Atlantic States Marine Fisheries Commission

American Lobster Benchmark Stock Assessment and Peer Review Report

Accepted for Management Use
August 2015

Vision: Sustainably Managing Atlantic Coastal Fisheries

Overview

The 2015 American Lobster Benchmark Stock Assessment occurred through an Atlantic States Marine Fisheries Commission (ASMFC) external peer review process. ASMFC organized and held a Data Workshop on November 19-21, 2013 and three subsequent Assessment Workshops on September 22-25, 2014, February 10-12, 2015, and April 29-May 1, 2015. Participants of the Data and Assessment Workshops included the ASMFC American Lobster Stock Assessment Subcommittee and Technical Committee. ASMFC coordinated a Peer Review Workshop for the American Lobster Assessment on June 8-11, 2015. Participants included members of the American Lobster Assessment Subcommittee and a Review Panel consisting of three reviewers appointed by ASMFC.

American Lobster Stock Assessment Peer Review Report (PDF Pages 3-30)
The Peer Review Report provides a detailed evaluation of how each Term of Reference was addressed by the Stock Assessment Subcommittee, including the Panel's findings on stock status and future research recommendations.

American Lobster Stock Assessment Report for Peer Review (PDF Pages 31-493)
This report describes the background information on data used, and analysis for the assessment submitted by the Stock Assessment Subcommittee to the Review Panel.

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American Lobster Stock Assessment Peer Review Report

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Vision: Sustainably Managing Atlantic Coastal Fisheries

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American Lobster Stock Assessment Peer Review Report

Conducted on
June 8-11, 2015
Woods Hole, MA

Prepared by the
ASMFC American Lobster Stock Assessment Review Panel

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Preface

Summary of the ASMFC Stock Assessment Review Process

The Stock Assessment Peer Review Process, adopted in October 1998 and revised in 2005 by the Atlantic States Marine Fisheries Commission (ASMFC or Commission), was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure stock assessments for all species managed by the Commission periodically undergo a formal independent review; (2) maintain the quality of Commission stock assessments; (3) ensure the credibility of the scientific basis for management; and (4) provide the public with a clear understanding of the stock assessment process and results. The Commission stock assessment review process includes an evaluation of input data, model development, model assumptions, scientific advice, and a review of broad scientific issues, where appropriate.

The Commission's *Benchmark Stock Assessment Framework* outlines options for conducting an independent review of stock assessments. These options are:

1. The stock assessment review process conducted by the Atlantic States Marine Fisheries Commission.
2. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).
3. The Southeast Data and Assessment Review (SEDAR) conducted by the National Marine Fisheries Service, Southeast Fisheries Science Center (SEFSC).

Twice annually, the Commission's Interstate Fisheries Management Program (ISFMP) Policy Board prioritizes stock assessments for all Commission managed species based on species management board advice and other prioritization criteria. The species with highest priority are assigned to a review process to be conducted in a timely manner.

In June 2015, the Commission convened a Stock Assessment Review Panel comprised of scientists with expertise in stock assessment methods, length-based modeling, commercial fisheries sampling and fishery-independent surveys, and lobster life history and ecology. The review of the American lobster stock assessment was conducted at the Northeast Fisheries Science Center in Woods Hole from June 8-11, 2015. Prior to the Review Workshop meeting, the Commission provided Review Panel members with the draft 2015 Lobster Stock Assessment Report.

The review process consisted of presentations by topic – data inputs, life history analyses, model results, reference points, and stock status – of the completed 2015 stock assessment. Each presentation was followed by general questions from the Review Panel. The Panel then held a closed-door session during which the documents and presentations were discussed and a review report prepared. The report is structured to closely follow the terms of reference provided to the Panel.

Acknowledgements

The Review Panel thanks the members of the American Lobster Stock Assessment Subcommittee and Technical Committee, as well as staff of the Atlantic States Marine Fisheries Commission, particularly Patrick Campfield and Megan Ware, for support during the review process.

Executive Summary

The Review Panel met in Woods Hole, MA, from June 8-11, 2015. Prior to the review workshop, Panel members read the stock assessment report and other relevant documents provided by the American Lobster (*Homarus americanus*) Stock Assessment Subcommittee (SASC). This report reviews the components of the stock assessment. Data collection, standardization of indices, trend analyses, and stock assessment models were undertaken by the SASC, and uncertainties quantified. **The Panel commends the SASC on the comprehensive approach taken and points out places for improvement in the sections that follow.**

The Review Panel concurs with the SASC conclusions, that the Southern New England (SNE) stock is severely depleted and in need of protection, while the Gulf of Maine (GOM) and Georges Bank (GB) stocks show record abundance. The Panel also agrees that there is evidence for significant migration between the Gulf of Maine and Georges Bank and these two biological stocks should be combined in model runs.

The Panel agrees with the SASC that the University of Maine statistical catch-at-length model and the suite of data-driven stock indicators are appropriate tools for accurately characterizing the status of lobster stocks and fisheries.

Model results of the UMM model show that the combined Gulf of Maine-George's Bank (GOM/GBK) stock is neither overfished nor undergoing overfishing. The recommended model runs of the UMM model result in increasing reference abundance levels in the GOM/GBK and decreasing effective exploitation until the mid-1990s then stabilizing with higher exploitation on males.

Reference abundance in the SNE stock increased from the early 1980s, peaked during the late 1990s, then declined steeply through the early 2000s to a record low level in 2013. Closer scrutiny reveals the inshore portion of the SNE stock has clearly collapsed. The SNE stock is clearly overfished according to both the model and the stock indicators. Fishing mortality does not appear to be extremely high and this supports the conclusion that biological factors have contributed to bringing the stock to this point. It is believed the offshore area of SNE depends on nearshore settlement as the source of recruits. Therefore, the offshore is also in jeopardy and the Technical Committee and Review Panel believe the stock has little chance of recovering unless fishing effort is curtailed. To be specific, according to the reference point defined by the time series of model outputs, the exploitation rate for the entire SNE stock does not lie in the overfishing zone; however, the definition was created without considering the possibility that the stock could be at the lowest abundance level ever and the production of recruits in the inshore area (on which the offshore area depends) could be brought to an extremely low level. It is noted that pre-recruits are not measured in the offshore surveys, so the effects of recruitment failure in the inshore would not be seen in the offshore until years later when the lobsters become available to the fishery and surveys. Hence, by any reasonable standard, it is necessary to protect the offshore component of the stock until increased recruitment can be observed.

Thus, although the UMM model indicates the Southern New England (SNE) stock is not undergoing overfishing, the SASC and Review Panel believe this is an extremely misleading result. Current methods for defining the overfishing level of fishing mortality are not designed for this kind of situation.

For SNE, the Panel recommends close monitoring of the stock to try to save it. Stock indicators should be updated annually and reported to the Management Board for appropriate action. For GOM/GBK, given the good condition of the stock, a five-year interval may be appropriate for a benchmark assessment. However, the stock indicators should be updated more frequently to detect signs of changing recruitment or other conditions.

Introduction

American lobster (*Homarus americanus*) is a bottom-dwelling crustacean found along the continental shelf of north eastern North America. In U.S. waters, the species is most abundant in inshore waters from Maine through New Jersey and in offshore waters from Maine to North Carolina. The species also has significant abundance in the Canadian Maritimes. Abundance declines from north to south.

American lobsters periodically shed their shell to grow in a process known as molting. Females must balance growth with reproduction as they do not molt while brooding eggs. Males deposit sperm in females who store the contribution internally until extrusion. Once extruded, eggs are fertilized and attached to the underside of the lobster. After being carried for 9 to 11 months, the eggs hatch and the new lobsters enter a larval stage. Once lobsters reach their fifth stage, the juveniles sink to the ocean floor where they remain.

Habitat has considerable impacts on the life history of lobsters. Temperature is the primary driving force as it influences a lobster's metabolism, spawning, development, and growth. The ideal temperature range for lobsters is 12-18 ^{o}C and the hatching of eggs typically occurs when surface water temperatures are above 12 ^{o}C.

Since the American lobster is highly influenced by temperature, climate change is expected to significantly impact the life history and distribution of the species. In the lobster's southern range, the number of days above 20 ^{o}C is increasing, threatening successful reproduction. Contrastingly, in the Gulf of Maine, the number of days in the ideal range of 12-18 ^{o}C is increasing, providing a potential benefit to the species. Climate changes are important to monitor and provide a strong justification for the timing of this benchmark stock assessment.

A review of the recent history of the lobster fishery shows a significant expansion in effort since the late 1940s when landings were around 25 million pounds. Over the past two decades landings rose to 150 million pounds in 2012 and 2013. While most of the landings are from the Gulf of Maine, the Southern New England stock, in contrast, has seen a sharp decline in its population since the late 1990s (ASMFC American Lobster Stock Assessment 2009). There are indications that the decline in SNE is due to climate change and diseases resulting in poor recruitment. Because of the importance of climate and climate-related ecological effects, the Stock Assessment Subcommittee (SASC) devoted considerable effort to exploring the implications of climate change on stock status.

This report reviews components of the stock assessment of American lobster conducted by the SASC. Data collection, standardization of indices, trend analyses, and stock assessment models were undertaken by the SASC, and uncertainties quantified. A notable feature of the assessment is the examination of stock structure with the resultant recommendation that the GOM and GBK units be combined for assessment purposes. The Panel commends the SASC on the comprehensive approach and points out places for improvement in the sections that follow. The Review Panel concurs with the SASC conclusions that the Southern New England stock is severely depleted while the Gulf of Maine and Georges Bank stocks show record abundance. The Review Panel also agrees there is evidence for significant migration between the Gulf of Maine and Georges Bank and these two biological stocks should be combined in model runs.

Terms of Reference for the Lobster Stock Assessment Peer Review

1. **Evaluate thoroughness of data collection and presentation and treatment of fishery-dependent and fishery-independent data in the assessment.**

The Panel notes that the SASC appears to have accessed all available data sources and tried to incorporate them either directly into the U of Maine model or into the stock indicator tables. Most data were used, and the Panel supports the SASC in their decisions. The Panel notes some shortcomings in both fishery-dependent and -independent data, but given the strong trends in the different stocks, these shortcomings do not weaken the conclusions of the assessment.

a. Consideration of data strengths and weaknesses

Fisheries dependent data - The SASC noted its overall confidence in the current landings data by weight but noted the quality of landings data has not been consistent spatially or over time. They noted the potential for underreporting for some periods of the time series and suggested future work should examine this possibility, particularly the period prior to the 100/500 rule for non-pot gear implemented in 1997.

The multiple data streams for landings present challenges for aggregating the data by the three stocks (GOM, GBK, SNE). Lobster landings (weight) from dealers is compiled in a NMFS database by port and month. While these data lack necessary spatial information, harvester reports provide spatial information. Landings data available by state varies; for example, there is 100% trip-level reporting in MA, NH, RI, CT, NY, & VTR vessels, but only 10% trip-level reporting in ME (where most landings occur). Spatial information for ME was based on port landed as reported to SAFIS (Standard Atlantic Fisheries Information System). Landings data from NJ and south are from Federal VTRs. The NMFS area reported is used to generate proportions of landings spatially.

Biological data on the composition of the lobster catch (size, sex, reproductive status and other biological measures) were available from a mixture of sources. Collectively these biosample data were used to convert landings data (weight) into lobster number and to assign sex ratio and size structure to landings data. These are critical inputs to the assessment model. Sources for biosamples were port samples (commercially retained catch only) and at-sea samples (retained plus discarded catch). Industry collected at-sea sample data have become available in recent years to supplement government sampling efforts. Tables 1.1 and 1.2 illustrate the variability in sampling efforts over time and by state.

Tables 1.1-1.2: At-sea and port sampling efforts by the states and federal government.

At-sea sampling	Inshore SAs	Offshore SAs	Started	Ended
ME	511, 512, 513	--	1985	
NH	513	--	1991	
MA	514, 521, 537, 538	--	1981	
RI	539	537, 616	1990	offshore- 2008, inshore
CT	611	--	1982	
NY	611, 612, 613	--	1984	sporadic in recent years
NJ	612, 615	616	2008	
DE	--	--	--	--
MD	--	--	--	--
Federal/offshore	recent: all Areas with landings		2012 (some 1995-1997)	

Port sampling	Inshore SAs	Offshore SAs	Started	Ended
ME	511, 512, 513	--	1967	2011
NH	513	464, 465, 515, 561, 562	2005	reduced 2013
MA	--	515, 562	2006	2009
RI	--	525, 526, 537, 616	2006	reduced 2012
CT	--	--	--	
NY	--	612, 613	2006	2009
NJ	--	--	--	
DE	--	--	--	
MD	--	--	--	
Federal/offshore	all Areas with landings		1980	

Even with the above limitations, the biosample database is extensive, and heavily fished inshore statistical areas are well sampled over time. However, the UMaine model requires data by statistical area, quarter, and year. Over the period covered by the model (1982 to present), there are substantial gaps, particularly in the first half of the time series and in less heavily fished statistical areas.

Although the data limitations were substantial, the Panel noted that the SASC took a thorough (and resource intensive) approach to fill the gaps (see below).

To better apportion existing sampling effort by various agencies, the SASC conducted a power analysis to determine levels of sampling needed to detect a difference in mean size of 20%. This analysis should be used to reallocate effort from well-sampled to poorly-sampled areas.

The SASC noted some uncertainty existed in length-weight relationships and these relationships were updated for many areas based on new data collected since the last assessment.

The Panel notes that information on fishing effort is limited. If the effect of effort reduction on stock status is to be understood, better information on total fishing effort is vital. Total traps fished by area are available but this is an insensitive measure of total fishing effort. What is needed is the number of trap hauls by area and time period. Some data on trap hauls are available from at-sea samples and from port-sampling programs where interviews were conducted with fishermen. *Opportunities to improve the collection of effort data should be taken.*

Fisheries-independent data – The SASC presented a multitude of fisheries-independent data sources available from various federal and state agencies: seven bottom trawl surveys, a ventless trap survey, settlement surveys for young-of-year, and larval surveys. Such a variety of sources has both strengths and weaknesses. Using data from separate trawl surveys with moderately different protocols means they are not directly comparable. The SASC noted these surveys were used primarily for trend analyses and as abundance indices to the UMaine model, and the Panel agrees with this approach. The SASC noted that trawl surveys are limited to trawlable bottom, which is generally not considered prime lobster habitat (cobbles to boulders). While lobster abundance on trawlable bottom may not be directly correlated with abundance on untrawlable bottom, the Panel notes the ventless trap survey may bridge the gap between different habitats and is encouraged that data from the ventless trap survey were included in the assessment for the first time. The Panel encourages exploration of the effect of different bottom habitat on trap survey catch rates to help interpret abundance trends on trawlable bottom.

Data from settlement and larval surveys (very spatially limited) were not incorporated into the population model because the minimum size in the model is 53 mm Carapace Length (CL). Trends in settlement and larval surveys were summarized in indicator tables. These provide some indication of future lobster abundance although analyses linking indicators and future landings are limited and complicated by uncertainties in lobster growth and variability in the number of years it takes for a settler to reach minimum legal size.

No single bottom trawl survey covers all portions of a stock area. The NEFSC samples deeper waters and generally does not cover state waters and state surveys are specific to their jurisdictional waters. All survey data used in the assessment were from surveys that were random-stratified by depth and region, with spring and fall time periods. Data collected in each survey are the sex and carapace length of each lobster to develop size-specific mean number per tow. For one analysis (SNE model sensitivity run), number per unit of swept area was also used.

b. Justification for inclusion or elimination of available data sources,

The Panel notes that elimination of data sources was minimal and most data were incorporated into stock indicator tables or the population model. For the SNE area, the number of available surveys exceeded the maximum number that could be incorporated in the model (16). As a result, 1-2 surveys were eliminated based on judgment as to which were giving meaningful trends. In addition, select surveys were input as combined males and females after inspection revealed male and female trends and lengths were similar.

c. Calculation of catch-at-length matrix

Major effort was expended to develop the catch-at-length matrix and the process was surprisingly complex. The Panel notes this complexity was due both to the model constraints (requirements for data by area, quarter, and year) and the paucity of biosamples in select areas. The SASC developed an approach to fill gaps that should make future updates easier, but more model flexibility is needed. Gap filling was needed most for the first half of time series; they combined across years instead of quarters which is unusual but necessary in this case and the approach is justified, due to seasonal variability in catch size composition. The approach for gap filling was well described but the Panel notes the basis for some decisions (minimum number of individuals measured per sample, number of samples per area/quarter/year) was not well justified. The Panel recommends modifying the model to reduce the analytical time needed to develop the catch-at-length matrix. In addition, *the Panel recommends exploring the combination of winter/spring periods into one, again to save data gathering and computation time.*

d. Calculation and/or standardization of abundance indices

Abundance indices were not standardized with generalized linear models nor with general additive models but rather they were standardized within surveys to number per standard tow (bottom trawl surveys), number per trap haul (ventless trap survey), number per unit area (settlement surveys) or number per cubic meter (larval survey). For SNE, a sensitivity run was also conducted on the trawl data standardized by swept area.

2. Evaluate the methods and models used to estimate population parameters and reference points for each stock unit

a. Use of available life history information to parameterize the model(s)

The Panel believes the SASC was thorough in its review and use of life history information and environmental data to parameterize the models. In particular, the SASC is to be commended for its use of temperature data to explore changes in natural mortality in SNE, and its use of a wide variety of data types to examine movements between the GOM and GBK areas. The SASC was also creative in using environmental data in sensitivity runs to inform the expected recruitment in the model.

A recurrent theme in the stock assessment report and in the review of the assessment was the need for updated information on growth and maturity. The lack of current information may be causing the model to fail to reproduce the observed abundance of large lobsters (>100 mm). This lack of current information does not preclude use of the model to see trends in abundance and exploitation over time, but likely affects the magnitude of these estimates. The Panel did not see an alternative way to deal with this problem.

b. **Model parameterization and specification (e.g. choice of CVs, effective sample sizes, likelihood weighting schemes, etc.).**

Among the data types, a variety of approaches were used for estimating or setting initial CVs, effective sample sizes, and variances. These are somewhat arbitrary but not without precedent (following Methot 2000) and the Panel found the approaches reasonable. The likelihood formulations for continuous variables after log transformation were either normal or a robust formulation following Chen et al. (2000) or Fournier et al. (1990). A number of size bins were pooled to achieve a minimum number of observations for length frequencies and this varied by year; this approach differed from the previous assessment and was justified as following the dynamic binning in Methot's Stock Synthesis model.

The components of the likelihood representing different data types were given equal initial weights in the base run of the model. The SASC then conducted sensitivity runs to justify the weighting scheme. Although it is possible in certain cases to estimate effective sample sizes to use as weights for the length compositions, in general it is difficult to determine objectively appropriate weights because issues of non-sampling errors predominate. For example, good quality data inserted into a mis-specified model may lead to misleading model outputs; therefore, insisting a data type receive weight proportional to the quality of the data may lead to misleading model outputs because the data are essentially misinterpreted by the model. Similarly, bad quality data, even if extensive, can cause problems when inserted into a likelihood. The Panel felt that starting with equal weights and then exploring the sensitivity of the model outputs to changed weights was a reasonable approach and provided informative results about conflicts among the data types (landings vs. length compositions).

c. **The choice and justification of the preferred model. Was the most appropriate model used given available data and life history of the species?**

Substantial work went into the development of the University of Maine model specifically for application to American lobster. The UMaine model was used in the previous assessment (ASMFC 2009) and the SASC was specifically directed to use this model; no other model type was put forward. The model used almost all available data. For SNE, a few survey indices of abundance had to be eliminated or combined due to software limitations. However, this was justified on the basis of visual examination of the indices.

A variety of configurations of the University of Maine model were tried (differing in the years of data analyzed, the structure of the abundance indices formulation (linear vs. nonlinear), weightings, combining GOM and GBK, etc.). The Panel is satisfied that the final model run (base run) was the appropriately configured run.

3. Evaluate the estimates of stock abundance and exploitation from the assessment for use in management. If necessary, specify alternative estimation methods.

The Panel agrees with the SASC that there are strong reasons to believe the assessment model effectively captures the trends in abundance and effective exploitation rate over time; the Panel further concurs that the absolute values of abundance and exploitation rate are less reliably determined. Reasons for concluding the trends are reliable are:

- The model outputs are consistent with what is observed in the stock indicators
- The assessment model is consistent with results from the previous assessment and appears stable with respect to sensitivity model runs; the sensitivity runs generally affect the scaling of the model results rather than trends in the model results
- The potential problem arising from the need to fill in holes in the input data (length frequencies), which is particularly notable in the early years, does not appear to be important judging from runs in which the early data were discarded (Figure 5.1.3).
- The model does not suffer from retrospective inconsistencies and model diagnostics are generally good.

On the other hand, analysis of residuals suggests the model is not replicating the occurrence of large animals (>100 mm) seen in the catch (model underestimates large animals), possibly because of misspecification of the growth transition matrices. This can affect the magnitude of stock abundance estimates. Additionally, for Southern New England, a reasonable adjustment to the natural mortality rate was made; however, the magnitude of the adjustment affects the scaling of the model results thus generating some uncertainty.

The Panel does not feel that alternative estimation methods are needed for providing estimates of stock abundance and exploitation. The Panel agrees with the SASC that the trends in abundance and exploitation are well determined and the estimates of absolute levels are less certain. It is felt that both the stock indicators and the model outputs are valid for making stock status determinations.

4. Evaluate the methods used to characterize uncertainty in estimated parameters. Were the implications of uncertainty in technical conclusions clearly stated?

The SASC investigated uncertainty in their analyses through evaluating the precision of the estimates, retrospective analyses, and sensitivity runs. The UMaine model estimates the uncertainty in the model parameters with asymptotic confidence limits and credible intervals from Markov Chain Monte Carlo simulations. Both of these intervals were deemed by the SASC to have “grossly understated the true uncertainty in the basecase results” (Table 4.1). The SASC investigated the nature of the narrow intervals through likelihood profiles; those runs are discussed in TOR #5. The Review Panel supports their conclusion and their recommendation to examine uncertainty through sensitivity runs.

Table 4.1: Asymptotic confidence and MCMC credibility intervals with 95% coverage for mean reference abundance and effective exploitation during 2011-2013.

Type of interval	Abundance		Exploitation	
	Lo bound	Hi bound	Lo bound	Hi bound
		GOM		
Asymptotic	239	258	0.47	0.48
MCMC	231	255	0.49	0.51
		GOMGBK		
Asymptotic	239	257	0.48	0.49
MCMC	233	255	0.49	0.50
		SNE		
Asymptotic	9.6	10.3	0.26	0.28
MCMC	9.2	10.2	0.27	0.31

5. Evaluate the diagnostic analyses performed, including but not limited to:

a. Sensitivity analyses to determine model stability and potential consequences of major model assumptions

Sensitivity analysis included a 'standard' set of runs that were carried out with the base-case model for each stock area. The standard set consisted of runs with: M +/- 0.05, recruit covariates turned off, the growth matrix from the last assessment which gives faster growth, gear selectivity shifted forward (to the right) and backward (to the left) by one size group (5 mm CL), linear catchability for all surveys, and conservation selectivity from the last assessment. The assessment team also generated likelihood profiles that varied average recruitment over a range from 0.8 to 1.2 times the base-case level. As mentioned above, the team took this analysis a step further by overlaying the likelihood profiles for landings and for length composition on recruitment and demonstrated that the narrow confidence intervals were the result of a mismatch in the locations of minima – the minimum for landings occurred at a recruitment level less than that of the base case while the minimum for length composition occurred at a recruitment level greater than the basecase (see Figures 5.1.1 and 5.1.2).

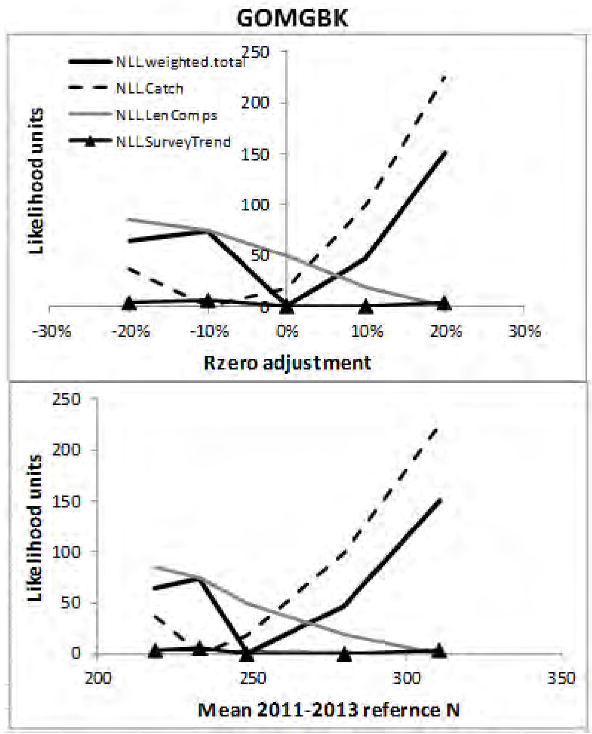

Figure 5.1.1: Likelihood profile results for GOM/GBK.

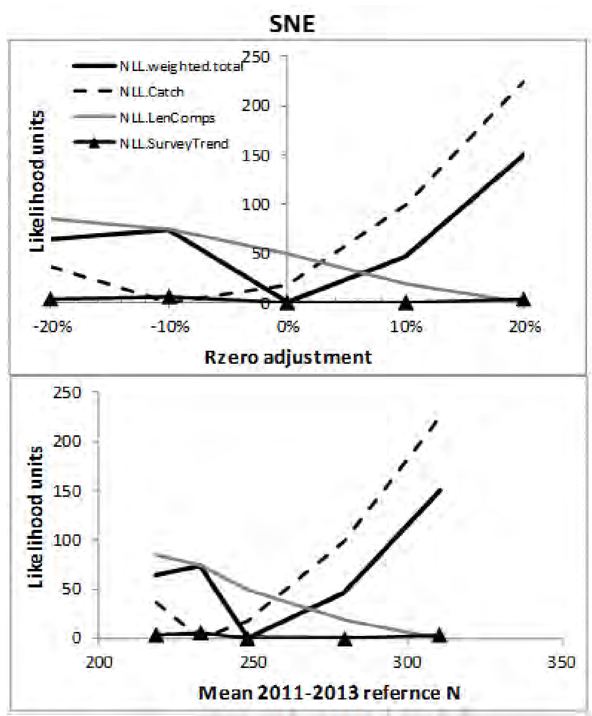

Figure 5.1.2: Likelihood profile results for SNE.

Of the standard set of sensitivity runs, the run shifting the gear selectivity to the right had the strongest effect on the models which was quite apparent in the effective exploitation plots. In SNE, another sensitivity run used temperature (days > 20 C) as a recruit covariate and another run used a single survey based on swept area. There was consistency among the sensitivity runs with the relative abundance showing less variability than the effective exploitation. The Panel was concerned that the stability depended on the gap-filling in the early years and the use of a single growth transition matrix per stratum. While alternative growth matrices were not feasible, gap-filling was evaluated by a run that started in 1997. The truncated model produced results similar to those in the basecase for the entire period for the GOM/GBK stock (Figure 5.1.3.). The Panel agrees that the suite of sensitivity runs produced more reasonable precisions than did either the asymptotic or MCMC based confidence limits.

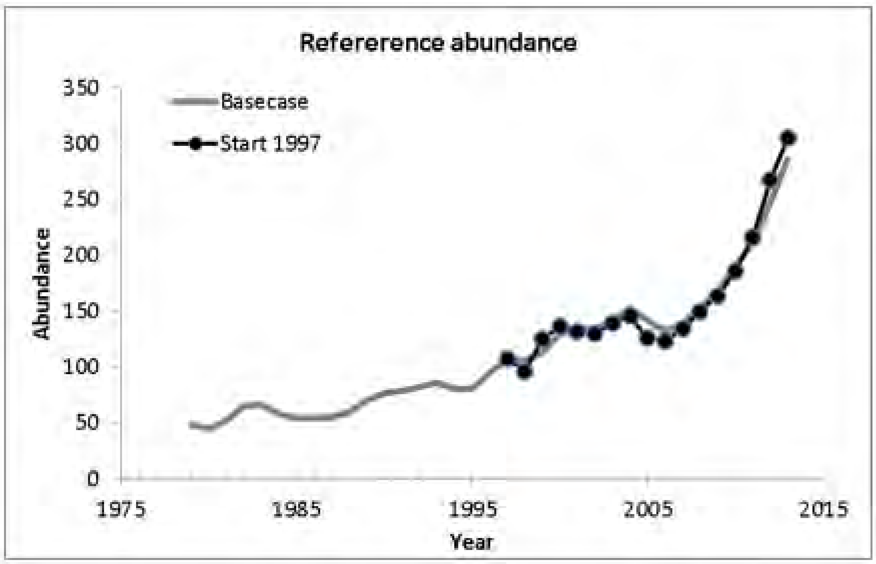

Figure 5.1.3: Reference abundance estimates for GOM/GBK during 1979-2013 from the basecase model and for 1997-2013 from a sensitivity run.

b. Retrospective analysis

The retrospective analyses, using seven peels, indicated mild retrospective patterns and that the estimated trends and scales for recent years are stable (GOM/GBK Fig. 5.2.1 and SNE, Fig. 5.2.2). The Panel was quite impressed by the lack of retrospective patterns.

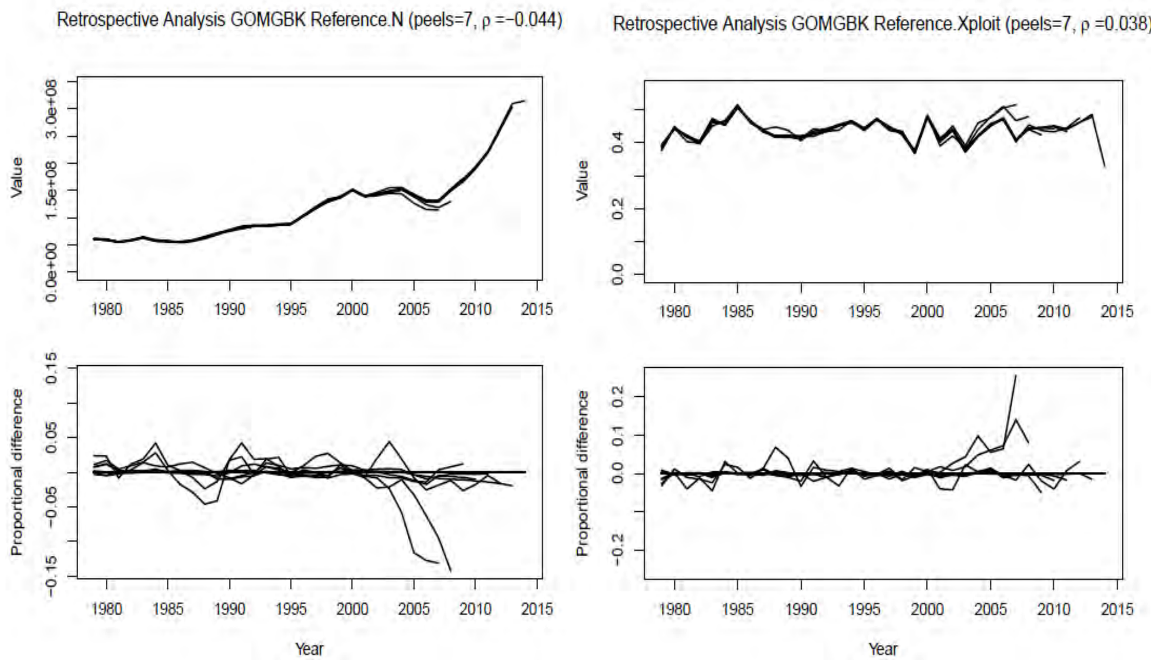

Figure 5.2.1 a-b. Retrospective analysis for GOM/GBK lobster reference abundance estimates (left) and effective exploitation estimates (right) from the basecase model.

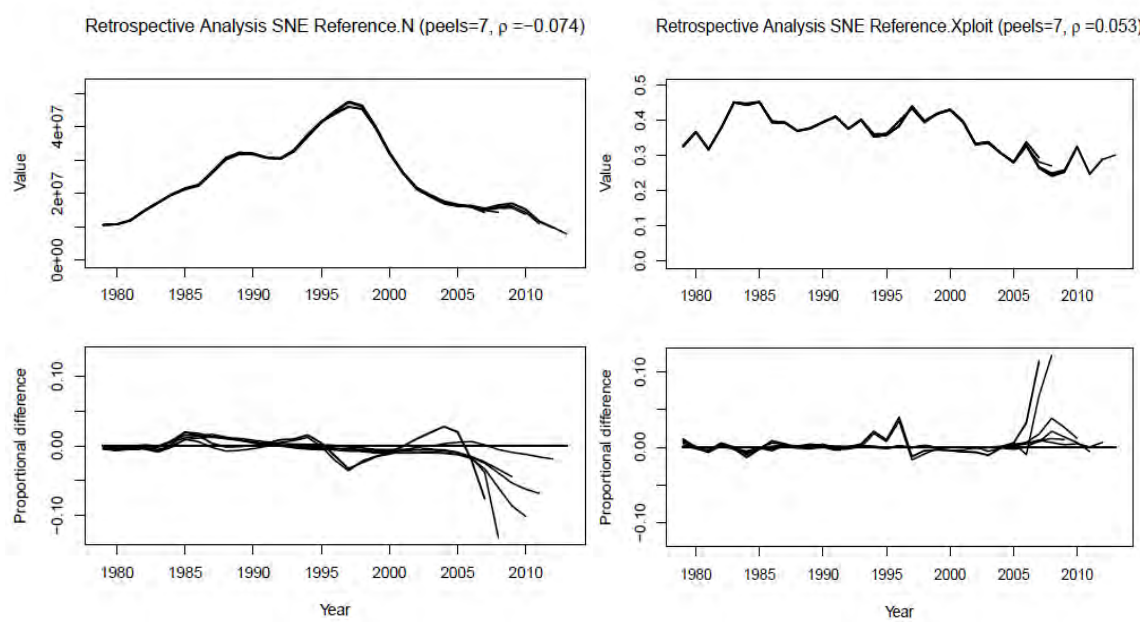

Figure 5.2.2 a-b. Retrospective analysis for SNE lobster reference abundance estimates (left) and effective exploitation estimates (right) from the basecase model.

6. Evaluate the preparation and interpretation of indicator-based analyses for stocks and sub-stock areas.

The Panel supports the inclusion of indicator tables ('model-free indicators') summarizing indicators of mortality, abundance and fishing performance for each of the stocks. The indicators provide information which is used to assess the robustness of abundance and exploitation estimates from the UMaine model. The approach of categorizing each indicator into lowest quartile (<25%), middle 2 quartiles (25-75%) and upper quartile (>75%) is simple, objective and identifies years that are associated with good or poor stock status. An example of the display for one of the abundance indicators (spawning stock abundance) for the GOM/GBK stock unit follows (Table 6.1):

Table 6.1 GOM/GBK Abundance and Exploitation Indicators from Assessment Report, Table 5.2.4.2A and 5.2.4.1. Darkest shading is the worst condition.

SPAWNING STOCK ABUNDANCE		
Mean weight (g) per tow of mature females		
Survey	NESFC *fall*	NESFC *spring*
1981	304.27	173.96
1982	223.09	74.35
1983	264.22	125.99
1984	189.82	188.73
1985	328.01	1138.49
1986	206.27	286.30
1987	179.30	219.81
1988	271.72	184.18
1989	407.16	130.78
1990	289.98	220.91
1991	326.86	204.07
1992	293.28	202.01
1993	277.73	200.30
1994	360.16	280.51
1995	452.00	141.92
1996	555.40	465.08
1997	398.24	410.45
1998	438.12	449.94
1999	929.85	411.02
2000	457.89	484.73
2001	718.46	625.39
2002	1350.72	849.37
2003	701.10	1139.33
2004	716.95	1141.16
2005	593.44	762.80
2006	968.92	811.80
2007	752.12	805.69
2008	1270.51	1316.45
2009	1811.80	1140.39
2010	1662.97	1249.92
2011	2206.17	1053.94
2012	1910.13	1703.54
2013	1853.09	1322.28
2008 - 2013 ave	**1785.78**	**1297.75**
25th	293.28	202.01
median	452.00	449.94
75th	929.85	1053.94

EXPLOITATION RATE (landings / survey ref. pop'n)		
Landings (lbs) by area / Reference pop'n (survey weights (lbs) > 77 mm, sexes combined)		
Survey	NESFC *fall*	NESFC *spring*
1981		
1982	1.42	1.29
1983	1.18	1.56
1984	1.07	1.90
1985	0.94	0.97
1986	0.62	0.73
1987	0.73	0.92
1988	0.95	0.62
1989	0.81	0.82
1990	0.85	1.67
1991	0.97	1.41
1992	0.90	1.19
1993	1.07	1.22
1994	1.02	1.76
1995	0.86	1.43
1996	0.64	0.97
1997	0.70	0.91
1998	0.89	0.84
1999	0.85	1.07
2000	0.80	0.64
2001	0.85	0.49
2002	0.96	0.86
2003	0.92	0.65
2004	1.37	0.81
2005	1.35	1.00
2006	1.79	0.94
2007	1.59	0.73
2008	1.35	0.82
2009	1.05	0.83
2010	1.01	0.90
2011	0.79	0.76
2012	0.88	0.66
2013	0.81	0.63
2008 - 2013 ave	**0.982**	**0.766**
25th	0.84	0.75
median	0.93	0.88
75th	1.07	1.10

The Panel recommended a few changes to the indicators to make the annual values more comparable. For example, (i) the quartile calculations used the entire available time series, rather than the reference years used in the determination of stock status (1982-2003 for GOM/GBK; 1984-2003 for SNE) and the recommendation is to fix the reference period and calculate the quartiles in relation to the appropriate fixed period; and (ii) the calculations for 'Full Recruit Abundance (Survey)' and 'Recruit Abundance (Survey)' were developed with variable sizes because of changes in the minimum legal size and the recommendation is to adopt a consistent definition for the lengths pertaining to recruits and full-recruits.

