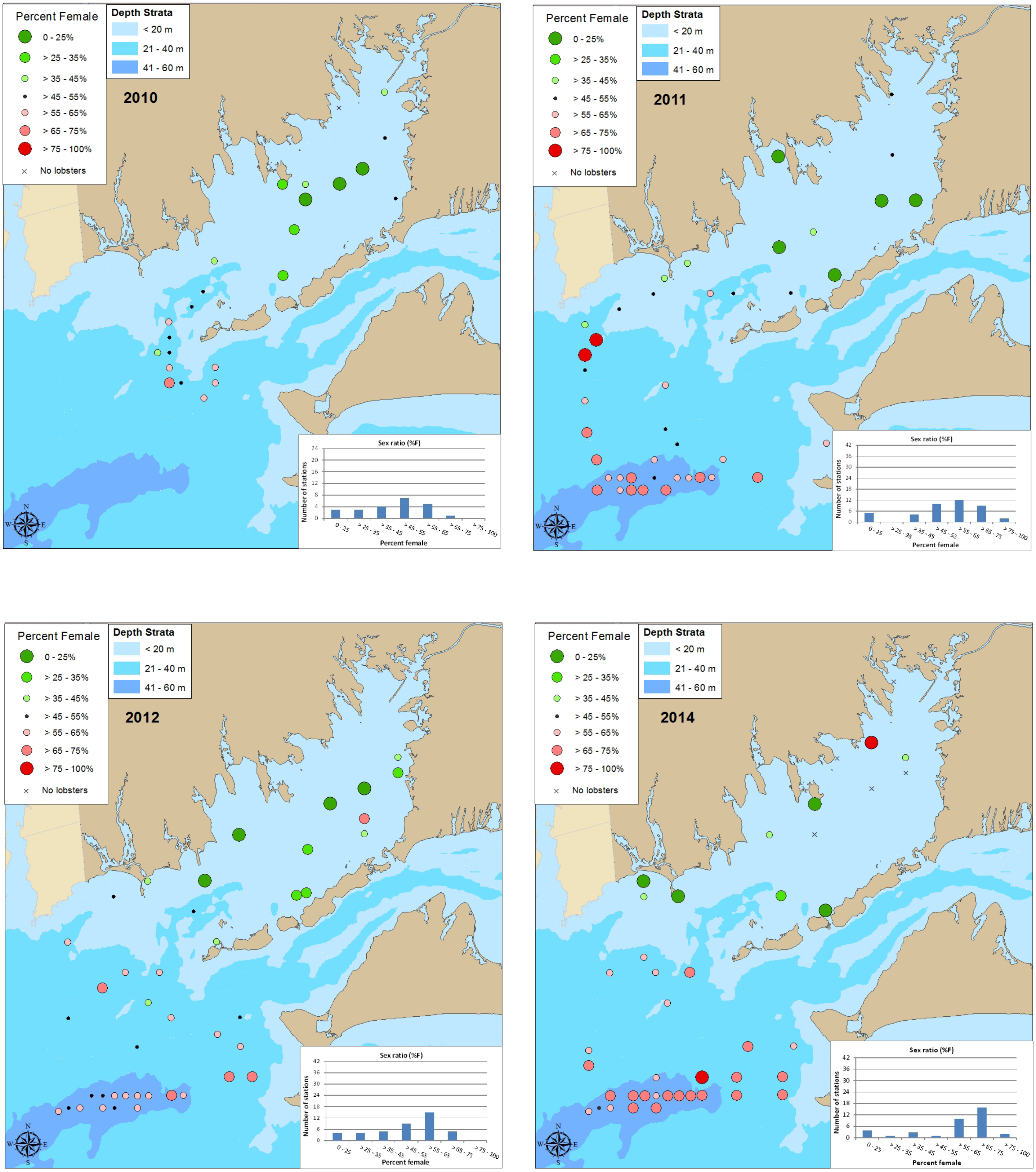


Figure 28 Continued. Percent of the catch that was female at each sampling station each year, 2010–2014. No survey was conducted in 2013. Larger, darker red dots indicate female skew, while larger, darker green dots indicate male skew. Histogram shows the number of stations that fell within each mapped sex ratio range (stations with no lobsters are not included in histogram).

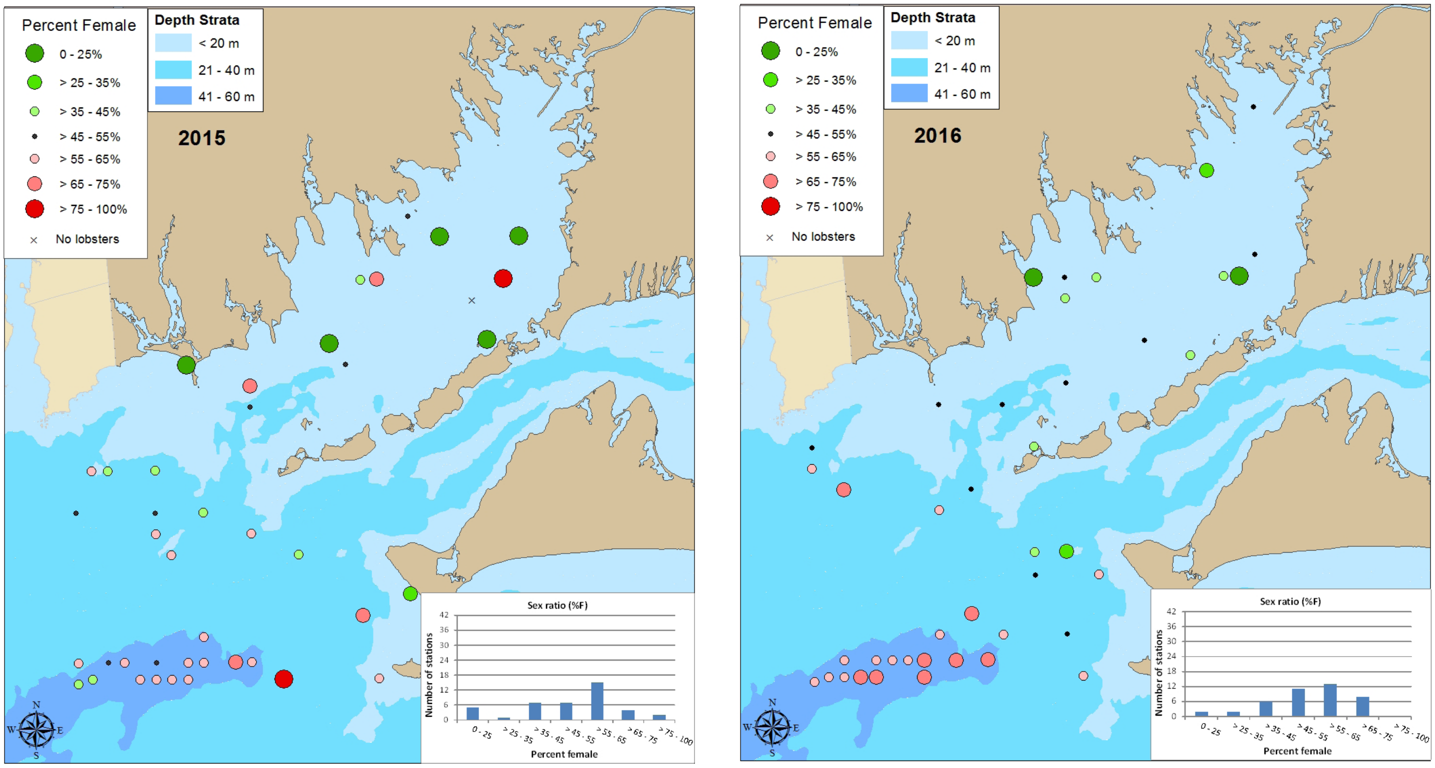


Figure 28 Continued. Percent of the catch that was female at each sampling station each year, 2015 and 2016. Larger, darker red dots indicate female skew, while larger, darker green dots indicate male skew. Histogram shows the number of stations that fell within each mapped sex ratio range (stations with no lobsters are not included in histogram).

Table 14. Annual percentage of the female catch that was egg-bearing (including recently hatched clutches) by size category and by depth stratum, 2006–2016.

Original area

Sublegal	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)	3.3	1.2	3.8	6.3	0.9	6.8	3.0	ND	12.2	0.0	7.9
Mid (21-40m)	7.9	8.9	12.0	10.0	10.1	8.3	2.3	ND	36.4	12.3	6.1
Deep (41-60m)											
TOTAL	6.8	7.8	11.6	9.5	9.4	7.5	2.7	ND	14.9	11.5	7.0

Legal	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)	7.5	6.1	7.7	13.3	0.0	19.4	8.8	ND	9.1	9.1	6.3
Mid (21-40m)	19.9	11.7	18.8	19.2	17.3	10.5	10.0	ND	25.0	5.5	5.8
Deep (41-60m)											
TOTAL	17.0	11.0	18.3	18.2	15.4	14.9	9.5	ND	13.3	6.1	6.1

Expanded area

Sublegal	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)						8.0	3.0	ND	12.2	10.4	7.9
Mid (21-40m)						7.1	10.6	ND	16.7	11.5	9.1
Deep (41-60m)						5.8	7.8	ND	11.9	5.3	10.8
TOTAL						6.8	8.5	ND	14.8	9.4	9.6

Legal	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Shallow (0-20m)						24.6	8.8	ND	9.1	18.3	6.3
Mid (21-40m)						11.5	12.4	ND	20.1	12.8	10.2
Deep (41-60m)						5.3	9.4	ND	8.6	4.4	9.2
TOTAL						9.6	10.7	ND	14.4	10.2	9.2

Table 15. Percent of the sublegal and legal-sized female catch with a v-notch (1/8" definition) and percent of legal-sized females with a v-notch by depth strata, in the original survey area and the expanded survey area.