Given the importance of temperature to lobster life history and links made in the assessment to increased temperature in SNE and decreased lobster recruitment and abundance in SNE, the Panel recommends that an environmental indicator table be developed to illustrate changes in the temperature environment over time. The table should be based on existing (and as yet potentially unaccessed) bottom and surface temperature time series from different locations in each stock area.

7. Evaluate the current and recommended reference points and the methods used to calculate/estimate them. Evaluate stock status determination from the assessment or specify alternative methods.

The Panel agrees with the SASC that traditional reference points, based on yield and spawning biomass per recruit and based on MSY considerations, are not appropriate given the life history and recruitment trends of lobster, and the current configuration of the per-recruit model. Instead, the Panel agrees with the choice of selected trend-based abundance and exploitation reference points determined from the model for an appropriate time period. (The panel noted that the definitions of stock indicators could be improved to make them consistent with the definitions used for determining stock status; the SASC agreed and has revised them.)

The Panel agrees that the GOM/GBK combined stock is not overfished and overfishing is not occurring. This is clearly shown by both the model results and the stock indicators. (Separate determinations for GOM and GBK were not deemed appropriate by the SASC and the Panel.)

The SNE stock is clearly overfished according to both the model and the stock indicators and, in fact, the abundance level is the lowest on record. Closer scrutiny reveals the inshore areas have extremely low abundance. Fishing mortality does not appear to be extremely high, supporting the conclusion that biological factors have contributed to bringing the stock to this point. It is believed the offshore area of SNE depends on nearshore settlement as the source of recruits. Therefore, the offshore is also in jeopardy. The SASC and Panel believe the SNE stock has little chance of recovering unless fishing effort is curtailed. To be specific, according to the reference point defined by the time series of model outputs, the exploitation rate for the entire SNE stock does not lie in the overfishing zone; however, the definition was created without considering the possibility that the stock could be at the lowest abundance level ever and the production of recruits in the inshore area (on which the offshore area depends) could be brought to an extremely low level. Hence, by any reasonable standard, it is necessary to protect the offshore component of the stock until increased recruitment can be observed.

8. **Review the research, data collection, and assessment methodology recommendations provided by the Technical Committee and make any additional recommendations warranted. Clearly prioritize the activities needed to inform and maintain the current assessment, and provide recommendations to improve the reliability of future assessments.**

The Panel agrees with the SASC that updating growth is imperative. The growth transition matrices are critical to the model. Currently, growth is the based on tagging work from decades ago and growth probably has changed in recent years but there are no current data. Along with growth, maturity is important, especially female maturity, because female growth is directly linked to reproduction because a female does not molt if she is carrying eggs. If females mature at smaller sizes, their growth slows down earlier than what the existing transition matrices predict.

The second priority task is to investigate stock connectivity. In the current assessment, the Georges Bank model was unsatisfactory and the fit of the Gulf of Maine model improved when the two 'stocks' were combined. The SASC noted that the movement of larger lobsters between the two regions produced unrealistic results because the model could not account for the changes in population number especially the larger lobsters on Georges Bank. Therefore, a study is needed to validate combining the two stocks into a single stock. The SASC suggested tagging lobsters on Georges Bank in the fall and winter and then tracking them through the spring and summer. The Panel supports the need for this research.

The third priority task is to increase the sea sampling for biological samples to complement the landings in offshore waters. The model requires information on the lengths, sexes, reproductive state, and weights of the lobsters caught in the different strata and, lacking these samples, the necessary associated gap-filling presented a major challenge to the SASC for those strata with landings but lacking length samples.

Another priority that was obvious to the Review Panel throughout the SASC presentations and discussions, was the rigidity of the UM model and difficulty in its reconfiguration. Using ADModel Builder (Fournier *et al.* 2012) is a good platform but the code should be rewritten to be more flexible and efficient.

9. **Review the recommended timing of the next benchmark assessment relative to the life history and current management of the species.**

For SNE, the Panel recommends close monitoring of the stock to try to save it. Stock indicators should be updated annually and reported to the Management Board for appropriate action. For GOM/GBK, given the good condition of the stock, a five-year interval may be appropriate for a benchmark assessment. However, the stock indicators should be updated frequently to detect signs of changing recruitment or other conditions.

Advisory Report

A. Status of stocks: Current and projected, where applicable

The combined GOM/GBK stock is neither overfished nor undergoing overfishing. The landings have been increasing since the late 1980s and have accelerated since 2008; and the recruitment trend based on the NEFSC trawl survey has been in the upper 25 percentile for the past five years (Assessment Report Table 5.2.4.2C) which lessens any concern of whether it can last. The effective exploitation index is rated neutral (25-75 percentile) and, between the fall and spring surveys, has been neutral half the time in the past ten years (Assessment Report Table 5.2.4.1).

The story is quite different for the SNE stock. The stock is overfished with four out of the six inshore surveys indicating abundances less than the 25th percentile (Assessment Report Table 5.2.3.2A) and recruitment also having three out of the six inshore surveys indicating that recruitment was also below the 25th percentile. The SNE region has shown the greatest increase in water temperature as measured by the number of days with temperatures above 20 ºC. As fishers have left the inshore fishery, effort has decreased and fishers have shifted to more offshore locations. However, the inshore and offshore areas are linked and offshore exploitation jeopardizes stock maintenance and recovery.

B. Stock Identification and Distribution

In the 2009 Assessment (ASMFC 2009), American lobster were assessed as three distinct stocks; the Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE). Lacking genetic differentiation, American lobster stocks were separated on the basis of multiple factors including: regional rates of maturity and growth, size distribution, distribution and abundance trends of adults and juveniles, patterns of migration, location of spawners, the dispersal and transport of larvae, and considerations for large scale patterns in physical oceanographic processes (temperature regime and currents).

In the current assessment, three stocks were again assumed but the data and models indicated that GBK was inseparable from GOM. The conclusion was based on differences in abundance and size composition between spring and fall surveys indicating that lobsters are very likely moving between the two areas. In addition, the model fit for GBK alone was poor but markedly improved when the model was run for GOM+GBK combined. The Review Panel supports the decision to view GOM and GBK as strongly linked and assessed as one stock, and encourages future research that will quantify the level of connectivity between the two areas.

C. Management Unit

The management unit for American lobster is the entire Northwest Atlantic Ocean in U.S. waters and its adjacent inshore waters where lobsters are found from Maine through Virginia. The Atlantic States Marine Fisheries Commission (ASMFC) manages the lobster fishery under the authority of the Atlantic Coastal Fisheries Cooperative Management Act. The ASMFC manages state waters (0-3 miles from shore) and the National Marine Fisheries Service (NMFS) manages the lobster fishery in federal waters (3-200 miles from shore). The fishery management plan

(FMP) provides for the management of lobster throughout their range. For management purposes, the management unit is subdivided into seven lobster conservation management areas (LCMAs) that cut across stock boundaries in many cases. Management units do not correspond to stock units defined in this assessment (see B. Stock Identification and Distribution).

D. Landings

The lobster fishery has a long history and landings data are available from the 1800s. The historical landings data provide a general characterization of lobster population trends over the past two centuries but must be viewed with caution since all fishery-dependent data are confounded in terms of size, location, and other market driven forces. Periods of high and low landings have been recognized for many years. Terms such as commercial extinction were in use in 1903. Low productivity, as measured by landings, extended for long periods; coast wide landings declined over a 25-year period from 1889 to 1915 and remained low for another 30 years.

Gulf of Maine - Lobster landings in the Gulf of Maine were stable between 1981 and 1989 averaging 14,600 metric tons (mt), and then increased steadily from approximately 20,000 mt in early 1990s to approximately 35,000 mt in the mid-2000s. From 2007 to 2013 landings nearly doubled, reaching the time series high of 64,087 mt in 2013. Annual GOM landings have been in the upper quartile of the time series (1982-2013) since 2007.

More than 98% of the total GOM catch has come from inshore NMFS statistical areas. The increase in landings in GOM was dominated by catch from Maine, particularly from the mid-coast portion of the state which has accounted for >50% of the entire GOM catch since 2003. Landings from New Hampshire varied without trend around a mean of 630 mt between 1981 and 2007; then from 2008 to 2013 they increased by 92%, reaching a time series high of 1,554 mt in 2012. Massachusetts landings increased from 1981 to 1990 and remained high between 1991 and 2000 (averaging 4,979 mt). Starting in 2001, Massachusetts landings declined reaching a time series low in 2005 (3,227 mt), with six out of the seven lowest landings values in the time series occurring between 2001 and 2007. Since 2008, landings in Massachusetts have increased steadily and have remained above the time series median in 2011 through 2013.

Georges Bank - Lobster landings in the GBK stock unit varied around the time series mean of 1,371 metric tons (mt) between 1981 and 2002. From 2003 to 2013 landings increased substantially, reaching a time series high of 2,394 mt in 2005, and have remained well above the time series mean through 2013. Landings in the GBK stock have remained in the upper quartile for the time series (1982-2013) for 8 of the last 9 years.

Catch from the state of Massachusetts comprised the majority of the GBK landings, averaging 71% of the total since the early 1990s. The proportion of the Georges Bank fishery attributable to Massachusetts has increased over time, while the proportion attributable to Rhode Island has decreased. The trend is related to where the respective fisheries in Massachusetts and Rhode Island operate on Georges Bank. The majority of the Massachusetts landings from the Georges Bank stock are harvested on the northern and eastern side of the bank, which have experienced lobster landings increases over the course of the time series. Conversely, the majority of the Rhode Island fishery on Georges Bank occurs on the southern edge of the bank, in which landings have been highly variable but generally lower in the latter half of the time series. Prior to 1993, New Hampshire did not have consistent landings in GBK. From 1993 to 2003, NH landings were stable, averaging 124 mt. Since 2004, NH landings have increased and have remained more than double the time series mean, reaching a time series high of 516 mt in 2013. Landings from all other states comprised less than 5% of the GBK landings throughout the time series.

Southern New England - Lobster landings in SNE increased sharply from the early 1980s to the late 1990s, reaching a time series high of 9,935 mt in 1997. Landings remained near time series highs until 1999, then declined dramatically back to levels observed in the early 1980s. In sharp contrast to GOM, SNE landings from 2003 through 2012 varied at low levels around a mean of 2,500 mt. In 2013, catch dropped to a time series low of 1,509 mt. Commercial landings in SNE are below the lower quartile for the times series (1984-2013).

The majority of the catch from 2008 to 2013 in SNE was landed by Rhode Island (1981 to 2007 mean = 37%), followed in descending order by New Jersey and South (33%), Massachusetts (14%), New York (10%) and Connecticut (6%). This represents a marked change from previous periods when New York and Connecticut were the 2nd and 3rd largest producers respectively, and reflects the dramatic declines in catch in Long Island Sound. In general, catch in the inshore statistical areas in SNE have had the largest declines and are all now below previous lows observed in the early 1980s. Catch in the offshore/nearshore statistical areas have less variability in trend, but it should be noted that 9 out the 10 lowest catches landed in the time series have occurred since 2002.

E. Data and Assessment

Data

Fisheries dependent data - The SASC expressed overall confidence in the current landings data by weight but noted the quality of landings data has not been consistent spatially or over time. They noted the potential for underreporting during some periods of the time series. Given the recent strong trends in landings and measures of abundance, the Review Panel's view is that potential underreporting in an earlier period would not affect the conclusions of the assessment.

For data on the composition of the lobster catch (size, sex, reproductive status and other biological measures) samples were available from a mixture of sources. Collectively the biosample data were used to convert landings data (weight) into lobster number and to assign sex ratio and size structure to landings data. These are critical inputs to the assessment model which requires data by area, quarter and year. Although the data limitations were substantial the Panel finds that the SASC took a thorough (and resource intensive) approach to fill the gaps. The Panel notes that information on fishing effort is limited and opportunities to improve the collection of effort data should be taken.

Fisheries-independent data – The SASC presented a multitude of fisheries independent data sources available from various federal and state agencies: seven bottom trawl surveys, a ventless trap survey, settlement surveys for young-of-year, and larval surveys. Trawl survey data and ventless survey data were used for trend analyses and for input as abundance indices to the UM model, while settlement and larval surveys were used as stock indicators only. Within stock areas the trends in the trawl surveys were in general agreement (an exception was the Massachusetts trawl survey which has not shown an upward trend in the GOM). The SASC noted that all trawl surveys are limited to trawlable bottom, which is generally considered outside of prime lobster habitat (cobbles to boulders). The panel encourages exploration of the effect of different bottom habitat on trap survey catch rates to help interpret abundance trends on trawlable bottom.

Overall the Review Panel believes the SASC made best use of the available data.

Assessment

The SASC used both model-free stock indicators based on quartiles of annual values and a length-based model developed at the University of Maine that was used in the 2009 assessment. The stock indicators include effective exploitation (landings /survey), spawning stock abundance (mean weight of mature females by survey), full recruit abundance (number of legal sized lobsters by survey), recruit abundance (number of lobsters 10 mm below minimum size), survey lobster encounter rate (proportion of positive tows). Taken together, the stock indicators provide a comprehensive description of the lobster stocks.

The UM model provides a quantitative summary by integrating landings, length and sex measurements, and surveys, on a spatial scale. When coupled with the growth matrices, the UM model provides rates of mortality, stock changes, etc. to provide managers with a thorough understanding of the condition and dynamics of the American lobster stocks.

F. Biological Reference Points

The SASC calculated the biological reference points ($F_{5\%}$, $F_{10\%}$, $F_{15\%}$, $F_{20\%}$, F_{MAX}, and $F_{0.1}$ using the UM model, Table III.1). By these metrics, overfishing is occurring in both the GOM and GOM/GBK stock. This seems implausible given the record abundance and recruitment observed in the stock over the last 20 years. It was not possible to calculate reasonable percent spawning biomass per recruit reference points (*$F_{5\%}$, $F_{10\%}$, $F_{15\%}$* or *$F_{20\%}$*) for the SNE stock because the relatively high assumed natural mortality, early sexual maturation (100% mature prior to recruiting to the fishery), and recent shifts in fishery selectivity towards larger lobsters (via increased minimum size regulations) make it impossible, based on the calculations, to fish hard enough to reduce mean lifetime egg production per recruit to even 20% the virgin level, let alone lower levels.

Table III.1. Per-recruit mortality-based reference points by stock. Red shading indicates the reference period estimate exceeds the threshold reference points. Green shading indicates the reference period estimate, i.e., 2011-2013, does not exceed the threshold reference points. From Assessment Report, Table 7.4.1.

	GOM	GBK	GOM/GBK	SNE
2011 -2013 Reference F	0.48	1.54	0.48	0.27
$F_{5\%}$	0.45	N/A	0.44	> 0.4
$F_{10\%}$	0.36		0.34	> 0.4
$F_{15\%}$	0.3		0.29	> 0.4
$F_{20\%}$	0.26		0.25	> 0.4
F_{MAX}	0.36		0.26	> 0.4
$F_{0.1}$	0.17		0.15	0.24

The Review Panel believes these reference points are not meaningful and may be misleading.

G. Fishing Mortality

While fishing mortality is calculated by the model, the SASC prefers to use 'effective exploitation' as the primary descriptors of annual fishing pressure when presenting assessment model results. Effective exploitation is the estimated annual catch in number from the model divided by the number of lobster 78+ mm CL on January 1 plus the number that will molt and recruit to 78+ mm CL during the year.

Effective exploitation and full recruit fishing mortality (*F*) have similar trends but full *F* is higher and more variable. The relationship between the exploitation and fishing mortality measures in stock assessment results is not one-to-one because of variability in size selectivity due to changes in regulations, size structure and recruitment. In contrast, the relationship between effective exploitation and full *F* is one-to-one in per recruit modeling which assumes constant size selectivity and recruitment.

The effective exploitation index for the GOM/GBK stock has been rated neutral (25-75 percentile) and, between the fall and spring surveys, has been neutral half the time in the past ten years (Assessment Report Table 5.2.4.1). However, both relative abundance and recruitment have been in the upper quartile in recent years, indicating the stock can sustain this pressure under the current environmental conditions. While the effective exploitation in the SNE is rated as neutral, the inshore abundance and recruitment has frequently been in the lower quartile in recent years and is currently at the lowest level.

H. Recruitment

Recruitment in the two stocks has been quite different with recruitment in the upper quartile in the GOM/GBK stock and neutral or in the lower quartile in the SNE stock. In the inshore portion of the SNE stock, recruitment has been extremely low in recent years.

I. Spawning Stock Biomass

Spawning stock biomass is difficult to measure with the wide range of ages of lobsters recruiting to the fishery. Lipofuscin work suggested that as many as five to eight year classes of lobsters constitute the lobsters entering the fishery in a given year. The SASC recommended using the relative abundance (the number of lobsters 78+ mm CL on January 1 plus the number that will molt and recruit to 78+ mm CL during the year) as a measure of stock abundance. The relative abundance of lobsters in the GOM/GBK based on the NEFSC trawl survey has been in the upper quartile in recent years (Assessment Report Table 5.2.4.2A). The relative abundance in the SNE has been neutral or below the lower quartile especially with the inshore surveys (Assessment Report Table 5.2.3.2A).

J. Bycatch

Little data are currently available on commercial discards of lobster in the lobster fishery. Sea sample data indicate substantial regulatory and market driven discard of sublegal, oversized, v-notched females, and ovigerous females. The regulatory discards are accommodated in the modeling as a component of gear selectivity and as conservation discards. Studies describing discard mortality in the trap fishery and/or bycatch mortality in the trawl fishery are limited but consistent in their findings that most mortality factors are relatively low.

K. Other Comments – None.

L. Sources of Information (Literature Cited)

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Atlantic States Marine Fisheries Commission

American Lobster Stock Assessment for Peer Review Report

August 2015

Vision: Sustainably Managing Atlantic Coastal Fisheries

Atlantic States Marine Fisheries Commission

2015 American Lobster Stock Assessment Report for Peer Review

Conducted on
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Woods Hole, Massachusetts

Prepared by the

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Terms of Reference for Stock Assessment
2015 American Lobster Stock Assessment

1. Estimate catch and catch-at-length from all available fishery dependent data sources including current and historical commercial, recreational, and discard data.
    a. Provide descriptions of each data source (e.g. geographic location, sampling methodology, variability, outliers). Discuss data strengths and weaknesses (e.g. temporal and spatial scale, gear selectivities, sample size) and their potential effects on the assessment.
    b. Justify inclusion or elimination of each data source.
    c. Explore improved methods for calculating catch-at-length matrix.

2. Present the abundance data being considered and/or used in the assessment (e.g. regional indices of abundance, recruitment, state-federal and other surveys, length data, etc.).
    a. Characterize uncertainty in these sources of data.
    b. Justify inclusion or elimination of each data source.
    c. Evaluate the utility of using industry catch rates as indices of abundance.
    d. Describe calculation or standardization of abundance indices.

3. Evaluate new information on life history such as growth rates, size at maturation, natural mortality rate, and migrations.

4. Use University of Maine Model (UMM) to estimate population parameters (e.g., effective exploitation rate, abundance) for each stock unit and analyze model performance.
    a. Modify UMM as necessary to incorporate new data sources, explore estimation of growth parameters, and estimate uncertainty.
    b. Evaluate stability of model. Perform and present model diagnostics.
    c. Perform sensitivity analyses to examine implications of important model assumptions, including but not limited to growth and natural mortality.
    d. Explain model strengths and limitations.
    e. Justify choice of CVs, effective sample sizes, or likelihood weighting schemes.
    f. State assumptions made and explain the likely effects of assumption violations on synthesis of input data and model outputs.
    g. Conduct projections assuming uncertainty in current and future conditions for all stocks. Compare projections retrospectively with updated data.

5. Develop simple, empirical, indicator-based trend analyses of reference abundance and effective exploitation for stocks and sub-stock areas.

6. Update the current fishing mortality and abundance biological reference points. If possible, develop alternative MSY-based reference points or proxies that may account for changing productivity regimes.

7. Characterize uncertainty of model estimates, reference points, and stock status.

8. Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters and reference points.

9. Report stock status as related to current overfishing and overfished reference points (both current and any alternative recommended reference points). Include simple description of the historical and current condition of the stock in layman's terms.

10. Address and incorporate to the extent possible recommendations from the 2009 Benchmark Peer Review and 2010 CIE review.

11. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

12. Recommend timing of next benchmark assessment and intermediate updates, if necessary relative to biology and current management of the species.

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Executive Summary

American lobster (*Homarus americanus*) supports one of the most valuable commercial fisheries in the Northeast U.S. with an annual estimated revenue in excess of $461 million in 2013 (NMFS, 2015). The United States' management unit for American lobster is the Northwest Atlantic Ocean and its adjacent inshore waters where lobster are found from Maine through North Carolina. The Atlantic States Marine Fisheries Commission (ASMFC) manages the lobster fishery in state waters (0-3 miles from shore) and the National Marine Fisheries Service (NMFS) manages the lobster fishery in federal waters (3-200 miles from shore), both under the authority of the Atlantic Coastal Fisheries Cooperative Management Act. For management purposes, the management unit is subdivided into seven lobster conservation management areas that cut across the three biological stock unit boundaries.

Currently, American lobster is managed under Amendment 3 to the Interstate Fishery Management Plan and its subsequent Addenda, I-XXIV. The plan is designed to minimize the chance of population collapse due to recruitment failure. The goal of Amendment 3 is to have a healthy American lobster resource and management regime, which provides for sustained harvest, maintains appropriate opportunities for participation, and provides for cooperative development of conservation measures by all stakeholders.

Total landings in the fishery have steadily increased in the past thirty-five years. Up until the late 1970's, landings were relatively constant at about 14,000 mt. However, by 2000, landings almost tripled to roughly 39,000 mt and by 2006 grew to 42,000 mt. Landings in 2013 were roughly 68,000 mt. US lobster landings are primarily comprised of catch from inshore waters (0 to 12 nautical miles).

Historically, the stock has been divided into three biological units based on regional differences in life history parameters. They are the Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE). Each stock is comprised of both an inshore and offshore component with the GOM and SNE areas being predominantly inshore fisheries and the GBK area being predominantly an offshore fishery.

GOM supports the largest fishery, constituting approximately 76% of the U.S. landings between 1981 and 2007 and accounting for approximately 87% of landings since 2002. Landings in the GOM were stable between 1981 and 1989, averaging 14,600 mt, and then increased dramatically from 1990 (19,200 mt) to 2013 (64,000 mt). Landings averaged 51,000 mt from 2008-2013.

GBK constitutes a smaller portion of the U.S. fishery, with landings averaging 2,235 mt between 2008 and 2013. Like the GOM, landings were stable in the 1980's and then quickly doubled in the early 2000's to a high of 2,400 mt in 2005.

Before 2011, SNE was the second largest fishery, accounting for 19% of the U.S. landings between 1981 and 2007; however, a sharp decline in the population has significantly reduced catch. Landings peaked in the 1990's, reaching a time series high of 9,935 mt in 1997. Since this time, landings have precipitously dropped to a time series low of 1,500 mt in 2013.

In this assessment, the University of Maine statistical catch-at-length model was used to estimate abundance and mortality of male and female lobsters by size for each stock unit. This was the primary model used in the 2009 assessment and it was updated to calculate sex-specific size distributions of new recruits, accommodate nonlinear surveys, and estimate growth transition matrices internally from tag data. In addition, trends in a suite of non model-based stock status indicators of mortality, abundance, and fishery performance were examined using a “traffic light approach.”

Current abundance of the GOM stock overall is at a record high. Abundance estimates show an increasing trend starting in 1988 and then an increasing slope after 2007. Recent recruitment levels are also at or near record highs.

Results of the model for GBK were not accepted because they did not fit survey trends, landings, or survey length data. This provided strong evidence that the GBK is not a closed population. Furthermore, seasonal patterns in the NEFSC survey showing a migration of large females (>100 CL) from the GOM in the spring to the GBK in the fall corroborated this population dynamic. As a result, the GOM and GBK biological stocks were combined into a single stock (GOM/GBK) and model run. This combined stock was able to effectively model recruitment size compositions and seasonal variations in the location of large females.

Trends from the GOM/GBK model showed that abundance increased after 1979 and at an accelerated pace after 2007. Recruitment and spawning stock abundance have remained high between 2008 and 2013. Exploitation estimates declined after 1979 until the mid-1990’s and then remained stable with higher exploitation on males than females. Current exploitation rates remain on par with the 2008-2013 average.

Contrastingly, abundance estimates for the SNE stock show a sharp decline through the early 2000’s to a record low level in 2013. Basecase estimates for recent recruitment are near zero and the lowest on record. In particular, the inshore portion of the stock shows a dramatic decline in spawning stock abundance and the proportion of positive tows in surveys. Effective exploitation trended downwards in the early 2000’s and remained at relatively low average levels during 2011-2013.

Reference abundance and effective exploitation are used as reference points in this model. Reference abundance is the number of lobster 78+ mm CL on January 1 plus the number that will molt and recruit into the 78+ mm CL group during the year. Effective exploitation is the annual catch (in number) divided by the reference abundance. Based on these reference points, a stock is considered “overfished” if model abundance is less than the 25th percentile relative to the 1982-2003(GOM, GBK, GOM/GBK) or 1984-2003 (SNE) reference period. “Overfishing” would occur if exploitation is greater than the 75th percentile relative to the 1982/1984-2003 reference period. In either of these cases, corrective management action should be implemented.

The GOM stock shows a dramatic increase in abundance since the late 1980’s. Furthermore, the exploitation rate is below the reference threshold. ***Therefore, the GOM lobster stock is not depleted and overfishing is not occurring.***

While the GBK model results were not accepted, an empirical approach based on survey and landings data was used instead. Based upon this approach, ***the GBK stock is not depleted and overfishing is not occurring.***

The GOM/GBK stock is in favorable condition based on the recommended reference points. The stock is well above the reference abundance threshold and slightly below the effective exploitation threshold. ***Therefore the GOM/GBK lobster stock is not depleted and overfishing is not occurring.***

The SNE stock is in poor condition based on the recommended reference points. The stock is well below the reference abundance threshold and below the effective exploitation threshold. ***Therefore the SNE lobster stock is depleted but overfishing is not occurring.***

Table 1. Revised threshold reference points with stock status variables for lobsters in each stock area (annual effective exploitation rate and reference abundance in number of lobsters).

Variable	GOM	GBK	GOM/GBK	SNE
Effective Exploitation				
Effective exploitation threshold	0.54	1.83	0.5	0.41
Recent effective exploitation (2011-2013)	0.48	1.54	0.48	0.27
Effective exploitation below threshold?	YES	YES	YES	YES
Reference Abundance (millions)				
Abundance threshold	52	0.8	66	24
Recent abundance (2011-2013)	247	1.57	248	10
Abundance above threshold?	YES	YES	YES	NO

The assessment recommends that the GOM and GBK biological stocks be combined into a single stock. Furthermore, the assessment shows the SNE stock is not rebuilding and is experiencing recruitment failure. A longer and more geographically widespread harvest moratorium in SNE would be necessary to increase spawning stock abundance enough to boost recruitment and allow the stock to rebuild.

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External Appendices, which address GOM model outputs (Appendix 3), GBK model outputs (Appendix 4), Combined GOM/GBK model outputs (Appendix 5), SNE model outputs (Appendix 6), and Comparison of catch for key species between old and new door configurations for the RI Trawl Survey (Appendix 7), are available from the Commission upon request at info@asmfc.org.

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1.0 INTRODUCTION

American lobster (*Homarus americanus*) supports one of the most valuable commercial fisheries in the Northeast U.S. with an annual estimated revenue in excess of $461 million in 2013 (NMFS, 2015). The U.S. lobster resource occurs in continental shelf waters from Maine to North Carolina. Historically, three stocks have been identified based primarily on regional differences in life history parameters. They are the Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE) (Figure 1.1). Each stock supports both an inshore (0-3 miles) and offshore (3-200 miles) component; however total U.S. lobster landings are primarily comprised of catch from nearshore waters (0 to 12 nautical miles).

1.1 MANAGEMENT UNIT

The management unit for American lobster is the entire Northwest Atlantic Ocean and its adjacent inshore waters where lobster is found from Maine through Virginia. The Atlantic States Marine Fisheries Commission (ASMFC) manages the lobster fishery in state waters (0-3 miles from shore) and the National Marine Fisheries Service (NMFS) manages the lobster fishery in federal waters (3-200 miles from shore), both under the authority of the Atlantic Coastal Fisheries Cooperative Management Act. The fishery management plan (FMP) is written to provide for the management of lobsters throughout their range. The FMP is designed to specify a uniform program regardless of lines that separate political jurisdictions, to the extent possible. The different management authorities are expected to take necessary actions to apply the provisions of this FMP in waters under their respective jurisdictions. For management purposes, the management unit is subdivided into seven Lobster Conservation Management Areas (LCMAs) that cut across stock boundaries in many cases (Figure 1.1). Management units do not correspond to stock units defined in this assessment (see section 3.2).

1.2 REGULATORY HISTORY

The ASMFC American Lobster Board approved Amendment 3 to the FMP in December of 1997. The plan is designed to minimize the chance of population collapse due to recruitment failure. The goal of the amendment is to have a healthy American Lobster resource and management regime, which provides for sustained harvest, maintains appropriate opportunities for participation, and provides for cooperative development of conservation measures by all stakeholders. To achieve this goal, the plan adopts the following objectives:

1. Protect, increase or maintain, as appropriate, the brood stock abundance at levels which would minimize risk of stock depletion and recruitment failure;
2. Develop flexible regional programs to control fishing effort and regulate fishing mortality rates;
3. Implement uniform collection, analysis, and dissemination of biological and economic information; improve understanding of the economics of harvest;
4. Maintain existing social and cultural features of the industry wherever possible;
5. Promote economic efficiency in harvesting and use of the resource;
6. Minimize lobster injury and discard mortality associated with fishing;
7. Increase understanding of biology of American lobster, improve data, improve stock assessment models; improve cooperation between fishermen and scientists;

8. Evaluate contributions of current management measures in achieving objectives of the lobster FMP;
9. Ensure that changes in geographic exploitation patterns do not undermine success of ASMFC management program;
10. Optimize yield from the fishery while maintaining harvest at a sustainable level;
11. Maintain stewardship relationship between fishermen and the resource.

Amendment 3 defines overfishing for the American lobster resource to occur "when it [any stock] is harvested at a rate that results in egg production from the resource, on an egg-per-recruit basis, that is less than 10% of the level produced by an unfished population" (ASMFC, 1997). The primary management measures used to prevent overfishing include a minimum size, protection of ovigerous females, and trap limits.

Amendment 3 established a framework for area management, which includes industry participation through seven Lobster Conservation Management Teams (LCMT). LCMTs were encouraged to develop recommendations for a management program, which suits the needs of the area while meeting targets established in the plan. The Board adopted a three-phase approach to incorporate the LCMT recommendations, which involved three addenda to Amendment 3. Addendum I incorporated measures from the LCMT proposals directed at effort control. After consideration of the stock assessment and peer review results in ASMFC (2000), the Board initiated the development of Addendum II in August 2000 to continue implementation of the 1998 LCMT proposals. Addendum III incorporates the alternative management measures presented to the Board for the purposes of meeting F10% by calendar year 2008.

Addendum IV address four different issues of lobster management: a proposal from the Area 3 LCMT; concern about stock conditions in Area 2; new information about vent selectivity; and a desire to change the interpretation of the most restrictive rule.

American lobster Addendum IV outlines a transferable trap program for Area 3. This program allows Area 3 lobster fishermen to transfer trap tags to other lobster fishermen. Along with other measures, the addendum Area 3 transferability program establishes an overall trap cap and conservation taxes for transferring traps.

Addendum IV includes an interim benchmark goal based on survey information and a Total Allowable Landings to be used as a performance measure. This Addendum includes an effort control program and gauge increases for Area 2.

Addendum IV changes the circular vent size requirement from 2 1/2 inches to 2 5/8 inches. In addition, vent sizes of 2 1/16" rectangular and 2 11/16" circular are required for those LCMA's (LCMA 3, 2, OCC) that have scheduled increases to a 3 1/2" minimum legal carapace length.

Addendum IV applies the most restrictive rule on an area trap cap basis without regard to the individual's allocation. Fishermen who designate multiple management areas on their permits are bound by the most restrictive management measures of those areas' trap caps. They are allowed to fish the number of traps they are allocated in that most restrictive area.

Addendum V amends the overall trap cap set by Addendum IV based on comments gathered at public hearings expressing concern that the overall trap cap of 2600 may be too high. Addendum V includes an overall trap cap of 2200 with the higher tax imposed when the purchaser owns 1800 to 2200 traps.

Addendum VI replaces two of the effort control measures of Addendum IV, permits and eligibility period. No new Area 2 permits will be distributed after December 31, 2003 and to qualify for an Area 2 permit endorsement, a permit holder must document landings between January 1, 1999 and December 31, 2003.

Addendum VII established a multi-state effort control program for Lobster Conservation Management Area 2 that governs traps fished in state and federal waters to cap effort (traps fished) at 2003 levels and allows adjustments in traps based on future stock conditions. The plan limits participation to permit holders who have been active in the fishery in recent years, creates permit-holder specific trap limits that are unique and based on reported traps fished and landings, and establishes a transfer program that allows the transfer of trap allocations with a conservation "tax".

Addendum VIII established reporting and monitoring requirements, which were replaced by addendum X. Addendum X requires at least 10% harvester reporting and 100% mandatory dealer reporting. It also established fishery independent monitoring requirements. Addendum VIII also established new reference points recommended by the 2005 assessment and peer review report.

Addendum IX set a 10% conservation tax for LCMA 2 trap allocation transfers. Addendum XI incorporates rebuilding measures in response to the 2005 assessment finding that the SNE stock is depleted and overfished. It also implements delayed implementation measures which create a species-specific mechanism of ensuring that a state meets its obligations under the plan in a way that minimizes the probability that a state's delay in complying does not adversely affect other states' fisheries or conservation of the resource. Table 1.2 summaries the current regulations used to manage the seven LCMAs.

Addendum X established a coastwide reporting and data collection program that includes 100% dealer and at least 10% harvester reporting, at-sea sampling, port sampling, and fishery-independent data collection replacing the requirements in Addendum VIII.

Addendum XI established measures to rebuild SNE stock, including a 15-year rebuilding timeline (ending in 2022) with a provision to end overfishing immediately. The Addendum also establishes measures to discourage delayed implementation of required management measures.

Addendum XII established measures for a trap transfer program. In order to ensure that the various LCMA-specific effort control plans remain cohesive and viable this addendum does three things. First, it clarifies certain foundational principles present in the Commission's overall history-based trap allocation effort control plan. Second, it redefines the most restrictive rule. Third, it establishes management measures to ensure that history-based trap allocation effort control plans in the various LCMAs are implemented without undermining resource conservation efforts of neighboring jurisdictions or LCMAs. Addendum XIII solidified the transfer program for OCC and stops the current trap reductions. Addendum XIV alters two aspects of the LCMA 3 trap transfer program. It lowered the maximum trap cap to 2000 for an individual that transfers traps. It changes the conservation tax on full business sales to 10% and for partial trap transfers to 20%. Finally, Addendum XV established a limited entry program and criteria for Federal waters of LCMA 1.

Addendum XVI established new biological reference points to determine the stock status of the American lobster resource (fishing mortality and abundance targets and thresholds for the three stock assessment areas). The addendum also modifies the procedures for adopting reference points to allow the Board to take action on advice following a peer reviewed assessment.

Addendum XVII established a 10% reduction in exploitation for LCMAs within Southern New England (2, 3, 4, 5, and 6). Regulations are LCMA specific but include v-notch programs, closed seasons, and size limit changes. Addendum XVIII reduced traps allocated by 50% for LCMA 2 and 25% for LCMA 3. Addendum XIX modifies the conservation tax for LCMA 3 to a single transfer tax of 10% for full or partial business sales.

Through Addendum XX, the American lobster offshore pot fleet fishing in Closed Area II developed an agreement with the groundfish sector to prevent gear conflicts and protect concentrations of ovigerous female lobster. The two industries drafted an agreement that would give equal access to the area.

The Board directed the Plan Development Team (PDT) to scale the size of the SNE fishery to the size of the resource in the SNE stock. The PDT drafted an addendum that addressed this issue with trap reductions and changes to the transferability programs. The Board split the addendum, with the trap reductions addressed through Addendum XVIII (approved 2012) and this Addendum (XXI) addressing changes in the transferability program for Areas 2 and 3. Previously, the most recent transferability rules were established in Addenda XII and XIV. This Addendum modifies some of the rules contained in Addenda XII and XIV, as well as establishes additional guidelines. Further modifications to the single and aggregate ownership caps for Area 3 will be considered under Draft Addendum XXII.

Addendum XXII is the third in a series of addenda that respond to the depleted condition of the Southern New England (SNE) lobster resource by scaling the capacity of the SNE fishery to the size the SNE resource. It implements Single Ownership and Aggregate Ownership Caps in Lobster Conservation Management Area 3 (LCMA 3, federal waters). These measures are intended to enhance the ability of lobster business owners to plan for their future fishing operations as trap reductions are initiated. Addendum XXIII permitted LCMA 3 lobster fishermen or companies to have their trap allocations reduced by 5% per year for five years. The Single Ownership Cap allows LCMA 3 permit holders to purchase lobster traps above the trap cap of 2,000 traps. Any traps purchased above the trap cap may not be fished until approved by the permit holder’s regulating agency once the trap reductions commence. This will allow permit holders to maintain a profitable business over the course of the trap reductions while reducing latent effort (i.e. unfished traps) in the fishery. The Aggregate Ownership Cap limits permitted

LCMA 3 lobster fishermen or companies from owning more traps than five times the Single Ownership Cap, unless the permit holder had the ability to purchase a higher amount prior to NOAA Fisheries publishing a present day control date. Similar management caps were approved for LCMA 2 in August 2013.

Addendum XXIII updates Amendment 3's habitat section to include information on the habitat requirements and tolerances of American lobster by life stage.

Addendum XXIV aligns state and federal measures regarding trap transfer measures. Specifically it removes the 10% conservation tax when whole fishing businesses are transferred, sets a minimum 10 trap allocation transfer increment, and allows transfers between states among permit holders who are authorized to fish both state and federal waters within a single lobster management area. Table 1.2 summaries the current regulations used to manage the seven LCMAs.

1.3 ASSESSMENT HISTORY

The models used to assess American lobster stocks since 1992 (NEFSC 1992; NEFSC 1993; NEFSC 1996; ASMFC 2000) are length cohort analysis, the Collie-Sissenwine (a.k.a. modified DeLury) model, and the life history (a.k.a. egg production per recruit or EPR) model. The Collie-Sissenwine model (CSM) was used to estimate abundance and fishing mortality rates in the stock using landings and bottom trawl survey data. The life history model was used to estimate egg production per recruit reference points such as F10%, the fishing mortality rate that allows female lobster recruits opportunity, on average, to spawn 10% of the number of eggs that would be spawned in the absence of a fishery. The F10% reference point was used in lobster stock assessments to determine if overfishing was occurring until ASMFC 2000. Previous stock assessments generally concluded that fishing mortality rates were high for lobster and above the F10% reference point in particular, especially in near shore regions that are heavily fished.

Early in 1996, a Lobster Review Panel was convened by ASMFC and NMFS to provide advice on stock structure, stock assessment, abundance changes, management, and benthic ecology (ASMFC 1996). The Panel concurred with NEFSC's (1996) conclusion that the lobster resource was overfished (F> F10%) in all areas. The Panel endorsed the stock assessment methods and stock definitions used by NEFSC (1996) and made a number of recommendations for future research and development.

Conclusions and recommendations from the 2000 assessment (ASMFC 2000) were similar to conclusions and results from previous assessments. Overfishing was occurring in all three stock areas (i.e. recent fishing mortality rates > F10%) according to the overfishing definition in the Fishery Management Plan for American lobster (ASMFC 1997). Stock assessment committee members agreed that all three stocks were subject to growth overfishing, the fishing mortality rate that maximizes yield in weight per recruit. At that time, the abundance and recruitment levels were high and the majority agreed that recruitment overfishing was not occurring. At that time, a number of new assessment approaches were investigated for American lobster. A panel of reviewers (ASMFC 2000b) generally supported results and conclusions from the 2000 assessment (ASMFC 2000), but noted serious shortcomings in biological and fishery data used to assess the stock, and recommended further work on new modeling approaches.

In preparation for the 2006 assessment, the American Lobster Stock Assessment Model Technical Review panel (ASMFC 2004) evaluated the CSM model and three new potential modeling approaches for lobster based on simulation analyses. Problems were identified in all three new approaches and shortcomings in biological and fishery data were noted. The 2004 Model Review Panel recommended that the University of Maine model, a forward-projecting size-based approach that tracks numbers of lobster in a range of size groups by sex, season, and year in addition to estimating yield and spawning biomass per recruit reference points (Chen et al. 2005a), be implemented for the entire lobster stock once the necessary data became available and when analysts could demonstrate sufficient information content in the size data. The 2006 Peer Review Panel also recommended using the University of Maine model because it provides a better foundation for incorporating size composition data from multiple sources simultaneously, capturing the seasonality of the fishery and the lobster life history, and providing a comparable estimate of fishing mortality and reference points. Based on these recommendations the technical committee moved forward in the current assessment using a modified University of Maine model (ASMFC, 2006).

The 2006 peer-reviewed stock assessment report, which included data through 2003, indicated the American lobster resource presents a mixed picture, with stable stock abundance throughout most of the GOM and GBK, low abundance and recruitment in SNE, and decreased recruitment and abundance in Massachusetts Bay and Stellwagen Bank, (statistical area 514). Of particular concern was SNE, where depleted stock abundance, low recruitment, and high fishing mortality rates had led the Peer Review Panel to call for additional harvest restrictions. One of the short comings of the biological reference points was that the status of each stock is solely based on comparison with a relatively recent 20 to 22-year trend. Trends for a suite of indicators were also examined for the same time period (1982 to present). Abundance of the GOM stock overall was relatively high compared to the 22-year time series. Fishing mortality was low compared to the past. Recruitment and post recruitment abundance for the southern GOM (statistical area 514) declined to historical lows. The GBK stock appeared to be stable; current abundance and fishing mortality were similar to their medians for the 22-year time series. The SNE stock abundance was relatively low compared to the 20-year time series and fishing mortality was relatively high.

For the 2009 peer-reviewed stock assessment, the University of Maine statistical catch-at-length model was used to estimate abundance and mortality of male and female lobster by size for each stock unit. The Collie-Sissenwine model (CSM) used in the 2006 assessment was updated as well for continuity purposes. In addition, trends in a suite of non model-based stock status indicators of mortality, abundance, and fishery performance were examined using a “traffic light approach.”

The 2009 report indicated the American lobster resource presents a mixed picture, with record high stock abundance and recruitment throughout most of the Gulf of Maine (GOM) and Georges Bank (GBK), continued low abundance and poor recruitment in Southern New England (SNE), and further declines in recruitment and abundance in NMFS Statistical Area 514 (Massachusetts Bay and Stellwagen Bank) since the last assessment.

Abundance of the GOM stock overall was at a record high compared to the 26-year time series. Recent exploitation rates had been comparable to the past whereas recruitment has steadily increased since 1997. Abundance of the GBK stock was at a record high compared to the 26-year time series and recent exploitation rates are at a record low. Recruitment had remained high in GBK since 1998. Sex ratio of the population in recent years was largely skewed toward females (~80% from 2005 to 2007). The Technical Committee noted the stock could experience recruitment problems if the numbers of males in the population are low. The Peer Review Panel noted particular concern regarding the status of the stock throughout the SNE assessment area and within Area 514 and recommended that further restrictions are warranted for both areas. The assessment showed current abundance of the SNE stock is the lowest observed since the 1980s and exploitation rates have declined since 2000. Recruitment has remained low in SNE since 1998. The assessment recommended revisions to the set of reference points used in the previous assessment (ASMFC 2006) for management of American lobster stocks but these recommendations were not approved by the management board.

2.0 LIFE HISTORY

2.1 CRITICAL COMPONENTS OF LOBSTER HABITAT

[*Portions excerpted from Addendum XXIII to the ASMFC Lobster Fisheries Management Plan: Habitat Considerations, written by Jason Goldstein, 2013*]

Habitat components which play a vital role in reproduction and growth, and therefore the long-term sustainability of lobster fisheries, include temperature, salinity, dissolved oxygen, pH, light and photoperiod, substrate, and diet. The first four habitat components play the largest role in stock sustainability (see summary in Table 2.1.1). The potential effects of all habitat components on stock status are discussed below.

Temperature

Temperature is the primary driving force influencing lobster metabolism, activity levels, spawning, development, growth, and possibly life span (Hawkins 1996, ASMFC 1997). Lobster of all life-stages are reported to live in areas that range broadly in water temperature from -1° C to over 25° C (Aiken and Waddy 1986, ASMFC 1997). It is the broad range in temperature regimes observed across their range that causes the significant variability in population vital rates such as growth, maturation, and recruitment.

Temperature is the key factor that determines the length of time females carry eggs and when eggs will hatch (Templeman 1940, Perkins 1972, Aiken and Waddy 1980, Tlusty et al. 2008, Goldstein 2012). Egg hatching typically occurs when surface water temperatures are generally above 12° C (MacKenzie 1988), varying between June-September depending on the region. After hatching, larval lobsters pass through four stages, a process that is usually completed in 25-35 days (Herrick 1896, see Table 1 in Templeman 1940). However, their pelagic duration is

highly temperature dependent (MacKenzie, 1988), and it has recently been suggested that it can be markedly shorter than previously thought (Annis et al. 2007). If larvae hatch at 10° C they can develop successfully through Stages I and II; however, beyond that, warmer water is needed to complete their development to Stage IV and the early benthic phase, Stage V (MacKenzie, 1988). Water temperature had a direct effect on the total cumulative survivorship to Stage IV, whereby 4%, 56%, 64%, 68%, and 47% survivorship was observed at 10° C, 12° C, 15° C, 18° C, and 22° C respectively (MacKenzie 1988). The temperature range observed with the highest survival rates also corresponds with the temperature range at which larval duration is shortest (MacKenzie 1988, Templemen 1940). Similarly, Sastry and Vargo (1977) reported significantly lower survivorship to Stage V at 10° C.

Differences in temperature also can influence growth patterns such as onset of molting in juveniles or the start or spawning in adults (Little and Watson 2005). Variations among thermal regimes have been documented to influence size at maturity and overall somatic growth (Estrella and McKiernan 1989, Little and Watson 2005, Wahle and Fogarty 2006, Bergeron 2011). There is a strong influence of water temperature on all aspects of reproduction, including maturation, spawning, molt cycle, oogenesis and hatching (see Waddy and Aiken 1995 for review). While elevated temperatures accelerate the onset of reproductive maturity, low temperatures tend to delay ovarian maturation (Templeman 1936, Waddy and Aiken 1995). Adult lobsters respond to even small changes in temperature (Crossin et al. 1998, Jury and Watson 2000) both behaviorally (e.g., movement) and physiologically (e.g., changes in cardiac cycle) (McLeese and Wilder 1958, Worden et al. 2006). Crossin et al. (1998) showed that lobsters tend to avoid water temperatures below 5° C and above 18° C and exhibit a thermal preference of 15.9° C. A similar value of 16.5° C was also found by Reynolds and Casterlin (1979).

Recent laboratory work on lobsters in Long Island Sound (LIS) has shown that as water temperature increased beyond a threshold of ~ 20.5° C, the respiration rate of lobsters increased significantly leading to stress as indicated by marked hemolymph acidosis (Powers et al. 2004, Dove et al. 2005). Lobsters held at 21° C and 23° C had significantly higher respiration rates than those held at 18º C and 19.5° C (Powers et al. 2004). A key point is that lobsters exposed to seawater temperatures below 20° C are not generally stressed as long as oxygen concentrations remain > 2 mg O_2L^{-1} and, recent work with lobsters in LIS confirmed that water temperatures > ~ 20.5° C induced respiratory stress (Powers et al. 2004, Dove et al. 2005) and depression of immunocompetence (Dove et al., 2005; Steenbergen et al., 1978). Thus, 20.5° C appears to be a key physiological threshold value for lobster. Temperature has direct effects on physiological processes such as gas exchange, acid-base regulation, cardiac performance, and protein synthesis among others that can negatively affect these animals under stressful thermal conditions (Whiteley et al. 1997). Prolonged exposure to water temperature above 20° C has also been linked to increased incidence of disease including epizootic shell disease (Glenn and Pugh, 2006) and a newly described disease, excretory calcinosis (Dove et al., 2004).

Salinity

Lobsters can be found inhabiting shallow coastal areas, bays, estuaries and subtidal areas where they are frequently subjected to conditions of dramatic fluctuations in salinity (e.g., spring run-off and large storm events). In general, the capacity to osmoregulate when exposed to low salinity varies with developmental stage, and the ability to osmoregulate is heavily influenced by temperature (Charmantier et al. 2001). Energetic demands on juvenile and adult lobsters engaged in osmoregulation influence their distributions and movements, particularly in estuarine habitats (Watson et al. 1999) and as a result, adult lobsters adopt behavioral strategies to avoid low salinity (Jury et al. 1994a,b).

Dissolved Oxygen
Lobsters require more oxygen as water temperature increases and hypoxic waters become more stressful as waters warm. For larvae, dissolved oxygen (DO) concentrations < 1.0 mg O_2/L and pH levels < 5.0 and > 9.0 are lethal (Ennis 1995). The lower lethal oxygen level for juveniles and adults ranges from 0.2 mg O_2/L at 5° C to 1.2 mg O_2/L at 25° C in 30 ppt (Harding et al. 1992). A study conducted in western Long Island Sound (WLIS) showed that in general, lobsters demonstrated a behavioral avoidance of DO levels < 2 mg/L, a lower critical threshold than other finfish and squid (Howell and Simpson 1994). During a severe hypoxic event in 1999 in WLIS, large congregations of lobsters were documented near the edges of hypoxic zones where DO was > 2 mg/L, having moved away from areas with lower DO (see review in Pearce and Balcom 2005). Prior to molting, juveniles and adults become more susceptible and sensitive to low DO as oxygen consumption peaks at molting (Penkoff and Thurberg 1982) and molting lobsters have been found to be less resistant to high temperature, low DO and salinity than lobsters during intermolt periods (Waddy et al. 1995). Because *H. americanus* exhibits prolonged maternal care of its brood (e.g., ventilation and fanning of eggs), it is probable but not documented that ovigerous females require different conditions to successfully carry egg clutches through to hatch and may select habitats that contain sediments providing a high rate of oxygen exchange (e.g., Dungeness crabs, Stone and O'Clair 2002).

Ocean Acidification
Ocean acidification resulting from the global increase in atmospheric CO_2 concentration may become an emerging threat to American lobster through detrimental impact on larval development. Development of newly hatched *H. americanus* larvae (Hall and Bowden 2012) as well as larvae of the congener *H. gammarus (*Arnold et al. 2009) cultured in acidic seawater exhibited compromised exoskeletons (disruption of the calcification process) and decreased carapace masses.

Light and Photoperiod
Daily rhythms in lobsters are influenced by endogenous circadian clocks, synchronized to natural light:dark cycles (Lawton and Lavalli 1995). For pre-ovigerous adult females, reproduction seems to be regulated by photoperiod when temperatures rise above a minimum threshold; photoperiod becomes the overriding factor when winter water temperatures remain elevated (Hedgecock 1983, Aiken and Waddy 1980). In a field study of Long Island Sound lobsters, Weiss (1970) found that light intensity strongly affected burrow occupancy and foraging behavior. Juvenile lobsters usually stayed in their burrows whenever ambient light intensity exceeded 0.04 μWcm^{-2}.

Substrate
Post-larvae utilize a variety of habitat types (e.g., nearshore rocky areas, offshore canyons, enclosed embayments, estuaries) that differ in their abiotic and biotic features over spatial and temporal scales (Wahle 1993, Wilson 1999, Wahle et al. 2013). Although subtidal cobble beds are largely considered preferred settlement areas (Wahle and Steneck 1991), the plasticity in substrate settlement choice remains broad (Caddy 1986) and selection of substrate types is a complex process (Boudreau et al. 1990, Cobb and Wahle 1994, Wahle and Incze 1997). Howard and Bennett (1979) and Pottle and Elner (1982) found that lobsters tend to choose gravel rather than silt/clay substrates. Cobb et al. (1983) and Able et al. (1988) found postlarvae settle rapidly

into rock/gravel, macroalgal-covered rock, salt-marsh peat, eelgrass, and seaweed substrates. Wahle et al. (2013) observed recently settled lobsters as deep as 80 m, although most were abundant above the thermocline (typically < 20m, Boudreau et al. 1992) in summer-stratified regions (e.g., W. Gulf of ME and S. New England); likewise, depth-related differences were diminished in thermally mixed waters. In the absence of shelter juvenile lobsters require substrate that they can manipulate to form a shelter, especially YOY lobsters (Lawton and Lavalli 1995). The need for specific shelter size may be resolved by the lobster's ability to manipulate its environment, resulting in the construction of suitable shelter from otherwise uninhabitable substrate. Based on tag returns (Geraldi et al. 2009), lobsters that were initially caught and released on barren sediment moved farther and faster than those initially caught in traps on rocky substrate. Complex hard-bottom areas between soft-sediment patches (e.g., eelgrass beds) can serve as corridors and passageways (see Micheli and Peterson 1999) for decapod crustaceans engaged in short- or long-term movements (Selgrath et al. 2007).

Diet

Lobsters forage among a wide spectrum of plants and animals that include crustaceans, mollusks, echinoderms, polycheates, macroalgae, and plankton. The natural diet of larval and postlarval lobsters includes the wide variety of phytoplankton and zooplankton available to them (Ennis 1995). Zooplankton has been shown to provide an adequate diet for the growth and survival of shelter-restricted juveniles and supplements the diet of emergent phase juveniles (Barshaw 1989, Lavalli 1991). Lobsters are known to temporally shift their diet depending on season or habitat (Elner and Campbell 1987, Conklin 1995) and are considered keystone predators, capable of driving the trophic dynamics in many benthic communities (Mann and Breen 1972). There is typically peak feeding activity for adults between June and July; feeding activity then remains high in September even as temperatures begin to fall, and females maintain a higher level of feeding activity than males, at least until mid-February (Lawton and Lavalli 1995). Given the widespread use of baited traps, it is very likely that the nutritional value of this food source plays a significant role in habitat selection in some areas. Since many lobsters enter and vacate traps repeatedly (Jury et al. 2001), it is likely that most lobsters feed from traps before they are finally captured. In areas of intense fishing pressure, trap bait may provide a significant energy subsidy, supplementing the natural food resources available on lobster grounds (Lawton and Lavalli 1995, Grabowski et al. 2010).

2.2 TEMPERATURE EFFECTS AND CHANGING CLIMATE CONDITIONS

Temperature has a pervasive and direct influence on all aspects of lobster life history (see section 2.1. for complete details) The broad range in temperature regimes observed across their geographic range causes significant spatial variability in population vital rates such as growth, maturation, and recruitment. Similarly, changes in temperature regimes over time are likely to introduce substantial variability in these key vital rates and will likely challenge equilibrium assumptions underlying most population models and biological reference points.

The North Atlantic Ocean has undergone significant and widespread warming over the last century (Trenberth et al. 2007, Friedland and Hare 2007, Belkin 2009). In the Gulf of Maine a 1° C increase in the annual mean sea surface temperature has been observed since 1880 (Sherman and Lentz 2010). Nixon et al. (2004) reported that summer sea surface temperatures

(SST) in the 1990's at Woods Hole, MA were 1° C warmer then SSTs recorded during the time span of 1890 - 1970. On the Northeast Shelf the rate of warming has increased over last 35 years with net increases ranging from 0.23° C to 0.31° C (Belkin 2009, Nye 2010, Sherman et al. 2013).

This warming trend has been particularly pronounced within the coastal waters of New England since the late 1990's. In the Gulf of Maine annual deviations from the time series mean (1960 to 2012 mean = 9.1° C) in SST at Boothbay Harbor, Maine have exhibited a strong positive trend recently, with deviations of more than 1°C above the mean in eight of the last eleven years (Figure 2.2.1a). Similar, albeit less pronounced anomalies in SST mean temperature (1960 to 2014 mean = 11.4° C) are seen in Southern New England at Woods Hole, MA (Figure 2.2.1b).

Although changes in annual mean temperatures are instructive for describing overall regional trends, they do not provide sufficient context relative to changes in thermal habitat for American lobster. A better indicator of thermal habitat for cold-blooded marine animals is the amount of time the temperature remains within the species' preferred temperature range (Taylor et al. 1956, Nye 2010.) Warming of the Northeast shelf has dramatically altered thermal habitat and has led to changes in abundance, poleward shifts, and increases in depth distribution for many species including; cod, red hake, yellowtail flounder (Nye et al. 2009), black sea bass, and scup, (Bell et al. 2014). Depending on the thermal preferences of the species and the latitude of the region in question, warming can have both positive and negative effects on thermal habitat. Changes in thermal habitat for American lobster were first noted by Taylor et al. (1956) who documented declines in catch in Southern New England and increases in catch in the Gulf of Maine from 1900 to 1950 in association with warming trends in both regions. More recently Fogarty et al. (2007) suggested habitat contraction and population declines in SNE in relation to an increase in the number of days water temperature exceeded 20° C, concurrently with habitat expansion and population increases in the GOM in relation to an increase in the number of days water temperature exceeded 12° C.

Increasing water temperatures in the NW Atlantic have likely led to major changes in lobster life history, including smaller size at maturity as evidenced by roughly a 5 mm shift in the observed minimum size of egg-bearing females observed in the commercial catch (MEDMR, NHF&G, MADMF unpublished data, Pugh et al. 2013), changes in distribution of adults (ASMFC 2010 and see Section 4.2.1.3, Figures 4.2.1.3.3.1 and 4.2.1.3.3.2), and changes in mean growth increment (DNC 2013). These changes can be both positive and negative and likely have had significant influence on recruitment and natural mortality. We propose that the optimum temperature range for lobster recruitment is from 12° to 18° C. The lower bound 12° C is the minimum temperature required for larvae to develop beyond Stage I (MacKenzie 1988), as well the minimum temperature necessary for planktonic lobster larvae to recruit to the benthos (Annis 2005, Annis et. al. 2013). Additionally, MacKenzie (1988) found substantial increases in total cumulative survivorship to Stage IV for larvae held at fixed temperatures between 12° to 18° C, as compared to larvae held at temperatures above or below this range. The upper bound, 18° C, also represents the temperature threshold that, once exceeded, adult and juvenile lobsters actively avoid (Crossin et al. 1998).

In the GOM the number of days that SST has been within the optimal range for lobster life history processes has increased substantially since the late 1990's (Figure 2.2.2). While trends in SST may be reflective of overall changes in ocean temperatures, one may reasonably question their applicability to a benthic organism like American lobster. Although continuous bottom water time series are shorter in length and do not provide the same degree of historical context, they do provide a good indicator of benthic habitat suitability in recent history. For example, the bottom water temperature at Manomet Point, MA (southern GOM; SA 514) at 18 m depth has exhibited strong positive anomalies from the time series mean since 2008 (Figure 2.2.3), indicating an increase in the duration of "optimal" temperature time periods for lobster life history processes since this time.

Southern New England (SNE) represents the southern extent of the geographic range of American lobster in coastal waters. As such the primary habitat constraint within this region is water temperature. Prolonged exposure to temperatures in excess of 20° C has been shown to increase physiological stress, decrease immune competence, increase rates of disease, and decrease rates of larval survivorship (see Section 2.1). Thus we propose 20° C as a temperature threshold and a possible mechanism behind increases in natural mortality in SNE. There has been a dramatic and widespread increase in the spatial range and duration of water temperatures above 20° C in the coastal waters of SNE, which have experienced a pronounced warming period since the late 1990's (Nixon et al. 2004, ASMFC 2010). Specifically, there has been a substantial increase in the duration of time (number of days) in the late summer when the mean bottom water temperature remains above 20° C. These trends were observed in sea-surface temperatures recorded in Woods Hole, MA (NOAA unpublished data) (Figure 2.2.4), as well as bottom water temperatures from upper Buzzards Bay (Cleveland Ledge 11m depth; MADMF unpublished data) (Figure 2.2.5) and eastern Long Island Sound (Dominion Nuclear Power Station, 11 m depth; DNC 2013) (Figure 2.2.6).

2.2.1 Relationship between temperature and recruitment

Continuous sea surface temperature readings recorded in Boothbay Harbor, ME from 1905-2012 were examined to determine the long term trend in daily average water temperature in reference to optimal and stressful thresholds for lobster (see Figure 2.2.2). Annual data were converted to

the number of days each year with a daily mean between 12° and 18° C. This optimal temperature time series showed a strong positive relationship with the summed indices of young-of-year (YOY) lobsters surveyed on the southern coast of ME (statistical areas 512 and 513 east; see Model-free Indicators Table 5.2.1.2D), accounting for 23% of the variance in YOY relative abundance ($F = 6.078$, $df = 18$, $p = 0.025$, Figure 2.2.1.1). When both the temperature and YOY time series were regressed separately against year to de-trend each time series, their resulting residual patterns were not strongly correlated ($r = 0.344$, $df = 18$, $p = 0.162$).

A much stronger relationship was evident between sea surface temperature trend (i.e. number of days annually with average temperature 12° - 18° C, smoothed with a 2-year average) and annual recruit-size (lobster ≤ 10 mm below minimum legal size) indices generated from the ME Trawl Survey catches (Figure 2.2.1.2). The annual number of days with optimal temperature, as described above, regressed with a 5-year lag (the approximate time it takes for a YOY lobster to reach recruit size), explained 70% of the variance in recruitment ($F = 31.61$, $df = 14$, $p = 0.0001$).

These two data sets were de-trended, as described above for YOY abundance and temperature, and then tested to determine if their pattern of change correlated independent of trend. The resulting significant correlation of their residual pattern ($r = 0.657$, $df = 12$, $p = 0.015$) strongly supports the argument that the duration of optimal temperature experienced during the first few years of a lobster's life is linked, if not directly causal, to ultimate recruit abundance.

The positive relationship between recruit abundance and number of optimal temperature days can be used to quantify the effect of temperature on resulting recruitment. The predicted recruitment pattern, resulting from the regression described above, has a significant positive slope of 1.83 ($R^2 = 0.38$, $df = 13$, $p = 0.015$), equivalent to 6% of the mean recruit index (mean = 31.04). This predicted slope indicates that recruitment from 2000-2012 increased on average 6% each year due to, or in synchrony with, the increase in the number of days with optimal temperature.

To examine coast-wide temperature trends, 46 years of daily averages in Boothbay from 1963 to 2011 were compared to similar data recorded at Woods Hole, MA. The correlation between the annual number of days within the "optimal" temperature range (12° to 18° C) at these two locations is significant and negative ($r = -0.49$, $df = 44$, $p = 0.0006$). It appears that as the number of days each year within the optimal temperature range declined in southern Massachusetts, the number of days in this temperature range increased in mid-coast Maine. The rate of increase in Boothbay surface water temperatures accelerated after 1999.

2.3 NATURAL MORTALITY

All assessment models are sensitive to the values chosen for natural mortality (M) and to the interaction between M and other parameters (Bannister and Addison 1986, Vetter 1988). Uncertainty in the nature of M for American lobster is compounded by the fact that aging techniques have not yet been fully developed and employed to determine a reliable maximum age for inshore and offshore stocks (see section 2.5). For this reason, previous assessments have adopted the convention of holding M constant over time and among all size and age groups (Quinn and Deriso 1999) based on life history criteria such as longevity, growth rate, and age at maturity (Pauly 1980, Hoenig 1983). American lobster's many traits fostering a relatively long life span and slow reproduction have led to the species' classification as "k-selected" with low natural mortality after the larval stage. A low and stable natural mortality rate seems reasonable for American lobster inhabiting stable environments in offshore canyons where they can attain very large size (>190 mm CL, Thomas 1973). A value of $M = 0.15$, based on an assumed maximum age of 20, was applied to all recruit and legal size lobsters in all early assessments (Fogarty and Idoine 1988, NEFSC 1993, 1996, 1999), as well as the most recent assessments (ASMFC 2006, 2009), except for the SNE stock where there was direct evidence of increased natural mortality after 1997. Research conducted by several institutions following a widespread die-off of lobsters in Long Island Sound in the fall of 1999 concluded that increasingly high water temperatures, in concert with hypoxia and possibly other environmental factors, were the cause of the die-off (Balcolm and Howell 2006).

Laboratory and field studies with American lobster have shown a preferred temperature range of 12° - 18° C, and a physiological stress response at temperatures exceeding 20° C (see section

2.1). There is a significant negative correlation between the annual relative abundance of recruit-size (10 mm CL below min size) lobsters, as measured in four fall surveys (NMFS_SNE, MA, RI, CT) from 1984-2009 and the annual number of days with average temperature above 20° C ($r = -0.572$) as recorded at the submerged intakes of Millstone Power Station (Figure 2.3.1). Regression of the residuals of recruit abundance over years versus residuals of duration of stressful temperature over years resulted in a significant positive trend ($df = 25$, $F = 10.67$, $p = 0.003$), giving further evidence of synchronization if not causation between the duration of stressful water temperature and resulting recruitment.

In light of this widespread change in habitat suitability for the SNE stock, as well as the documented mortalities in Long Island Sound, alternate runs of the University of Maine Model (UMM) were generated in the 2009 Assessment (ASMFC 2009) for the SNE stock using a 50% ($M = 0.225$) and 100% ($M = 0.30$) increase in the value of natural mortality for recent years 1998-2007. Following the 2009 assessment, alternative runs of the UMM were carried out for SNE to further address uncertainties about the assumed value of natural mortality (M) by determining which higher value of M during 1998-2007 would best fit the observed abundance-at-length and landings data, assuming $M = 0.15$ in 1984-1997 and a higher value thereafter. For each alternative run, the base M (0.15) was multiplied by values ranging from 1.1 to 3.0 in increments of 0.1 resulting in 20 alternative runs. Additional alternative runs were conducted assuming M in later years was 4, 5, and 6 times the base value of 0.15. The alternative model where M in later years was 1.9 times the base ($M = 0.285$) was the best fit, exhibiting the lowest total unweighted negative log likelihood, of all the model runs. These results showed that doubling the value of M in 1998-2007 allowed the model to better fit the observed data (Figure 2.3.2 and Table 2.3.1).

The negative relationship between recruit abundance and stressful-days (1984-2009, $R^2 = 0.40$, $df = 25$, $p = 0.0003$) can be used to quantify the effect of temperature on resulting recruitment. Regression of the predicted recruitment pattern based on the temperature pattern gives a significant ($R^2 = 0.47$, $df = 25$, $p > 0.0001$) negative slope of -0.396, equivalent to 3.8% of the mean recruit index (mean = 10.39, Figure 2.3.3). This predicted slope indicates that recruitment from 1984-2009 declined on average 3.8% each year due to, or in synchrony with, the increase in the number of days with stressful temperature.

The negative relationship between annual recruitment, as measured in the four SNE surveys, and the duration of stressful temperature (i.e. days with average temperature above 20° C as measured at Millstone Power Station) was used to develop a SNE-specific recruitment covariate as a sensitivity run for the model. An annual weighting factor based on the number of days with a mean bottom temperature > 20° C each year was developed (Table 2.3.2 and SNE basecase model). The model run using the temperature covariate fit the data better than the run with no covariate (see Table 6.3.4.3 and Figures 6.3.4.2 and 6.3.4.3), although it didn't fit as well as runs with cubic or quadratic covariates. This is due to the fact that the temperature weighting factor stabilized in recent years while recruitment has continued to trend downward. Further research is needed on this relationship.

2.3.1 Fish predation on lobster

Two information sources were available for the examination of predation on lobster by finfish: the NEFSC trawl survey data, and the more recent NEAMAP trawl survey data. The results summarized below were not incorporated into any modeling exercises, but are presented here as additional information on sources of natural mortality for lobster.

Stomach samples were taken from a wide range of potential lobster predators during 1982-2012 NEFSC winter, spring and fall bottom trawl surveys between Cape Hatteras and Georges Bank. Only 264 lobster were observed in the stomachs sampled. The top five lobster predators by frequency of occurrence were Atlantic cod, spiny dogfish, smooth dogfish, little skate and longhorn sculpin (Table 2.3.1.1).

Approximately 79,000 stomach samples were collected during spring and fall NEAMAP surveys from 2007-2012 in the Southern New England stock area between Cape Hatteras and Rhode Island. NEAMAP stations were located in state waters at depths usually less than 18 m (60 feet) but as deep as 37 m (120 feet) in some cases. The top five predators for lobster were winter skate, smooth dogfish, black sea bass, tautog and spiny dogfish (Table 2.3.1.2). Percentage of lobster by weight in the top five predators ranged from < 0.01% to 0.1%. Lobster ranked between 45 and 111 as prey for each predator (rank 1 is for the most common prey by weight in a predator's diet).

These extensive food habits datasets from NEFSC and NEAMAP bottom trawl surveys show little evidence of predation on lobster. However, NEFSC surveys were in federal waters deeper than typical habitat for small lobsters. NEAMAP surveys were carried out in relatively shallow state waters but not in juvenile habitats which were too shallow for bottom trawls. Also, NEAMAP surveys occurred when lobster abundance was relatively low in Southern New England. Thus, available finfish diet data may understate consumption, particularly for small juvenile lobsters.

2.4 SHELL DISEASE

Shell disease is characterized by lesions in the shell produced by external bacteria that digest the minerals in a lobster's shell. The disease is not contagious among individual lobster with intact shells (Chistoserdov et al. 2005, Quinn et al. 2012) and the suite of water-borne bacterial species associated with shell disease in the wild is similar from Maine to New York (Chistoserdov et al. 2005). Lab studies have shown that lobsters with shell disease can successfully molt out of the diseased shell and replace it with a new healthy one. Data gathered during a 3-year tagging study of commercially caught wild lobsters in Long Island Sound showed that approximately a third (38%) of lobsters tagged with shell disease were free of the disease when recaptured (N= 2,647 tag returns, CTDEP 2008). However, if the lesions penetrate completely through the shell, their immune system may become further compromised (Prince and Bayer 2005) and these lobsters may have difficultly extracting themselves from the old shell (Shields et al. 2012, Stevens 2009) and may die (Stevens 2009). Diseased lobsters, particularly females, have reduced growth increments relative to non-diseased lobsters (DNC 2013). Ecdysone, a hormone that controls the molting process in lobsters, has been found at levels well above normal in shell diseased lobsters, indicating that severe cases of the disease may interfere with normal molt schedules and also potentially impact reproduction in females (Laufer et al. 2005).

Calculating a specific mortality risk associated with shell disease alone is difficult. Since the disease is most prevalent and most severe in egg-bearing females, premature molting may cause undetected declines in reproductive success and egg survival. The ultimate cause of the disease is unknown, but it appears to be associated with environmental stressors affecting individuals that may be compromised in some way (Gomez-Chiarri and Cobb 2012, Shields et al. 2012). Several other health issues have been identified in Southern New England lobsters (Shields et al. 2012, Dove et al. 2004, Maniscalco and Shields 2006), which in conjunction with shell disease may point towards lethal and sublethal effects of stressful environmental conditions (Shields et al. 2012). Work by Wahle et al. (2009) shows that the addition of a variable associated with shell disease improves the relationship between YOY settlement and pre-recruit indices after 1997, which coincides with the timing of increased disease prevalence (as well as the occurrence of other observed health issues).

Shell disease prevalence has been monitored with increasing intensity over the past 30 years. The longest monitoring program began in 1984 by biologists studying the lobster population in the area surrounding Millstone Power Plant in eastern Long Island Sound (Figure 2.4.1, DNC 2013). The first record of the disease in that area was in 1988. However prevalence did not exceed 2% of the research trap catch until 1999 when the number of days with average bottom water temperature above 20° C exceeded 70 for the first time since records began in 1976. Every year after 1999 both disease prevalence and the number of days averaging >20° C have remained high.

Disease prevalence has increased in all Southern New England waters from Massachusetts to New York since the late 1990's, affecting up to 30% of observed animals in some years (Table 2.4.1). There is a strong correlation between annual prevalence in southern MA (SA 537-538) waters and in NY/CT Long Island Sound ($df = 10$, $r = 0.889$, $p < 0.001$). New Jersey has no monitoring program, however fishermen have reported very little incidence of disease in that state, and western Long Island Sound prevalence has never exceeded 1% of the observed commercial catch.

Monitoring programs began in Gulf of Maine states in the early 2000s. There is a south to north gradient of decreasing disease prevalence, with SNE lobster having the highest disease rates (2008 – 2013 average: 10.7% - 32.5%), followed by locations in the southern GOM (2.8%), with the lowest prevalence in New Hampshire and Maine waters (less than 1%, see Table 2.4.1). Shell disease was noted for the first time in Maine in April 2003 during Maine DMR field observations. During the 2003 and 2004 sampling season, 93 lobsters were recorded as having shell disease, which represented less than 0.05% of lobsters examined by Maine DMR staff. The largest number of shell-diseased lobsters were observed during a sea sampling trip in June 2004 when 22 of 426 lobsters sampled (5%) were scored as having shell disease. Shell-diseased lobsters were 0.02-0.6% of the catch annually observed by Maine DMR staff in 2005-2012 for the three southern statistical areas, and <0.05% in SA 467.

2.5 AGE

The American lobster is a long-lived species known to reach more than 18 kg (40 pounds) in body weight (Wolff 1978). The maximum age of American lobster is unknown because all hard parts are shed and replaced at molting, leaving no accreting material for traditional age determination. All previous assessments have estimated lobster age from per-molt growth increments and molt frequencies. Based on further assumptions regarding lobster molt probabilities, Cooper and Uzmann (1980) estimated that American lobster may live to be 100 years old.