Original area	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Sublegal	0.5	0.1	0.0	0.2	0.2	0.3	0.3	ND	0.0	0.2	0.3
Legals	19.6	4.9	3.8	5.2	2.7	2.7	2.7	ND	0.0	0.8	2.2

Legal-sized only	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow (0-20m)	1.9	0.0	7.7	8.9	4.0	0.0	0.0	ND	0.0	4.5	2.3
Mid (21-40m)	25.1	5.6	3.6	4.5	2.6	5.3	5.0	ND	0.0	0.0	1.9
Deep (41-60m)											

Expanded area	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Sublegal						0.5	0.4	ND	0.3	0.1	0.5
Legals						5.9	7.5	ND	2.9	2.3	3.6

Legal-sized only	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Shallow (0-20m)						1.8	0.0	ND	0.0	3.3	2.3
Mid (21-40m)						3.7	4.9	ND	2.6	1.3	3.1
Deep (41-60m)						8.4	10.2	ND	3.3	3.6	4.6

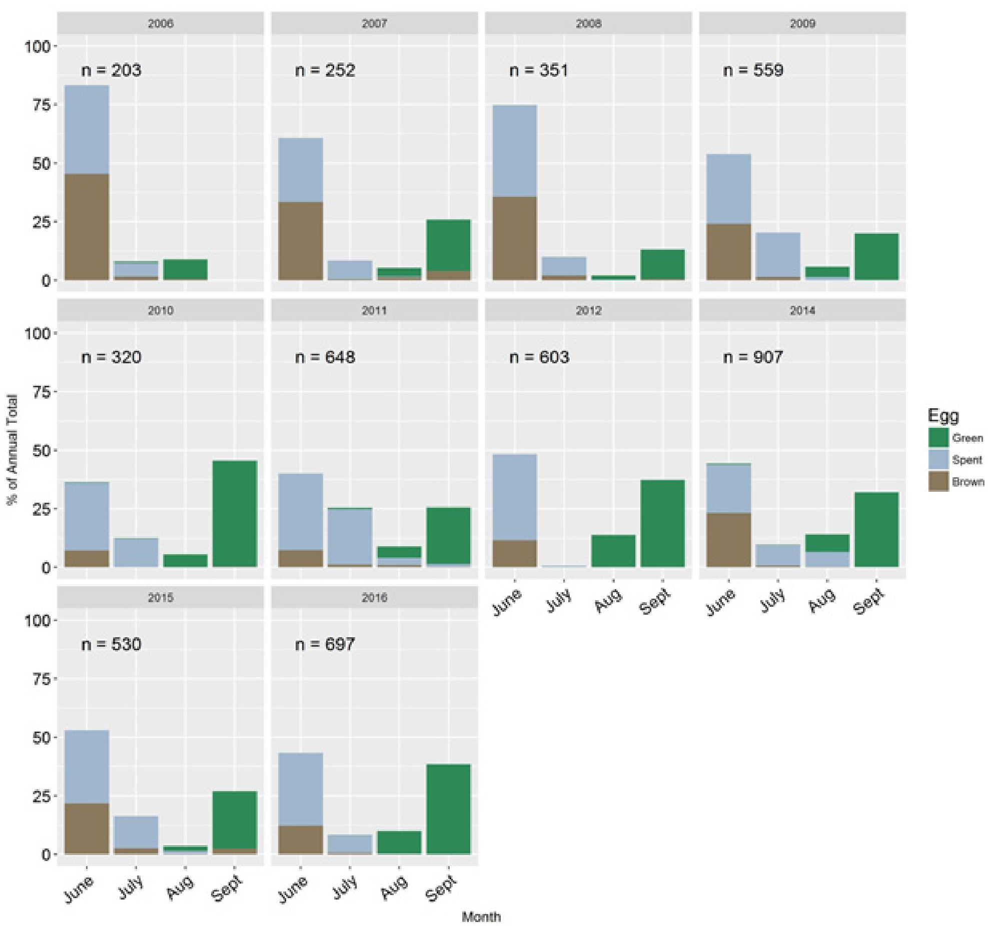


Figure 29. Annual timing of gross egg developmental stages for ovigerous females. Green = recently spawned, brown = well-developed and will hatch this year, spent = recently hatched.

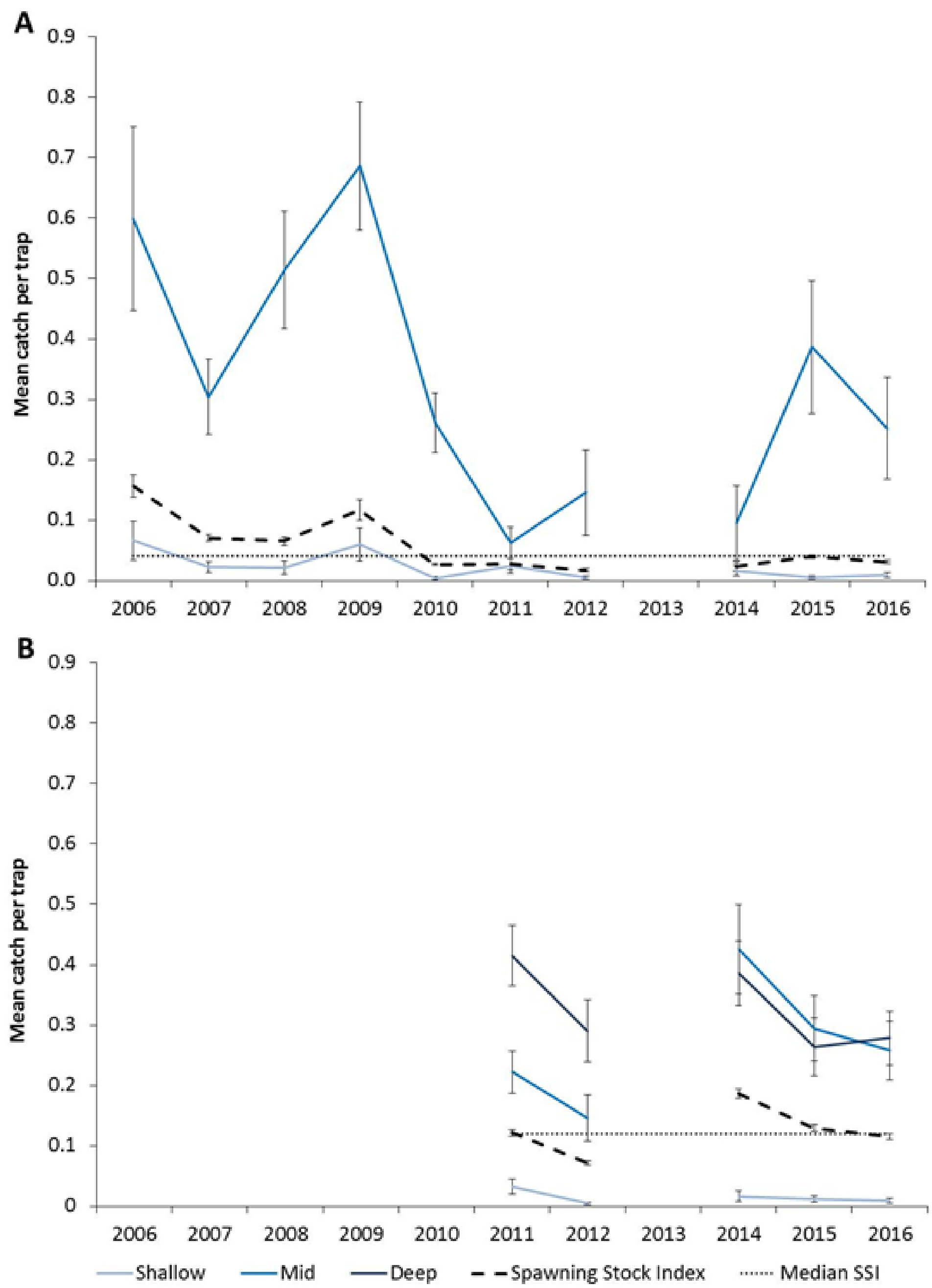


Figure 30. Annual spawning stock mean CTH_6 ± S.E. in each depth stratum and the spawning stock index (± S.E.; black dashed line) for (A) the original survey area and (B) the expanded survey area.

Shell disease in the SNE area is much more prevalent than in GOM, with a time series average of 14% of sublegal-sized lobsters and 17% of legal-sized lobsters having disease symptoms in the original survey area (Table 16). In most years, disease was more prevalent in lobsters caught in the mid stratum than the shallow stratum in the original survey area and has varied without a clear trend over the survey time period (Figure 32A). In the expanded survey area, an average of 14% of sublegal-sized lobsters and 17% of legal-sized lobsters had disease (Table 16). Disease was most prevalent in the deep stratum and least prevalent in the shallow stratum in the expanded survey area (Figure 32B). Shell disease affects certain components of the population more so than others (Table 16). In the original survey area 16.6% of all females had disease symptoms while 7% of males had disease. In the expanded survey area 20.2% of females and 6.5% of males had disease. In both survey areas, a much higher percentage of ovigerous females (including those that recently

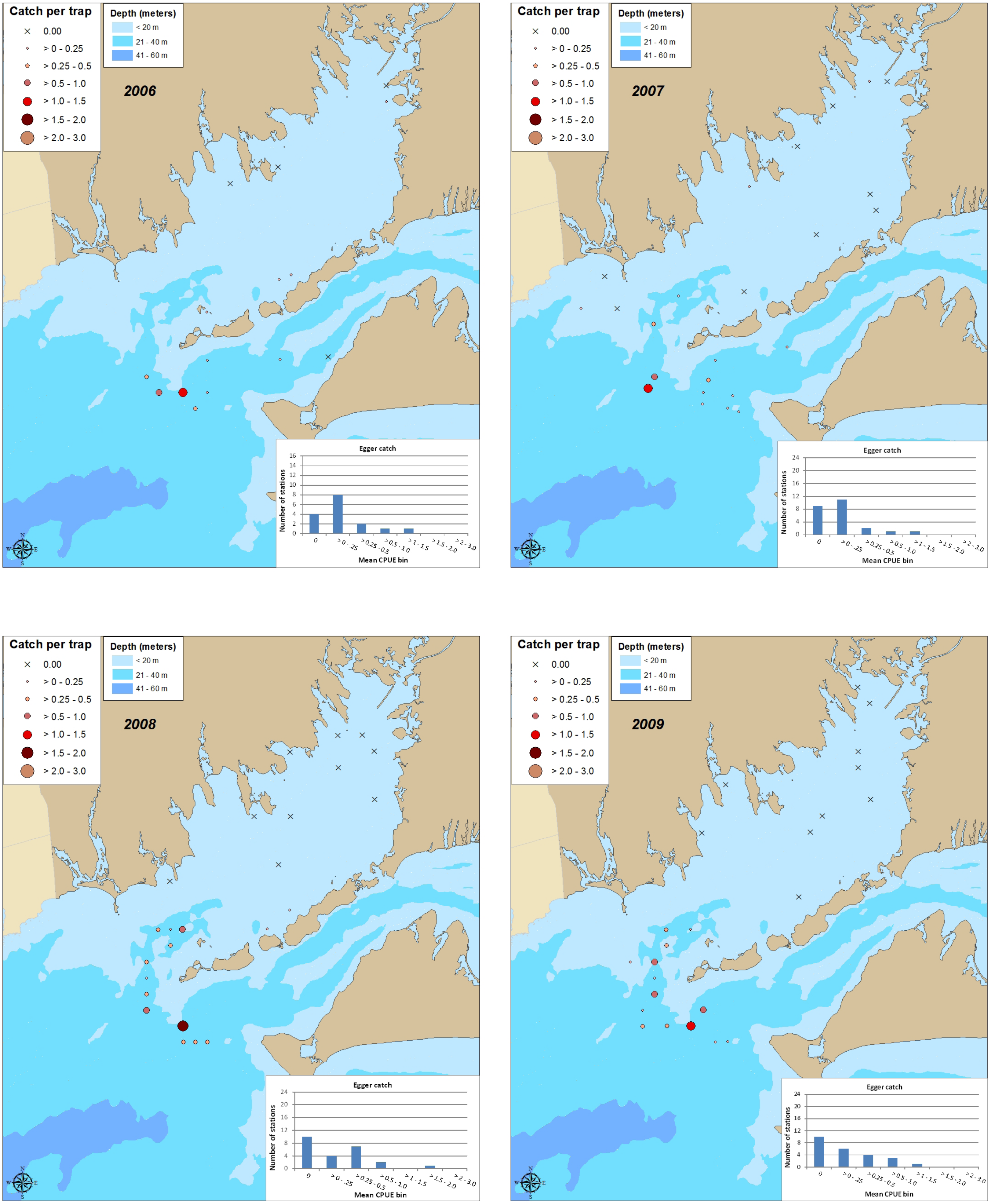


Figure 31. Mean CPUE of ovigerous females (green and brown eggs) at each sampling station, during each survey year, 2006–2009. Histograms show the number of stations that fell within each catch bin.