Studies conducted in the United Kingdom (UK) have aged European lobsters using lipofuscin measurements from neural tissue (Sheehy and Bannister 2002). These researchers have concluded that changes in lobster carapace length (mm CL) explained less than 5% of the variation in true age for 41 European lobsters examined over 12 years. Moreover, Sheehy reported that molting was so erratic and protracted that European lobsters between 70-80 mm CL required at least five years to fully recruit to legal size (81mm CL) in the trap fishery off the UK (Sheehy et al. 1996). Sheehy's findings suggest that as many as five to eight year-classes, rather than two based on length frequencies, recruit to the European lobster trap fishery each year. American lobster brain tissue has been isolated and analyzed (Wahle et al. 1996) using a methodology similar to that of Sheehy (1996) for known-age animals up to two years old. Giannini (2007) continued this work and the results are consistent with other findings for lipofuscin concentrations in wild populations of crustaceans (Sheehy et al. 1995, 1998, Medina et al. 2000, Ju et al. 2003, Kodama et al. 2005, 2006). The addition of more known-age animals, especially of older ages, will greatly improve the predictive capabilities of this relationship.

Variability in lipofuscin in animals of the same carapace length can be due to differences in age as well as environmental factors such as temperature (O'Donovan and Tully 1996, Tully et al. 2000). The effect of temperature on lipofuscin concentration rate was not included in the Giannini (2007) study and would be expected to have an effect on the predicted age structure, especially in inshore versus offshore populations. For example, the brain of a wild lobster caught in an otter trawl south of Nantucket, Massachusetts, weighing 23 lbs and measuring 213 mm CL, was analyzed and resulted in a predicted age of 25 years (Giannini 2007). All of the wild-caught animals examined by Giannini were captured from Long Island Sound, minimizing confounding variability due to differing temperature regimes. Even within this fairly homogeneous group, animals one molt-group below the minimum legal size (72-83 mm) represented as many as eight year-classes. This large range in age over a small range of size for lobsters just below harvestable size is very similar to the range in age Sheehey et al. (1996) found in recruit-size European lobsters, and again highlights the probability that recruitment to the fishery for most lobster populations is far more protracted than the size frequency alone would indicate.

Most recently, Kilada et al. 2012 have asserted that growth bands are detectable in the endocuticle of the gastric mill of American lobster, and that routine measurements of growth may be possible. In 2013, the Maine Department of Marine Resources contracted with the University of Maine to conduct age and growth experiments over a five year period using the methodologies described by Kilada et al. (2012). The proposed study will look at newly settled, juvenile and adult populations over the course of the study, providing what is hoped to be a comprehensive evaluation of this methodology and update for ageing.

2.6 GROWTH

American lobsters, like all crustaceans, grow incrementally in distinct molting events called ecdysis. Although growth appears to take place entirely during the molt, lobsters actually spend much of their lives preparing for, or recovering from, molting (Waddy et al. 1995). Growth rates are affected by two separate components, the size increase per molt, or molt increment, and the frequency of molting. Molt increments are reported as a percent change in carapace length or as the actual change in carapace length per molt. Increments are usually measured from tagged and recaptured lobsters or from lobsters that molted and grew while held in captivity (including those in lobster traps). The frequency of molting is often reported as the probability of lobster at a given size molting in a given year, but is sometimes reported as intermolt duration (the time spent between molts).

Various factors are known to influence the frequency of molting and size of molt increments, such as nutrient availability (Castell and Budson 1974, Capuzzo and Lancaster 1979, Aiken 1980, Bordner and Conklin 1981), density of lobsters (Stewart and Squires 1968, Aiken and Waddy 1978, Van Olst et al. 1980, Ennis 1991), presence of larger more dominant lobsters (Cobb and Tamm 1974, 1975), or variations in temperature (Hughes et al. 1972, Aiken 1977).

In general, the frequency of molting increases with temperature (Aiken 1977). However this increased frequency can be countered by a reduction in molt increment. For example, blue crabs raised in warmer water were shown to have smaller molt increments (Leffler 1972). Comparison between molt increments of lobsters estimated from tagging studies in US offshore waters (Uzmann et al. 1977, Fogarty and Idoine 1988) and those measured in warmer areas (DNC 2008) indicates this also is true of adult lobsters. In addition, summer seawater temperature appears to have confounding effects on growth by decreasing the size at which lobsters become sexually mature (Templeman 1936, Estrella and McKiernan 1989, DNC 2008, see section 2.7.1). Mature females sacrifice somatic growth for ovarian development, and tend to molt on a slower (at least two-year) cycle, extruding eggs and molting in alternate years (Herrick 1911, Aiken and Waddy 1976). Some studies suggest that a proportion of mature females, particularly first time spawners, molt and extrude eggs during the same season (Aiken and Waddy 1976, 1980, Ennis 1980, Robinson 1980, Ennis 1984, Briggs 1985). The overall consequences of these competing temperature-related factors affecting the frequency of molting and the size of molt increments in females is that somatic growth is generally slower in warmer regions.

Recent work by Tang et al. (2015) would suggest that habitat type impacts lobster growth. They report that age three and four lobsters are larger in mud habitats than in cobble habitats. Direct age determination followed Kilada et al. (2012) methodologies. These results are intriguing as cobble bottom is generally considered a preferred habitat (Wahle and Steneck 1992) for lobster. If the lobster population expands into previously underutilized habitats, differential growth will again confound estimates. If the demographic bottleneck (Wahle and Steneck 1991) is released for lobsters, allowing occupation by vulnerable life stages in previously marginalized soft bottom habitats, and these habitats are advantageous for growth, current estimates for growth will again need to be evaluated.

2.6.1 Growth matrices

Growth transition matrices used in assessment modeling were updated for SNE and data for GOM and GBK were combined to estimate a single growth transition matrix for GOM, GBK and GOM&GBK. Growth calculations were separated by stock, quarter and sex. All growth calculations were carried out for pre-molt sizes in increments of 1 mm and then aggregated to 5 mm size groups for growth transition matrices used in the University of Maine Assessment Model (UMM).

Growth transition matrices are calculated in terms of molt increments (size increase per molt) and the probability of molting. Increments are usually measured from tagged and recaptured lobster or individuals that molted and grew while held in captivity or caught in traps. Mature females are thought to molt less frequently than males because eggs extrusion and molting cannot occur during the same year. In calculating growth transition matrices, lobsters were assumed to molt at the beginning of summer (July 1) with relatively small immature individuals molting again at the beginning of fall (September 1). See ASMFC (2009) for more information.

2.6.1.1 Molt Probability

Annual probabilities for lobsters in the main summer molt were calculated from logistic functions using parameters for female lobsters in GOM and SNE from ASMFC (2009) and for female and male lobsters in GBK from Fogarty and Idoine (1988) (Table 2.6.1.1.1). Molt probability was based on the same information in the last assessment but the calculations used in ASMFC (2009) were more complex in order to support a Life History Model (aka EPR model) which is no longer used. Molt probability curves for males and females in SNE and GOM were assumed to be the same for lack of better information. The molt probability curves for the combined GOM&GBK area were calculated by averaging curves for GOM and GBK using the mean number at-length per tow in NEFSC spring and fall bottom trawl surveys as weights.

Assessment model calculations include “double” molting by small immature lobsters in the fall, after the summer molt (Table 2.6.1.1.2). Annual probabilities for double molting in SNE were predicted values from a quadratic linear regression fit to figures on p. 73 in ASMFC (2000). Annual probabilities for GOM and GBK were calculated by fitting a quadratic linear regression to figures also on p. 73 in ASMFC (2000). Molting probabilities in the summer and fall differ but molt increment distributions were assumed to be the same.

2.6.1.2 Molt Increments

Molt increment models in this assessment are similar to those from the previous assessment (ASMFC 2009) but were fit to substantially more increment data for the SNE and GOM stock areas (Table 2.6.1.2.1 and Table 2.6.1.2.2). The additional data helped estimate the models directly with fewer assumptions. No new data were available for GBK but GOM and GBK data were combined for use in the GOM, GBK and GOM&GBK areas. Only data for pre-molt sizes ≥ 50 mm were used because 50 mm is the lower bound of the first size group in the UM model (although ASMFC (2009) used data for smaller lobsters).

The first step in using molt increment data was to identify and remove information from lobsters that did not molt, molted more than once, or were obviously errors. This was done by visually identifying minimum and maximum bounds for single molt increments and growth rates (increment/pre-molt size) in plots of both variables against pre-molt size and, where available, days at liberty (days between marking and recapture for tagged lobsters) (Table 2.6.1.2.3). Like ASMFC (2009), we used "broken stick" models for GOM and GOM&GBK with mean molt increment increasing linearly with pre-molt size until lobsters reach a threshold. After reaching the threshold, mean molt increment is constant. The mean molt increment model had three parameters for each sex and region. For a lobster starting at pre-molt size L:

$$\bar{I}_L = \begin{bmatrix} a + bL \; for \; L < f \\ \\ a + bf = k \;\; for \; L \geq f \end{bmatrix}$$

where $\bar{I}_L$ is the predicted mean increment, a is an intercept parameter, b is a slope, f is an inflection point and $a + bf = k$ is the maximum increment. The parameters a, b and f were estimated by fitting the model pre-molt size and increment data available for each sex and area. The new model for GOM predicts mean molt increments similar to those used in the last assessment and the new model for GOM&GBK predicts mean molt increments intermediate between GOM and GBK in the last assessment (see Table 2.6.1.2.1). Residual variances from the new models for each area were similar to variances in the previous assessment.

There was no evidence in the SNE molt data for an initial increase in mean increments or an inflection point so median molt increments (8 mm for females and 11 mm for males) were used for all pre-molt sizes (Table 2.6.1.2.2). The slope and inflection parameters could not be directly estimated in the last assessment but were approximated after making some assumptions. The new mean increment estimate was similar to the maximum increment in the last assessment (ASMFC 2009) (Table 2.6.1.2.2).

The distribution of molt increments around their mean is important in modeling growth. We used beta distributions $B(\alpha_L, \beta_L)$ and results from the mean molt increment model to describe this variability. The first step was to transform the predicted mean molt increment and variance of residuals from the model to proportions of the range between the minimum and maximum increments assumed in calculations (Table 2.6.1.2.3). The parameters α_L and β_L were calculated from the transformed mean and variance by the method-of-moments. Next, 10,000 random numbers representing transformed increments were drawn from $B(\alpha_L, \beta_L)$ for each 1 mm pre-molt size and converted back to the original scale. Finally, the starting size and final size (pre-molt size + increment) were assigned to size bins used in modeling to determine the distribution of post-molt sizes for each initial size group.

2.6.3 Growth Transition Matrices

Growth transition matrices used in the UMM reflect both molt probability and molt increment distributions for each pre-molt size group. Pre- and post-molt size groups in the model were 5 mm wide (i.e. 50-54.9, 55-59.0, …, 220-225 mm CL), where 5 mm is smaller than the assumed minimum molt increment in nature , so that all molting lobsters must exit their pre-molt size group. In quarters where no growth occurs, the transition matrices are all one along the diagonal because lobsters all stay in the same size group. In quarters where growth occurs, there are probabilities along the diagonal that reflect the probability that a lobster in a pre-molt size group did not molt or grow. The remaining probability for each size group is spread among the size groups reached by lobsters that molted. The probability for the post-molt size group adjacent to the pre-molt group will be zero if the minimum molt increment exceeds 10 mm. The distribution of molt increments is usually bimodal with a mode at the pre-molt size group for lobsters that did not molt and a mode at a larger size group for lobsters that molted.

Apparent growth is the mean and distribution of body size for a cohort at the beginning of the winter quarter in the years after recruitment with no fishing mortality. Apparent growth is automatically calculated by the assessment model and can be used to illustrate changes in growth assumptions and effects of mortality. For comparisons, we calculated apparent growth in preliminary UMM model runs for each stock using the new growth transition matrices. In a second run, we fixed the distribution of new recruits at their estimated values and recalculated apparent growth using growth transition matrices from the last assessment (ASMFC 2009). Results indicate that lobsters of both sexes in all areas are assumed to grow more slowly than previously and that the difference in assumptions is pronounced for SNE (Figure 2.6.3.1). The reduction in growth occurred because molt probabilities curves were assumed to apply to the entire population in this assessment. In the previous assessment, growth curves were calculated by increasing the molt probability for individuals that did not molt in the previous year, so that molt probability rates were effectively higher.

2.7 REPRODUCTION

American lobster, like many decapods, has a polygynous mating system, where a single male mates with multiple females, and a male's relative social dominance appears to be correlated to his mating success (Atema 1986, Cobb 1995). In this type of mating system, the female gametes (eggs) are generally considered to be the limiting resource, which suggests females should be protected from harvest. This has typically been the case in management of crustacean fisheries, with the purpose of protecting the spawning stock. However, when there is competition for mates and mate choice that affects fitness, intensive fishing may have a strong negative impact on reproductive success (Rowe and Hutchings 2003).

Recent research in several crustacean fisheries has suggested that the assumption of plentiful sperm may not be safe in certain circumstances (see, e.g. MacDiarmid and Butler 1999, Hines et al. 2003, Sato et al. 2005). Sperm limitation occurs when the amount or quality of sperm received by females is insufficient to fertilize the entire compliment of potential eggs. This could happen when there are an insufficient number of mature males, or when the males that are available cannot (or do not) provide enough sperm to their female partners. Thus if the sex ratio is too female-skewed, and/or the mature males present are all relatively small, the potential for sperm limitation exists. With regards to American lobster, Gosselin et al. (2003) reported that male size was related to female seminal receptacle load. More recent work suggests that sperm limitation may result from large discrepancies between the sizes of males and females or from highly skewed sex ratios coupled with a synchronous female molting period (Pugh 2014). There is now sufficient evidence in multiple commercially exploited crustacean species to suggest a need for heightened awareness of population size structure and sex ratio with regards to impacts on reproductive success (see MacDiarmid and Butler 1999, Hines et al. 2003, Sato et al. 2005, MacDiarmid and Sainte-Marie 2006, Sainte-Marie et al. 2008).

Reproduction in this species affects both annual egg production and growth, as female lobsters must trade-off between brooding eggs and molting. Generally, once a female has reached sexual maturity, it is assumed that she molts in one year, then broods and hatches a clutch in the next year, resulting in a biennial cycle of growth and reproduction (see Waddy et al. 1995 for review). As the female gets larger, the interval between molts increases, and females > 120 mm may skip molts to produce two clutches of eggs (Waddy and Aiken 1986). Changes in intermolt duration after sexual maturity affect the growth matrix that underlies the assessment model.

Fecundity is currently not implicitly utilized in the assessment process; instead it is assumed that because fecundity increases with female size (Herrick 1896, Estrella and Cadrin 1995), spawning stock biomass (SSB) is an appropriate substitute for estimating the reproductive potential of a stock. As such, SSB is included as a model-free indicator of stock health (see section 5.1.2).

2.7.1 Maturity

Determination of female size at maturity is critical not only to generating accurate estimations of SSB, but also to correctly estimating growth. Female size at maturity has been negatively correlated to warm summer water temperatures, such that higher summer temperatures lead to maturation at smaller sizes (see Waddy et al. 1995 for review, Little and Watson 2003; Watson et al. 2013). Fogarty (1995) and more recently Watson et al. (2013) reviewed maturity studies that defined geographic differences in size at maturity. Maturation at small size occurs in relatively warm water locations of the Gulf of St. Lawrence and inshore SNE (Aiken and Waddy 1980, 1986, Van Engel 1980, Estrella and McKiernan 1989, Landers et al. 2001, Comeau and Savoie 2002), while larger sizes at maturity have been documented along the Maine coast and into deeper, offshore Gulf of Maine waters as well as the Bay of Fundy (Krouse 1973, Campbell and Robinson 1983, Fogarty and Idoine 1988).

Maturity is most accurately determined by dissecting the female and determining the ovary stage, a technique that incorporates the color and weight of the ovaries, the size of oocytes within the ovary, and the female's body size (Aiken and Waddy 1980, Waddy and Aiken 2005). The ovarian staging methodology represents a highly accurate means of evaluating female maturity, but requires the sacrifice of the animal and the developing eggs. Cement gland staging was developed as an alternative technique which could be performed in the field without sacrificing the female (Aiken and Waddy 1982). Using this technique, the maturity stage is assessed based on the degree of engorgement of cement glands on the female pleopods. However, this method is only accurate when employed one to two months prior to spawning and produces spurious results outside this time frame (Waddy and Aiken 2005). There were also subsequent problems with stage interpretation and regional variability in results, which may have been due to geographic variation in the proportion of females that molt prior to spawning in a given year, as well as variation in the timing of molting and spawning within a season. These issues with cement gland staging prompted the ASMFC Technical Committee to declare that the more definitive ovarian staging procedure is the preferred standard.

Estimates of the proportion of females that were mature at given sizes have been derived from logistic regressions fit to proportion mature at-length data. A major shortcoming of this approach stems from management measures that tend to protect mature females from fishing once they reach legal size. Because of such protection the proportions of mature legal-sized females are artificially inflated as fishing differentially removes immature females. This results in a biased profile of the proportion mature-at-size above the minimum legal size.

Maturity ogives for each stock were derived primarily from data on ovarian and cement gland staging of lobsters collected from several locations in state waters of Maine (ME), Massachusetts (MA), Rhode Island (RI), and New York (NY). ME and NY studies used ovarian staging while the MA study (Estrella and McKiernan 1989) used cement gland development data which were verified with ovarian staging. The RI study combined ova stage 4 females (Aiken and Waddy 1982; determined based on ovary color as seen by external examination, ala 'candling') with ovigerous females as a maturity index.

All ogives were defined by the logistic function:

$$P_{matCL} = 1/1+e^{(\alpha+\ \beta*CL)}$$

Where P_{matCL} is the proportion mature at length (CL).

The specific method used to calculate the maturity ogive for each stock is described below. Parameter estimates for the final, average maturity ogives are:

Stock Area	α	β
GOM	27.243	-0.300
GBK	18.256	-0.183
SNE	14.288	-0.188

Gulf of Maine Female Lobster Maturity

In an attempt to account for geographic differences in female lobster sexual maturity within the Gulf of Maine (GOM) stock unit, maturity ogives from different portions within GOM were weighted by landings and combined to produce an average maturity ogive. Maturity ogives for three regions in the GOM were utilized. Two were based on ova diameter data collected by the state of Maine (Boothbay Harbor and Sorrento, ME). The third was based on several maturity indicators (D. Pezzack, Department of Fisheries and Oceans, Canada, personal communication) and represents the offshore section of the GOM (Brown's Bank, Canada).

Weighting factors were derived as proportions of the 2008 to 2012 mean GOM landings based on combined landings from statistical areas that are representative of where each maturity curve originated. The maturity curve from lobsters sampled around Boothbay Harbor, ME was used to represent the inshore southwest portion of the Gulf of Maine, and was weighted with the proportion of landings from statistical areas 513 and 514 combined. The maturity curve from lobsters sampled from Sorrento, ME was used to represent the inshore northwest portion of the Gulf of Maine, and was weighted with the proportion of combined landings from statistical areas 511 and 512. The maturity curve from lobsters sampled from Browns Bank, Canada is representative of the offshore Gulf of Maine, and was weighted with the proportion of combined landings from statistical areas 464, 465, and 515. The three weighted curves were then combined to create a maturity ogive representative of the entire GOM. A logistic function was used to fit the combined curve and to obtain the parameters ($\alpha = 27.243$, $\beta = -0.300$). The resulting combined maturity ogive is considered representative of the whole GOM stock unit, and estimates the size at 50% maturity to be 91 mm CL.

Georges Bank Female Lobster Maturity
The maturity ogive for the Georges Bank stock was based on ovigerous condition (adjusted for the interaction between growth and extrusion) of lobsters collected from northern Georges Bank (Cooper and Uzmann 1977, Fogarty and Idoine 1988). No weighting was applied, as this was the only maturity data source available. The estimated size at which 50% of females are mature is 100 mm CL.

Southern New England Female Lobster Maturity
In an attempt to account for geographic differences in female lobster sexual maturity within the Southern New England (SNE) stock unit, maturity ogives from different regions within SNE were weighted by landings and combined. Maturity ogives were available from five regions within the SNE assessment area. They are as follows; Long Island Sound based on a re-analysis ova diameter data from Briggs and Mushacke (1979), Buzzards Bay based on ova diameter adjusted cement gland data collected by the state of MA (Estrella and McKiernan 1989), the south shore of Long Island based on ova diameter data collected by the state of NY (Briggs and Mushacke 1980), Block and Hudson Canyons based on ova color determined by external observation (‘candling,’ see above) from lobsters collected by the state of RI, and Coastal Rhode Island Canyons (Statistical Area 539) based on ova color determined by external observation (‘candling,’ see above) from lobsters collected by the state of RI.

Weighting factors were derived as proportions of 2008 to 2012 average SNE landings based on combined landings from statistical areas that are representative of where each maturity curve originated. The maturity curve from lobsters sampled in the southern New England canyons was weighted with the proportion of landings from statistical areas 616 and 537 combined. The maturity curve from lobsters sampled in Buzzards Bay, MA was weighted with the proportion of landings from statistical area 538. The maturity curve from lobsters sampled in inshore RI waters was weighted with the proportion of landings from statistical area 539. The maturity curve from lobsters sampled in Long Island Sound (CT data) was weighted with the proportion of landings from statistical area 611. The maturity curve from lobsters sampled from the ocean side of Long Island, New York was weighted with the proportion of landings from statistical areas 612 and 613 combined. The five weighted curves were then combined to create a maturity ogive representative of the entire SNE. A logistic model was fit to the combined curve to obtain the parameters ($\alpha = 14.288$, $\beta = -0.188$). The resulting combined maturity ogive is considered representative of the whole SNE stock unit, and estimates the size at 50% maturity to be 76 mm CL.

Evidence for shifts in size at maturity

In most locations, it has been several decades since maturity data were last collected. Over this time period, climate change has resulted in warming ocean temperatures (see section 2.2) that likely impact lobster physiology. The size of ovigerous females has been decreasing near the Millstone Power Plant in eastern Long Island Sound since the 1980's, and the annual mean ABD:CL ratios have been increasing over the same time period, suggesting that females are maturing at smaller sizes (Landers et al. 2001, DNC 2013). In Massachusetts Bay, MADMF commercial trap sampling data showed an increase in the percentages of smaller females bearing eggs since the late 1980's, particularly evident in the 76 – 80 mm size class which has never been subject to fishing pressure (Pugh et al. 2013). Finally, Canadian researchers have documented decreases in the size at maturity for lobsters in some areas when recent data were compared to data from the late 1970's (J. Gaudette, DFO St. Andrews Biological Station, New Brunswick, Canada, personal communication). Due to the documented relationship between warmer waters and smaller sizes at maturity (see Waddy et al. 1995 for review, Little and Watson 2003; Watson et al. 2013), it is likely that warming trends have caused decreases in size at maturity throughout the lobsters' range, and updates to maturity data are strongly recommended (see Section 8.3).

2.8 GENETIC INFORMATION

Currently there is no strong evidence for genetically distinct or isolated subpopulations of American lobster, although some recent studies have reported slight differentiations at various geographic scales. At the relatively large scale, Kenchington et al. (2009) have reported that lobsters in northern regions (Nova Scotia northwards) have lower overall genetic diversity than lobsters found in the Gulf of Maine and southwards. These authors suggest colonization of the northern regions during post-glacial periods by a founder population as a likely explanation for this latitudinal difference in genetic diversity. In the northern part of the lobster's range, Harding et al. (1997) reported slight but non-significant differences in the genetic makeup of lobsters from the Gulf of Saint Lawrence compared to Gulf of Maine lobsters. Similar slight distinctions between Gulf of Saint Lawrence and Gulf of Maine lobsters were previously reported by Kornfeld and Moran (1989).

On a slightly smaller geographic scale in the southern portion of the range, Crivello et al. (2005b) documented differences between ovigerous females from Western Long Island Sound when compared to those from Eastern LIS, Central LIS, and Hudson Canyon (females from these three locations could not be genetically distinguished). The authors suggested that the differentiation of the Western Long Island Sound lobsters may be a recent event, resulting from the 1999 die-off, as the differentiation was much greater than would be expected based on any geographic separation among these groups. An interesting additional note of support to the premise that WLIS lobsters may be relatively isolated from the rest of LIS is the high immunocompetence of WLIS lobsters compared to ELIS lobsters (Homerding et al. 2012). These separate studies seem to support the idea that the genetic structure of WLIS lobsters is a result of selective forces producing a lobster adapted to the stressful environment of WLIS. Crivello et al. (2005a) reported that WLIS does receive larval input from maternal sources from more eastern LIS locations, as well as offshore areas, so persistence of the observed genetic differentiation over time will further support the contention that WLIS lobsters are uniquely adapted to survive in this environment at the southern extent of their inshore distribution.

Bordering ELIS, Rhode Island Sound lobsters represent a more distinct group based on preliminary data presented by Atema (J. Atema, Boston University, personal communication). This study suggests that lobsters from Maine, New Hampshire, and offshore areas are relatively well-mixed, while southern groups are more fragmented. However, none of these studies provide sufficient evidence to support incorporating genetic data into the definition of lobster stocks or sub-stocks for the purposes of fisheries management and stock status assessment. Genetics is still an emerging field for this species, and should be monitored closely in the future to assist with the understanding of stock structure and linkages. Reductions in the abundance of the Southern New England stock may have affected the genetic composition of the remaining lobsters, and the production of even more isolated groups of lobsters is probable as optimal habitat contracts due to climate change.

2.9 STOCK DEFINITIONS

In the 2009 Assessment (ASMFC 2009) American lobster were assessed as three distinct stocks; the Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE). Stocks for American lobster were differentiated on the basis of multiple factors including; regional rates of maturity and growth, size distribution, distribution and abundance trends of adults and juveniles, patterns of migration, location of spawners, the dispersal and transport of larvae, and considerations for large scale patterns in physical oceanographic processes (temperature regime and currents). The stock boundary lines fall along NMFS statistical reporting area lines, because this is the highest level of spatial resolution in which commercial catch data can be aggregated. Current stock definitions are described in terms of bottom trawl survey strata in Table 2.9.1 and in terms of statistical areas used to report landings in Table 2.9.2, and are mapped in Figure 2.9.1 (NEFSC survey strata).

A primary consideration for stock differentiation in the last stock assessment was evidence of the relative importance of inshore / offshore connectivity and individual movement rates along the coastline and continental shelf. However, due to population increases and shifts in size compositions in the GOM over the intervening years, it has become evident from both survey data and model performance that migrations of large female lobsters between the GOM and GBK stock areas are sufficiently common to complicate the assessment of either of these stock areas in isolation from the other.

Movement patterns from past tagging studies

Although tagging studies on American lobster conducted to-date have not been sufficient to precisely characterize stock exchange, they have successfully documented a number of general patterns relative to lobster movement. In general small, immature lobster in inshore areas have limited movement (< 30 km, Harriman 1952, Cooper 1970, Lund *et al.* 1973, Spurr 1974, Estrella and Morrissey 1997, Fair 1977, Krouse 1977, Ennis 1984, Campbell and Stasko 1985 and 1986). Larger, mature lobsters typically move over larger ranges but have only occasionally been recorded to travel across stock boundaries (Bumpus 1899, Morrissey 1964, Dow 1974, Krouse 1977, Groom 1978, Fogarty et al. 1980, Briggs 1985, Campbell and Stasko 1986, Estrella and Morrissey 1997, MADMF unpublished). Studies along the outer continental shelf found a seasonal onshore-offshore migration and lateral movement between offshore canyons (Cooper and Uzmann 1971, Holland and Keefe 1977, Uzmann et al. 1977). However, days-at-large for many of these studies are on the order of weeks and spatiotemporal patterns of fishing effort by the industry can create biased patterns in tag-return rates. In a study conducted by MADMF, virtually all of the lobsters recorded to have traveled >40km before recapture were larger females, though higher percentages of females than males were initially tagged. Many of these studies suggest that movement or migration behaviors may be sex-dependent and may be spurred by ontogenetic shifts in behavioral patterns or habitat requirements. As a result, the functional connectivity among stock areas due to movement or migration may be dependent on the stock size and sex composition.

Indicators of seasonal migrations between stock areas from surveys and assessment models. Throughout the NEFSC trawl survey time series, there is a general pattern of higher catches observed in the fall compared to the spring surveys (see Figures 4.2.1.2.1.1 through 4.2.1.2.1.3), probably due to both recruitment of individuals to the survey gear through molting and differences in seasonal availability to the surveys. However, on Georges Bank, the seasonal difference is most extreme and sex ratios have become increasingly skewed towards females in recent years, such that the fall survey has become dominated by large females that are not evident in the spring (Figure 2.9.2). We investigated this further by comparing survey indices for GBK and GOM specifically for females >100 mm CL, hereafter "large females." Though the survey indices are noisier for a subset of the population, the NEFSC survey catches far more large females on GBK in the fall than in the spring (Figure 2.9.3). Conversely, the GOM survey catches fewer large females in the fall than the spring (Figure 2.9.4). However, a survey index for the combined GOM/ GBK area shows no clear seasonal trends with similar abundances in the spring and fall (Figure 2.9.5).

We get a similar seasonal pattern for the mean length composition for the survey time series. Abundances are higher for all females in the fall than the spring for GBK, though particularly for large females, accounting for both growth-recruitment and migration (Figure 2.9.2). For GOM, however, the seasonal shifts are size-dependent, with higher densities in the fall than the spring for smaller females but lower densities in the fall than the spring for large lobsters (Figure 2.9.6). Length compositions for GOM and GBK combined show higher densities in the fall than spring for smaller females but very similar densities for large females (Figure 2.9.7).

Due to this apparent movement of large females between the two stock areas, the assessment models for the GOM and GBK estimate very different recruitment size compositions. The GOM model estimates that most recruits coming into the model are 53 mm CL, the smallest size bin that the model tracks, with approximately 90% of recruits ≤67 mm CL and no recruitment above 73 mm CL (Figure 2.9.8). This suggests that new lobsters coming into the GOM stock are growing in from smaller sizes. Conversely, the GBK assessment model estimates a very broad size composition of female recruits with a modal size around 93 mm CL and 90% of the recruits distributed between 63 and 132 mm CL. Thus, most of the females observed in the fall GBK survey that were not observed in the spring survey are too big to have grown in from smaller lobsters during the summer molt. This effect disappears in combined GOM / GBK models with a recruit length composition much more similar to the GOM recruit length composition.

GOM/GBK Dynamics

Historically, female lobsters have enjoyed differential protection over male lobsters. Long standing regulations like a prohibition on egg-bearing females have been in place coastwide since the turn of the 20th century and v-notching (the practice notching the tail of egg-bearing females to mark them as known and protected breeders) has been common practice in Maine since the 1940's. In 1999 several regulations designed to protect spawning stock biomass in the GOM (LMA1) were put into place by the ASMFC. These include; a 5" (127 mm CL) maximum size , mandatory v-notching of all egg-bearing females, and a 100 lobsters per day/500 lobsters per trip catch limit on the mobile gear fishery (a fishery that has historically targeted large lobsters seasonally). The implementation of these regulations has coincided with unprecedented increases in recruitment in the GOM. The combination of these regulations and large scale increases in recruitment has effectively created a mechanism for a large number of female lobsters to mature and grow to large sizes. As noted above, large egg-bearing females are the demographic within the lobster population most likely to make large scale seasonal migrations. These movements appear to be related to behavioral thermoregulation designed to enhance the annual heat budget of developing eggs (Cowan et al. 2007). Additional evidence of this migration can be seen by looking at tagging studies conducted off the outer coast of Cape Cod, MA, located on the border of the GOM and GBK stocks. Lobsters tagged in the spring in coastal waters east of Cape Cod have a net westerly movement crossing into Massachusetts Bay and Cape Cod Bay (see Morrisey 1964 and Estrella and Morrissey 1997), whereas lobsters tagged in the fall in Massachusetts Bay and Cape Cod Bay have a net easterly movement crossing into the waters east of Cape Cod (Fair 1977, MADMF unpublished data). Finally, commercial fishermen fishing on Georges Bank regularly note the presence of v-notched females there, yet v-notching is not mandated nor commonly practiced in this management area (LMA 3).

The accumulation of large female lobsters from the GOM is most apparent when viewed as the combination of GOM and GBK. It appears that the GOM is effectively a source of large females, and GBK is a seasonal sink for them. This has likely always been the case, however it has now become more evident with the large-scale increase in this demographic within the lobster population. These empirical data and model results provide compelling evidence that there is a significant seasonal migration of large female lobsters between the GOM and GBK and that this dynamic justifies these stocks be combined into one stock. For this assessment we will provide assessment results for GOM, GBK, SNE and for GOM/GBK combined.

3.0 FISHERY DESCRIPTION

3.1 BRIEF HISTORY OF THE LOBSTER FISHERY

American lobster is often mentioned in documents about New England colonies as an abundant species and a dependable source of bait and food. Wood (1635) commented on lobster abundance that "their plenty makes them little esteemed and seldom eaten." Numerous citations indicate that lobsters were easily captured in Canada and New England and were used for food, bait, and fertilizers. Early fisheries were conducted by hand, dip net, and gaffs in shallow waters along the shoreline (Nicosia and Lavalli 1999). Lobsters were also taken in a labor intensive fishery using hoop nets along the shoreline. Wooden lath traps became the dominant gear by 1840. Early vessels were row boats or powered by sail. The use of gasoline powered engines started around 1905.

Rathbun (1884) described the lobster fishery as beginning around 1800 along the coast of Massachusetts, in particular on Cape Cod and near Boston. The initial fishery supplied large lobsters (> 3 lb) for the fresh market located in New York and Boston. The fishery was conducted in shallow, near-shore areas. Smack boats cruised the coast catching and/or buying lobsters from local fishermen and would carry the catch to Boston and New York markets. When declining catch rates of marketable lobsters were unable to supply the markets, the fishery expanded to New Hampshire and Maine waters in the 1840s. A second market for "small" lobsters (between 2-3 lb) for canning developed in Maine. Canning began in 1843 and 23 canneries were operating in Maine by 1880. In 1855, market lobsters were 3 lb or greater, culls for the cannery market were between 2 and 3 lb, and lobsters less than 2 lbs were discarded. Rathbun reported the following "average" sizes, in total length, at the four principle markets for lobster in the early 1880s:

Portland, Maine	10.5" TL	(92 mm CL)
Boston, Massachusetts	11-11.5" TL	(97-101 mm CL)
New Haven, Connecticut	10.5" TL	(92 mm CL)
New York, New York	10.5-15" TL	(92-133 mm CL)

From 1870 to 1880, the lobster fishery experienced declines in catch per trap and average size of lobsters. The fishery responded by expanding the area fished, increasing the number of pots set, extending the fishing season, and fishing single pots instead of trawls in order to cover more area. As average size of the catch declined, markets adjusted by lowering the size of acceptable lobsters. Similar trends occurred throughout the range of the lobster fishery. In Buzzard Bay (SNE stock), lobsters averaged 3 lb (approx. 120 mm carapace length) in 1840 and 2.5 lb in 1880. Today, an average lobster landed from Buzzards Bay weighs 1.18 lb.

A comparison of length frequency also confirms that size structure in the inshore waters was wider in the 19th century than today. The length frequency of ovigerous females captured in 2007 from Buzzards Bay and in 1894 from Cox Ledge (Buzzards Bay) are shown in Figure 3.1.1. Despite concerns about declining size of the catch in the 19th century, it is obvious that the size structure in the 1890s was much broader in Buzzards Bay than is found today.

The decline in lobster landings coast-wide led states to implement minimum sizes and closed seasons. The decline of the fishery seen in Massachusetts' waters spread coast-wide. The New Jersey fishery was carried out extensively in the 1860s, but was nearly wholly abandoned as unprofitable by 1870, despite proximity to the largest lobster market in New York. Even with indication of a revival in 1872, the lobster fishery in New Jersey has remained small to present day. The fishery in New York and Hell's Gate was also extensively carried out before becoming abandoned due to unprofitable fishery conditions. The Provincetown fishery was abandoned except for men that were too old to participate in alternative fisheries. Large decreases in landings, catch rate, and average sizes were noted in Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine.

The decline caused the implementation of a series of management regulations in Maine (78.9 mm carapace length April 1 to August 1, remainder of year 92.3 mm, closed season August 15 to October 1), New Hampshire (92.3 mm), Massachusetts (92.3 mm, closed season June 20 to Sept 20), Rhode Island (87.8 mm), Connecticut (87.8 mm), and New York (92.3 mm). Maine also instituted protection for egg-bearing females.

Landings, average size, and catch per trap continued to decline over the next twenty years in all states and Canada. In Massachusetts, the number of lobsters > 92 mm per trap declined from 80 per trap in the early 1880s to approximately 30 per trap in 1907 (Figure 3.1.2). In comparison, the catch per trap of lobster > 92 mm in Massachusetts fishery in 1995-1998 ranged from 5 to 7 per trap (Figure 3.1.2). Concerns about the growing crisis in the fishery led to a Convention in 1903 to develop recommendations for uniform legislation in states to protect lobsters. Representatives from Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and Canada attended. Lobster stocks were considered to be in a critical state with declines in average size of the catch and catch per trap haul. Management measures under consideration were increases in minimum size, slot limits, gear modifications to change selectivity, closed seasons, trap limits, v-notching protection for females, limited access to permitted fishermen only, and hatchery stock enhancement through hatchery propagation. The slot limit was advocated to increase egg production by protecting the larger, more fecund lobsters. Protection of berried females and prohibition of landing shelled lobster meat were enacted.

The Convention of 1903 failed to establish uniform regulations because of a concern to tailor regulations to meet local conditions. Enforcement of existing regulations was considered to be problematic everywhere. Scientists also noted the inadequacy of landing statistics. In general, scientists believed that stock declines were fishing-related and landings were inflated through increased effort, technological improvements, and spatial and temporal expansion of the fishery. The comparative impacts of fishing mortality and natural mortality rates through predation and disease on abundance were debated.

States responded to the crisis in various ways. Rhode Island and Massachusetts dropped the minimum size to 78.9 mm carapace length, Connecticut raised the minimum size from 78.9 mm to 79.3 mm. In 1907, Maine increased the size limit to 4.75” total back shell. From 1907 onward, states implemented many small changes in the minimum size, protection for egg-bearing females, and prohibition on landing lobster meat. Maine instituted a maximum carapace length. Voluntary v-notching programs were enacted in Maine and Massachusetts.

Landings remained low, averaging approximately 5,000 metric tons (mt) from the 1920s through the 1940s. Total landings increased slowly from 1940 through 1970, averaging near 14,000 mt through the late 1970s. Landings have since doubled and are near 37,000 mt in recent years. With the advent of more efficient vessels, the offshore trap fishery intensified after the mid-1960s with 2,500 mt landed from the offshore canyons in 1965. The deepwater trap fishery has dominated the offshore landings since 1972, while prior to that it was primarily bycatch in the otter trawl groundfish fishery. The size distribution of lobsters in the offshore fishery was much wider than the inshore fishery. Skud (1969) concluded that “canyons that were more heavily fished had lower catch per trap and a smaller mean size.” He also reported that the modal size of lobsters from Veatch and Lydonia Canyons was smaller in 1965-67 than in 1956 and the decrease in size was greatest in Veatch Canyon. The length frequency of lobsters in Hudson Canyon was similar to Veatch Canyon in 1965-1967. A comparison of length structure in Veatch Canyon in 1965-1967 with length frequency in Hudson Canyon in 1991 and 2003 indicates continued truncation of the length frequency (Figure 3.1.3), although some of the changes can be attributed to differential gear selectivity. In 2003, 80% of lobsters from Hudson Canyon were within 1 molt group of the minimum legal size.

Several conclusions can be drawn from reviewing lobster history. Large lobsters were found in inshore shallow water throughout the species’ range. Declines in size structure and catch per trap that occurred in the 1880s were attributed to increased fishing effort throughout the range of the fishery. These declines were initially local (Boston to Provincetown) and then spread coast-wide. Terms such as “commercial extinction” were in use in 1903. Low productivity, as measured by landings, extended for long periods; coast-wide landings declined over a 25-year period from 1889 to 1915 and remained low for another 30 years. These historical landings data provide a general characterization of lobster population trends over the past two centuries but must be viewed with caution since all fishery-dependent data are confounded in terms of size, location, and other market-driven forces. Discarded sizes were never recorded and only economically productive areas were fished.

Most of the current management measures under consideration today (minimum sizes, v-notching, closed season, maximum size, slot limits, trap limits, protection of egg bearing females) were either discussed or implemented over 100 years ago. In many cases, regulations such as minimum sizes and closed season are less restrictive today than 100 years ago. Arguments about the merits of uniform measures were countered by the need to tailor management measures to meet local needs. With the exception of private property rights, resource managers from the late 19th to early 20th century would be familiar with scientific, social-economic, and political arguments present in decision-making process for managing lobster today.

3.2 CURRENT STATUS

The U.S. lobster fishery is conducted in each of the three stock units: Gulf of Maine, Georges Bank, and Southern New England. Each area has an inshore and offshore component to the fishery. In the Gulf of Maine, the inshore fishery dominates the total stock harvest. The offshore fishery dominates in the Georges Bank stock unit; however in recent years the catch from the inshore portion of Georges Bank (SA 521) has increased substantially. While historically the inshore fishery dominated in Southern New England, since the late 1990s the offshore fishery has accounted for the largest portion of the total catch. This change is the direct result of dramatic declines in the catch from the inshore portion of SNE, as the waters have become increasingly warm and often exceed the thermal stress threshold of 20° C for lobster. The Gulf of Maine supports the largest fishery, constituting an average of 79% of the U.S landings between

1981 and 2013. It has accounted for at least 90% of the total U.S. landings since 2009 and reached a time series high of 95% in 2013. Southern New England has historically accounted for the second largest fishery, with an average of 22% of the U.S. landings between 1981 and 2001. However, this fishery has experienced dramatic declines in landings, accounting for 9% or less of the U.S. landings since 2002, and reaching a time series low of 2% in 2013. Georges Bank constitutes the smallest portion of the U.S. fishery, averaging 5% of the landings from 1981 to 2013. During this time period the relative contribution of the Georges Bank fishery to the total U.S. fishery has remained fairly stable.

The total number of commercial fishing permits issued in the U.S. lobster fishery varied without trend between 1981 and 1995 (Table 3.2). Starting in 1996, the total number of permits steadily declined, reaching the time series low of 7,940 in 2013. This pattern is not homogeneous among states. The states of Connecticut, Maine, and Massachusetts have exhibited declines in the number of licenses issued from highs observed in the early to mid-1980s. The number of permits issued in Rhode Island varied in a saw-tooth fashion from 1990 to 2001, has experienced steady declines since that time, and reached a time series low of 874 permits issued in 2013. In New Hampshire, the number of permits issued has varied without trend around a time series mean of 323 permits over the entire time series. The state of New York had a sharp increase in the number of permits issued from the early 1980s to the mid-1990s, reaching the high of 1,265 permits in 1994. Subsequently, the number of NY permits issued dropped dramatically from 1995 to 2013, where it reached a time series low of 326 permits.

Traps are the predominant gear type employed in the U.S. lobster fishery. Between 1981 and 2013 traps accounted for an average of 96% of the total landings. All other gear types (otter trawl, gill net, dredge, SCUBA) accounted for the remaining 2% of the total landings. The standard unit of fishing effort is difficult to define in the American lobster fishery; there is no linear relationship between the number of traps fished and fishing effort. Many factors affect the catch rates of lobster traps including location, bait, trap design, soak time, temperature, and the presence of other animals (Cobb, 1995). This complicates the relationships between catches or CPUE and abundance and/or densities, as well as between effort and mortality (Miller 1989, 1990; Karnofsky and Price 1989; Addison and Bell 1997; Addison and Bannister 1998). A comprehensive description of the factors affecting lobster catchability and trap efficiency is provided in a previous assessment (ASMFC 2000). The number of trap hauls would be a better metric of fishing effort, but unfortunately these data are either not currently collected, or not historically available from most jurisdictions within the U.S. lobster fishery. To characterize fishing effort, we present the total number of traps reported fished by state within each stock. Although it is not the best characterization of fishing effort in a trap fishery, it is the only metric that is broadly available.

The operational characteristics of the U.S. lobster fishery have changed significantly over the time series of data presented in this assessment. There have been substantial increases in the average trap size and average boat size. The predominant type of trap used in the fishery has changed from the traditional wood lath traps to wire mesh traps. Advances in radar, sonar, and navigational electronics have increased the efficiency of fishing vessels. Each of these factors affects catch rates and overall yield, and has substantially increased the fishing power of the U.S. lobster fleet since the 1980s.

3.2.1 Gulf of Maine

The Gulf of Maine fishery is primarily carried out by fisherman from the states of Maine, Massachusetts, and New Hampshire. This fleet is comprised mainly of small vessels (22 to 42 ft) that make day trips in nearshore waters (< 12 miles). The Gulf of Maine also has a smaller scale offshore fishery comprised of larger boats that make multi-day trips.

Commercial lobster landings in the Gulf of Maine were stable between 1981 and 1989 averaging 14,600 metric tons (mt), and then increased steadily from approximately 20,000 mt in early 1990s to approximately 35,000 mt in the mid-2000s. From 2007 to 2013 landings nearly doubled, reaching the time series high of 64,087 mt in 2013. Ten of the 11 highest lobster landings recorded in the GOM stock have occurred since 2003 (Table 3.2.1.1). Greater than 98% of the total GOM catch has come from the inshore NMFS statistical areas (SA) of 511, 512, 513, and 514, with only small contributions from the offshore SAs of 464, 465, and 515. This increase in landings in GOM was dominated by catch from Maine, particularly from the mid-coast portion of the state (SA 512) which has accounted for >50% of the entire GOM catch since 2003. In Maine there was a five-fold increase in landings from 1981 to 2013. Landings from New Hampshire varied without trend around a mean of 630 mt between 1981 and 2007. From 2008 to 2013 they increased by 92%, reaching a time series high of 1,554 mt in 2012. Massachusetts landings increased from 1981 to 1990 and remained high between 1991 and 2000 (averaging 4,979 mt). Starting in 2001, Massachusetts landings declined reaching a time series low in 2005 (3,227 mt), with six out of the seven lowest landings values in the time series occurring between 2001 and 2007. Since 2008 landings in Massachusetts have increased steadily and have remained above the time series median in 2011 through 2013.

The number of traps fished in the Gulf of Maine was fairly stable between 1982 and 1993 averaging approximately 2.3 million traps (Table 3.2.1.2). From 1993 (2.2 million) to 1994 (3.2 million) the number of traps fished in the GOM increased dramatically. After 1994 the number of traps reported gradually increased reaching the time series high of 3,571,261 traps in 2005 (Table 3.2.1.2). The number of traps fished has remained above the time series median (3.1 million) since 1998. The state of Maine accounts for the greatest proportion of the total fishing effort within the GOM stock. Maine accounted for an average of 87% of the total number of traps fished in the GOM between 1982 and 2013. In the Maine fishery, traps varied without trend around an average of 2 million between 1982 and 1993, and then increased substantially reaching a time series high of 3.16 million in 2005. Since that time, there has been a slight decrease in the number traps reported in Maine. The trend in the Massachusetts portion of the fishery is markedly different. Traps increased substantially from a time series low in 1982 (247,415 traps) to a time series high in 1991 (399,010 traps), remained fairly stable between 1992 and 2002, averaging 382,555 traps, declined gradually from 2003 to 2007, and then increased to roughly median levels in the most recent years. Effort data for the New Hampshire fishery is only available from 2004 to present, during which time traps fished varied without trend around a median of 71,328 traps.

3.2.2 Georges Bank

The Georges Bank fishery is primarily carried out by fisherman from the states of Massachusetts and Rhode Island, with a smaller number of participants from Connecticut and New Hampshire. This fleet is comprised of larger vessels (55 to 75 ft) which make multi-day trips in offshore waters (> 12 miles). Georges Bank also has a smaller-scale inshore fishery comprised of smaller boats that make day trips along the outer arm of Cape Cod, MA.

Commercial lobster landings in the GBK stock unit varied around the time series mean of 1,371 metric tons (mt) between 1981 and 2002 (Table 3.2.2.1). From 2003 to 2013 landings increased substantially, reaching a time series high of 2,394 mt in 2005, and have remained well above the time series mean through 2013. Catch from the state of Massachusetts comprised the majority of the GBK landings, averaging 71% of the total GBK landings since the early 1990s. The proportion of the Georges Bank fishery attributable to Massachusetts has increased over time, whereas the proportion attributable to Rhode Island has decreased. This trend is related to where the respective fisheries in Massachusetts and Rhode Island occur on Georges Bank. The majority of the Massachusetts landings from the Georges Bank stock are harvested on the northern and eastern side of the bank (NMFS SAs 521, 522, 561, and 562), which have experienced lobster landings increases over the course of the time series. Conversely, the majority of the Rhode Island fishery on Georges Bank occurs on the southern edge of the bank (NMFS SAs 525 and 526), in which landings have been highly variable but generally lower in the latter half of the time series. Prior to 1993, New Hampshire did not have consistent landings in GBK. From 1993 to 2003, NH landings were stable, averaging 124 mt. Since 2004, NH landings have increased and have remained more than double the time series mean, reaching a time series high of 516 mt in 2013. Landings from all other states comprised less than 5% of the GBK landings throughout the time series.

The number of traps fished on Georges Bank is not well characterized, due to a lack of mandatory reporting, and/or a lack of the appropriate resolution in the reporting system. Massachusetts is the only state that has a time series of effort data for this stock (Table 3.2.2.2). As such, Massachusetts data are discussed here as an index of relative effort for the Georges Bank stock. The number of traps fished on Georges Bank increased by roughly 30% from 1982 to 1992 (Table 3.2.2.2). From 1993 to 2009 the number of traps varied without trend around a mean of 43,000 traps. Since 2010, the number of traps increased and has remained above 50,000 traps.

3.2.3 Southern New England

The Southern New England fishery is carried out by fisherman from the states of Connecticut, Massachusetts, New York, and Rhode Island, with smaller contributions from the states of New Jersey, Delaware, and Maryland. This fleet is comprised mainly of small vessels (22 to 42 ft) that make day trips in nearshore waters (< 12 miles). Southern New England also has a considerable offshore fishery comprised of larger boats (55 to 75 ft) that make multi-day trips to the canyons along the continental shelf.

Commercial landings in the Southern New England stock increased sharply from the early 1980s to the late 1990s, reaching a time series high of 9,935 mt in 1997 (Table 3.2.3.1). Landings remained near time series highs until 1999, then declined dramatically back to levels observed in the early 1980s. From 2003 through 2012 catch varied at low levels around a mean of 2,500 mt. In 2013, catch dropped to a time series low of 1,509 mt. The majority of the catch from 2008 to 2013 in SNE was landed by Rhode Island (mean = 36% of total), followed in descending order by New Jersey and South (34%), Massachusetts (14%), New York (10%) and Connecticut (6%).

This represents a marked change from previous periods when New York and Connecticut were the 2nd and 3rd largest producers respectively, and reflects the dramatic declines in catch from Long Island Sound (SA 611). In general, catch in the inshore statistical areas (538, 539, and 611) in SNE has had the largest decline and landings in all three SAs are all now below previous lows observed in the early 1980s (Figure 3.2.3.1). Landings in the offshore/nearshore statistical areas (537, 612, 613, 614, 615, and 616) have less variability throughout the time series, but it should be noted that nine out of the ten lowest landings in the time series have occurred since 2002.

The estimated total number of traps reported fished for the Southern New England stock unit only includes data from Connecticut, Massachusetts, and New York (Table 3.2.3.2). Rhode Island data are not included in the totals because these data were not consistently collected throughout the time series. As such, the magnitude of the traps fished provided for SNE is likely to be substantially underestimated because RI has historically had the largest fishery in this stock. Despite this limitation, we expect that the total number of traps fished for SNE based only on data from Connecticut, Massachusetts and New York accurately depicts the trends in fishing effort in this stock unit. This expectation is based on the very close agreement in trends in traps fished among Connecticut, Massachusetts, and New York, as well as the close agreement in landings trends among all jurisdictions within the SNE stock unit.

Between 1981 and 1998 the number of traps fished in SNE increased six-fold and reached a series high of 588,422 traps in 1998. Between 1999 and 2013 the number of traps fished declined by 74%, reaching the time series low (151,970) in 2013 (Table 3.2.3.2). This large decline in fishing effort is most likely the result of a combination of declining stock size and substantial increases in operating cost in the fishery associated with fuel and bait.

4.0 DATA SOURCES

4.1 FISHERY-DEPENDENT DATA SOURCES

4.1.1 Commercial Catch

4.1.1.1 Data Collection Methods

Maine

Lobster landings information from dealers is compiled in the National Marine Fisheries Service (NMFS) weighout and canvass database by port and month. Landings reporting was voluntary by dealers prior to 2004, after which time monthly landings reports became mandatory and a requirement for license renewal. In 2008, the mandatory dealer reporting increased its resolution of data to the daily trip level. A lookup table was supplied by the Maine Department of Marine Resources (DMR) to the ASMFC, linking port landed (designated by NMFS port codes) with likely statistical area from which lobsters were harvested. For all years it was assumed that port codes sufficiently characterized the spatial distribution of landings in Maine.

During the 1990s, the Maine lobster fishery was in a period of rapid growth. New dealers were buying significant quantities of lobsters in locations where previously minor fisheries existed, seasonal dealers began buying lobsters out of trucks/vans and lobster smacks, and Canadian processing plants began buying excess lobsters from Maine. Given the magnitude of the changes in the fishery, it is very likely that significant landings were missed through the voluntary landings reporting program during the period of 1997 through 2003.

New Hampshire

New Hampshire lobster harvesters have been reporting annual lobster landings from state waters since 1969 to the New Hampshire Fish and Game Department (NHFG). Between 1969 and 1985 lobster harvesters were required to report landings on an annual basis and those reports were compiled to produce total annual landings. No effort data were reported during this time period. Between 1986 and 2005, a random selection (RSL) of a percentage of licensed lobster harvesters and all new entrants into the lobster fishery were required to report harvest and effort data. The reported data were expanded to reflect the total estimated inshore landings of lobsters. The RSL reports were submitted monthly and collected the following trip-level information: month and day fished, number of gear fished (both monthly and daily totals), area fished, average set over days/pot, weight of harvest, gear size, did fish or did not fish, and incidental catch. The reports submitted by new entrants were submitted annually and represented monthly-summarized catch and effort information from New Hampshire state waters. Beginning in 2006, all licensed lobster harvesters were required to report harvest and effort data. Harvesters are required to report monthly, trip-level data including all the Atlantic Coastal Cooperative Statistics Program (ACCSP) standard data elements if they land 1,000 pounds or more the previous year, or annual, monthly-summarized data if they land less than 1,000 pounds the previous year.

In cooperation with NMFS, NH instituted mandatory lobster dealer reporting in 2005 and began collecting all data required under ACCSP standardized data submission standards. NH lobster dealers report transaction-level data on a monthly basis through use of paper logbooks and flat files to NHFG for entry into the EDR (Electronic Dealer Reporting program), or directly to EDR.

Historically, the quantity of lobsters landed in New Hampshire harvested from federal waters was derived from a combination of NMFS weighout and canvas database and federal vessel trip reports (VTRs). NMFS has mandatory reporting of harvest data from the majority of federally permitted vessels that land in NH through VTR data.

For the current assessment (2008-2013), total monthly landings from dealer reports (EDR), catch data from federal VTRs, and catch data from state logbooks were used to calculate landings values. In order to assign areas to the dealer report records and calculate effort estimates, VTRs and state logbooks were used to identify statistical areas and effort values. This was necessary as dealer reports do not contain area and effort data.

Massachusetts

Prior to 2008, all commercial lobster permit holders (coastal, offshore, and seasonal or student) received a detailed annual catch report form with their license renewal application. This report requested the following information on a monthly basis: method of fishing; number and type of gear used; effort data (set-over days, number of trips per month, etc.); pounds of lobsters caught; areas fished; principal ports of landing; and information relative to the vessels and traps used in the fishery.

In 2008, the Massachusetts Division of Marine Fisheries (MADMF) began the transition to a trip-level reporting system, which included all the previous information reported but on a finer time scale. For 2008, 10% of harvesters were randomly selected to provide trip-level reports, with the remainder reporting using the old method. In 2009, 20% of harvesters provided trip-level reports, and starting in 2010, 100% of harvesters were required to provide trip-level reports. Those vessels with Federal reporting requirements reported lobster landings to NMFS via the VTR system and not to MADMF after 2009. Total landings for the time period 2010-2013 for this assessment were the combined data from MADMF state-permitted harvester trip-level reports and VTR data from federally permitted MA vessels. Landings data prior to 2010 are from annual and trip-level reports provided to MADMF from all MA permit holders (including those who also had Federal permits).

Rhode Island

Commercial lobster fishery landings data prior to April 1994 were collated directly from the NMFS weighout and canvass database. In 1999, Rhode Island initiated a mandatory commercial lobster catch/effort logbook reporting program as part of the ACCSP. These data are used in conjunction with the NMFS Vessel Trip Report (VTR) landings data system to calculate total Rhode Island lobster landings by statistical area. Beginning in 2003, RI logbook data and NMFS VTR data were used in place of NMFS dealer reports for the assessment. Based on an analysis of logbook versus NMFS dealer data (M. Gibson, RIDFW, pers. comm.), landings in some earlier years (1981-1982 and 1995- 1998) were adjusted upward to compensate for likely under-reporting of landings in those years. For the years 1981-1982, the sum of 1982-1989 NMFS weighout and canvass numbers were divided by the sum of 1982-1989 NMFS weighout numbers and that ratio (~1.041) was then multiplied by 1981-1982 canvas numbers to obtain final adjusted landings for each year. For the years 1995-1998, the sum of 1999-2003 NMFS weighout and canvas numbers were divided by the sum of 1999-2003 NMFS weighout numbers and that ratio (~1.118) was multiplied by 1995- 1998 canvas numbers to obtain final adjusted landings for each year. For the years 2004 to the present, total commercial lobster landings are compiled from combined RI logbook and NMFS VTR data.

Connecticut

Landings are recorded in the NMFS weighout and general canvas database as landings at state ports. Connecticut also records landings by licensed commercial fishermen in any port (inside or outside CT) by means of a mandatory logbook system that provides catch and effort information from 1979 to the present. This mandatory monthly logbook system provides detailed daily catch data by species, area, and gear as well as port landed, traps hauled, set over days, and hours trawled (for draggers). The logbook provides a means to look at fundamental changes in the operating characteristics of the lobster fishery within Long Island Sound. Since 1995, the program has required fishermen to report information on the sale and disposition of the catch, including the state or federal permit number of the dealer to whom they sold their catch. Seafood dealers are also required to report all of their individual purchases from commercial fishermen using either the NOAA form Purchases from Fishing Vessels, a Connecticut Seafood Dealer Report, Abbreviated Form for Lobster Transactions Only, or through the ACCSP's Standard Atlantic Fisheries Information System (SAFIS). A quality assurance program has been established to verify the accuracy of reported statistics through law enforcement coverage and electronic crosschecking of fisherman catch reports, law enforcement boarding reports, and seafood dealer reports.

New York
New York commercial lobster landings from 1981 through 2003 were obtained from the NMFS weighout and canvass database. The NMFS weighout and canvass data from 1998 through 2006 were compared to NY Recall Survey data for the same years. The difference in reported landings ranged from -4% (NY recall higher than NMFS) to 33% (NMFS data higher than NY recall). The three highest percentage differences occurred in 2004 through 2006. Preliminary comparison of Federal dealer data and NY recall survey information from this time period indicated there was some double counting of landings. Since the differences between NMFS and NY landings were not large before 2004, lobster landings data provided by NMFS for the period from 1981 through 2003 were utilized. Due to the potential magnitude of double counting from 2004 through 2007, NY conducted an analysis to reconcile the lobster landings data. NY and NMFS staff collaborated on the development of the reconciliation process, and NY staff conducted the analysis. This reconciliation process is described in the 2009 ASMFC Lobster Assessment (ASMFC 2009).

In 2008, NY required lobster permit holders to fill out State Vessel Trip reports (SVTR), which collected similar information as the Federal VTR. Due to concerns about compliance with the new requirement, the NY recall survey was also continued through 2011. Starting in 2012, the NY recall survey was discontinued. Staff at the ACCSP took over the reconciliation process described in the last Assessment (ASMFC 2009) to determine the best annual estimate of commercial landings for NY.

The number of pots fished was collected through the NY recall survey from 1998 through 2011. Starting in 2008, NY has collected daily trap haul data through the SVTR.

New Jersey South
New Jersey, Delaware, Maryland, Virginia, and North Carolina collect no landings data for American lobster. Total monthly landings from the NMFS weighout and canvass database were used to calculate landings data for this recent stock assessment.

4.1.1.2 Commercial Discards/Bycatch

Little data are currently available on commercial discards of lobsters in the lobster fishery. Sea sample data indicate substantial regulatory and market driven discards of sublegal, oversized, v-notched females, and ovigerous females. The regulatory discards are accommodated in modeling as a component of gear selectivity and as conservation discards. Studies describing discard mortality in the trap fishery and/or bycatch mortality in the trawl fishery are limited but consistent in their findings that most mortality factors are relatively low. A two-year study of both trap and trawl catches in Long Island Sound showed that hardshell (intermolt) lobsters suffered little damage by commercial trawling, with the incidence of immediate mortality by month never exceeding 0.5% in the trap fishery or 2.2% in the trawl fishery (Smith and Howell 1987). Additionally, this study examined delayed mortality (up to 14 days) in the laboratory and found it occurred almost exclusively in hard-shelled lobsters that sustained major damage to the carapace or tail, or in new-shelled (recently molted) lobsters. Ganz (1980) also found low immediate mortality to trawl-caught American lobsters in Narragansett Bay, RI, and low damage rates during intermolt periods. Both of these studies found that damage rates were higher immediately following molting, but that newly molted animals made up a very small percentage of the catch because of their reclusive behavior. Two other studies of the scallop (Jamieson and Campbell 1985) and rake (Scarratt 1972) fisheries found that although the gear could damage American lobster, the lobsters emigrated from the area during the harvest season and so the gear had no significant impact on the lobster population present on the grounds at other times of the year. The model used in this assessment assumes a 0% discard mortality rate.

4.1.2 Recreational Catch

Maine

In 1997, a five-trap recreational lobster license was established. The number of licenses issued has ranged from 485 in 1997 to 1,778 in 2013 with a peak of 2,178 in 2008. Since 2001, all license applicants must complete a 50 question exam on Maine lobster laws and lobster biology. A maximum of two recreational licenses may be assigned to each vessel. In 2008, a mandatory harvester logbook program was initiated, where 10% of each Maine Lobster Management Zone licenses were selected for trip level reporting.

New Hampshire

Recreational lobster fishing in New Hampshire represents those harvesters that fish with 5 traps or less with no sale of harvested lobsters allowed. Recreational catch and effort data have been collected in the same manner as the commercial lobster harvest for state landings. Between 1969 and 1985 mandatory annual reports from all lobster harvesters in state waters were compiled to produce annual lobster harvest totals. Between 1986 and 2005, a random selection (RSL) of a percentage of recreational licensed lobster harvesters and all new recreational entrants into the state lobster fishery were required to report catch and effort data. The reported data were expanded to reflect the total estimated inshore landings of lobster. The RSL reports were submitted monthly and collected the following trip-level information: month and day fished, number of gear fished (both monthly and daily totals), area fished, average set over days/pot, weight of harvest, gear size, did fish or did not fish, and incidental catch. The reports submitted by new entrants were submitted yearly and represented monthly-summarized catch and effort information.

Beginning in 2006, all recreational lobster harvesters are required to report monthly-summarized harvest and effort data on an annual basis. Any recreational harvester may elect to use the Electronic Harvester Reporting Program (EHTR) to report trip-level data on a monthly basis. Recreational catch in New Hampshire state waters from 1989-2012 averaged 0.5% (range of 0.2%-0.8%) of the total New Hampshire inshore lobster landings, with licenses making up 32% (range of 26%-37%) of the total New Hampshire state lobster licenses.

Massachusetts

The Massachusetts recreational lobster license allows harvest of lobsters using a maximum of 10 traps, SCUBA gear, or a combination of both. Recreational harvesters may take no more than 15 lobsters per day. Basic recreational lobster catch and effort data (i.e. number of lobsters harvested, number of traps fished) have been collected via the permit-renewal process since 1971. The report form was modified in 2007 to include an 'area-fished' component. Consequently, recreational catch and effort data are now available by stock area. In 2010, the recreational lobster permit and reporting systems were incorporated into the new MA Saltwater Fishing licensing system. The average number of permits issued during the period from 2008-2013 was 9,330 and on average 54% of those permits were reported as fished, while an average of 29% of permit holders did not report. From 2008-2013 an average of 239,894 pounds were landed by the MA recreational lobster fishery.

Rhode Island
Prior to the implementation of the Rhode Island/ACCSP catch/effort logbook data collection program in 1999, no catch/effort data were collected regarding the Rhode Island recreational lobster trap and lobster diver fisheries. Since 1999, recreational lobster trap and lobster diver license holders have been asked to provide their monthly lobster catch and effort data in a report that is submitted annually. The submission of recreational lobster catch/effort data is voluntary. During the period 1999-2007, RI recreational lobster landings have averaged 0.224% of the total RI lobster landings. Reporting has decreased significantly since this period and further analysis of the recreational landings of lobster in RI is deemed unreliable.

Connecticut
From 1983 to 1999, the recreational lobster fishery in Connecticut landed between 38,000 and 105,000 lobsters annually, equivalent to a maximum of 6% of commercial landings during those years. Since the mortality event that occurred in Long Island Sound in 1999, the recreational lobster fishery in Connecticut waters has landed 15,000 – 30,000 lobsters, equivalent to about 2% of commercial landings. Total pots fished recreationally ranged from 4,000 - 9,500 in 1983-1999 then declined to less than 2,000 in 2001 following the 1999 die off. The number of license holders has also declined, ranging from 1,200–2,800 issued between 1983 and 1999, and dropping to 900-377 issued between 2000 and 2011. On average, 73% of recreational lobster license holders reported using their licenses between 1983 and 1999. Following the die-off, not only were fewer licenses issued, fewer license holders reported fishing, with an average of only 50% actively fishing between 2000 and 2006. However, with the lowest number of recreational licenses in 2011 due in part to decreased availability and also to an increase in the license fee in 2011, most license holders (76%) reported fishing their license in 2011. Approximately one in five license holders captured lobsters recreationally while diving in Connecticut waters between 1983 and 1999. From 2000 to 2006, that number dropped by almost half, with approximately one in ten capturing lobsters while recreationally diving. The number of people recreational harvesting by scuba diving dropped to less than 4% in 2011. From 1983 to 1999, three in four active license holders set traps to capture lobsters. Since 2000, the majority (average of 87% of active license holders) of recreational lobstermen in Connecticut fished for lobsters with traps.

New York
Recreational lobster permit holders are required to complete an annual Recall Landings Survey for the previous year when they apply for their current year's license. These data have been collected since 1998. New York recreational lobster landings from 1998 – 2013 averaged 0.5% (range of 0.1%-1.5%) of the total New York landings. NY has required non-commercial lobster

permits to harvest lobster recreationally since 1977. The number of licenses ranged from 2,549 in 1991 to 750 in 2013. On average, 64% of the harvest was from traps and 32% from diving.

New Jersey
New Jersey collects no recreational landings data for American lobster. However, a recreational lobster pot permit is available which allows the permittee to fish up to 10 lobster traps in state waters. Hand-harvest by divers is also allowed and requires no permit; spearfishing for lobster is prohibited. Recreational harvesters may take no more than six lobsters per day.

4.1.3 Biological Samples

4.1.3.1 Data Collection Methods: Port and Sea Biological Samples

Maine
Fully implemented in 1967, DMR conducted port sampling during ten randomly selected days each month from April through December through 2011 when the program was discontinued. Port samplers surveyed lobster dealers along the entire coast who bought from at least five commercial lobstermen. This survey was designed to produce unbiased expanded estimates of catch, effort, sex, and size distribution of the landed catch for the entire fishery on a monthly and annual basis (see Appendix 1). Recorded data included number of traps hauled during each trip, number of days traps were immersed, total weight of catch, number of lobsters caught, and hydrographic information. Ten lobsters from each boat were randomly selected to provide individual length and weight data, as well as sex, claw, and shell condition.

A sea sampling program was started in 1985 during the months of May through November aboard commercial lobster vessels using observers to record data. Prior to 1998, sea sampling was limited to only three locations with repeated trips made aboard the same vessels. This program was expanded in 1998 to sample each of Maine's seven lobster management zones three times a month during the months of May through November. A limited winter sampling program has been developed in recent years that averages one sampling trip per month per statistical area from December through April. Biological data collected include carapace length (mm), cull status, sex, egg development stage, second abdominal width (discontinued in 1998), v-notch/mutilation condition, presence and condition of eggs, molt condition and finfish bycatch (species and length). In 2003, the incidence of shell disease and dead lobsters in traps were incorporated into the sampling protocol.

New Hampshire
NHFG conducts a monthly sea sampling program from May through November aboard commercial fishing vessels in three general areas off the coast of New Hampshire, all located within Statistical Area 513. Data collected since 1991 include catch per unit effort (CPUE), bait type, carapace length, sex, molt stage, cull status, v-notch condition, and presence of eggs.

A port sampling program was initiated in 2005 to collect both CPUE and biological data on harvest landed in New Hampshire. A total of six samples are taken each month from May-November; four from state waters and two from vessels fishing in federal waters. During each visit, 100 lobsters are sampled and an interview with the captain is conducted. Biological data collected include carapace length (mm), sex, molt stage and cull status. The captain's interview consists of a variety of questions including: number of trawls hauled, traps per trawl, number of set days, percent of traps that were single parlor, location of area fished and average trap depth.

Massachusetts
The MADMF has conducted a commercial lobster trap sea sampling program since 1981 to collect both biological and CPUE data. Seven fixed regions (the Provincetown region was added in 2008) are distributed throughout state waters to represent all three stock areas, and are sampled at least once per month from May-November by observers aboard commercial lobster boats. Recorded data include carapace length (mm), sex, shell hardness, culls and/or other shell damage, external gross pathology, mortality, presence of extruded ova on females, as well as trap locations (latitude and longitude) and water depth (from chart plots).

The MADMF conducted a port-sampling program from 2006 - 2009. This program was specifically structured to obtain data from offshore lobster fisheries conducted in the Gulf of Maine and on Georges Bank, and targeted NMFS Statistical Areas (SA) which comprised the majority of offshore landings within each stock unit. NMFS SA 515 was sampled for the offshore Gulf of Maine, and SA 562 was sampled for Georges Bank. One trip per month was conducted in each area. A target number of 600 lobsters were sampled during each trip. Biological characteristics including, carapace length (mm), sex, shell hardness, cull status and/or other shell damage, and external gross pathology were recorded.

Rhode Island
The RI Department of Environmental Management has conducted an inshore and offshore trap sea sampling program since 1990. Sampling areas include Narragansett Bay, Rhode Island Sound, mid-continental shelf areas (30-60 fathoms; discontinued after March 2003), and canyon areas (70-200 fathoms). Collected data include catch (weight and number), effort (number of trap-hauls, set-over days), trap type, bait type, bottom type, depth, trap location (LORAN), surface and bottom water temperature, carapace length, sex, presence and developmental stage of extruded eggs, relative fullness of egg mass, shell hardness (molt status), cull status, shell damage/disease, v-notch status, and mortality. Inshore sea sampling was conducted each month (2 sea sampling trips per month) and offshore sea sampling was conducted quarterly (February, May, August, and November). In 2008, offshore sea sampling (Lobster Conservation Management Area (LCMA) 3) was discontinued for safety reasons; however, additional sea sampling was initiated in the "offshore" portions of LCMA 2 as compensation. In 2012, all sea sampling was discontinued beginning May 1 due to discontinuation of federal funding; however, sea sampling did continue during June-December 2012 with support of RI state funds. Partial federal funding (50% of original funding amount) was reinstated in June 2013 and a reduced sea sampling regimen for LCMA 2 only was adopted.

An offshore port sampling program was initiated in January 2006. The primary objective of the Offshore Port Sampling Program is to collect lobster length frequency and other biological data (i.e. sexual maturity, shell disease frequency and severity,) from offshore NMFS statistical areas (LCMA 3) where lobster landings are emanating, but do not have any sampling data to properly characterize the length frequency distribution of the landings from those areas. Accurate area-specific length frequency data are vital for lobster stock assessment purposes in order to provide significantly better quality data used for stock status determinations. This program was also discontinued in 2012 as noted above for the sea sampling. With the partial funding re-established, 2 port samples are collected monthly and efforts are made to sample from NMFS SA 525, 526, 537 and 616 at least once every two months.

Connecticut

The Connecticut Department of Environmental Protection Marine Fisheries Division has conducted sea sampling trips since 1982 with commercial trap fishermen within Long Island Sound. From 1982-1999, an average of 15 sea sampling trips were taken each year (range 6-28 trips per year). Following the die-off in 1999, expanded sampling effort increased the annual average to 41 trips for 2000-2007 (range 19-77 trips per year). With reduced landings and effort, sea sampling trips were scaled back from 2008 to 2012 with an average of 19 trips taken (range 9 to 29). Two trips were taken in 2013 as trips were scaled back due to the loss of funding which supported lobster monitoring. Biological information was recorded for all lobster of all sizes in as many trap hauls as possible. These data include: carapace length (to the nearest mm; 0.1mm for the mm interval encompassing the legal minimum), sex, shell hardness, relative fullness of egg mass, developmental stage of eggs, cull status, and any signs of shell damage or disease. From 1992-1998, pleopods were taken from a large number of females for cement gland staging to determine length at maturity.

New York

NY State Department of Environmental Conservation sea sampling data are collected on cooperating commercial vessels in Long Island Sound (SA 611) and the Atlantic Ocean side of Long Island (NMFS SA 612 and 613). Data collected include catch, size, sex, egg status, shell disease, soak time, and water quality. Additional analysis of the fishery has been conducted using information supplied on lobster permit applications, such as catch, pots fished, area fished, and number of participants. Fishing effort (number of traps used) can be calculated from this information. Sampling in SA 612 and 613 has always been sporadic and sampling in SA 611 was very poor during 1995-1998, 2003, and 2012-2013.

A port sampling program began in 2005. The main objective of the program is to enhance the collection of biological data from lobsters harvested from LCMAs 3, 4 and 5. A communication network was developed with cooperating dealers and fishermen who fish these areas. This network is contacted to identify days and times of vessel landings to provide sampling opportunities. Utilizing this network of contacts allows for the sampling of a high percentage of lobster fishing trips landed in NY from the appropriate LCMAs. A random sample of at least 100 lobsters is collected from the catch before it is culled. Sampling protocol adheres to the standards and procedures established in NMFS Fishery Statistics Office Biological Sampling Manual. This program was expanded to collect data from LCMA 6 starting in 2013. In past assessments, sea sampling data were used to estimate size distribution of landings by area; in this assessment, port and sea sampling lengths have been combined by statistical area and month in years for which port samples were available (see Appendix 1).