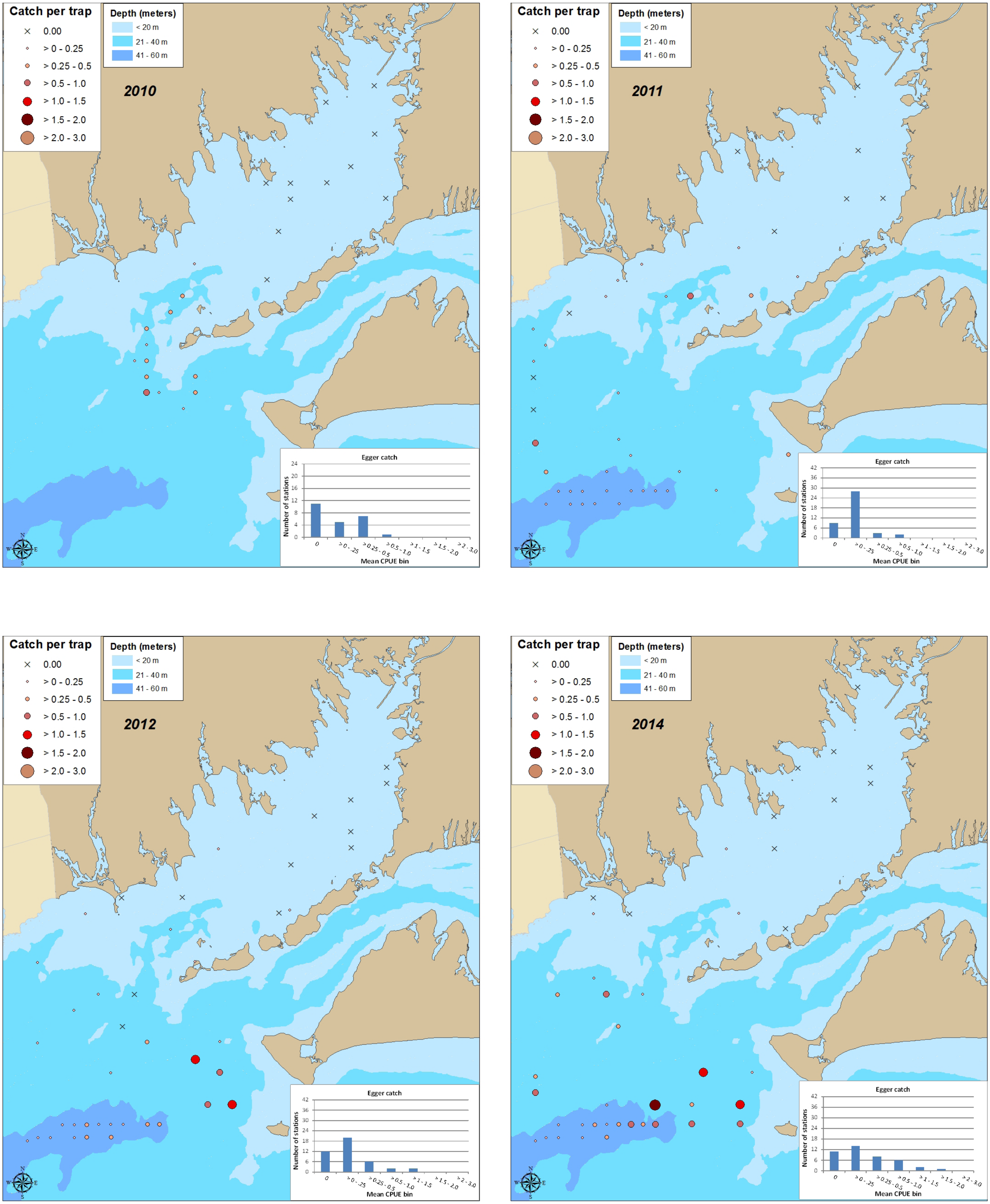


Figure 31 Continued. Mean CPUE of ovigerous females (green and brown eggs) at each sampling station, during each survey year, 2010–2014. No survey was conducted in 2013. Histograms show the number of stations that fell within each catch bin.

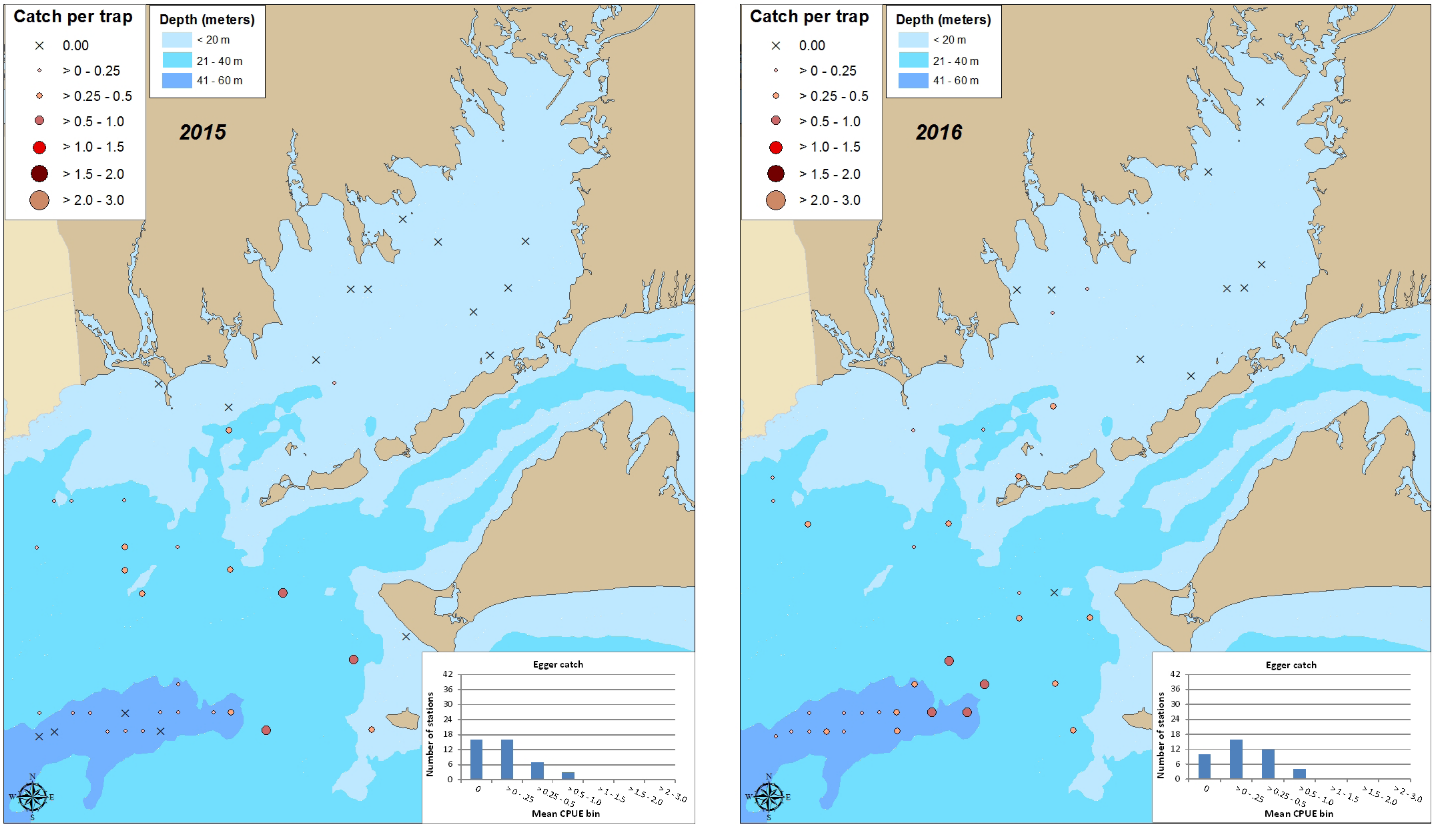


Figure 31 Continued. Mean CPUE of ovigerous females (green and brown eggs) at each sampling station, during each survey year, 2015 and 2016. Histograms show the number of stations that fell within each catch bin.

Table 16. For each survey area, the percentage of sublegal and legal lobsters with shell disease, percentage of female and male lobsters with disease, percentage of ovigerous (females with eggs and females with recently hatched clutches) and non-ovigerous females with disease.

Original area	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Sublegal (< 86 mm)	9.9	8.2	20.7	16.0	13.0	15.3	11.9	ND	15.8	15.3	11.9
Legal (≥ 86 mm)	22.3	15.3	23.4	24.0	12.7	22.5	18.3	ND	16.4	13.7	4.9
Female	19.0	13.1	27.0	22.4	14.7	11.0	10.4	ND	15.5	18.9	14.4
Male	1.7	4.1	13.0	8.2	10.9	6.6	10.5	ND	5.3	5.4	7.3
Female ovig. & recently hatched	66.5	65.1	78.3	76.2	56.6	48.0	75.6	ND	76.2	71.2	78.0
Female non-ovigerous	10.5	5.5	14.9	8.2	6.0	7.0	6.2	ND	2.1	10.0	6.5

Expanded area	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Sublegal (< 86 mm)						15.3	11.9	ND	15.8	15.3	12.2
Legal (≥ 86 mm)						22.5	18.3	ND	16.4	13.7	15.2
Female						23.0	17.9	ND	20.8	21.1	18.4
Male						6.9	6.6	ND	6.8	6.3	5.8
Female ovig. & recently hatched						63.0	55.0	ND	55.0	62.8	62.6
Female non-ovigerous						13.8	11.7	ND	10.5	12.1	10.3