New Jersey

The New Jersey Division of Fish and Wildlife has conducted at-sea observer sampling aboard commercial lobster trap vessels in LCMAs 4 and 5 since 2008 and has completed a total of 78 trips through 2013. Sampling is conducted randomly twice a month from May-October and once a month during the rest of the year except during closed periods when sampling does not take place (February and March since 2013). Biological data collected include carapace length (mm), cull status, sex, egg development stage, v-notch/mutilation condition, presence and condition of eggs, and molt condition.

National Marine Fisheries Service (NMFS)
The Northeast Fisheries Observer Program (NEFOP) has collected data from vessels engaged in the lobster fishery as funding allows since 1991. NEFOP is assigned sea days by the NOAA NMFS Northeast Fisheries Science Center (NEFSC) on a yearly basis as part of the Standardized Bycatch Reporting Methodology. NEFOP has collected lobster fishery data each year from 2012-2015. A total of 84 sea days were observed in the lobster fishery in the 2012 – 2013 fishing year and 124 days in the 2103-2014 fishing year. Inshore and offshore vessels based in ports from Maine to New Jersey are covered by the program. Data collected by NEFOP observers include carapace length (mm), molt stage, shell disease, sex, presence of eggs, v-notch condition, number of claws, kept and discarded catch weights, bycatch data (including finfish lengths and weights), gear and bait characteristics, haul locations, water depth, trip costs, and incidental takes.

The port sampling program for the NMFS Greater Atlantic Regional Fisheries Office has conducted port-sampling for lobster throughout the region since 1983, collecting between ~70-100 samples per year in the past decade. Annual sample requests are stratified by region, stock area, gear type, and calendar quarter. In recent years, there has been some effort to allocate NMFS sampling resources to be complimentary to spatial coverage of port sampling by state agencies. Port samplers select vessels for sampling based on current and historical landings data, real-time vessel tracking, and local knowledge of the fisheries. A standard lobster sample consists of 100 length measurements with gender.

Atlantic Offshore Lobstermen's Association (AOLA)
Since 2001, a subset of the fishing industry members of the AOLA has collected at-sea, fishery dependent data in portions of LCMA 3. From 2001-2008, each participant sampled 10 randomly selected traps from within a pre-designated trawl of approximately 40 traps total. Traps were sampled once per trip, approximately weekly. For each participating vessel, the designated trawl and traps were held constant during the entire sampling period; however, in many cases, the gear were moved to accommodate normal fishing operations. Data collected included: location, average bottom depth, carapace length, sex, egg presence, egg stage, and in some cases v-notch condition. From 2009-present, most participants sampled 200 lobsters once per calendar quarter. Data collected remained as described for the 2001-2008 period, with the addition of number of traps sampled. Over the entire time series 63,749 lobsters were sampled by 20 vessels across 11 NMFS statistical areas. The number and location of vessels participating varied annually. During the period of 2013-2015, some AOLA participants transitioned to the data sampling program administered by the Commercial Fisheries Research Foundation (CFRF).

Commercial Fisheries Research Foundation (CFRF)
The CFRF has conducted a fishery-dependent lobster data collection project since June 2013, and provided 2013-2014 data for this assessment. The CFRF project involved 12 vessels and

offered coverage of inshore and offshore SNE, GBK, and offshore GOM. Typically, three samples were collected per month from the fisherman's regular catch, and catch data from a small string of ventless traps was also collected as those traps were fished. Only data from the regular catch samples were included in the biosamples data. For sampling the regular catch, the fisherman decided the day(s) that samples would be collected, but the trawl(s) sampled on those days were selected at random. Data from all traps in a sampled trawl were collected, starting with the first trap hauled until either the entire trawl or 100 lobsters had been sampled (including any remaining lobsters in the trap). Collected data included date, time, and location, sex, size, egg-bearing and v-notch status, shell hardness and other observations on lobster biology and condition. Data were collected on tablet personal computers and periodically uploaded to a database at CFRF where they were QA/QC'd and provided to ACCSP.

4.1.3.2 Size structure of commercial catch

The size structure of the commercial catch is shown for each stock based on the commercial sea and port sampling data. For the GOM stock, both male and female commercial size structures have been relatively stable over much of the time series (Figures 4.1.3.2.1 and 4.1.3.2.2). After increasing slightly since the early part of the time series, female median length has varied by only 3 mm over the last decade (89 - 91 mm). Similarly the 75th percentile for length has been consistent at 93-94 mm over the last decade, with the exception of 2006 when it rose to 96 mm. Male median lengths have varied from only 89-90 mm over the last decade, and the 75th percentile was similar to females ranging only from 93-94 mm since the late 1990s. In both sexes (more dramatically in females than males), there was a four-year period in the early 1990s when median length temporarily increased to the largest in the time series before returning to 'normal.'

The median size of both sexes in the GBK commercial catch has increased over time, more so for the females than males (Figures 4.1.3.2.3 and 4.1.3.2.4). Median size also varies more in this stock than in the other two stocks, ranging from 101-118 mm in females and from 94-104 mm in males over the last decade. Males are generally smaller than females, with female median size close to or larger than the 75th percentile in male lengths throughout much of the last decade.

The median length of both sexes in SNE has increased over time, likely resulting from multiple increases in the minimum legal size (indicated by the lower whiskers) throughout much of the inshore range (Figures 4.1.3.2.5 and 4.1.3.2.6). Over the past decade, males in the commercial catch have been larger than females, with median sizes ranging from 90-94 mm since 2003, while female median sizes have ranged from 88-91 mm over that time frame. Since the early 1990s the 75th percentiles of male lengths have been larger than female 75th percentiles.

4.1.3.3 Sampling Intensity

The lobster stock assessment is a data intensive analytical assessment. It requires representative biological data from each stock area to inform the model about the dynamics occurring in those areas through time. This data feed is reliant on samples collected across the various stock ranges by state and federal fisheries biologists. These sampling events occur both at port as well as out at sea. The amount of sampling effort has been variable over time, and the following is an analysis to look back over recent time periods to analyze how well each area in each quarter is being sampled from the various statistical areas. It is hoped that this analysis can help redirect sampling effort in a more efficient manner, as well as highlight the areas in need of greater sampling effort.

To perform this analysis, existing data from the port and sea sampling datasets were gathered from all sources from 2008 through 2012. The datasets were split into their stock units based on the statistical areas sampled. The data were then split out by year and by quarter. These subset datasets were then analyzed using a power analysis in R statistical software (R Core Team 2014) for length (carapace length) frequency by trip, one of the critical data metrics needed for the analytical assessment. The carapace length data were determined to be normally distributed for the most part (Figure 4.1.3.3.1); therefore the R function "power.t.test" was used for the analysis. The power.t.test function calculates the power of a sample using the sample size, the standard deviation of the mean of the sample, and an effect size, which is used to determine the non-centrality parameter. The analysis assumed a t distribution and tests the power of the samples' ability to detect differences within this assumed distribution. The effect size was calculated using the following equation:

$$d = \frac{\mu_1 - (\mu_1 * 0.2)}{\sigma}$$

This calculation was used to determine whether a difference in means of approximately 20% was detectable in our samples with a pooled standard deviation. The rest of the data were populated with the sample information directly from the data. The R function allows the user to leave either the sample size or the power argument empty, and the function calculates and returns information for the missing element, so if the sample size is empty, it uses the provided power level to calculate the needed sample size, and if the power argument is empty, it returns the power of the sample based on the sample size and other arguments included. For the analysis to get the needed sample size in this exercise, a theoretical power of 0.9 was used, with a significance level of 0.1.

In general the analysis showed that some areas were sampled very well while others were either not sampled or not sampled well. There was also annual variability in the sampling amongst the stock areas. In addition, it was apparent that offshore sampling was generally poorer than sampling from inshore areas. In the Gulf of Maine, NMFS Statistical Areas (SA) 512 and 513 were well sampled, but more sampling effort is needed in the offshore areas, and in general could be increased in most other areas (Table 4.1.3.3.1). Georges Bank was generally poorly sampled (Table 4.1.3.3.2). For Southern New England, SA 539 and in some years SA 611 were well sampled, but increased sampling effort is needed in the more offshore areas and more consistent sampling effort is needed overall (Table 4.1.3.3.3).

If use of the current length based assessment model is continued, these sampling intensity data should be used to help bolster the biological sampling in areas that are currently not sampled well. These data elements are critical for the assessment process and getting good biological data is important to inform the assessment, so that the analytical information can be used by managers with confidence. The guidelines on sampling below are meant to inform the sampling intensity that currently exists. The "needed samples" information shown in Tables 4.1.3.3.1 – 4.1.3.3.3 was generalized into broad categories of whether more than 50% additional samples (++) are needed, more samples are needed but not more than 50% (+), fewer samples are needed by 50% (--), or fewer samples are needed but not more than 50% fewer (-). These are meant to be guidance as to which areas tend to have higher sampling variability and therefore need a higher sampling frequency than currently occurs. In addition, the power metric used for this analysis was fairly high, so some of the "needed samples" information are high. The best approach would be to examine the well-sampled areas for extraneous sampling occurring those areas, and redirect those resources to some of the more poorly sampled areas.

This analysis could be improved, as it focused on only one metric, carapace length, in determining sampling intensity. Incorporating additional variables such as egg status, other sex-specific information, and the level of importance that a particular statistical area has in the fishery (i.e. a statistical area that has very high landings is more important to characterize well than an area with very low landings) would enhance complexity to produce an even more comprehensive sampling strategy.

4.1.4 Development of Estimates from Biological Data

Biosampling data from port- and sea-sampling are used for multiple model inputs including proportions of landed catch, legal proportions, conservation discard rates, and the landed sexratio which is used for apportioning the landings by sex. Proportions of landed catch by sex and statistical area are used to calculate the sex ratio of landings by statistical area and the resulting landings are used to weight the landings size composition across statistical areas. The composition of the catch from sea-sampling data is used to calculate the legal proportions and conservation discard rates by size and statistical area, which are also then weighted by landings across statistical area. The process of calculating these inputs is described in Appendix 1.

4.1.4.1 Changes to legal size limits

A complete table showing the least restrictive minimum and maximum size limits for each stock unit is listed in Table 4.1.4.1.

4.1.4.2 Updated L-W parameters

The relationship between the length of a lobster's carapace and the weight of that individual was updated for this benchmark assessment. This relationship is an important biological characteristic to define for the species, and these data are used in different aspects of the assessment, such as to determine the overall weight of lobsters from trawl survey catch (number and length information).

The data were collected from the National Marine Fisheries Service (NMFS) NEFSC trawl survey data set going back to 2001, and samples were available up through 2014. Lobsters were sampled for size, weight, and sex. Other biological attributes were also collected but were not needed for this analysis. In addition to the biological attributes of each individual lobster, station location was collected, so the stock area that each lobster came from was determined and analyzed separately.

All data from the NMFS trawl survey as described above were used for the length-weight analysis. The individual carapace length in mm and weight in kg were analyzed using a linear regression on the log transformed data. The data were both combined and split out by sex, and were analyzed separately for each stock area. So for each stock area there were three analyses done, one for males, one for females, and one for the sexes combined:

$Ln(W_{stock,sex}) \sim Ln(CL_{stock,sex})$; where W=weight in kg, CL=carapace length in mm

One final note is that the datasets were truncated to carapace lengths greater than 49 mm. This was done because there were few data points for lobsters smaller than this size in the trawl survey dataset, and there appeared to be non-linearity in the information for sizes this small, which was not seen in the larger size classes. The data for this size range was not deemed relevant for the stock assessment analyses, therefore these smaller animals were dropped from the analysis.

Once the linear parameters were determined from each analysis on the log transformed data, the information was back-transformed for use in the length-weight equation:

$W = \alpha * CL^{\beta}$; where α =back-transformed intercept term, β =slope term

The parameter estimates for all of the regression information are presented in Tables 4.1.4.3.1 and 4.1.4.3.2, and model fits to the data are presented in Figures 4.1.4.3 A-C.

4.2 FISHERY-INDEPENDENT DATA SOURCES

4.2.1 Trawl Surveys

Data used in this assessment were obtained from bottom trawl surveys conducted by the NMFS Northeast Fisheries Science Center (NEFSC) on the continental shelf as well as from inshore bottom trawl surveys conducted by the North East Monitoring and Assessment Program (NEAMAP), and the states of Connecticut, Maine, New Hampshire, Massachusetts, New Jersey, and Rhode Island. Information from long term surveys conducted by the Millstone Power Station and the University of Rhode Island were also included but not used in the models (see Section 4.2.4). NEFSC, NEAMAP, CT, MA, ME, NH and RI conduct trawl surveys during the spring and fall. More detailed information on survey area and timing, years surveyed, sampling design, gear, and methods for each survey is presented in the text below, as well as in Table 4.2.1.1.

4.2.1.1 Trawl Survey Methods

Maine/New Hampshire

Trawl survey data have historically been limited in Maine and New Hampshire nearshore waters. In the fall of 2000, the Maine/New Hampshire trawl survey was initiated as a comprehensive inshore survey. The inshore trawl survey is conducted during the spring and fall of each year, same as that of the NMFS offshore surveys. It is a stratified random design modeled after the NMFS and Massachusetts Division of Marine Fisheries (MADMF) surveys. The design includes

four depth strata: 5 – 20 fathoms (~9 – 37 m), 21 – 35 fathoms (~38 – 64 m), 36 – 55 fathoms (~66 – 101 m), greater than 56 fathoms (~102 m) (its outer boundary roughly delineated by the 12-mile limit), and 5 regions based on oceanographic, geologic, and biological features. The fourth stratum was added in the spring of 2003; it expands the coverage area to equal that area covered by the NEFSC survey and allows some overlap between this survey and the NMFS Gulf of Maine offshore survey area (Chen et al. 2006). The addition of the fourth stratum slightly reduces the sampling pressure in the shallower strata, which has been of concern to fixed gear fishermen in the past. To randomize the survey area (~4,000 square nautical miles (nm^2)), each depth stratum was divided into 1 nm^2 sampling grids. A target of 100 stations was selected for sampling in each survey resulting in a sampling density of about 1 station per 40 nm^2. This density compares to NEFSC of 1 station per 260 nm^2 and Massachusetts' 1 station per 19 nm^2. The number of stations per stratum was allocated in proportion to each stratum's area. When a station is encountered that cannot be towed, an alternate tow is selected nearby over similar depth.
For a full description of the gear please see Chen et al. (2005b). A standard trawl tow, 20 minutes duration, was made at each station. Shorter tow times were accepted under certain circumstances. Tow speed was maintained at 2.1 to 2.3 knots and tow direction was oriented toward the tidal current whenever possible. All sampling was conducted during the day. After each tow, the net was brought aboard and emptied onto a sorting table. All individuals were identified and sorted by species. All lobster were immediately separated and processed while the rest of the catch was sorted. Total weights (by sex), carapace length (mm), shell condition, presence and stage of eggs, V-notch condition, and trawl damage were recorded for all individuals.

Massachusetts

Since 1978, annual spring and autumn bottom trawl surveys of Massachusetts territorial waters have been conducted by the Resource Assessment Project of the MADMF. The objective of this survey is to obtain fishery-independent data on the distribution, relative abundance and size composition of finfish and select invertebrates.

The study utilizes a stratified random sampling design. The survey area is stratified based on five bio-geographic regions and six depth zones. Trawl sites are allocated in proportion to stratum area and randomly chosen in advance within each sampling stratum. Randomly chosen stations in locations known to be untowable due to hard bottom are reassigned. Sampling intensity is approximately 1 station per 19 nm^2. A minimum of two stations are assigned to each stratum.

A standard tow of 20-minute duration at 2.5 knots is attempted at each station during daylight hours with a 3/4 size North Atlantic type two seam otter trawl (11.9 m headrope/15.5 m footrope) rigged with a 7.6 cm rubber disc sweep; 19.2 m, 9.5 mm chain bottom legs; 18.3 m, 9.5 mm wire top legs; and 1.8 x 1.0 m, 147 kg wooden trawl doors. The codend contains a 6.4 mm knotless liner to retain small fish. Abbreviated tows no shorter than 13 minute duration are accepted as valid and expanded to the 20 minute standard. The F/V *Frances Elizabeth* conducted all surveys through fall 1981. The NOAA ship R/V *Gloria Michelle* has been the survey platform for every survey since spring 1982.

Standard bottom trawl survey techniques are used when processing the catch. The total weight and length-frequency of each species are recorded directly into Fisheries Scientific Computer System (FSCS) data tables. Collections of age and growth material, and biological observations are undertaken during the measuring operation. For lobster, specific data collected include sex, carapace length (mm), and starting in 1995 the egg-bearing status and v-notch status of females.

Rhode Island

The year 2013 marked the 35^{th} year of RIDFW's seasonal trawl survey. The survey was initiated in 1979 to monitor recreationally important finfish stocks in Narragansett Bay, Rhode Island Sound, and Block Island Sound. The survey employs a stratified random design and records aggregate weight by species, frequency, individual length measurements, and various physical data. For lobster, collected data include carapace length, sex, shell hardness, and presence of extruded ova. In 1990, a monthly component was added to the survey, which includes 13 fixed stations in Narragansett Bay. Together, both components of the survey aim to monitor trends in abundance and distribution, to determine population size/age composition, and to evaluate the biology and ecology of estuarine and marine finfish and invertebrate species occurring in RI waters. Over the years this survey has become an important component of fisheries resource assessment and management at the state and regional levels.

In 2005, the RIDFW replaced the research vessel and survey gear that has been utilized by the survey since its inception. The R/V *Thomas J. Wright* was replaced with a 50' research vessel, the R/V *John H. Chafee*. During the spring and summer of 2005, a series of paired tow trials were conducted using modern acoustic equipment and new nets designed to match the trawl net used by the NMFS. The results of this experiment were used to calibrate the old and new vessels in order to maintain the continuity of the survey time series. Unfortunately, the new net design was too large for the new research vessel and could not be successfully towed in many of the areas required by the trawl survey. Because of this a new net was designed in the same dimensions as the net previously used for the survey, which is now used for the trawl survey. By using a similar net design to the previous survey net, the continuity of the survey is able to be maintained, though analysis to confirm this is still pending.

In 2012 new doors were installed on the R/V *John H. Chafee.* A rigorous calibration experiment was done to calibrate the new trawl configuration with the new doors to the old trawl configuration with the old doors. The analysis has been conducted, but is unpublished at this point. A draft of the analysis can be found in Appendix 7. The findings of the analysis were that there were not significant differences in the catch of lobster between the old and new door datasets.

A standard tow of 20-minute duration at 2.5 knots is attempted at each station during daylight hours. The net is a two seam otter trawl (12.2 m headrope/16.8 m footrope) rigged with a 7.9 mm chain link sweep hung 30.5 cm spacing with 13 links per space. The fishing circle of the net is 533.4 cm x 11.4 cm; with 11.4 cm mesh (#42 thread) wings all the way back to the codend. The codend is 5.1 cm mesh (Euro Web 3 mm thread) and contains a 6.4 mm mesh liner to retain small fish. The trawl has Thyboron Type 4 44" doors which are 99 cm in length, 86 cm high (.86 m^2 surface area) and weigh 115 kg a piece. The doors have 36 kg of ballast weight that can be added to each of them. They also are fitted with "Notus Trawlmaster" door spread sensors which provide door spread measurements during the entire tow.

Connecticut
The CT Department of Environmental Protection Marine Fisheries Division has conducted a spring trawl survey in Long Island Sound since 1985 and a fall survey since 1984. Sampling was not conducted during the fall of 2010 due to vessel breakdown. The sampling gear employed is a 14 m otter trawl (9.1 m headrope, 14 m footrope) with 102 mm mesh in the wings and belly, 76 mm mesh in the tail piece, and 51 mm mesh codend towed at 3.5 knots for 30 minutes from a 12.8 m research vessel (1984-89) or the 15.2 m research vessel (1990-present). Forty stations are scheduled to be sampled monthly during a spring survey (April, May, June) and a fall survey (September and October) for a total of 200 samples annually. The trawl survey employs a stratified random sampling design with four depth strata (0-9 m, 9.1-18.2 m, 18.3-27.3 m, 27.4+ m) and three bottom substrate types (sand, mud, and transitional). The sampling area is divided into 1.85 x 3.7 km (1 x 2 nautical mile) sites and includes all trawlable CT and NY waters west of New London and east of Greenwich, CT. Sampling intensity is one station per 68 km^2 (20 nm^2) or less.

Biological data recorded for each tow include total weight (1992- present), carapace length (mm), sex, shell hardness, relative fullness of egg mass, developmental stage of eggs, cull status, and any signs of shell damage (new or old) or disease. From 1992-98, pleopods were taken from a large number of females for cement gland staging to determine length at maturity.

New Jersey
The New Jersey Division of Fish and Wildlife has conducted a groundfish survey along the New Jersey coast since August 1988. The survey area is about 1,800 square miles of coastal waters between Sandy Hook, NJ and Cape Henlopen, DE and from a depth of 18 to 90 ft (5 – 27 m). The area is divided into 15 strata that are bounded by the 30, 60, and 90 ft (9, 18, and 27 m) isobaths. The survey design is stratified random. Since 1990, cruises have been conducted five times a year; in January, April, June, August, and October. For this assessment, data from April and June were combined to represent "Spring," and October represented "Fall." Two 20-minute tows are made in each stratum, plus one more in each of the nine larger strata, for a total of 39 tows per cruise in all months except January, when the additional tows are omitted. The trawl gear is a two seam three-in-one trawl (so named because all the tapers are three to one) with 12 cm mesh in the wings and belly and 7.6 cm in the codend with a 6.4 mm liner. The headrope measures 25 m and the footrope 30.5 m. Rubber cookies measuring 2 3/8 inch (60.3 mm) in diameter are used on the trawl bridles, ground wires, and footrope. Five different vessels have been used to conduct the surveys to date.

NMFS, NEFSC
The NMFS Northeast Fisheries Science Center (NEFSC) bottom trawl survey began collecting lobster data in 1967 (fall) and 1968 (spring). The spring survey is generally conducted from March to May. The fall survey is generally conducted in September and October. Lobster data used in this assessment are from both the spring and fall survey beginning with 1982, as lobster survey data prior to 1982 have not been fully audited.

The NEFSC bottom trawl survey utilizes a stratified random sampling design that provides estimates of sampling error or variance. The study area, which now extends from the Scotian Shelf to Cape Hatteras including the Gulf of Maine and Georges Bank is stratified by depth. The stratum depth limits are < 9 m, 9-18 m, >18-27 m, >27-55 m, >55-110 m, >110-185 m, and >185-365 m. Stations are randomly selected within strata with the number of stations in the stratum being proportional to stratum area. The total survey area is 2,232,392 km^2. Approximately 320 hauls are made per survey, equivalent to one station roughly every 885 km^2.

Most survey cruises between 1967 and 2008 were conducted using the NOAA ship R/V *Albatross IV*, a 57 m long stern trawler. However some cruises were made on the 47 m stern trawler NOAA ship R/V *Delaware II*. On most spring and autumn survey cruises, a standard, roller rigged #36 Yankee otter trawl was used. The standardized #36 Yankee trawls are rigged for hard-bottom with wire foot rope and 0.5 m roller gear. All trawls were lined with a 1.25 cm stretched mesh liner. BMV oval doors were used on all surveys until 1985 when a change to polyvalent doors was made (catch rates are adjusted for this change). Trawl hauls are made for 30 minutes at a vessel speed of 3.5 knots measured relative to the bottom (as opposed to measured through the water).

Beginning in 2009, the spring and fall trawl survey were conducted from the NOAA ship R/V *Henry B. Bigelow*; a new, 63 m long research vessel. The standard *Bigelow* survey bottom trawl is a 3-bridle, 4-seam trawl rigged with a rockhopper sweep. This trawl utilizes 37 m long bridles and 2.2 m^2, 550 kg Poly-Ice Oval trawl doors. The cod-end is lined with a 2.54 cm stretched mesh liner. The rockhopper discs are 40.64 cm diameter in the center section and 35.56 cm in each wing section. Standard trawl hauls are made for 20 minutes on-bottom duration at a vessel speed over ground of 3.0 kts.

The R/V *Henry B. Bigelow* with a new bottom trawl and protocols replaced the R/V *Albatross IV* in 2009 for NEFSC spring and fall bottom trawl surveys. Paired tow calibration studies were carried out during 2008 and the data used to estimate length-based calibration factors which convert lobster catches by the *Albatross* into equivalent catches by the *Bigelow*, or vice-versa (Jacobson and Miller 2012). From the calibration, the *Bigelow* appears to be more efficient than the *Albatross* at catching lobster, particularly for recruits and pre-recruits. Calibration factors $\rho_L = \frac{C_{Bigelow,L}}{C_{Albatross,L}}$ ranged from about 6.18 (CV 19%) at 50 mm CL to 1.54 (CV 62%) for lobster 210 mm CL (Table 4.2.1.1.1). Survey catch and catch at length data collected by the *Bigelow* during 2009-2014 were adjusted to *Albatross* units $C_{Albatross,L} = \frac{C_{Bigelow,L}}{\rho_L}$ so that consistent data were available for 1978-2014.

Northeast Area Monitoring and Assessment Program (NEAMAP)

The ASMFC developed NEAMAP in the late 1990s as a cooperative state-federal program modeled after their Southeast Area Monitoring and Assessment Program (SEAMAP). The first survey to be developed under NEAMAP was the NEAMAP Mid-Atlantic/Southern New England (M-A/SNE) Nearshore Trawl Survey, which has been conducted by the Virginia Institute of Marine Science since its inception. Specifically, field sampling for this trawl survey began with a fall pilot cruise in 2006. The first full-scale survey cruise was conducted in the fall of 2007, and spring and fall cruises have occurred each year since 2008. NEAMAP M-A/SNE samples the inshore waters from Cape Cod, MA south to Cape Hatteras, NC, where samples from the NMFS NEFSC survey are limited due to depth constraints of the NEFSC survey vessel. At each station the net is trawled along the bottom for 20 minutes, at an average speed of 3 knots. The NEAMAP M-A/SNE Survey uses the 400 cm x 12 cm, three-bridle four-seam bottom trawl designed by the Mid-Atlantic / New England Fishery Management Council Trawl Survey Advisory Panel for all sampling operations. This net is paired with a set of Thyboron, Type IV 66" doors. Wingspread, doorspread, headrope height, and sweep bottom contact are monitored using a digital Netmind® Trawl Monitoring System. The 27.4 m F/V *Darana R* was used for all surveys.

The NEAMAP M-A/SNE Survey employs a stratified random sampling design stratified by region and depth (6.1 m - 12.2 m and 12.2 m - 18.3 m from Montauk to Cape Hatteras, and 18.3 m - 27.4 m and 27.4 m - 36.6 m in BIS and RIS). NMFS inshore strata definitions were adopted for use by the NEAMAP Survey with minor modifications to align regional boundaries more closely with state borders. Each region / depth stratum combination was subdivided into a grid pattern, with each grid cell (measuring 1.5 minutes Latitude x 1.5 minutes Longitude; 1.8 nm^2) representing a potential sampling site. The target sampling intensity is approximately 1 station per 30 nm^2, which results in sampling 150 sites per cruise. The number of sites sampled in each stratum is determined by proportional allocation, based on the surface area of each stratum. A minimum of two sites are assigned to the smallest of the strata (i.e., those receiving less than two based on proportional allocation). When American lobsters are captured, 25 individuals are sub-sampled for full processing. This includes the collection of individual carapace length (eye notch to back of carapace), individual weight, sex, presence/absence of shell disease, and egg presence and stage (females only) for each of these specimens. If more than 25 lobsters are captured in a single tow, aggregate weight, count, and individual carapace length are measured for the remainder.

4.2.1.2 Survey Trends

All of the bottom trawl survey data in this assessment are random stratified mean numbers per tow with CVs computed using standard formulas instead of the delta mean numbers per tow that were used in previous assessments (see Tables 4.2.1.2.1 – 4.2.1.2.3). Stratified mean numbers were used because they are easier to compute and very similar to delta mean indices used previously, based on comparison of the two techniques.

University of Maine model
Agencies provided bottom trawl survey data for each sex and survey as mean numbers per tow in two formats for direct use in the assessment model. In particular, survey abundance index data were for lobster 53+ mm and survey size composition data were aggregated into five mm size groups (53-57.9, 58-62.9, 63-67.9,….. 223-227.9 mm CL). For more specific details on modeling procedures see Section 6.1

4.2.1.2.1 Trawl survey abundance indices
GOM
The Maine-New Hampshire Gulf of Maine (GOM) trawl survey indices show a dramatic increasing trend over the 14-year spring time series which is mirrored in the 15-year fall time series except for a modest decline in 2012-2013 (Figures 4.2.1.2.1.1 and 4.2.1.2.1.2). Maximum catch was recorded in spring 2014. The Massachusetts GOM trawl survey indices vary without trend across the time series in both seasons with consistently higher abundance in fall catches compared to spring. Maximum catch was recorded in fall 1990; however the second highest

catch was recorded in fall 2011. The NEFSC GOM trawl survey indices show low catches in the early years of the time series for both spring and fall, with an increasing trend after 1999 in spring and after 2008 in fall. Fall catches are consistently higher than spring. Maximum catch was recorded in fall 2013.

GBK
The NEFSC Georges Bank (GBK) trawl survey shows a slight upward trend across the time series in both seasons with consistently higher catches in fall compared to spring (Figure 4.2.1.2.1.3). Maximum catch was recorded in fall 2012.

SNE
The Rhode Island trawl survey indices of relative abundance for both spring and fall were low in the 1980s, increased to highs in the mid-1990s, and have declined to time series lows in the most recent years (Figures 4.2.1.2.1.4 and 4.2.1.2.1.5). Higher catches predominately were observed in the fall compared to spring survey. The Connecticut-New York survey shows similar but sharper trends in both fall and spring to the RI survey (Figures 4.2.1.2.1.4 and 4.2.1.2.1.5). Indices increased from low levels in the early 1980s, peaked in 1999, and dramatically declined thereafter. Time series lows for both indices occurred between 2010 and 2013. NEFSC SNE fall survey indices varied without trend at moderate levels until 1996, and then decline thereafter (Figures 4.2.1.2.1.4 and 4.2.1.2.1.5). Spring indices varied wildly with peaks observed in the mid-1980's, early 2000's, and 2014. The Northeast Area Monitoring Assessment Program (NEAMAP) SNE survey's short time series (2007-2013) tracks the RI and CT/NY surveys, with declining trends in both seasons. Maximum catch was recorded for both seasons in 2008.

The Massachusetts SNE trawl survey only had adequate lobster catches in the spring for generating indices. Relative abundance was low in the early 1980s, increased markedly in the late 1990s and declined precipitously after 2002 (Figure 4.2.1.2.1.6). The New Jersey SNE survey had adequate lobster catches in spring only, with catches generally at low levels after 2002. Maximum catch was recorded in 1996.

4.2.1.2.2 Size structure of survey catches

GOM
NMFS NEFSC trawl survey represents the offshore portion of the GOM, and size structure of lobsters was generally larger than observed in the inshore surveys. The median size of females caught in fall NEFSC surveys varied around 80 mm, and the size range of females was slightly larger in the most recent decade (Figure 4.2.1.2.2.1). Males in the fall NEFSC survey tended to be slightly smaller than females, varying between 70-80 mm (Figure 4.2.1.2.2.2). In spring NEFSC surveys, there was more inter-annual variation in the median size of females than in the fall survey, and median sizes ranged between 80 – 100 mm most years (Figure 4.2.1.2.2.3). Again, males were slightly smaller than females in spring NEFSC surveys and did not vary as much as females, ranging between 70-80 mm most years (Figure 4.2.1.2.2.4).

For the two inshore GOM surveys (ME/NH and MA), sizes tended to be smaller than the NEFSC survey both for seasons. The median sizes of both males and females in the ME/NH survey varied from 60-70 mm in the fall (Figures 4.2.1.2.2.5 and 4.2.1.2.2.6), and was similar in the spring (Figures 4.2.1.2.2.7 and 4.2.1.2.2.8). In the MA fall survey, more variation in median size was apparent for females and males earlier in the time series, and tended to stabilize in the more recent decade, varying around 60-65 mm (Figures 4.2.1.2.2.9 and 4.2.1.2.2.10). Both males and females caught in the spring MA surveys tend to be slightly larger than those from fall surveys, varying around 70 mm for most of the time series (Figures 4.2.1.2.2.11 and 4.2.1.2.2.12).

GBK

Lobster observed in the GBK portion of the NEFSC trawl survey were generally larger than in the other two stocks, and the median size for females was generally larger than for males (Figures 4.2.1.2.2.13, 4.2.1.2.2.14, 4.2.1.2.2.15, and 4.2.1.2.2.16). There was a notable increase in the median size (and the size range) of both sexes in the spring survey starting in the early 2000s (Figures 4.2.1.2.2.15 and 4.2.1.2.2.16). The increase in male sizes from the spring survey was not observed in the fall survey (4.2.1.2.2.14), where male median size ranged between 70-90 over the last 5 years (compared to spring males 80-110 over the last 5 years).

SNE

In the SNE stock, both sexes observed in the NEFSC fall survey ranged in median size from 70-90 mm in most years (Figures 4.2.1.2.2.17 and 4.2.1.2.2.18). In the fall survey, there appeared to be a slight increase in median size of females from the late 1990s through about 2008, while the last five years of the survey saw female median sizes range from only 60-80 mm (Figure 4.2.1.2.2.17). Both sexes in the spring survey had median sizes ranging from roughly 70-80 mm (Figures 4.2.1.2.2.19 and 4.2.1.2.2.20), and particularly in the males there was a large amount of inter-annual variation over the last decade (Figure 4.2.1.2.2.20).

The median sizes of lobsters from inshore surveys were only slightly smaller than from the offshore survey. The MA spring survey showed female median sizes ranging from 50-70 mm (Figure 4.2.1.2.2.21) and male median sizes ranging from 60-70 mm (Figure 4.2.1.2.2.22). In RI, both sexes in the fall survey had median sizes that varied from 60-70 annually (Figures 4.2.1.2.2.23 and 4.2.1.2.2.24). This was similar for males in the spring RI survey (Figure 4.2.1.2.2.26), and for females for the first half of the time series (Figure 4.2.1.2.2.25). Females observed during the latter half of the spring RI time series (since ~2000) were slightly larger, varying between 70-80 mm (Figure 4.2.1.2.2.25). The CT spring and fall surveys observed both males and females with median lengths ranging from 60-70 mm in most years (Figures 4.2.1.2.2.27, 4.2.1.2.2.28, 4.2.1.2.2.29, and 4.2.1.2.2.30). In the last three years of both fall and spring CT surveys, female median lengths were smaller than at any other time in the series (< 60 mm) (Figures 4.2.1.2.2.27 and 4.2.1.2.2.29). The NJ spring survey showed large inter-annual variations in the median lengths of males and females throughout the time series, with no apparent pattern over time (Figures 4.2.1.2.2.31 and 4.2.1.2.2.32). In the short time series of the NEAMAP survey, for both fall and spring females appeared to have slightly larger median sizes than males, at roughly 70-80 mm for females vs around 60-75 mm for males (Figures 4.2.1.2.2.33, 4.2.1.2.2.34, 4.2.1.2.2.35, and 4.2.1.2.2.36).

4.2.1.3 Spatial Components

Trawl survey catch data were examined for any spatial patterns or trends. Data from each survey were binned into 5 year time periods, starting with 1976 (1976 – 1980). As various surveys came on-line, their data were incorporated into the appropriate time bin. Data used included trawl coordinates (Latitude and Longitude for the start of the tow) and catch per tow for all sizes of lobsters, for ovigerous females only, and for large lobsters (>127 mm CL) only. Not all data were available every year for each survey (see table below). Spatial data are presented in maps produced using ArcGIS for each stock, in 5 year time bins (Figures 4.2.1.3.1.1 A through 4.2.1.3.3.6 H).

Survey Agency	Data available		
	All lobster sizes	Ovigerous females ("Eggers")	Large lobsters (≥127 mm CL)
NMFS	1976 - 2012	1995 - 2012	1978 - 2012
Maine	2000 (fall) - 2012	2000 (fall) - 2012	2000 (fall) - 2012
Massachusetts	1978 - 2012	1995 - 2012	1978 - 2012
Rhode Island	1980 - 2012	2008-2012	1980 - 2012
Connecticut	1984 - 2012	1984 - 2012	1984 - 2012
New Jersey	1988 (fall) - 2012	NA	1988 (fall) - 2012
NEAMAP	2007 - 2012	NA	NA

4.2.1.3.1 GOM spatial distribution (trawl surveys)

GOM Fall Surveys - all lobsters

For most of the time series (1976 – 1999), inshore (<100 m) GOM is not well represented except within MA state waters (SA 514) (Figures 4.2.1.3.1.1 A – H). The available data show higher densities in waters along the 100 meter isobath compared to densities in the deeper offshore portions of the Gulf of Maine. In the 1996-2000 time block there was a slight increase in the percentage of positive tows in the NMFS survey (Figure 4.2.1.3.1.1 E), and another larger increase in positive tows after 2005 (Figures 4.2.1.3.1.1 G and H). In eastern-most GOM, portions of SA 464 and SA 465 had relatively consistent catch rates with a higher percentage of positive tows than other deep water areas from 1976-2005 (Figures 4.2.1.3.1.1 A - F). The percentage of positive tows then increased in these areas during the 2006-2010 time period (Figure 4.2.1.3.1.1 G).

Deep water portions of the GOM that historically had many negative tows also showed an increase in the percentage of positive tows during the 2006-2010 time block, particularly in the offshore portions of SAs 511 and 512 (Figure 4.2.1.3.1.1 G).