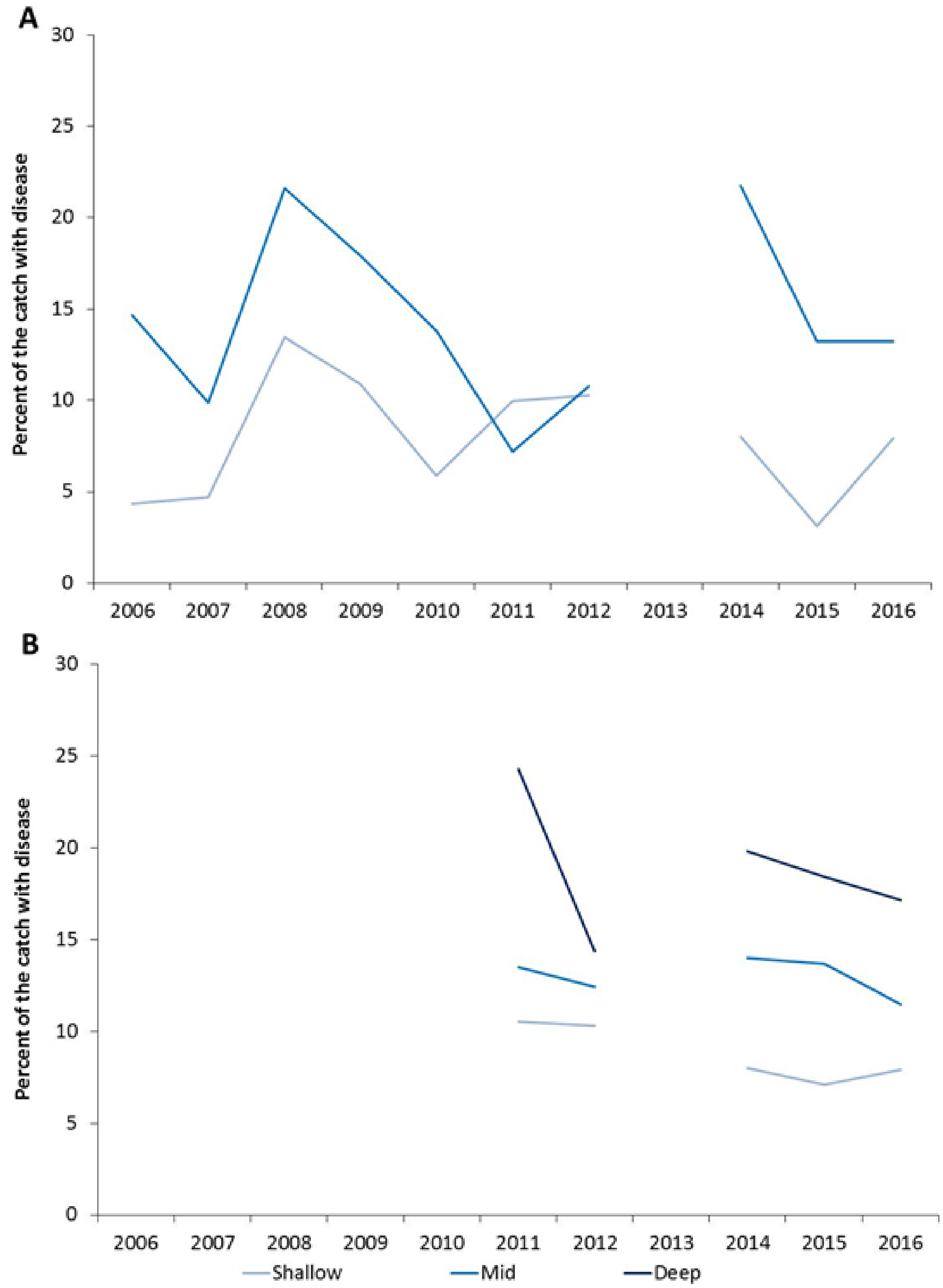


Figure 32. Percentage of the catch with shell disease by depth stratum from 2006–2016 in the original survey area (A) and the expanded survey area (B).

hatched a clutch) had disease compared to non-ovigerous females. These patterns likely reflect an interaction of increased intermolt duration and the accumulation of shell disease symptoms over time, as larger lobsters, particularly reproductive females, are more likely to have prolonged intermolt durations (Glenn and Pugh 2006).

Shell disease incidence was generally highest in the mid stratum, at the mouth of Buzzards Bay and at the mouth of Vineyard Sound from 2006–2010 (Figure 33). The expansion of the survey area starting in 2011 made it apparent that lobsters with disease were not necessarily concentrated around the end of the Elizabeth Island chain as earlier survey years suggested but were distributed throughout the mid and deep strata of the survey area. These were also the regions where the higher catch rates were observed (Figures 22 and 23). In most years only those sampling stations inside Buzzards Bay had catches with less than 5% of the lobsters having disease.

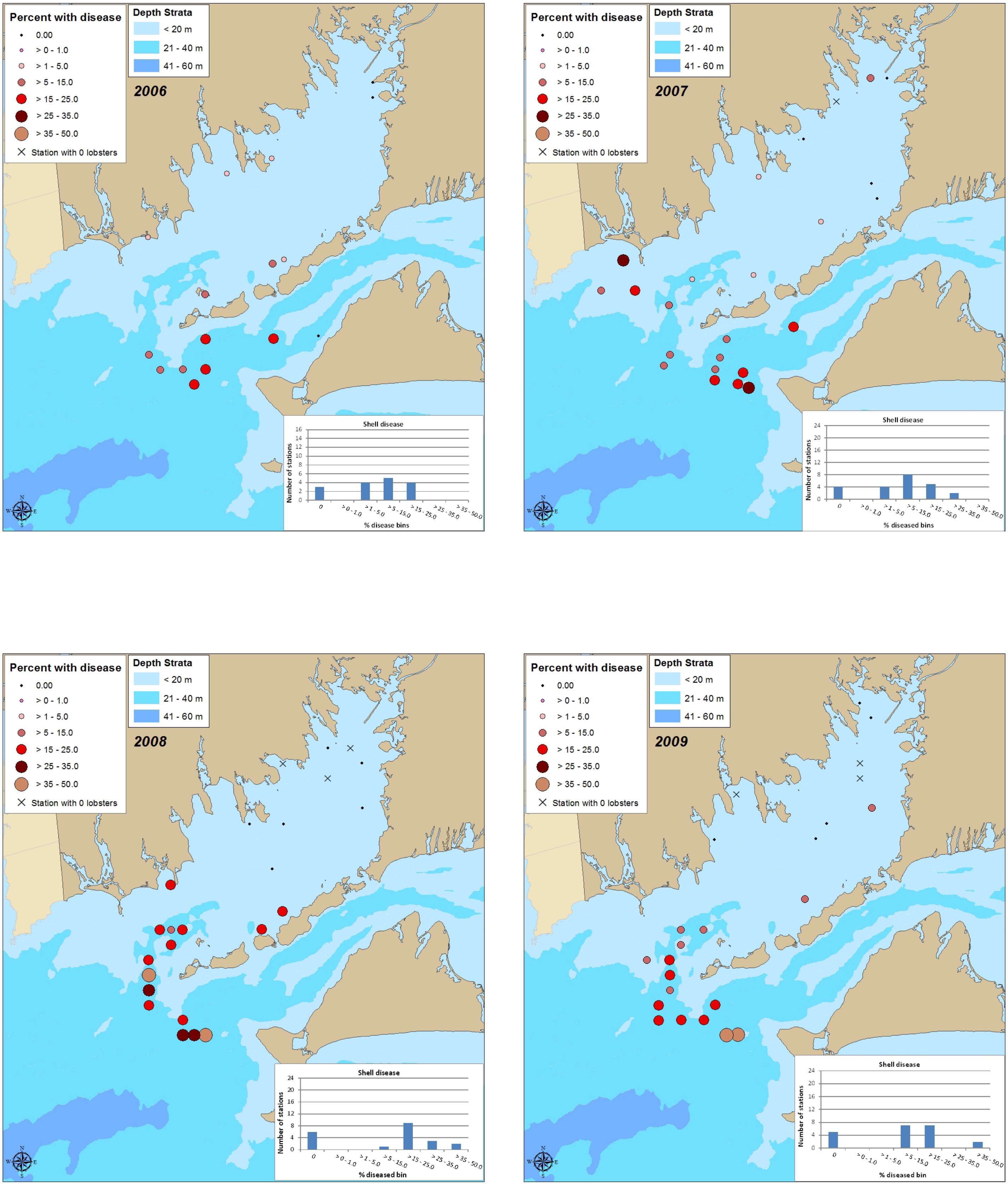


Figure 33. Percentage of the catch with shell disease at each sampling station, 2006–2009. Histogram shows the number of stations that fell within each disease percentile range.

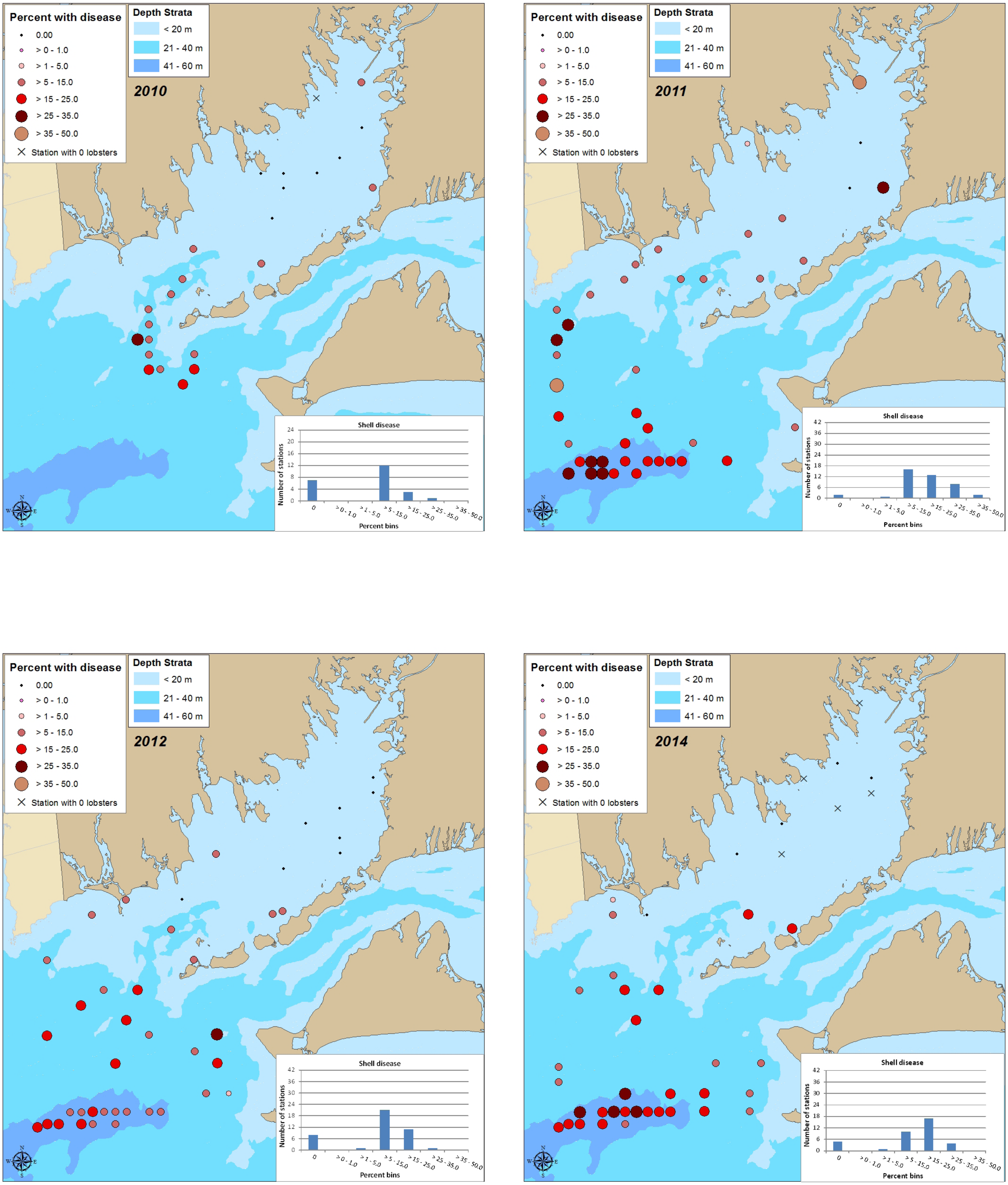


Figure 33 Continued. Percentage of the catch with shell disease at each sampling station, 2010–2014. No survey was conducted in 2013. Histogram shows the number of stations that fell within each disease percentile range.

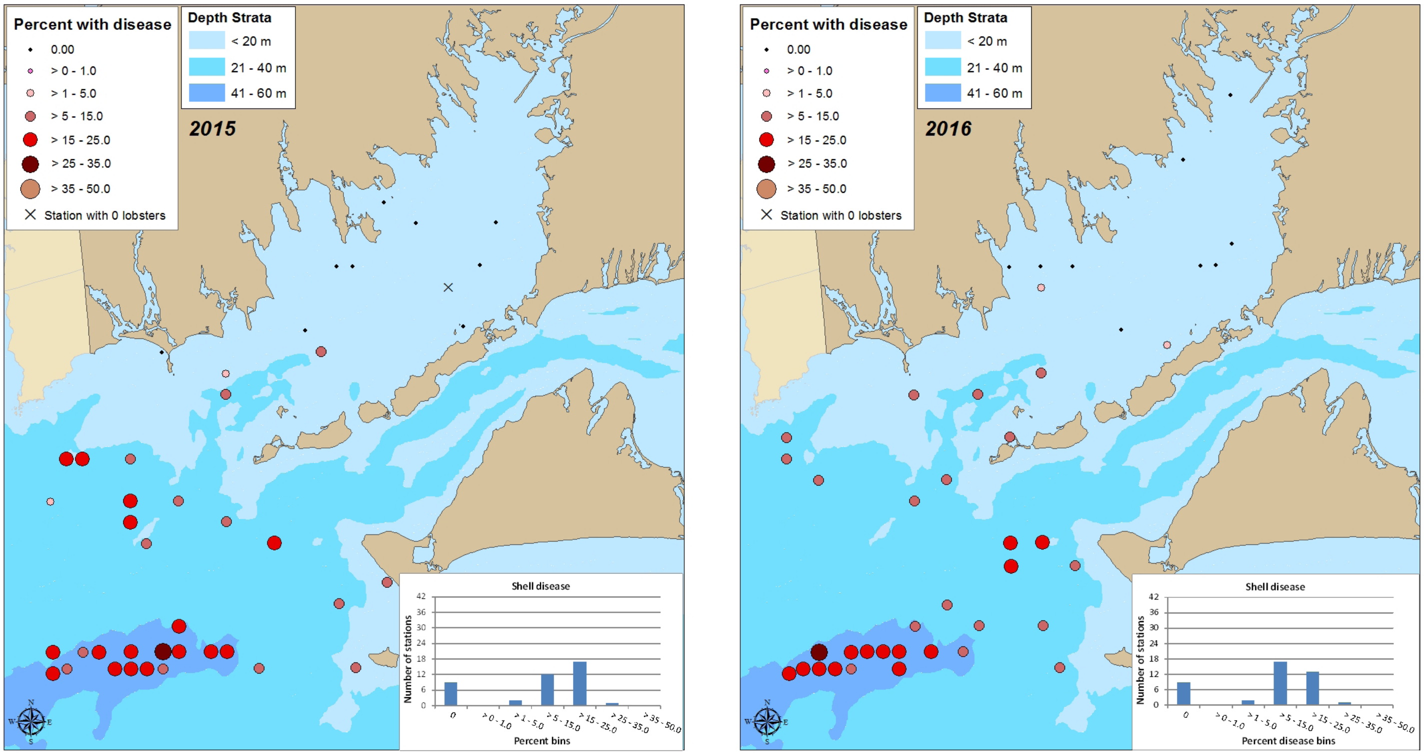


Figure 33 Continued. Percentage of the catch with shell disease at each sampling station, 2015 and 2016. Histogram shows the number of stations that fell within each disease percentile range.

Temperature Monitoring

Average daily bottom water temperatures in the GOM survey area were generally cooler in June than September in all depth strata, although the degree of change within a year varied by stratum and year (Figure 34). Temperature was much more variable within a sampling season in the shallow stratum than the other depth strata. The shallow stratum was also consistently warmer than the other two strata. Minimum daily averages for any survey season ranged from 5.4°C (in 2008) to 9.8°C (2006) and maximum daily averages ranging from 14.4°C (2007) to 19.0°C (2016) in the shallow stratum. Daily averages in the mid stratum ranged from a low of 4.9°C in 2008 to a high of 15.7°C in 2010. In the deep stratum the lowest daily average during any survey season was 4.1°C in 2007 and the highest was 10.4°C in 2016. Over the course of the entire time series, there were no days with a mean temperature ≥ 20°C, and only 1 day with a mean temperature ≥ 19°C (in 2016).

In the SNE survey area daily means in both the shallow and mid depth strata were above 10°C for the entire sampling season every survey year (Figure 35). The shallow stratum in the SNE survey area was much warmer than the same depth range in GOM, with minimum daily averages ranging from 13.8°C (in 2006) to 16.7°C (2010) and maximum daily averages ranging from 22.0°C (2007) to 24.4°C (2016). The mid stratum in SNE experienced minimum daily means from 11.0°C (2008) to 14.5°C (2012) and maximum daily means from 17.8 (2007) to 20.1°C (2010). In the two years for which there were data in the deep stratum, daily means within a survey year ranged from 11.5°C to 14.6°C (2012) and from 9.4°C to 15.9°C (2014). Daily average temperatures in the shallow stratum exceeded 19°C for more than 70% the survey season each year, and in the last three years 80-82% of the survey season was 19°C or warmer in the shallow stratum (Table 17). Temperatures have exceeded 20°C for more than 70% of the season since 2010. The 2016 survey season was the warmest season so far, with daily averages over 24°C in the shallow stratum for nine days in August. These data suggest that the shallow stratum in the SNE survey area is not desirable lobster habitat in terms of their thermal preferences (Crossin et al. 1998, Jury and Watson 2013), and many years had prolonged periods of time above physiologically stressful temperatures (Steenbergen et al. 1978, Powers et al. 2004, Dove et al. 2005).

Table 17. Percent of time (days) in each survey year for the SNE survey area when daily average bottom water temperatures in the shallow stratum (1 to 20 m) were above 19° C and 20° C. There were 92 survey days in 2006, and 122 days in all other years.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
19 degrees	79	70	75	**70**	81	77	80	ND	81	80	82
20 Degrees	54	50	66	**53**	61	73	70	ND	70	71	76

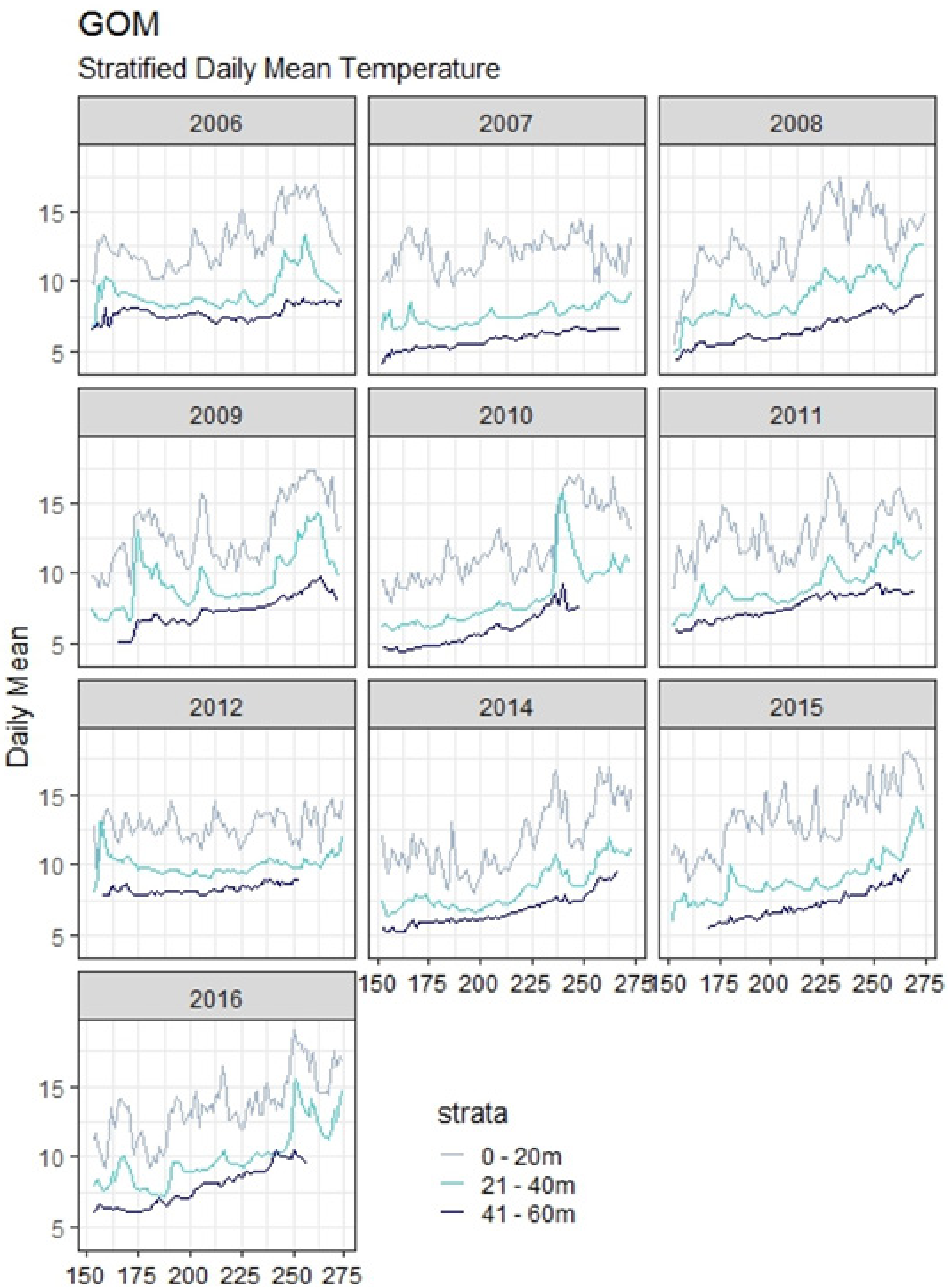


Figure 34. Mean daily temperature by depth strata in the GOM survey region for each survey year 2006–2016. Julian days 150 through 275: May 30 through Oct 2 (May 31 through Oct 3 for leap years 2008, 2010, 2016).