In the southern-most portion of the GOM (SA 514), there was generally an increasing trend in density through 2000 (Figures 4.2.1.3.1.1 A - E), a decrease during the 2001-2005 time period (Figure 4.2.1.3.1.1 F) followed by increases from 2006-onwards (Figures 4.2.1.3.1.1 G and H). The southern portion of SA 514 (Cape Cod Bay) remained at lower densities during the 2006-2010 time frame, with most of the negative tows occurring in this area (Figure 4.2.1.3.1.1 G). However, there was a re-appearance of slightly higher catch tows in the most recent time period (Figure 4.2.1.3.1.1 H). Concentrations of higher densities appeared generally from the Salem Sound region to the Plymouth area.

With the onset of the ME/NH inshore survey in 2000, a complete GOM spatial picture became available. The inshore population dramatically increased during the 2006-2010 time period, particularly in northern SA 513 and throughout SA 512 (Figure 4.2.1.3.1.1 G). This pattern appeared to continue during 2011-2012, when the percentage of negative tows was lowest for all three surveys (Figure 4.2.1.3.1.1 H).

GOM Spring Surveys - all lobster

Catch from the NMFS spring survey was sporadic in the early years of the time series, but since 2000 has been relatively evenly distributed throughout the offshore GOM (Figure 4.2.1.3.1.2 A - H). This was contrary to the distribution of catch in the fall season, which was generally limited to the vicinity of the 100 meter isobath prior to the population expansion from 2006 onwards. In general there were more positive tows in the deeper water portions of the GOM during the spring than fall.

Starting with 1996-2000 (Figure 4.2.1.3.1.2 E), abundance generally began to increase throughout the GOM, with a slight increase in the percentage of positive deep-water tows in 1996-2000 (Figure 4.2.1.3.1.2 E), and a more dramatic increase from 2001 onwards (Figures 4.2.1.3.1.2 F - H). Again, portions of SAs 464 and 465 consistently showed positive tows throughout the time series with relatively consistent catch rates from 1976-2000 (Figures 4.2.1.3.1.2 A - E) followed by an increase in positive tows during the 2006-2010 time period (Figure 4.2.1.3.1.2 G).

In the southern GOM (SA 514), there was an increase in the percentage of positive tows after 1980. Low densities were relatively evenly distributed throughout SA 514 from 1996 onwards (Figures 4.2.1.3.1.2 E - H), unlike fall catch rates which tended to indicate concentrations of abundance in certain locations.

Similar to the fall increase in abundance, spring survey tows encountered higher densities of lobsters along coastal Maine (northern SA 513, 512, and 511) from 2006 onwards (Figures 4.2.1.3.1.2 G and H). Survey data showed that the population expanded, particularly in mid-coast and eastern Maine. These increases were not observed in inshore SA 514, which continued to have consistently low and evenly distributed densities.

GOM Fall and Spring Surveys - ovigerous females

The deeper-water portions of the GOM in the fall generally had lower densities of ovigerous females than inshore areas (Figure 4.2.1.3.1.3 A - E). The percentage of positive tows increased over the time series. This increase was slightly more evident in the offshore survey area (NMFS survey), which increased from 8% positive tows in 1996-2000 (Figure 4.2.1.3.1.3 B) to 29% positive tows in 2011-2012 (Figure 4.2.1.3.1.3 E).

Similar to the fall surveys, spring surveys indicate that offshore areas generally have lower densities of ovigerous females than inshore areas (Figures 4.2.1.3.1.4 A - E). Spring surveys also showed an increase in the percentage of positive tows, more so than fall surveys. This increase was more noticeable in offshore areas where the NMFS survey increased from 11% positive tows in 1996-2000 (Figure 4.2.1.3.1.4 A) to 35% positive tows in 2011-2012 (Figure 4.2.1.3.1.4 D). Tows that caught more than five ovigerous females were very rare in both seasons.

GOM Fall and Spring Surveys - large lobsters (≥127mm)

From 1976 through 1995 catch rates of large lobsters (≥127mm) during fall surveys were relatively low and generally limited to SA 512 (Figure 4.2.1.3.1.5 A – D). Starting in the early 1990s, the percentage of positive tows in the NMFS survey began to increase, with increases in the percentage of positive tows in the MA survey starting after 1996. These increases continued through the end of the time series primarily in inshore areas, but to a lesser extent in the deeper offshore areas as well (Figure 4.2.1.3.1.5 D – H) .

Between 1976 and 1995 spring catch rates of large lobsters (>127 mm CL) in the GOM were low and generally limited to SA 512 and, to a lesser extent, SAs 511 and 465 (Figure 4.2.1.3.1.6 A – D). Catch rates began to increase in 1996-2000 similar to the trend seen in the fall survey (Figure 4.2.1.3.1.6 E). In contrast to the fall survey, catches of large lobsters were not limited to the inshore areas in the GOM but were more evenly distributed throughout all of the GOM. Increases were particularly evident from 2001 onwards (Figure 4.2.1.3.1.6 F - H).

Tows that caught more than 5 large lobsters were more common in the fall than spring season, and generally occurred in the 50 – 100 m depth range. Large lobsters appeared to be more dispersed in the spring season than in the fall.

4.2.1.3.2 George's Bank Spatial Distribution (trawl surveys)

GBK Fall and Spring Surveys - all lobsters

The percentage of positive tows was higher in fall surveys than spring surveys, and lobsters were generally dispersed across the George's Bank region in the fall. (Figures 4.2.1.3.2.1 A - H). Slightly higher densities (concentrations of positive tows) occurred in the northern and eastern regions (SAs 561, 562, 551, and 552), particularly in recent years (Figures 4.2.1.3.2.1 F through H), when densities generally increased. There was a corridor of consistent positive tows along the western portion of the Great South Channel into the eastern bank of Outer Cape Cod, indicating a linkage between the inshore and offshore portions of the stock.

The general distribution of all lobsters on Georges Bank in the spring has the highest densities in the deep waters off the bank to the north and east (Figures 4.2.1.3.2.2 A - H). Lobsters became more abundant in recent years, and the distribution expanded from the eastern-most portion in a southwesterly direction along the edge of the shelf (from SAs 551 to 552 and 562) (Figures 4.2.1.3.2.2 F and G).

GBK Fall and Spring Surveys - ovigerous females

Ovigerous females were more common in the fall than the spring surveys (Figures 4.2.1.3.2.3 A - E and Figures 4.2.1.3.2.4 A - D respectively). The different seasonal distributions were very distinct, with ovigerous females located on the north or southeastern periphery of the bank (deeper waters) in the spring and in shallower waters in the fall. The marked difference in distribution of ovigerous females on and off of Georges Bank between the spring and fall surveys is striking. There is a clear shift from deep water habitats along the margins of the bank in the spring (particularly the northern margins) to shallower habitats up on the bank in the fall. Further, it appears that larger lobsters, especially ovigerous females, may be driving this pattern. This suggests exchange of older individuals between the GOM and GB stock with much of the GB spawning stock moving off the bank for the winter and spring.

GBK Fall and Spring Surveys- Large lobsters (≥ 127 mm CL)

Large lobsters (≥ 127 mm CL) were more dispersed in the fall than spring (Figures 4.2.1.3.2.5 A - H and Figures 4.2.1.3.2.6 A - H), and densities started to increase in the mid 2000s, particularly in the eastern portions of the stock (Figures 4.2.1.3.2.6 G and H). Densities of large lobsters along the corridor between the Bank and the inshore portion of SA 521 are not particularly high or concentrated, suggesting that this linkage may be primarily driven by slightly smaller individuals. Large lobsters (≥ 127 mm CL) in the spring were primarily distributed around the periphery of the Bank, at depths of 100 m or greater (Figures 4.2.1.3.2.6 A - H). Densities of large lobsters increased after 2005, concentrated mainly around the northeastern tip of the Bank (SAs 551 and 552) (Figures 4.2.1.3.2.5 G and H, Figures 4.2.1.3.2.6 G and H).

4.2.1.3.3 SNE spatial catch distributions (trawl surveys)

SNE Fall and Spring Surveys - all lobsters

Northern inshore portions of SNE (SA 538, 539, 611) show a coherent pattern of evenly distributed moderate to low catch densities in the fall and spring until 1990 (Figures 4.2.1.3.3.1 A - C and Figures 4.2.1.3.3.2 A - C). Higher density 'concentration' areas became evident from 1986-2000 in the western and central basins of Long Island Sound, Narragansett Bay, and RI Sound in fall and spring surveys, as well as Buzzards Bay and off the Elizabeth Islands in spring surveys (Figures 4.2.1.3.3.1 C - E and Figures 4.2.1.3.3.2 C - E). Catch densities in these 'hot spots' diminished by 2001-2005, with all inshore catches declining to low densities by 2012 (Figures 4.2.1.3.3.1 F - H and Figures 4.2.1.3.3.2 F - H). A small area of moderate catches remained until the mid-2000s in Rhode Island Sound, but declined to low catch rates by 2011 and 2012.

Generally spring and fall distributional patterns were similar, although mid-shelf catch densities were lower in spring with many zero catches in southern areas after 1985 (Figures 4.2.1.3.3.1 A H and Figures 4.2.1.3.3.2 A - H). Low catch rates were consistently distributed throughout SA 537 during the entire time series. In SA 612 – 613 and further south, catch locations were more scattered and all with low catch rates. Some low densities were concentrated coastally just south of the Hudson outflow, offshore along the Hudson River Drainage and distributed along the shelf break, while other locations were much patchier with 0-catch tows distributed throughout. The percentage of 0-catch tows in NJ Survey increased to 90% after the late 1990s.

SNE Fall and Spring Surveys - ovigerous females

Documentation of ovigerous females was sparse in both spring and fall (Figures 4.2.1.3.3.3 A - G and Figures 4.2.1.3.3.4 A - G). Where data were available, catches almost exclusively occurred inshore (SAs 538, 539, 611). Higher density 'concentration' areas were particularly evident in the western and central basins of Long Island Sound, and to a lesser extent in RI Island Sound. Catch densities in these 'hot spots' diminished by 2001-2005 (Figures 4.2.1.3.3.3 E and 4.2.1.3.3.4 E), with all inshore catches declining to low or zero densities by 2012 (Figures 4.2.1.3.3.3 G and 4.2.1.3.3.4 G). Low catches of ovigerous females were observed only sporadically in mid-shelf waters and southern waters (SA 537, 612, 613, 614-616, 621-622) throughout the time series. Spring and fall distributional patterns were generally similar with slightly lower densities recorded in fall survey seasons.

SNE Fall and Spring Surveys - Large lobsters (≥ 127 mm CL)

There were very few observations of large (≥127 mm CL) lobsters in the SNE stock area during the entire time series in both spring or fall surveys, with never more than 1-5 in a tow (Figures 4.2.1.3.3.5 A - H and Figures 4.2.1.3.3.6 A –H). These larger lobsters seemed to occur slightly more often in fall than spring seasons, and there were more occurrences in the first few years of the time series (1976-1980) than any other time (Figures 4.2.1.3.3.5 A and 4.2.1.3.3.6 A).

4.2.2 Coast-wide Ventless Trap Survey (VTS)

The coast-wide ventless trap survey (VTS) was initiated in 2006 with the intention of answering the need for a standardized fishery-independent survey designed specifically to monitor lobster relative abundance and distribution. This need was specifically identified in the 2004 Lobster Stock Assessment (ASMFC 2006). Of all the possible methods for surveying lobster populations, traps have the fewest associated limitations in relation to habitat factors because they can be used on complex substrate (Smith and Tremblay 2003). A number of factors influence their catchability, which can be difficult to interpret. In pilot surveys conducted by MADMF using a stratification scheme that incorporated depth and substrate type, depth was found to be the driving environmental factor in patterns of catch and size distribution (MADMF unpublished data).

4.2.2.1 Survey Methods

The coast-wide VTS employed a random stratified survey design, using NMFS Statistical Area (SA) and depth as the primary strata classifications. The SAs included in the survey were 511, 512, 513, and 514 in the Gulf of Maine stock, and 538, 539, and 611 in the Southern New England stock unit. The survey was a cooperative effort between state fisheries agencies and commercial lobstermen, who were contracted to fish the survey gear.

The areal extent of the survey encompassed the state waters portion of Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, and New York. For sampling logistics the following areas were excluded from the study area: a) In Maine (SA 511, 512, 513), the estuaries associated with the Kennebec and Penobscot Rivers, b) in New Hampshire (SA 513) Great Bay, the Piscataqua River and Hampton Harbor, c) in Massachusetts SA 514, the southwest corner of Cape Cod Bay which contains expansive shallow sandy flats, and in SA 538 the Vineyard Sound and Nantucket Sound areas due to unsuitable lobster habitat and conflicts with mobile gear fleets, d) in Rhode Island, the western portion of Block Island Sound, and e) in New York and Connecticut, only the Long Island Sound portion of SA 611 was sampled, excluding Fishers Island Sound. USGS bathymetry maps were used to identify depth strata. The survey design used three depth strata that span the range of depths in which lobster are typically fished in inshore waters: 1 - 20 m, 21 - 40 m, and 41 - 60 m. A bathymetry map of the study area was overlaid with a one-minute latitude/longitude grid, and each grid cell was assigned a strata based on its bathymetric attributes. A fixed number of sampling stations (grid cells) were randomly selected within each strata in each SA, and new stations were selected each survey year.

In every state except Maine, each station was sampled with one six-pot trawl, in which vented and ventless lobster traps were alternated (3 of each per trawl). Maine deployed the gear either as two three-pot trawls or as one six-pot trawl. Stations were sampled twice per month with a three night soak time between baited hauls on the following schedule:

	Months sampled							
Survey state - stock (SA)	2006	2007	2008	2009	2010	2011	2012	2013
Maine - GOM (Area 511, 512, 513)	June - Aug	June - Aug	June - Aug	June - Aug	June - Aug	June - Aug	June - Aug	June - Aug
New Hampshire - GOM (Area 513)	--	--	--	June - Sept	June - Sept	June - Sept	June - Sept	June - Sept
Massachusetts - GOM (Area 514)	July - Aug	June - Sept	June - Sept	June - Sept	June - Sept	June - Sept	June - Sept	--
Massachusetts - SNE (Area 538)	June - Aug	May - Nov	June - Sept	June - Sept	June - Sept	June - Sept	June - Sept	--
Rhode Island - SNE (Are 539)	July - Sept	June - Aug	June - Aug	July - Sept	July - Sept	July - Sept	June - Aug	June - Aug
New York - SNE (Area 611)	Sept - Nov	June - Sept	July - Oct	July - Oct	--	--	--	--

The different timing from state to state was partly intended to encompass the major molting period in each area and was somewhat impacted by funding availability and timing.

Trap deployment, maintenance, and hauling were contracted to commercial fishermen. Fishermen were required to haul survey gear on as close to a three-day soak time as possible in an attempt to standardize trap catchability among sampling trips. All trawls were reset in the same assigned location each time. All traps used in the survey were of a standard design with dimensions 40” x 21” x 16” a single parlor, and 5” entrance heads. The size of the escape vent in vented traps varied by region based on regulations. The lack of standardization of vent sizes among sub-areas could potentially bias CPUE estimates of both sublegal and legal lobsters in vented traps by region; however, indices for the current assessment are all calculated using only ventless traps.

At-sea samplers (agency staff members) recorded catch in number of lobsters, number of trap hauls, set-over-days, bait type, trap type, and for each lobster; carapace length (to the nearest mm), sex, shell hardness, culls and other shell damage, external gross pathology, mortality, the presence of extruded ova on females, and shell disease symptoms. Trap locations were confirmed with assigned station coordinates after each haul via GPS.

4.2.2.2 Development of Abundance Indices

For calculating survey indices for the VTS, we used only the ventless traps and discarded the data from the co-located vented traps. For the GOM stock, the Massachusetts and Maine surveys were initiated in 2006 but the New Hampshire survey did not start until 2009. We retained the NH survey in the regional indices because it showed a common dynamic and similar density with the MA and ME surveys. Indices with and without NH were similar and the NH survey is a continuing data stream. For SNE, both the MA and Rhode Island surveys started in 2006 but the New York survey started in 2007 and ended in 2009. Due to the shortness of the NY survey, the fact that including the NY survey had a large impact on the combined index, and that the survey is not continuing, we chose to calculate the SNE index using only the MA and RI surveys. Because MA did not run a VTS survey in the GOM or SNE in 2013 and the MA data were strongly influencing the combined indices, no combined VTS indices were calculated for 2013 for GOM or SNE. Additionally, the survey index was constrained to the months of June, July and August when all agencies were conducting their surveys.

The targeted soak time for the VTS is three days but this is not always consistent. To address varying soak times, we investigated calculating VTS indices assuming linear or nonlinear relationships between soak time and catch rates as well as disregarding soak time effects. Though soak time is known to affect catch rates, particularly on relatively short soaks, results of the comparisons were robust to the different calculation methods. Thus, we assumed a linear increase in catch and standardized all trap catches to three days by dividing catch by soak time to get catch per day and multiplying by three.

Because survey sites were not moved within a survey season, each survey site was treated as an effective replicate and samples within the season as repeated measures. To get the season average for a survey site, we first averaged the catch in the traps across traps in a trawl, then across trawls within a month, then across months in a season. Calculating the survey indices from the survey site averages then used standard stratified-random equations with the depth and region strata used in the survey design from each state agency:

$$Catch_y = \frac{\sum_{str} \frac{\sum_s Catch_{s,str,y}}{N_{str,y}} \times A_{str}}{\sum_{str} A_{str}}$$

where $Catch_{y,s,str}$ is the mean catch at site s in stratum str and year y, $N_{y,str}$ is the number of sites in stratum str and year y and A_{str} is the area of a given stratum.

Length compositions for the VTS are calculated in a similar way but by calculating the stratified mean catch for each size bin and then standardizing across bins within a year to sum to one.

Spatial GIS Analysis

Spatial trends in catch rates for ventless traps were analyzed using GIS software. Plots were constructed by site and year with associated histograms of catch bins by statistical area. Catch rates for this analysis were calculated as mean catch per trap haul by sampling station by year (2006-2013) for the months of July-August. It is important to note that sampling intensity during this time series was not consistent due to survey funding. Most notably, for the GOM, the NH survey in the southern portion of SA 513 didn't begin until 2009 and SA 514 wasn't sampled in 2013. In SNE, SA 611 was only sampled from 2007-2009 and SA 538 wasn't sampled in 2013.

University of Maine Model

The coast-wide VTS was used in the University of Maine model in the current assessment. For an in-depth description of modeling procedures see Section 6.1.

4.2.2.3 Survey indices, spatial patterns and length compositions

GOM Ventless

VTS indices for the GOM at the stock scale were generally stable from 2006 – 2010, then increased sharply nearly doubling by 2012 (Figure 4.2.2.3.1 A and B). Females were more abundant than males through the time series (Figure 4.2.2.3.1 A). On a per-state basis, densities were highest in ME and lowest in MA with intermediate densities in NH (Figure 4.2.2.3.1B). Examining survey indices by statistical area and depth strata, there were minimal differences and a common trend in catch rates across depths for the northern statistical areas (Figure 4.2.2.3.2 A and B). However, catch rates were higher and more stable in the shallow strata than the deeper strata in the southern statistical areas (Figure 4.2.2.3.2 C and D). SA 511 and 512 had the highest densities at the beginning of the time series and catches doubled in SA 512 to a regional high of around 25 lobsters per trap. However, the greatest proportional growth in catch rates was in the deep strata in SA 514 which increased from less than 2 to nearly 8 lobsters per trap by 2012.

High catch rates were observed near Penobscot Bay and Casco Bay in SA 512 and 513 with an additional hot spot in the northern half of SA 514 (Figure 4.2.2.3.3 A - H). In 2011, SAs 512 and 513 had a higher percentage of stations in the 11-20 and 21-40 catch bins than in the 6-10 and 11-20 catch bins respectively (Figure 4.2.2.3.3 F). In 2012 and 2013 all SAs saw an overall increase (except SA 514 in 2013, where there was no data) (Figure 4.2.2.3.3 G and H). One station in SA 512 averaged more than 60 lobster per trap haul in 2011 (Figure 4.2.2.3.3 F).

From 2006 – 2010, SA 514 as a whole consistently had lower mean CPUEs than the other GOM SAs, with more than 50% of stations annually falling in the 0.01-5 catch bin (Figure 4.2.2.3.3 A - E). Additionally, SA 514 was the only SA during the time series with a mean annual catch rate of zero lobster for a station (in 2010; Figure 4.2.2.3.3 E). The southern portion of SA 514 (Cape Cod Bay) consistently had more stations in the lowest catch bin of .01-5 lobster than other SAs. In 2011 and 2012 SA 514 saw an increase in the percent of stations in the higher catch bins, a dynamic that is consistent with the northern SAs (Figures 4.2.2.3.3 F and G). Overall, catch rates in the GOM showed an upward trend over the time series and midcoast Maine consistently showed the highest catch rates.

Catch length composition was consistent across years with a sharp mode in the largest sublegal size and very few individuals larger than 88 mm CL (Figures 4.2.2.3.4 A). Length composition differed by sex with a tendency for females to accumulate around 80 mm CL, though composition was similar between sexes for individuals >88 mm CL (Figures 4.2.2.3.4 B).

SNE ventless
VTS indices for SNE declined ~30% over the time series with higher catch rates for females than males (Figure 4.2.2.3.5 A). Catch rates were highest in RI and lowest in MA with LIS being similar to MA in the years the LIS survey was conducted (Figures 4.2.2.3.5 B). Abundance patterns with depth were reversed in SNE from GOM, with higher catch rates in the deeper strata (Figures 4.2.2.3.6 A - C). Catch rates were similar in the deeper strata for RI and MA which were higher than LIS. For the shallow strata, catch rates were highest in RI and lowest in LIS.

From 2007 through 2009 a high proportion of the catch was in the 0.01-5 bin, and sites with higher catch rates generally appear to be in deeper portion of SA 611 (Figures 4.2.2.3.7 B - D). During this time period low catch rates were also observed in the upper reaches of Buzzards Bay in SA 538, whereas relatively high catch rates were observed further south near the mouth of Buzzard Bays and Narragansett Bay. From 2006 – 2009, from 8% to 25% of stations in SA 539 averaged 21-40 lobsters per trap haul, and from 4% to 12% of stations in SA 538 were in this catch range (Figures 4.2.2.3.7 A - D). After 2009, there were never more than 10% of stations in SA 538 (0% to 5% of stations) or 539 (0% to 8% of stations) that averaged 21-40 lobsters per trap haul (Figures 4.2.2.3.7 E through G). The highest percentage of 0-catch stations in SA 539 occurred in 2013 (2013 SNE map not available).

Catch length composition was consistent across years with a mode in the largest sublegal size and very few individuals larger than 88 mm CL (Figure 4.2.2.3.8 A). However, the mode was less well defined than GOM, being spread across three size classes. Like GOM, length composition differed by sex with a tendency for females to accumulate around 73 - 83 mm CL, and composition was similar between sexes for larger size classes (Figure 4.2.2.3.8 B).

4.2.3 Settlement and Larval Surveys

The youngest life stages for which quantitative data exist is for late-stage larval and newly settled lobster (Stages IV and V respectively). Ovigerous females hatch eggs in the summer and the larvae follow with a 6-8 week planktonic life phase (Ennis 1995). In SNE the planktonic phase is sampled by surface plankton nets towed at fixed stations in western Long Island Sound (Giannini 2008) and gantry-mounted in power station outfall (DNC 2008). After settlement to the bottom, the newly metamorphosed lobsters can be sampled by divers using air lift suction samplers (Wahle and Incze 1997). Settlement was measured in natural cobble substrate (Wahle and Steneck 1991), and settlement strength was defined as the abundance of newly settled lobster (0+ year class: ≤10 mm CL in ME, ≤12 mm CL in MA SA 514, ≤ 13 mm CL in MA SNE, ≤13 mm CL in RI) in cobble nurseries after the end of the settlement season. A standardized survey of this type has been conducted at stations in mid-coast Maine since 1989, Rhode Island since 1990, and Massachusetts since 1995.

Density estimates of newly settled lobster were investigated for evidence of variability in regional settlement strength and for temporal trends that could be used at some point to predict landings in the fishery. This approach has been used successfully for the western Australian rock lobster(*Panulirus cygnus)* fishery (Phillips and Booth 1994). The Australian fishery predicts nearly 75% of their landings based on the long-term relationship between the settlement of the puerulus (the pelagic, postlarval stage) on artificial collectors and the size of the commercial catch four years later.

Observations of settlement patterns in Maine indicate coherent trends among sites in the same region across years (Palma et al. 1999). The similarity in trends in Maine suggests that factors affecting settlement success vary on a regional basis, a finding which enhances the possibility that annual sampling could provide sufficient data for documenting temporal changes in regional year class size when first established and, possibly as they reach fishable size. Earlier studies have demonstrated that annual differences in the abundance of newly settled young-of-year lobsters reliably foretell the number of 1-year-olds in the nurseries a year later (Wahle and Incze 1997, Wahle et al. 2003). The extent to which trends in settlement will eventually affect landings in any given year depends on the survival of juvenile lobsters after settlement, variability in their growth, and the number of year classes that contribute to the size group that recruits into the fishery. The probable mixing of year classes in recruit size classes dampens year-to-year fluctuations in recruitment that would otherwise be caused by annual variation in settlement densities.

For this assessment larval data were supplied by Connecticut and Millstone Power Station (DNC 2008) and settlement data were provided by Maine, New Hampshire, Massachusetts, and Rhode Island, and for midcoast Maine (1989-2000) by Richard Wahle, University of Maine, Darling Marine Center, Walpole, ME.

Within the GOM, updated Young of Year (YOY) survey data indicate that the more northern surveys (SAs 511 and 512) were positive, but the more southern areas (513E, 513W, and 514) were neutral to negative. In 2013, three of the five YOY indicators were below the 25th percentile (see Table 5.2.1.2 D). Settlement in all regions in GOM is trending down. This indicates a potential for declines in recruitment in future years and is a pattern to pay particular attention to in coming years.

In SNE, all YOY surveys are at or below the median, and half are below the 25th percentile for the period of 2008-2013 (Table 5.2.3.2 D). The RI and ELIS (CT) surveys have consistently been below the 25th percentile since 2007. The declining pattern of larval production and settlement in Southern New England would predict low levels of recruitment to the fishery in coming years.

4.2.4 Additional Survey Information considered

Since 2002, landings and fishery-independent abundance indices for the GOM and GBK stocks have increased to historic high levels while landings and abundance indices for the SNE stock have fallen ten-fold. Other than landings data, long-term data sets characterizing lobster populations are scarce, making it very difficult to determine if this dichotomy among lobster stocks has occurred in past decades on a stock-wide basis. In addition to large-scale state and federal trawl survey data used in this assessment, there are two small-scale but long-term trawl surveys located in the SNE region. These sources include a research trawl program administered by the University of Rhode Island, Graduate School of Oceanography (URI_GSO, J. Collie pers. comm.) at two fixed sites in Narragansett Bay, RI, begun in 1959, and a standardized trawl survey administered by Dominion Nuclear Connecticut (DNC 2013), at six fixed stations in the vicinity of the Millstone Power Station in northeastern Long Island Sound, begun in 1976.

The longest of these two time series was generated by the URI_GSO program. This survey recorded a period of extremely low abundance at the beginning of the time series in the early 1960s (Figure 4.2.4.1). Reasons for this period of low abundance are unknown. The Millstone survey time series begins a decade and a half after the URI_GSO survey, but both the URI_GSO Survey and the Millstone Trawl Survey show highest abundance throughout the 1990s, with relatively lower abundance in the 1980s as well as since 2001 (Figure 4.2.4.1). For the 36 years when their relative abundance indices overlap, these two time series correlate well ($r = 0.66$, $df = 35$, $p < 0.001$). Indices for 2011-13 in both time series are below their respective 25th percentiles, as they were for brief periods (only one to two years) in the late 1970s and early 1980s.

In addition to these two long-term SNE region focused surveys, long-term trap monitoring and larval sampling programs are also available for two areas adjacent to nuclear power plants in Connecticut (SNE stock area) and New Hampshire (GOM stock area). Although both datasets are spatially limited, the longevity of these monitoring studies provides corroboration of trawl survey trends as well as useful insight into lobster densities within their respective study areas under similar scientific methodologies that are directly comparable. In CT, Millstone Power Station (DNC 2013) conducts these studies, and in New Hampshire data are compiled for NextEra Energy Seabrook Environmental Monitoring Program by Normandeau Associates Inc. (NAI 2012). Both power stations conduct ventless lobster trap sampling and lobster larval sampling as part of their annual monitoring programs. Trends in sublegal lobster abundance can be traced in these two long-term studies as an indicator of recruitment rate to each stock. Differences in recruitment appear to be at least a partial explanation for their divergent trajectories.

In the Millstone study, abundance indices of lobster generated by the ventless research trap data (set May-October) have declined since 2002 to below the 25th percentile for the time series (Figure 4.2.4.2). Additionally, larval entrainment densities at the Millstone station declined from a median annual value of 0.76 (delta mean density/1000 m^3 of water entrained) for 1984-2001 to 0.37 for 2002-2012, or a 51% decline (Figure 4.2.4.3). These data indicate that the population's production rate of young recruits is falling along with the falling abundance of the surviving spawning stock in the area of the Millstone monitoring program. These data corroborate trends seen in other SNE regional datasets.

In contrast to the downward trends seen in the Millstone Power Plant data, a similar long-term study conducted off the coast of New Hampshire shows a general upward trend in the catch rate of sublegal-sized animals over a 38 year time series (Figure 4.2.4.4). Catch rates were relatively low at the beginning of the time series (1975-1994), with CPUE (number/15 traps standardized to 2 day set time) values ranging from 40-80 lobsters per 15-trap trawl, whereas in recent years (1995-2012) catch rates almost doubled, ranging from 80-120 lobsters per trawl. A similar pattern is evident in larval densities collected by neuston net at fixed stations near the power station intakes and in the vicinity of the power plant off the coast of NH (Figure 4.2.4.5). Annual densities (number/1000 m^3 of water sampled) at both stations showed a significant positive slope ($p < 0.011$, df = 35 and 31, respectively) over the time series. The average density in 2002-2012 was 30-31% higher than the average in 1982-2001 at each station. These trends corroborate trends from other regional datasets.

The contrasting trends between the two long-term data sets, which were collected using fishery-independent scientific methodologies, corroborate the conclusion that the SNE stock has declined in part due to a prolonged period of poor recruitment not experienced by the GOM stock. Importantly, the apparent continued decline in reproductive success by SNE adults suggests that protections given to the current low level of adult abundance have not translated into any increase in recruitment of young lobsters or resulted in stock rebuilding. In the past, a small spawning stock has rebounded quickly when protective measures were implemented and the physical environment was favorable. However, without favorable environmental conditions conducive to robust recruitment events (see Section 2.2), it appears that the poor condition of the SNE stock will continue.

These data sources were not adopted directly into the analytical assessments for the respective stock units primarily due to the limited spatial extent of these surveys, especially because more spatially robust data sets in the same stock areas are readily available. However, all of these data sets are most valuable as supporting evidence for the trends seen in the data that were used in the assessment directly. In addition, the long duration of these surveys gives a greater historic perspective to the changes in the lobster population abundance by stock area, and so provide good context for how the population trends cycle.

5.0 STOCK INDICATORS

In addition to standard model-based fishing mortality and abundance estimates, a number of empirical stock indicators were examined to judge stock status. These indicators provide information about the overall health of each stock independent of the assessment model. Three categories of indicators were generated: mortality, abundance, and fishery performance. The annual status of each indicator time series was characterized as positive, neutral, or negative based on its quartile ranking (details below). Fishery performance indicators were classified in the same manner as abundance indicators, with the exception of the number of traps fished and set over days, which were classified like a mortality indicator. For all indicators, the terminal six-year average (2008 - 2013) will be used to assess the status relative to the reference time period(1982 – 2003 for GOM and GBK, 1984 – 2003 for SNE).

5.1 STOCK INDICATOR METHODS

5.1.1 Mortality Indicator

Exploitation rate is used as an indicator of mortality, and is characterized as shown below.

	< 25th percentile	**Between 25th and 75th percentile**	**> 75th percentile**
Exploitation rate	Positive	Neutral	Negative

Exploitation rate is the landings (in weight) divided by the reference population (all lobsters > 77 mm, converted to weight (see Section 4.1.4.2) from each trawl survey. A separate value was calculated for each survey by assigning the appropriate landings based on statistical area(s) covered by the survey (Tables 2.9.1 and 2.9.2).

5.1.2 Abundance Indicators

Four indicators were generated to assess relative abundance, total spawning potential, and year class strength of each stock. These include: spawning stock biomass index, recruit abundance, full-recruit abundance, and an index of larval production or young-of-year (YOY) settlement. Annual abundance indicators were characterized as shown below.

	< 25th percentile	**Between 25th and 75th percentile**	**> 75th percentile**
Spawning stock abundance	Negative	Neutral	Positive
Full recruit abundance	Negative	Neutral	Positive
Recruit abundance	Negative	Neutral	Positive
Recruitment indices (larval or YOY)	Negative	Neutral	Positive

The spawning stock abundance index reflects the reproductive potential of the stock in a given year relative to each survey. It represents the annual total weight of mature females (based on maturity ogives, see Section 2.7.1) for each survey, calculated as:

$$SSB = \sum_{CL=1}^{\infty} (\#\,females\,) * (proportion\;mature) * (weight)$$

The full recruit abundance is the mean number per tow of lobsters (sexes combined) that have been legal to harvest throughout the entire time series (size ranges vary by stock. GOM ME/NH and MA surveys: ≥ 83 mm CL, NEFSC survey: ≥ 90 mm CL. GBK NEFSC survey: ≥ 90 mm CL. SNE MA, RI, and CT surveys: ≥ 86 mm CL, NEFSC survey: ≥ 90 mm CL). The recruit abundance is the mean number per tow of lobsters (sexes combined) that have been below harvestable size throughout the entire time series (71 – 80 mm CL for all surveys). . The recruit abundance is intended to represent an approximation of the number of lobster that might be expected to molt into the fishery within one year of the survey.

Young of the Year indices represent potential recruitment to the population. These indices include an annual estimate of the mean density (delta mean per 1000 m^3 water) of all larvae (ELIS) or Stage IV larvae (CLIS) or of mean density (mean # per m^2) of newly settled young-of-year (YOY) lobsters (all other locations). Sustained high levels of larval or YOY density would indicate favorable production. Along with surveys conducted by state agencies, additional data for these indices were provided by R.Wahle (GOM) and by the Dominion Nuclear Power Station (ELIS). There are no available recruitment indicators for GBK.

5.1.3 Fisheries Performance Indicators

Eight indicators were used to describe the performance of the fishery in each stock area: effort, total landings, partial landings (from those sources for which effort data were available), gross CPUE (partial landings/traps), price per pound, gross stock revenue (adjusted and un-adjusted) and revenue per trap (adjusted and un-adjusted). Fishery performance indicators were classified in the same manner as abundance indicators, with the exception that the number of traps fished and set over days were classified like a mortality indicator. For indicators where the price per pound was used, an adjusted value was computed to account for inflation based on the unprocessed fish consumer price index (CPI) with 2013 as the base year (www.bls.gov).

	< 25th percentile	**Between 25th and 75th percentile**	**> 75th percentile**
Effort (# of traps)	Positive	Neutral	Negative
Total stock landings (lbs, all sources)	Negative	Neutral	Positive
Partial landings (lbs, sources with corresponding effort data)	Negative	Neutral	Positive
Gross CPUE (partial landings/traps)	Negative	Neutral	Positive
Set-over-days	Positive	Neutral	Negative
Price per pound	Negative	Neutral	Positive
Revenue (based on total stock landings)	Negative	Neutral	Positive
Revenue per trap (based on gross CPUE)	Negative	Neutral	Positive

The number of traps was used as an indicator of effort, and is based on the number of trap tags issued by each jurisdiction (ME) or the number of traps reported fished (MA, CT, NY). Data included here are only for those jurisdictions with complete time series. In the GOM, trap numbers were available from ME and MA dating back to 1982. For the SNE stock, data from MA and NY start in 1981, while data from CT were available starting in 1984, so data from these jurisdictions from 1984 onwards were used. Effort data from NH start in 2004, and from RI start in 2001, thus were not used due to the short time series available. These data are only a proxy for effort as they do not account for how many traps were actually deployed in the fishery, the average set-over days, or changes in gear efficiency/design.

Total landings for the stock are landings from all sources (jurisdictions) and represent a common indicator of fishery performance. Partial landings are landings from only those jurisdictions for which effort data (traps) were available. These landings were used in calculations of gross CPUE (partial landings / traps), and revenue per trap (see below).

When available, the annual average soak time of traps was used as an additional indicator of fishery performance by stock area. Regulations limiting trap numbers or changing economic conditions would be expected to change the observed soak time. Reviews by Krouse (1989) and Miller (1990) indicated that soak time is related to trap efficiency and ultimately total removals. However; this relationship is poorly understood as additional factors likely contribute (gear, bait, bottom type, water temperatures, trap saturation etc.). Soak time information was available from Maine and Massachusetts. On Georges Bank, information was available from Massachusetts only. In Southern New England, information was available from Massachusetts and Connecticut.

The average ex-vessel price was queried to provide an estimate of value to the fishermen for each pound of lobster landed (personal communication from the National Marine Fisheries Service, Fisheries Statistics Division, Silver Spring, MD). In areas where the total catch has changed significantly over the assessment period, average price per pound was an indicator of price elasticity. To assess how ex-vessel price has changed relative to inflation, price per pound was adjusted to 2013 US dollars using the unprocessed fish consumer price index (www.bls.gov).