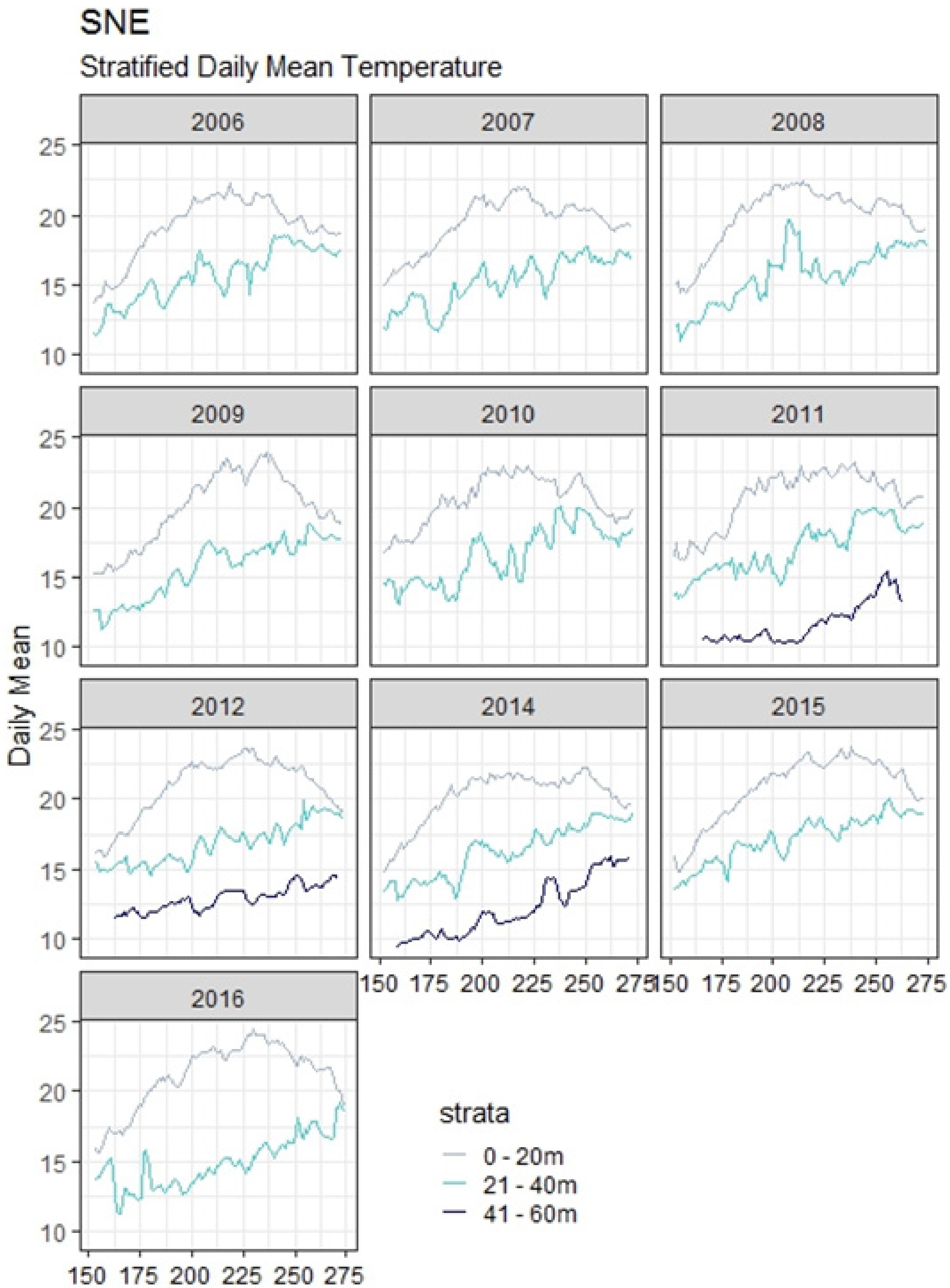


Figure 35. Mean daily temperature by depth strata in SNE survey region for each survey year 2006–2016. Julian days 150 through 275: May 30 through Oct 2 (May 31 through Oct 3 for leap years 2008, 2010, 2016).

Discussion

Population abundance and size composition

Most of the lobsters observed by the survey were sublegal-sized, in both GOM and SNE survey regions. Sublegal lobsters in the northern survey area (GOM) were nearly twice as abundant as in the SNE survey area after 2007 and experienced a clear increase over time (see Figures 5 and 19). Abundance of sublegal-sized lobsters in the original SNE area declined slightly over time and there was considerable variation from year to year. Abundance of legal-sized lobsters in GOM was also more than twice as high as legal-sized abundance in SNE in most years (see Figures 5 and 19). Both areas experienced an increase over time in legal-sized abundance, but it was slightly more pronounced in GOM than the SNE area (original SNE survey area) with the exception of 2016.

The data from the expanded SNE survey area suggested that the additional spatial coverage did allow the survey to overlap better with existing lobster distribution. Abundance indices (stratified mean CTH_6) for sublegal and legal-sized lobsters were higher in the expanded survey area than in the original survey area, and annual estimates of standard error were lower.

To compare the precision of the data from the GOM and SNE survey areas, annual coefficients of variation (CVs) were calculated for the stratified mean CTH_6 from each survey area and size class (Figure 36). Lower CVs indicate the estimate of the mean is more precise. The GOM survey for both sublegal and legal-sized lobsters showed relatively low and stable CVs over time. With the exception of 2014, CVs were lower in GOM than in the expanded SNE survey, and much lower than the CVs from the original SNE survey area which were very high with considerable interannual variation. The CVs from the expanded SNE survey area were much lower than those from the original SNE survey area, indicating that data from the expanded survey area were a better estimate of population size.

The spawning stock index in GOM was around two to four times higher than in the SNE expanded survey area (2011–2016), and from 10 to nearly 100 times higher than in the original SNE survey area (2006–2016). The spawning stock indices also followed diverging trends over the time series, increasing in GOM and decreasing in the original SNE survey area (see Figures 15 and 30). In both northern and southern survey areas the mean spawning stock CTH_6 was lowest in the shallow depth stratum, suggesting that ovigerous females

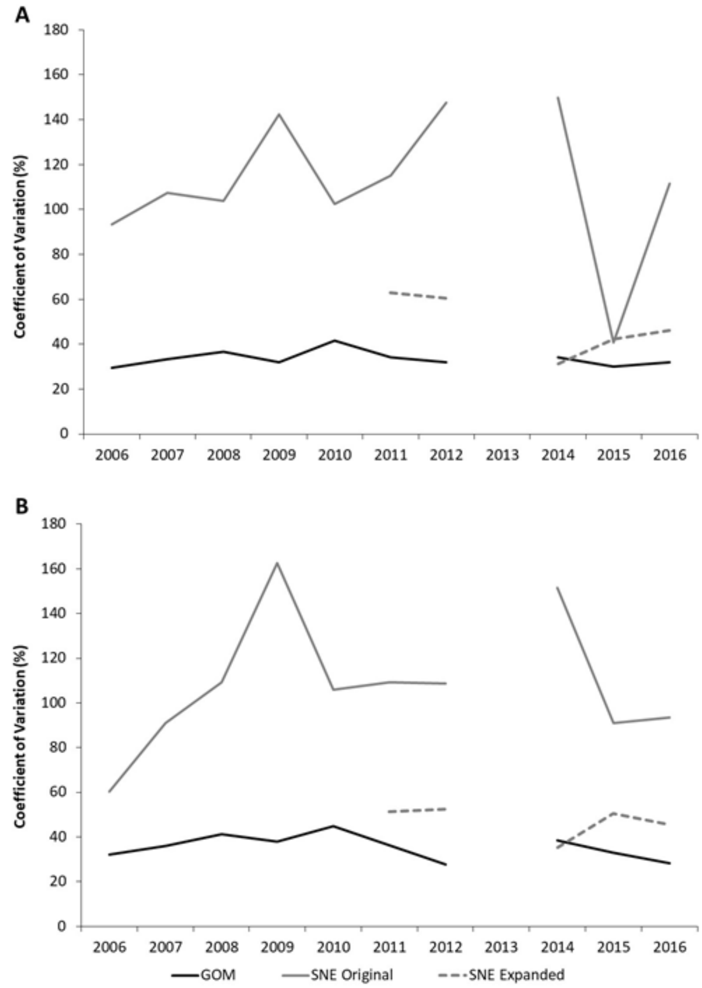


Figure 36. Annual coefficients of variation (CVs) for the sublegal-sized (A) and legal-sized (B) indices (stratified mean CTH6) of each survey.

may prefer deeper, cooler waters in which to release their larvae (Carloni and Watson 2018).

The truncated size distribution and consistently high proportion of the marketable catch within one molt increment of minimum legal size in both survey areas (GOM and SNE) indicate that the fisheries in both areas are heavily exploited and recruit-dependent. Only a relatively small proportion of lobsters make it past their first molt into the legal-size range, limiting additional opportunity for reproduction. Since reproductive output of both males and females increases with increasing size (Pugh et al. 2015, Estrella and Cadrin 1995), maintaining larger individuals in the population would likely benefit total egg production and population resiliency.

Legal-sized females have slightly higher survivability than males due to the differential protection received by ovigerous and v-notched females. In addition, as females reach sexual maturity, they tend to accumulate within certain size bins compared to males, as growth rates slow due to the onset of sexual maturity. This difference in growth rates in conjunction with differential protection may contribute to female-skewed sex ratios at larger sizes. Female-skewed sex ratios were slightly more common for legal-sized females in the SNE survey area than in GOM (see Figures 10 and 24 and Tables 5 and 13). More females are sexually mature in the SNE survey area by the time they reach minimum legal size (Estrella and McKiernan 1989), meaning a higher proportion of legal-sized females would be 'eligible' for this protection from harvest in the SNE area than in GOM. In GOM most females enter the fishery before they are capable of reproducing, due to the larger size at maturity, meaning they experience similar exploitation rates as males for their first molt increment into the legal-size range. However, there is evidence to suggest that size at maturity has decreased in GOM (Pugh et al. 2013, Waller et al. 2019), which should increase the proportion of legal-sized females protected from harvest due to egg-bearing status. Mandatory v-notching in GOM also ensures that mature females have additional opportunities to produce eggs, especially if fishermen are v-notching sublegal ovigerous females (so they will molt into the legal-size range already protected).

It is important to note that the 2006 survey season was shorter and had fewer sampling stations in both survey areas than the other survey years (see Survey Design Section). These differences may complicate comparisons between data from 2006 and the rest of the time series. The seasonal time period over which a survey is conducted can affect the catch results due to changing water temperatures and habitat conditions (Tremblay and Smith 2001, Smith and Tremblay 2003, Jury and Watson 2013, Watson and Jury 2013). Previous analyses of ventless trap survey data indicated that the expansion of the survey to a four-month period allowed us to capture additional information regarding catch rates, ovigerous females (related to the timing of egg extrusion and distribution of females), and shell disease (DMF unpublished data).

Depth, Temperature, and Lobster Demographics

There were patterns in lobster catch and size distribution related to depth in both survey areas. These patterns were likely related to ontogenetic changes in movements expressed by lobsters and to the temperature regime experienced in each depth stratum.

Postlarval lobsters typically settle to the bottom in shallow inshore waters and spend the early part of their life span restricted to shelters to avoid predation (Wahle and Steneck 1991, 1992). As lobsters grow, they move progressively further from their shelter while foraging. Only at adult stages do movements become more extensive, although some lobsters appear to remain 'resident' most of their lifetimes (see Karnofsky et al. 1989, Lawton and Lavalli 1995, Bowlby et al. 2007). Based on these ontogenetic changes in mobility, we expected to see smaller lobsters in the shallow stratum of our survey area.

In GOM, the shallow stratum had the highest CTH_6 of sublegal lobsters, and the smallest size distribution of lobsters, which fit our expectations. Additionally, the water temperatures in the shallow stratum of GOM provided a nearly ideal thermal habitat for lobsters (see Crossin et al. 1998, Jury and Watson 2013), ranging from 10°C to 16°C. Temperatures above 10°C stimulate the molting process (Waddy et al. 1995), elicit higher activity levels (McLeese and Wilder 1958), and generally are conducive to growth and reproductive processes. The shallow stratum in the GOM survey area would have provided a better thermal environment than either the mid or deep stratum, which in most years had average temperatures below 10°C for much of the study time period.

The strata-specific CTH_6 in the SNE survey area displayed a different pattern in relation to depth, with higher CTH_6 of both legal and sublegal lobsters in the mid depth stratum. However, size distribution comparisons showed that the shallow stratum was composed of smaller lobsters than the mid stratum. The difference in the depth-related CTH_6 patterns between the SNE survey area and GOM is most likely related to temperature. The shallow stratum in the SNE area is extremely warm in relation to the thermal preferences exhibited by lobsters (see Crossin et al 1998, Jury and Watson 2013). Temperatures in the shallow stratum averaged above 20°C for more than a half of the survey period each year (≥ 70% of the survey period since 2010), and ≥ 19°C for 70% of the survey time period in all years. Temperatures above 20°C are considered stressful and have been linked to increased disease incidence and compromised immune systems (Stewart et al. 1969, Powers et al. 2004, Dove et al. 2004, Dove et al. 2005, Glenn and Pugh 2006), and lobsters will actively avoid waters warmer than 19°C (Crossin et al. 1998). While these shallow inshore areas may remain viable settlement habitat due to the availability of shallow complex bottom, the currently unsuitable thermal regime may cause increased rates of natural mortality in younger shelter-restricted lobsters, and likely drive emigration to deeper, cooler waters in those lobsters without predation pressures restricting their movement.

Differences in size at maturity between the two survey areas may also explain the variations in catch relative to depth. Lobsters reach sexual maturity at smaller sizes in warmer waters, and Estrella and McKiernan (1989) showed that 50% of lobsters in Buzzards Bay (SNE survey area) were mature by 76 mm, compared to 87 mm in Cape Cod Bay and Boston Harbor (GOM). Smaller size at maturity means that the movement patterns exhibited by mature adult lobsters would manifest at smaller sizes in the SNE survey area than in the cooler GOM, causing lobsters to move away from shallow inshore waters earlier in life.

Temperatures may also influence the sex ratio of lobsters in a particular location. Generally, the deeper strata in GOM tended to be female-skewed, particularly since 2012. In the SNE area, this pattern of female-skew in deeper waters was more evident, and the shallow stratum was typically male-skewed. More detailed spatial dynamics were evident when examining sampling station-specific sex ratios, which tended to be more male-skewed in shallower, warmer areas or areas that were less exposed to open waters. This was evident in GOM at stations in Cape Cod Bay and Boston Harbor, and was particularly apparent in the SNE area where most stations inside Buzzards Bay were male-skewed.

Percentages can be slightly misleading where catch rates were very low, as they were in the shallow stratum of the SNE area. For example, the five highly male-skewed SNE stations in 2007 were stations with average catch rates of less than one sublegal lobster per trap haul, and less than 0.25 legal-sized lobsters per trap haul. However, when coupled with abundance estimates and environmental information, sex ratios are extremely useful for describing lobster population demographics. For example, while the abundance estimates suggest that very few lobsters utilize the interior of Buzzards Bay (Figures 22 and 23), those few that do are likely to be males. This supports previous literature stating that male lobsters tend to be more tolerant of environmental extremes (Howell et al 1999, Watson et al 1999, Jury and Watson 2013), as the shallow interior of Buzzards Bay regularly exceeds 20°C during the summer months (see Temperature Monitoring Section), temperatures considered to be physiologically stressful for lobsters (Dove et al. 2005, Steenbergen et al 1978).

The physiological demands of reproductive females may determine differences in thermal preferences between males and females. Ovigerous females appear to move between different depths in order to manage embryonic development (Campbell 1986, Cowan et al. 2007, Goldstein and Watson 2015), which is highly dependent on temperature (see Talbot and Helluy 1995). Larger ovigerous females have been shown to make seasonal movements that tend to stabilize the temperature regime to which their clutch is exposed, while smaller ovigerous females that do not make these movements experience more variation in temperature over the brooding period (Cowan et al. 2007). These movement patterns would tend to place larger mature females in the deeper waters, which are more stable due to decreased influence of winds and tides. Additionally, the movements of mature non-ovigerous females may be related to thermal demands of ovary maturation and spawning, which require exposures to both low and high temperatures (Waddy et al. 1995).

If thermal habitat is the primary environmental variable behind lobster distribution, it is possible that the warming trend in Southern New England waters is causing a contraction of available lobster habitat, which could have consequences to the population and the fishery. A contraction in available habitat would result in a decrease in environmental carrying capacity, and issues such as crowding and other negative density-dependent effects may impact life history parameters such as growth rates and natural mortality. Additionally, if habitat becomes patchy and fragmented due to suboptimal temperatures, isolated pockets of lobsters become particularly vulnerable to exploitation, and Allee effects may cause decreases in individual and population-level fitness (Stephens et al. 1999, Robertson and Butler 2009). This change in the distribution and availability of habitat and environmental carrying capacity will need to be addressed when determining the path forward for SNE lobster management.

Shell Disease

Shell disease has been a concern for the fishery for nearly two decades now. It is far more prevalent in the SNE survey area than in GOM, although it is important to note that disease prevalence has increased in GOM over the latter part of the time series. While there was a large difference in the percentage of the population affected by disease, patterns in the demographics of the lobsters affected were similar between the two survey areas. Larger lobsters, and particularly ovigerous females, are much more likely to have shell disease than smaller lobsters or males. The observed trends in shell disease prevalence are likely related to the intermolt duration of various sizes and life history stages of lobsters (Glenn and Pugh 2006). Molt frequency declines as lobsters reach sexual maturity (reviewed in Waddy et al. 1995). This is particularly true for female lobsters, who may spawn a year or more after mating and then carry the eggs for another 9-11 months, making their intermolt duration upwards of at least two years. Shell disease symptoms accumulate on the shell of the lobster over time, so the longer the time period between molts, the longer the available time for disease to manifest and progress. Evidence suggests that disease prevalence is related to prolonged periods of stressful temperature conditions and is likely one of a number of health problems resulting from this stress (Glenn and Pugh 2006, Shields 2013). Temperature also impacts biological processes like growth rates and sexual maturation, which will also influence the north-south gradient of increasing disease prevalence observed in our survey data and in other monitoring programs (Glenn and Pugh 2006, Castro and Somers 2012).

The spatial data show that diseased lobsters were caught in deeper waters, which was generally true in both survey areas. This seems somewhat contradictory to the hypothesis that disease incidence is related to warmer water temperatures. However, it is unclear how and when shell disease is acquired, and the distribution of diseased lobsters may either be a result of having disease or may just be reflective of which component of the population is more susceptible. It is possible that lobsters with shell disease seek out cooler deeper water to ameliorate the spread or secondary symptoms of disease by slowing their metabolism or possibly slowing the growth rate of the associated bacteria. It is also possible that the pattern in spatial distribution of diseased lobsters is due to the tendency for larger, mature lobsters (especially females) to utilize the deeper habitats, and that these are also the lobsters that happen to be more susceptible to disease. Controlled experiments are necessary to clarify the effects of shell disease on lobster behavior, including movement and habitat preferences.

Disease rates observed in the ventless trap surveys are generally less than rates observed in commercial trap monitoring programs. This difference appears to be related to the inherent biases associated with fishery-dependent sampling, namely that commercial fishermen target concentrations of large lobsters, which happen to be the component of the lobster population more likely to exhibit disease symptoms. The ventless trap survey, as a fishery-independent survey, likely provides a better population-level picture of shell disease prevalence and allows for tracking disease prevalence over a broader size range of lobsters.

Conclusion

The random stratified sampling design of the coastwide ventless trap survey provides estimates of lobster relative abundance that cannot be obtained from standard at-sea commercial trap sampling. The differences in CTH_6 by depth indicate that stratification by depth likely provides more accurate estimates of abundance by reducing variation that would be associated with this habitat characteristic in a simple random sampling design (see Levy and Lemeshow 2008). The time series of relative abundance for sublegal and legal lobsters has been incorporated into the stock assessment process as an additional index of abundance, complementing the existing trawl survey data (ASMFC 2015). The major benefits of this ventless trap survey in comparison to existing trawl surveys are a lobster-specific sampling gear that can be deployed on all bottom types, and that this survey design and methodology are standardized across most of the range of the inshore US fishery (ASMFC 2015).

Examination of our catch data by depth strata and by geographic location has provided information on lobster life history and demographic patterns that is otherwise difficult to obtain at this scale. The survey demonstrates that specific demographics (sex, size class, maturity status) within the lobster population are not distributed randomly. It has provided evidence that lobster distribution and abundance may be related to preferred thermal habitats, which vary based on depth and geographic location.

The depth strata used in this survey design do not represent similar thermal habitats over the entire geographic range of the Coastwide Ventless Trap Survey (Maine through Rhode Island). The differences between the shallow stratum north (GOM) versus south (SNE survey area) of Cape Cod, MA illustrate this clearly. Thus, for stock assessment purposes the abundance indices generated by this survey (and surveys conducted by the other states) should be treated separately based on some latitudinal gradient, such as NMFS statistical area, in order to appropriately account for the latitudinal differences in environmental conditions of the survey strata.

Acknowledgements

This survey is made possible by all of the participating industry members and DMF staff members who have completed the field work over the years. We would like to thank the captains and crews of the following vessels: F/V Andrea C (Cebula), F/V Julia H (Kelley), F/V Peter & James (Kandrick), F/V Sherri & Deke (DeCosta), F/V Cynthia Lee (Drake), F/V Sea Blitz (Cebula), F/V Susan T (Barrett), F/V Victoria Rose (Holtgrefe), F/V Stanley Thomas (Ring), F/V Finest Kind (Ryan), F/V Miss Carla (Sawyer), F/V Jill & Jennifer (Kelley), F/V A Touch of Grey and F/V International Harvester (Michaud), F/V Voyager (Jesse), F/V Karen M (O'Reilly), F/V Jeanne (Bartlett), F/V Mark Benjamen (Wheldon), F/V Finest Kind (DeCoste), F/V Sixpence and F/V Curmudgeon (Penney), F/V Blondie (Bleakley), F/V Goose (Emond),and F/V Divergence (Krussell). Thank you to DMF staff members (past and present) that have conducted the at-sea sampling for the survey: B. Basinski, S. Buso, J. Carr, L. Derleth, W. Helt, E. Morrissey, D. Perry, D. Scarpitti, M. Trainor, S. Voss, K. Whitmore, and S. Wilcox. M. Trainor assisted with the temperature data compilation and graphics, and E. Morrissey assisted with numerous graphics. Funding sources for the survey varied considerably in the early years, and came from: Atlantic States Marine Fisheries Commission's Atlantic Coastal Fisheries Management Act grants, Commercial Fisheries Research Foundation's Southern New England Cooperative Research Initiative, NOAA's Unallied Science grant, and mitigation monies from the Northeast Gateway and Neptune LNG projects. Starting in 2014, the survey has been funded by a portion of lobster permit fees (both commercial and recreational permits), and we are extremely grateful for the continued support for this survey by industry members. We would additionally like to thank Massachusetts Lobstermen's Association Executive Director Beth Casoni for her work advocating for dedicated funding to continue the survey.

Literature Cited

Atlantic States Marine Fisheries Commission (ASMFC). 2015. American lobster stock assessment for peer review report. 438 pp.

Bowlby, H. D., J. M. Hanson, and J. A. Hutchings. 2007. Resident and dispersal behavior among individuals within a population of American lobster Homarus americanus. Marine Ecology Progress Series, 331: 207–218.

Campbell A. and A. B. Stasko. 1985. Movements of tagged American lobsters, Homarus americanus, off Southwestern Nova Scotia. Canadian Journal of Fisheries and Aquatic Sciences 42: 229–238.

Campbell A. and A. B. Stasko. 1986. Movements of lobsters (*Homarus americanus*) tagged in the Bay of Fundy, Canada. Marine Biology 92:393–404.

Carloni, J. T., and W. H. Watson III. 2018. Distribution of ovigerous American lobsters near the Isles of Shoals, New Hampshire. Bulletin of Marine Science, 94: 555–570.

Cowan, D. F., W. H. Watson III, A. R. Solow, and A. M. Mountcastle. 2007. Thermal histories of brooding lobsters, Homarus americanus, in the Gulf of Maine. Marine Biology, 150: 463–470.

Crossin, G. T., S. A. Al-Ayoub, S. H. Jury, W. H. Howell, and W. H. Watson III. 1998. Behavioral thermoregulation in the American lobster *Homarus americanus*. Journal of Experimental Biology 201: 365–374.

Dove, A. D. M., B. Allam, J. J. Powers, and M. S. Sokolowski. 2005. A prolonged thermal stress experiment on the American lobster, Homarus americanus. Journal of Shellfish Research, 24: 761–765.

Dove, A. D. M., C. LoBue, P. Bowser, M. Powell. 2004. Excretory calcinosis: a new fatal disease of wild American lobsters Homarus americanus. Diseases of Aquatic Organisms, 58: 215–221.

Ennis, G. P. 1984. Small-scale seasonal movements of the American lobster, *Homarus americanus*. Transactions of the American Fisheries Society 113: 336–338.

Estrella, B. T. and D. J. McKiernan. 1989. Catch-per-unit-effort and biological parameters from the Massachusetts coastal lobster (*Homarus americanus*) resource: description and trends. NOAA Technical Report NMFS 81, 21 pp.

Estrella, B. T., and S. X. Cadrin. 1995. Fecundity of the American lobster (*Homarus americanus*) in Massachusetts coastal waters. ICES Marine Science Symposium, 199: 61–72.

Glenn, R. P. and T. L. Pugh. 2006. Epizootic shell disease in American lobster (*Homarus americanus*) in Massachusetts coastal waters: interactions of temperature, maturity, and intermolt duration. Journal of Crustacean Biology, 26: 639–645.

Goldstein, J. S. and W. H. Watson III. 2015. Influence of natural inshore and offshore thermal regimes on egg development and time of hatch in hatch in American lobsters, *Homarus americanus*. Biological Bulletin, 228: 1–12.

Howell, W. H., W. H. Watson III, and S. H. Jury. 1999. Skewed sex ratio in an estuarine lobster (*Homarus americanus*) population. Journal of Shellfish Research, 18: 193–201.

Jury, S. H. and W. H. Watson III. 2013. Seasonal and sexual differences in the thermal preferences and movements of American lobsters. Canadian Journal of Fisheries and Aquatic Sciences, 70: 1650–1657.

Karnofsky, E. B., J. Atema, and R. H. Elgin. 1989. Natural dynamics of population structure and habitat use of the lobster, *Homarus americanus*, in a shallow cove. Biological Bulletin, 176: 247–256.

Krouse, J. S. 1977. Completion report, lobster tagging project #3-228- R, Oct. 1974 through Sept. 1977. NOAA, NMFS, Commercial Fisheries Research and Development Act 28 pp.

Lawton, P. and K. L. Lavalli. 1995. Postlarval, juvenile, adolescent, and adult ecology. In: Biology of the Lobster (*Homarus americanus*). J. R. Factor, ed. Academic Press, San Diego. Pp 47–88.

Levy, P. S. and S. Lemeshow. 2008. Sampling of Populations: Methods and Applications. John Wiley and Sons, Inc. Hoboken, New Jersey. 576 pp.

MacDonald, C., M. J. Tremblay, and D. Pezzack. 2001. A lobster recruitment index from standard traps. Canadian Technical Report Fisheries and Aquatic Science, 2328. pp 98–100.

McLeese, D. W. and D. G. Wilder. 1958. The activity and catchability of the lobster (*Homarus americanus*) in relation to temperature. Journal of the Fisheries Research Board of Canada, 15: 1345–1354.

Nelson, G. A. 2014. Cluster sampling: a pervasive, yet little recognizes survey design in fish eries research. Transactions of the American Fisheries Society, 143: 926–938.

Nelson, G. A. 2017 fishmethods: Fishery science methods and models in R. R package version 1.10–4. https://CRAN.R-project.org/package=fishmethods

Powers, J., G. Lopez, R. Cerrato, and A. Dove. 2004. Effects of thermal stress on Long Island Sound lobsters, *Homarus americanus*. Proceedings of Sea Grant Long Island Sound Lobster Health Symposium, University of Connecticut, Avery Point, Groton Connecticut, May 2004.

Pugh, T. L., J. S. Goldstein, K. L. Lavalli, M. Clancy, and W. H. Watson III. 2013. At-sea determination of female American lobster (*Homarus americanus*) mating activity: patterns vs. expectations. Fisheries Research, 147: 327–337.

Pugh, T. L., M. Comeau, K. Benhalima, and W. H. Watson III. 2015. Variation in the size and composition of ejaculates produced by male American lobsters, *Homarus americanus* H. Milne Edwards, 1837 (Decapoda: Nephropidae). Journal of Crustacean Biology, 35: 593–604.

Pugh, T.L. and R. P. Glenn. In prep. Demographic patterns of American lobsters (*Homarus americanus*) in Massachusetts Bay as documented by a ventless lobster trap survey.

R Core Team. 2016. R: A language and environments for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Robertson, D. N. and M. J. Butler IV. 2009. Variable reproductive success in fragmented populations. Journal of Experimental Marine Biology and Ecology, 377: 84–92.

Smith, S. J. and M. J. Tremblay. 2003. Fishery-independent trap surveys of lobsters (*Homarus americanus*): design considerations. Fisheries Research, 62: 65–75.

Steenbergen, J. F., S. M. Steenbergen, and H. C. Schapiro. 1978. Effects of temperature on phagocytosis in *Homarus americanus*. Aquaculture, 14: 23–30.

Steneck, R. S. 2006. Possible demographic consequences of intraspecific shelter competition among American lobster. Journal of Crustacean Biology, 26: 628–638.

Stephens, P. A., W. J. Sutherland, and R. P. Freckleton. 1999. What is the Allee effect? Oikos, 87: 185–190.

Stewart, J., J. Cornick, and B. Zwicker. 1969. Influence of temperature on gaffkemia, a bacterial disease of the lobster *Homarus americanus*. Journal of the Fisheries Research Board of Canada, 26: 2503–2510.

Talbot, P. and S. Helluy. 1995. Reproduction and embryonic development. In: Biology of the Lobster (*Homarus americanus*). J. R. Factor, ed. Academic Press, San Diego. Pp. 177–216.

Tremblay, M. J. and S. J. Smith. 2001. Lobster (*Homarus americanus*) catchability in different habitats in late spring and early fall. Marine and Freshwater Research, 52: 1321–1331.

Tremblay, M. J., C. MacDonald, R. R. Claytor. 2009. Indicators of abundance and spatial distribution of lobsters (*Homarus americanus*) from standard traps. New Zealand Journal of Marine and Freshwater Research, 43: 387–399.

Waddy, S. L. and D. E. Aiken. 1995. Temperature regulation of reproduction in female American lobsters (*Homarus americanus*). ICES Marine Science Symposium, 199: 54–60.

Waddy, S. L., D. E. Aiken, and D. P. V. de Kleijn. 1995. Control of Growth and Reproduction. Pp 217–266 in: J. R. Factor, ed. Biology of the Lobster *Homarus americanus*. Academic Press, San Diego, California.

Wahle, R.A. and R.S. Steneck, 1991. Recruitment habitats and nursery grounds of the American lobster (*Homarus americanus* Milne Edwards): a demographic bottleneck?, Marine Ecology Progress Series, 69: 231–243.

Wahle, R. A. and R. S. Steneck. 1992. Habitat restrictions in early benthic life: experiments on habitat selection and in situ predation with the American lobster. Journal of Experimental Marine Biology and Ecology 157: 91–114.

Waller, J. D., Reardon, K. M., Caron, S. E., Masters, H. M., Summers, E. L., & Wilson, C. J. 2019. Decrease in size at maturity of female American lobsters *Homarus americanus* (H. Milne Edwards, 1837)(Decapoda: Astacidea: Nephropidae) over a 50-year period in Maine, USA. Journal of Crustacean Biology, 39: 509–515.

Watson, W. H. III, W. H. Howell, and A. Vetrovs. Lobster movements in an estuary. Marine Biology, 134: 65–75.

Watson, W. H. III, and S. H. Jury. 2013. The relation ship between American lobster catch, entry rate into traps and density. Marine Biology Research, 9: 59–68.