Gross revenue to the fishery was estimated as the product of average price per pound and total stock landings (raw and adjusted). Finally, the average revenue per trap was estimated using the gross CPUE, which includes only landings from those jurisdictions with effort data.

5.2 STOCK INDICATOR RESULTS

In general the stock indicators should be interpreted cautiously, and often in relation to other indicators (for example, set-over-days as a performance indicator). While there are more than 30 years of data for most indicators, this time period may not be reflective of the entire productive range of the stock. The strengths of this approach are that the use of quartiles is objective and the focus on trends is straight-forward and free of modeling assumptions.

5.2.1 GOM

Mortality indicators expressed as mean exploitation rate for the years of 2008-2013 are all neutral or positive for the spring trawl surveys and positive for the fall surveys (Table 5.2.1.1). Annual exploitation rates from 2008-2013 are mostly positive with the exceptions of the MA spring survey which was neutral to negative. Also, the last two years of the ME/NH fall survey were negative and neutral.

Abundance indicators for recent years are mostly positive or neutral (Tables 5.2.1.2 A through E). Mean spawning stock abundance indicators for the years 2008-2013 are positive in all six surveys (Tables 5.2.1.2 A). Mean full recruit and recruit abundance (2008-2013) are positive for the all the NEFSC and ME/NH surveys. The MA full recruit abundance 2008-2013 mean is neutral both seasons, and the recruit indicator is positive for the fall survey and neutral for spring. (Tables 5.2.1.2 B and C).

Young-of-year indices generated from the American Lobster Settlement Index (ALSI) appear to be trending down (Table 5.2.1.2 D), particularly in SAs 513 and 514. The mean for the years 2008-2013 is mixed; positive in 511 and 512, neutral in eastern 513 and 514, and negative in western 513. In 2013 three of the five regions in the GOM were negative (< 25th quartile). Relatively low levels were observed early and late in the time series, whereas YOY catch rates in the early to mid-2000s were generally neutral or positive. This recent pattern of low settlement indicates a potential for declines in recruitment in future years.

Survey lobster encounter rates, expressed as proportion of positive tows, were positive to neutral when looking at the mean for 2008-2013 (Table 5.2.1.2 E). On an annual basis it's clear that the encounter rate has increased for all surveys in recent years, but this is particularly apparent with regards to the NEFSC survey. Since 2008, all of the NEFSC annual values describing the encounter rate for the fall and spring survey were positive (> 75th quartile).

Several of the GOM fishery performance indicators have been positive for recent years (Table 5.2.1.3); average landings, CPUE, revenue and revenue per trap were all positive based on the mean for 2008-2013. Effort, as number of traps reported, has been high and negative since 2001, although recent values are lower than earlier in the 2000s. The mean time lobster pots sit in the water between hauls, expressed as set-over-days, has increased in recent years and mean values for 2008-2013 are negative. Additionally, the price paid to fishermen per pound adjusted to unprocessed fish CPI is negative.

5.2.2 GBK

The effective exploitation mortality indicators for the reference period (2008-2013) are positive (Table 5.2.2.1). Relative exploitation rate derived from the NEFSC Surveys have remained below the 25th percentile in five out of the last six years in fall and for all six years in spring surveys.

Abundance indicators for the reference period (2008-2013) were positive for three of the four indicators (Tables 5.2.2.2 A through D). The spawning stock abundance index and full recruit abundance index were well above the 75th percentile for both the fall and spring NEFSC Surveys (Tables 5.2.2.2 A and B). The recruit survey abundance for the reference period was negative for both the spring and fall survey (Tables 5.2.2.2 C), and since 2008, seven of the 12 annual values were negative. The distribution of lobster in GBK as measured by the proportion of positive tows is positive, with all of the most recent years being above the 75th percentile (Tables 5.2.2.2 D).

GBK stock fishery performance indicators for recent years are mixed but generally positive (Table 5.2.2.3). The effort indicator as measured by the number of traps reported fished from Massachusetts vessels within the reference period was negative. Traps reported fished was above the 75th percentile for the last four years. Landings in the GBK stock are positive; they have remained above the 75th percentile since 2001. The gross CPUE performance indicator was positive (above the 75th percentile) for eight of the last ten years. The set-over-days fishery performance indicator for GBK is positive. It has remained below the 25th percentile since 2009. The unadjusted price per pound was neutral for the reference period. However, the price per pound adjusted for inflation was negative, and has been below the 25th percentile since 1998. The unadjusted revenue and unadjusted revenue per trap were positive; however the CPI-adjusted revenue and revenue per trap were neutral.

5.2.3 SNE

The mortality indicators based on exploitation rates are mixed across the SNE surveys. Exploitation has been at or above the time series 25th percentile for the majority of the period from 2008 to 2013 (Table 5.2.3.1) in this area. In the most recent years exploitation has been high, above the 75th percentile, for some of the inshore surveys (RI and CT specifically), with the highest exploitation value in the time series for RI fall occurring in 2013 and for CT fall in 2012. The 2008 through 2013 average exploitation is above the 75th percentile for the time series in the RI and CT fall surveys, and is above the 25th percentile for all other areas in SNE except for the fall NEFSC and spring RI surveys. Overall, exploitation appears to remain relatively high for both inshore and offshore areas in the most recent time period, with an indication that exploitation is very high in some inshore areas.

All abundance indicators for SNE are close to or below the medians for the time series (Tables 5.2.3.2 A through E). Average spawning stock abundance from 2008 to 2013 was below the 25th percentile in six of the eight surveys (well-below in CT surveys), and below the median in the other two surveys (Table 5.2.3.2 A). The 2008 to 2013 average full recruit abundance is below the median in six of the eight surveys, and below the 25th percentile for both CT surveys. Recruit abundance is worse, with the 2008 to 2013 average for all eight surveys at or below the 25th percentile. All four YOY abundance indices are below the median, and the RI and eastern LIS indicators are negative The YOY indicator warrants close monitoring as these signals indicate poor abundance of newly recruited lobster. The proportion of positive tows has declined dramatically in two of the inshore surveys (RI and CT), and the 2008-2013 average is below the 25th percentile (negative) in all six of the inshore surveys, and below the median in the NEFSC surveys (Table 5.2.3.2 E). Overall in the most recent time period, there are poor abundance signals coming from the inshore areas of SNE during the period from 2008 to 2013.

The fishery performance indicators are generally poor, with nine of the 12 available indicators considered negative for the 2008 to 2013 average (Table 5.2.3.3). Commercial landings, pounds per trap (CPUE), adjusted price-per-pound and all revenue indicators below the time series 25th percentile. Also, the average soak time was higher than the 75th percentile for the CT information, a negative indicator of performance. Landings in 2013 were the lowest in the time series. These all indicate poor fishery performance in the SNE stock area and should be considered by managers of the lobster resource in the SNE area. The exception was the average soak time in MA, which was lower than average soak times, potentially an indicator of better fishery performance; however the average for 2008 through 2013 was between the 25th and 75th percentiles. Additionally, effort (number of traps), was below the 25th percentile, and was the lowest on record in 2012 and 2013, likely related to significant attrition in the industry for the SNE area.

5.2.4 Combined GOM / GBK Indicators

Exploitation indicators for the GOM/GBK stock for the reference period (2008 - 2013) are mixed, being negative in the fall but positive in the spring indices (Table 5.2.4.1).

The reference average spawning stock biomass, full recruit, and recruit indicators for the GOM/GBK stock are positive, and have been at or above the 75th percentile for both fall and spring indicators since at least 2009 (Tables 5.2.4.2 A through C). YOY indicators for the GOM/GBK stock for the reference period are neutral to negative (see Table 5.2.4.2 D). Three of the five YOY indicators in GOM/GBK for 2013 were below the 25th percentile. Lobster settlement in all regions in GOM/GBK is trending down, and managers should take note of this trend, which indicates the potential for declines in recruitment in future years. Lobster distribution as described by survey encounter rate was positive over the last decade (Table 5.2.4.2 E). In particular, the federal survey has demonstrated a dramatically increasing trend in percent positive occurrence over the time series, indicating that lobster in GOM/GBK were generally more available in offshore areas compared to the early part of the time series.

The fishery performance indicators for the GOM/GBK stock were generally positive for the 2008 to 2103 reference period (Table 5.2.4.3). The fishing effort performance indicator for the GOM/GBK stock was negative for the reference period. The total landings performance indicator for GOM/GBK stock for the reference period was positive. Landings have been above the 75th percentile throughout the 2000s. Similarly, the gross CPUE in the GOM/GBK stock was positive for the reference period and has remained above the 75th percentile for the last decade. The average soak times in GOM/GBK stock have mixed results by region. They are negative in GOM portion and positive in the GBK portion. Unadjusted price per pound for the GOM/GBK stock was neutral for the reference period. However the price per pound adjusted for inflation is negative, and has been below the 25th percentile since the late 1990s. Both the unadjusted and adjusted gross revenues and revenue per trap were positive, with last five years above the 75th percentile for all indicators.

6.0 UNIVERSITY OF MAINE MODEL

6.1 UNIVERSITY OF MAINE MODEL METHODS

University of Maine model technical description

The University of Maine Stock Assessment Model (UMM) for American lobster (Chen et al. 2005) was the primary model used by ASMFC (2009) and the only analytical model used in this assessment. It was modified by the Lobster Stock Assessment Subcommittee with help from Dr. Chen's laboratory to estimate sex-specific size distributions for new recruits, separate recruitment parameters for females and males in each year, accommodate nonlinear surveys (exponential or saturating relationships), calculate per recruit models more accurately, estimate growth transition matrices internally from tag data, calculate variances for recruitments and survey trends internally so that data are self-weighted, and model expected recruitments using recruit covariates. Each of these features were used in the current assessment although the internally estimated growth transition matrix approach was dropped after testing because the method was not able to match the observed bimodal distributions of molt increments for lobsters that did and did not molt. The program code is C++ using AD-Model Builder libraries.

Descriptors of abundance and fishing pressure

In this assessment, we use "reference abundance" and "effective exploitation" as the primary descriptors of annual abundance and annual fishing pressure when presenting assessment model results including per-recruit reference points. Reference abundance is the number of lobsters 78+ mm CL on January 1 plus the number that will molt and recruit to 78+ mm CL during the year. The 78 mm CL size is the lower end of the 78-82 mm size group which contains the lowest historical minimum legal size (81 mm) for lobsters in all three stocks. Effective exploitation is the estimated annual catch in number from the model divided by reference abundance. In other contexts (e.g. stock indicators), reference abundance and effective exploitation are based entirely on survey and landings data.

Effective exploitation and full recruit fishing mortality (full F) have similar trends but full F is higher and more variable. The relationship between the exploitation and fishing mortality measures in stock assessment results is not constant because of variability in size selectivity due to changes in regulations, size structure and recruitment. In contrast, the relationship between effective exploitation and full F is one-to-one in per recruit modeling which assumes constant size selectivity and recruitment.

Population dynamics

Female and male lobsters have separate population dynamics (including recruitment, mortality and growth) in all models presented. Five mm size groups are used so that all lobsters leave their original size bin when they molt (tagging data indicate that the smallest molt increment for lobsters 53+ mm CL is about 5 mm). The model is length-based and there are 35 size bins (53-57.9, 58-62.9,…223+ mm CL). The last bin was a plus group. Size bins are identified by their lower bound so that, for example, the 53 mm size bin contains lobster 53-57 mm CL.

The total number of recruits for each sex, year and quarter ($R_{s,t,q}$) was:

$$R_{s,t,q} = \phi_q e^{\rho_{s,t} + r_{s,t}}$$

where $\rho_{s,t}$ is the logarithm of expected recruitment for sex s in year t, $r_{s,t}$ is an estimated annual "dev" parameter constrained to average zero, and ϕ_q is the proportion of total recruitment in quarter q. In this assessment, lobsters were assumed to recruit to the model only at the beginning of summer when the major summer molt occurs (ϕ_3 =0.6615) and at the beginning of fall when the secondary minor molt occurs (ϕ_4 =0.3385). Proportions for winter and spring were zero ($\phi_1 = \phi_2$ =0).

Expected recruitment can change over time because:

$$\rho_{s,t} = \alpha_s + \sum_j \beta_{s,j} K_{j,t}$$

where α_s and $\beta_{s,j}$ are estimated parameters and $K_{j,t}$ is an observation from recruit covariate j. The recruit covariates are data supplied by the user. . A single covariate was used in basecase model runs.

The size range for new recruits was specified by the user and usually set to the first five size groups. For Georges Bank, the range was much wider to allow for immigration of large lobsters that were migrants not previously part of the stock. The number of recruits in a single size group:

$$R_{s,t,q,k} = R_{s,t,q} B_{s,k} \pi_q$$

where $B_{s,k}$ is the proportion recruiting in each size group based on sex-specific beta distributions spread over the first N size groups (e.g. N=5) specified by the user. The model estimates shape and scale parameters that define the beta distribution for each sex.

The number of lobsters in each size group at the beginning of winter (first quarter) during the first year in the model was:

$$N_{s,t=1,q=1,k} = N_{s,t=1,q=1} p_{s,k}$$

where $N_{s,t,q,k}$ is abundance for sex s, year t, quarter q, size group k and $p_{s,k}$ is the corresponding proportion at the beginning of the first year. The proportions $p_{s,k}$ are supplied by the user and usually taken from equilibrium calculations in a preliminary model run with mortality equal to the average level during the first five years of the modeled period.

After the initial quarterly time step in the model and using vector/matrix notation, abundance at size was calculated:

$$\boldsymbol{N}_{s,t,q} = \boldsymbol{P}_{s,t,q-1} \boldsymbol{G}_{s,q-1} + \boldsymbol{R}_{\boldsymbol{s,t,q}}$$

where $\boldsymbol{P}_{s,t,q-1}$ is a vector of survivors at the end of the previous quarterly time step, $\boldsymbol{G}_{s,q}$ is the sex- and season-specific growth transition matrix, and $\boldsymbol{R}_{s,t,q}$ is a vector of recruits. Growth transition matrices $\boldsymbol{G}_{s,q}$ were calculated by simulation outside the assessment model (see Section 2.6, Growth) and were updated in this assessment for both sexes and all stock areas.

Growth occurs instantaneously at the end of quarterly time steps so that the growth transition matrix $G_{s,q-1}$ for quarter q-1 determines the size composition at the beginning of the subsequent quarter q. In this assessment, growth matrices applied at the end of the spring quarter accounted for growth during summer and growth matrices applied at the end of the summer quarter were used to account for growth during fall. The identity matrix was used for growth at the end of the fall and winter quarters because no growth occurs during winter and spring. Survivors in each quarterly time step were calculated:

$$P_{s,t,q,k} = N_{s,t,q,k} e^{-Z_{s,t,q,k}}$$

where $Z_{s,t,q,k}$ is an instantaneous quarterly mortality rate that includes mortality due to fishing and natural causes. As described below, total, fishing and natural mortality rates in the model may vary among years, quarters, sexes, and size groups. In particular:

$$Z_{s,t,q,k} = F_{s,t,q,k} + M_{s,t,q,k}$$

where $F_{s,t,q,k}$ and $M_{s,t,q,k}$ are instantaneous rates for fishing and natural mortality. Natural mortality is:

$$M_{s,t,q,k} = M_{s,q} \mu_t \sigma_k$$

where $M_{s,q}$ is a parameter (estimable but usually fixed at a user specified value), μ_t is a year specific multiplier and σ_k is size specific multiplier supplied by the user. Fishing mortality is:

$$F_{s,t,q,k} = F_{s,t,q} \, u_{s,t,q,k}$$

where $F_{s,t,q}$ is a fishing mortality parameter estimated in the model and $u_{s,t,q,k}$ is size selectivity in the fishery.

Commercial size selectivity in the assessment model relates size composition of the stock to length data from landings in the fishery. Fishery selectivity was modeled based on four contributing factors: 1) legal sizes (minimum and maximum legal size), 2) gear characteristics (changes in size of escape vents due to regulations), 3) conservation activities (discard of v-notched and ovigerous females), and 4) "other" effects such as fishermen behavior, lobster behavior, market preferences, etc. Selectivity due to legal sizes regulations, gear characteristics and conservation activities are estimated externally based on regulations and sea sampling data. Effects due to "other" effects (factor 4) can be estimated in the model as a normal or lognormal distribution with estimable mean and variance but this component of selectivity was ignored in base case models. Commercial selectivity in the model changes whenever one of the underlying factors changes (e.g. changes in legal size limits). In general, there were differences in commercial selectivity over time, between sexes, and among stock areas.

Based on the considerations above, commercial selectivity at size for each sex, year and quarter $u_{s,t,q,k}$ was computed:

$$u'_{s,t,q,k} = l_{s,t,k} g_{s,t,k} c_{s,t,q,k} o_k$$

$$u_{s,t,q,k} = \frac{u'_{s,t,q,k}}{\max\left(u'_{s,t,q,k}\right)}$$

Where the components for legal sizes ($l_{s,t,k}$) and gear ($g_{s,t,k}$) were the same for each quarter in a year but varied between the sexes and among years. The component for conservation discards ($c_{s,t,q,k}$) varied among quarters and years to model seasonal and annual differences in discard of ovigerous and v-notched females due to the annual reproductive cycle and changes in regulations. The component for other factors was not used for basecase runs in this assessment (o_k=1). The product of each factor was divided by the maximum value of the products so that the final fishery curve had a maximum value of one.

Survey trend predicted values and GOF

The model accommodates sixteen surveys that are defined in terms of size-selectivity patterns. Data for a particular survey may be for either or both sexes and might be collected during one or multiple quarters. Separate survey catchability parameters are used for each sex and quarter in the same survey. However, predicted values and goodness of fit for a survey are always calculated assuming the same size selectivity pattern. Predicted survey values were calculated:

$$\hat{I}_{j,s,q,t} = Q_{j,s,q} A_{j,s,t,q}$$

Where $\hat{I}_{j,s,t.q}$ is the predicted value for survey j and sex s during year t and quarter q, and $Q_{j,s,q}$ is a catchability parameter. $A_{j,s,t,q}$ is abundance available to the survey with possible adjustments to accommodate nonlinear effects:

$$A'_{j,s,t,q} = \sum_k s_{j,k} N_{s,t,q,k}$$

and

$$A_{j,s,t,q} = \tau_{j,s,q} + A'_{j,s,t,q}{}^{\gamma_{j,s,q}}$$

where $s_{j,k}$ is size-selectivity and the parameters $\tau_{j,s,q}$ and $\gamma_{j,s,q}$ account for survey indices that do not vary in proportion to abundance. In particular, the intercept parameter τ<0 is for surveys that reach expected values of zero before abundance declines to zero. The exponent parameter $\gamma > 1$ accounts for surveys that change faster than abundance (hyperdepletion) and $0 < \gamma < 1$ accounts for surveys that change more slowly than abundance (saturation). The intercept parameter was not used in this assessment but exponent parameters were used extensively.

The catchability parameters were calculated using a closed form maximum likelihood estimator that assumes lognormal survey errors:

$$Q_{j,s,q} = e^{\frac{1}{n_{j,s,q}} \sum_t \ln\left(\hat{I}_{j,s,t} / I_{j,s,t}\right)}$$

where $n_{j,s,q}$ is the number of survey observations.

Size specific survey selectivity relates size composition in the stock to length data from surveys. In this context, size selectivity includes effects due to gear design, overlap between the survey and stock, and size specific differences in capture efficiency. It was calculated:

$$s'_{j,k} = \frac{1}{1+e^{a_j\left(L_k-b_j\right)}} \frac{1}{1+e^{c_j\left(L_k-d_j\right)}}$$

$$s_{j,k} = \frac{s'_{j,k}}{\max\left(s'_{j,k}\right)}$$

where a_j, b_j, c_j and d_j are survey specific selectivity parameters and L_k is the size in mm at the middle of the length group k. Depending on the assumed or estimated values of the parameters, the selectivity curve will be either an ascending, descending or double logistic function. The calculated values $s'_{j,k}$ were divided by the maximum value so that the final survey selectivity curve had a maximum value of one.

Goodness of fit for survey data was calculated assuming that the log transformed data were from either a normal or robust (insensitive to outliers) Cauchy distribution (Chen et al. 2000). Log likelihoods were calculated:

$$\Delta = -n_{j,s} \log\left(\sigma_{j,s}\sqrt{2\pi}\right) - 0.5 \sum_t \left(\frac{\log\left(\hat{I}_{j,s,t}/I_{j,s,t}\right)}{\sigma_{j,s}}\right)^2$$

for the normal distribution and:

$$\Delta = \sum_t \ln\left\{\pi\lambda_{j,s}\left[1 + \left(\frac{\log\left(\hat{I}_{j,s,t}/I_{j,s,t}\right)}{\lambda_{j,s}}\right)\right]\right\}^{-1}$$

for the Cauchy distribution. In either case, $\sigma_{j,s}$ is the standard deviation calculated either internally from the residuals $\log\left(\hat{I}_{j,s,t}/I_{j,s,t}\right)$ or specified by the user as an arithmetic CV so that

$\sigma_{j,s} = \sqrt{\log\left(CV_{j,s}^2 + 1\right)}$. Assumed CVs were "tuned" manually to match the observed variability in residuals from a preliminary run so that the assumed and observed variances were similar. The internal method was used in most cases during this assessment.

Size composition predicted values and GOF

Predicted values for survey size composition data were calculated:

$$\hat{p}_{j,s,t,k} = \frac{s_{j,k} N_{s,t,q,k}}{\sum_i s_{j,i} N_{s,t,q,i}}$$

Predicted fishery size composition data were calculated in the same manner but using fishery selectivity curves $u_{s,t,q,k}$ in place of survey selectivity curves $s_{j,i}$.

A robust negative log likelihood from Fournier et al. (1990) was used to calculate goodness of fit for survey and fishery size composition data. For a single set of size composition data (i.e. for one sex, one fishery or survey and during one quarter of one year):

$$\Lambda = 0.5 \sum_{i=k_{first}}^{k_{last}} \ln\left(2\pi\left(\xi_i + 0.1/N\right)\right)$$

$$+ \sum_{i=k_{first}}^{k_{last}} N \ln(\tau)$$

$$- \sum_{i=k_{first}}^{k_{last}} \ln\left(\frac{-e^{r_k^2}}{2\left(\xi_{,i} + 0.1/N\right)\tau^2} + 0.01\right)$$

where N=k_{last}-k_{first}+1 is the number of size bins in the calculation, $r_k = \hat{p}_k - p_k$ is the raw residual for size group k, $\xi = \hat{p}_k(1 - \hat{p}_k)$ is a variance for $\hat{p}_k$, and τ is an inverse sample size parameter that scales the variance. In this model, τ=1/S where S was an assumed sample size specified by the user. The sample sizes were tuned in preliminary runs as described below.

The choice of the first and last size groups (k_{first} and k_{last}) used in calculating negative log likelihoods for size composition data may affect results because the model includes many size bins that have very low predicted proportions. Two approaches have been used to choose k_{first} and k_{last}. Both approaches treated k_{first} and k_{last} as plus groups so that

$$p^*_{k_{first}} = \sum_{j=1}^{k_{first}} p_j \text{ and } p^*_{k_{last}} = \sum_{j=k_{last}}^{35} p_j \,.$$

The dynamic binning approach used in this assessment for all basecase models chooses k_{first} and k_{last} for each set of length composition data such that the observed proportions $p^*_{k_{first}}$ and $p^*_{k_{last}}$ are ≥ 0.01, an approach borrowed from the Stock Synthesis Model (R. Methot). With dynamic binning, k_{first} and k_{last} may vary from year to year for the same survey, sex and quarter.

The static binning approach used k_{first} and k_{last} values that were specified by the user for the fishery and for each survey. With static binning, one set of k_{first} and k_{last} values were used for all length data from the commercial fishery, another set for all length data from survey 1, etc. Static binning was used for the GOM and SNE stocks in the last assessment but was not used in basecase models reported here.

The plausibility of user-specified sample sizes for catch-at-length data was evaluated using "effective" sample size (Methot 2000). Effective sample size (n_{eff}) is an estimate of the sample size that corresponds to the goodness of fit observed in preliminary models:

$$n_{eff} = Var(r)N \Big/ \sum_{j=k_{first}}^{k_{last}} \left[\hat{p}_j \left(1-\hat{p}_j\right)\right]$$

Sample sizes (S) assumed in initial model runs were the number of positive tows in a survey during each year or the number of trip-days sampled for commercial data. In final runs, assumed sample sizes were tuned so the trends and scale of assumed sample sizes matched the trend and scale of the effective sample sizes based on model fit. Tuning involved fitting a GAM model $n_{eff} \sim s(t)$ to preliminary effective sample size values where s is a scatterplot smoother. Predicted values from the GAM model were then used as sample sizes in likelihood calculations. Effective sample sizes were reduced to a maximum of 400 before fitting the GAM or use in the assessment model.

Landings predicted values and GOF

Numbers of lobsters landed were calculated:

$$L_{s,t,q,k} = \frac{F_{s,t,q,k}}{Z_{s,t,q,k}} N_{s,t,q,k}\left(1-e^{-Z_{s,t,q,k}}\right)$$

Landings in weight were $W_{s.t,q,k} = L_{s.t,q,k}\omega_{s,k}$ and $\omega_{s,k}$ is a sex- and length specific mean weight supplied by the user.

Likelihood calculations compared observed landed weight for each quarter and sex with predicted values $W_{s,t,q} = \sum_k W_{s.t,q,k}$ assuming the data had normally distributed measurement errors with a fixed CV. Thus, the variance used in likelihood calculations was $\kappa W_{s,t,q}$ where κ is the CV. The CV is potentially estimable but was fixed at 10% in this assessment.

Recruitment GOF
The log likelihood for log scale recruit deviation parameters $r_{s,t}$ was calculated assuming that they were normally distributed with mean zero and constant variance:

$$\Delta = -n \log\left(\sigma_s \sqrt{2\pi}\right) - 0.5 \sum_t \psi_t \left(\frac{r_{s,t}}{\sigma_s}\right)^2$$

where σ_s is the variance of the $r_{s,t}$ deviation parameters calculated in the model and ψ_t is an annual weight always set to one unless otherwise specified.

Parameter estimation
Parameters were estimated by minimizing the negative log likelihood:

$$\Xi = -\omega_j \Lambda_j$$

where Λ_j is the negative log likelihood for j^{th} data type or model component and ω_j is a weight equal 1 unless otherwise noted.

Per-recruit model and reference point calculations
Yield (both sexes) and female spawning biomass per recruit are calculated in the assessment model after it converges with key assumptions based on conditions during the final five years of the modeled period. In particular, commercial selectivity and natural mortality at size, the sex ratio at recruitment, seasonal distribution of recruitment, and ratio of female to male full recruit fishing mortality used in per recruit calculations are five year average values (for 2010-2014 in this assessment). Effective exploitation for the entire stock (females and males) is used on the x-axis in plots showing yield per-recruit for both sexes and female spawning biomass per recruit.

6.2 UNIVERSITY OF MAINE MODEL CONFIGURATIONS

Configuration of basecase assessment models
Table 6.2.1 summarizes basecase model configuration for each stock area with some explanations given below. Tables 6.2.2 – 6.2.5 summarize survey data used in each model.

Model years pre-1982 and 2014
Model runs were for 1979-2014 but only estimates for 1982-2013 were used in status determination. Data for 2014 were included to stabilize estimates for recent yearsbut were not used to determine status because commercial landings, sea sampling and survey data for 2014 were not available or were incomplete. Plots with survey estimates, data or residuals include 2014.

Recruitment covariates
Recruitments showed strong temporal trends that were difficult to model assuming constant expected recruitment so step, linear and polynomial functions were used to model trends in log expected recruitment over time based on recruit covariates (Table 6.2.1). In particular, quadratic functions (with covariates year and year^2) were used for SNE and GBK while linear functions (with the covariate year) were used for GOM and GOM/GBK.

Landings and commercial size data

Landings data for SNE and GOM were reported weights of lobster landed by year, quarter and sex while ASMFC (2009) used estimated numbers landed. Catch data for 1979-1982 may be less accurate because the figures were calculated from annual totals in old reports using average proportions by season and sex. Landings in 2014 were assumed to be the same as in 2013. Commercial size data were used only for years with adequate sampling (see Appendix 1).

Survey trend and length data

All available bottom trawl and ventless trap survey data were used for GBK and GOM. The data for each sex, season and survey program were modeled as separate survey indices with their own size selectivity and catchability parameters (See Tables 6.2.2 – 6.2.4 for more information). As much survey data as possible were used for SNE but NJ summer, fall, and winter survey data were excluded because there was no room in the model and because the data were highly variable (Table 6.2.5). In order to use as much SNE survey data as possible, female and male data from the same season and survey program were modeled using the same survey slot where possible. These indices share a size selectivity pattern but have different catchability parameters. All bottom trawl survey data were mean numbers per sampling unit.

Survey selectivity

Based on preliminary models and familiarity with the survey programs, basecase models for all three stock areas usually assumed that "offshore" NEFSC surveys had domed or ascending logistic size selectivity curves while "inshore" surveys had domed or descending logistic size selectivity curves (Tables 6.2.2 – 6.2.5). Increasing logistic selectivity is plausible for offshore surveys because large lobsters tend to be found further offshore in areas covered by the NEFSC surveys. Declining logistic selectivity curves are plausible for inshore surveys because large lobsters are found offshore in areas not covered by inshore programs. Inshore surveys may be domed with an increasing trend for small sizes because capture efficiency for small lobsters increases as they grow large enough to be retained by the gear and move into areas covered by the surveys.

Survey catchability

Surveys with limited geographic coverage may not measure trends in relative abundance in a linear manner for the entire stock because size distributions and trends in abundance are not the same in all areas. For example, inshore surveys might saturate and increase slowly as lobsters increase in abundance and accumulate offshore, outside the area covered by the survey. Similarly, offshore surveys might increase slowly while abundance is low and lobsters are concentrated inshore, and then increase more quickly as abundance increases, the stock occupies offshore habitat areas and large individuals that favor offshore habitats become more common. Abundance might decline more rapidly in nearshore areas than offshore or for the stock as a whole if water temperatures warm and nearshore habitat becomes unsuitable. Where necessary, the relationship between abundance and the survey was assumed to be nonlinear so that $I=QN^{\beta}$ where I is the predicted survey index, Q is a catchability parameter and β is a parameter estimated in the model (Tables 6.2.2 – 6.2.5). The choice of a saturating ($0 < \beta < 1$) or exponential ($\beta > 1$) relationship was based on the location of the survey relative to the stock, survey trends and preliminary model fits.

Commercial selectivity components

There are three components to commercial selectivity in this assessment: gear selectivity, legal selectivity and conservation selectivity (see Section 4.1.1, Commercial catch and Appendix 1). Legal selectivity is the proportion of a size group that is legal-size based on analysis of sea sample data (Appendix 1). Gear selectivity is based on the minimum size of escape vents required in traps, and is represented as the proportion that enter and are retained based on experimental data (ASMFC 2006). Conservation selectivity is the size-specific proportion of female lobsters caught that are discarded at sea due to eggs or v-notches based on analysis of sea sample data (Appendix 1). The best estimates available for each component were used in basecase model runs.

6.3 UNIVERSITY OF MAINE MODEL RESULTS, SENSITIVITY ANALYSIS AND DISCUSSION

Basecase model results

Sensitivity analyses are particularly important in this assessment because they are the primary measure of uncertainty. As in the previous assessment (ASMFC 2009), asymptotic and MCMC variances were implausibly small as uncertainty measures, (see Section 6.4.1). In lieu of conventional uncertainty calculations, the range of estimates from sensitivity analysis was used to characterize uncertainty in reference abundance and effective exploitation. Thus the range of recent (2011-2013) mean reference abundance and effective exploitation indices in sensitivity analysis tables is the best available information regarding uncertainty.

Sensitivity analysis included a “standard” set of runs that were carried out with the basecase model for each stock area. The standard set consisted of runs with: M +/- 0.05, recruit covariates turned off, the growth matrix from the last assessment (which gives faster growth), gear selectivity shifted forward (to the right) and backward (to the left) by one size group (5 mm CL), linear catchability for all surveys, and conservation selectivity from the last assessment Natural mortality is important because lobsters are difficult to age, environmental conditions may have increased natural morality in SNE, and because it may have a large effect on assessment results. Recruit covariates are a new approach for lobster in this assessment. Gear selectivity for this species is difficult to estimate, but has a large effect on assumed commercial selectivity curves. Numerous surveys were assumed to have strongly nonlinear catchability relationships (saturating or exponential) in basecase models for all stock areas. Nonlinear catchability relationships are used in interpreting survey trends, tend to increase uncertainty, and may have affected basecase model estimates. Sensitivity analyses designed to address stock-specific issues are also presented and used to describe uncertainty where appropriate.

This assessment includes a likelihood profile analysis for each area to examine the effects of variation in average recruitment over a range from 0.8 to 1.2 times the basecase level. For example, the “less 20%” run fixed mean log recruitment at $\log(\exp(r_s)*0.8)$, where r_s is the estimated mean log recruitment from the basecase model. The purpose of this analysis is to determine which data sets in the model support abundance estimates for recent years that are higher or lower than basecase estimates and to understand how each data set affects model results. Profile runs were not included in the set of standard and stock specific sensitivity runs used to characterize uncertainty.

6.3.1 GOM Basecase Results, Sensitivity Analysis & Discussion

GOM basecase model

Basecase reference abundance estimates increased starting in about 1988 and increased more rapidly after 2007 to record high levels in 2013 (Table 6.3.1.1 and Figure 6.3.1.1). Effective exploitation rates trended down after about 1990 and were relatively low from 2011-2013 (Table 6.3.1.1 and Figure 6.3.1.1). Recent recruitment levels are at or near record highs. Basecase estimates from this assessment are remarkably similar to estimates from the previous assessment (ASMFC 2009, Figure 6.3.1.1). See Appendix 3 for a complete set of plots showing input data, biological assumptions and estimates, model diagnostics and population estimates.

The basecase model converged with the maximum absolute gradient < 0.0001 and an invertible Hessian. Deviance residuals for survey trends showed noticeable patterns that ranged from weak to strong (Appendix 3 Figures 56-111) although nonlinear survey catchability assumptions were used to reduce such patterns (Appendix 3 Figure 55).

Uncertainty and sensitivity analyses

The basecase model was updated after sensitivity and retrospective analyses were completed by switching from quadratic to linear recruit covariates because the quadratic parameter was not statistically significant. Model properties and results were almost unaffected with abundance and exploitation estimates changing by < 1%. All profile and sensitivity runs described below are for the preliminary model but results are applicable to the final basecase.

Likelihood profile analyses for GOM with average log recruitment fixed at +/- 20% of the estimated level indicate that catch and survey trends generally fit best with abundance less than preliminary basecase estimates, while length data generally fit better with abundance estimates greater than preliminary basecase estimates (Table 6.3.1.2).

Sensitivity analyses for GOM included six stock-specific cases (Table 6.3.1.3 and Figures 6.3.1.2-6.3.1.3). Average reference abundance estimates during 2011-2013 from sensitivity runs ranged from -13% smaller to 5% larger than preliminary basecase estimates while average effective exploitation estimates during the same period ranged from -24% smaller to 7% larger. The runs down-weighting length data and shifting commercial gear selectivity to the right resulted in the largest differences from basecase results. Estimates generated by other runs were similar to preliminary basecase estimates.

It is possible that length data were given too much weight in fitting the basecase model, which could result in mis-estimation of stock size (Francis 2011). A run with a weight of 0.1 on all sources of length data was used to evaluate this potential problem. As expected based on profile analysis, abundance estimates were lower (–13%) and exploitation estimates were higher (5%) when length data were down-weighted; however the estimated trends were similar (Table 6.3.1.3 and Figures 6.3.1.2-6.3.1.3).

There were large differences between observed and predicted values for the NEFSC spring female survey index in 2014 and the NEFSC fall male survey index during recent years that may have practical implications (Appendix 3 Figures 58, 61, 86 and 89). The preliminary basecase model was rerun with a likelihood weight of 30 on the NEFSC fall survey trend for males and then again with a weight of 30 on the NEFSC spring survey trend for females to fit the data closely. Results show that male landings data prevented the preliminary basecase model from fitting the NEFSC fall male survey trend more closely because the negative log likelihood for male landings increased by about 560 units and estimated summer and fall landings were badly distorted in the sensitivity run prior to 2005 . Results for the spring survey suggest that landings data and size data for females (commercial, NEFSC spring and fall, MA spring and ME spring surveys) prevented the basecase model from fitting the NEFSC spring survey trend for females. Average reference abundance estimates during 2011-2013 were 12% (30x fall run) and 11% (30x spring run) lower than preliminary basecase estimates while average effective exploitation estimates were 0% and 6% larger (Table 6.3.1.3). Thus, NEFSC spring and fall survey data suggest a somewhat smaller stock size than that resulting from the preliminary basecase run, but similar effective exploitation levels (Table 6.3.1.3 and Figures 6.3.1.2-6.3.1.3).

The model had trouble fitting MA surveys which have flatter trends than other surveys and model estimates (Appendix 3 Figures 62-65). The spring MA surveys, in particular, have flat trends and strongly saturating catchability relationships with exponents of 0.2 (females) and 0.08 (males) and may provide little or no information about changes in lobster abundance while artificially reducing stock size estimates (Appendix 3 Figure 55). We reran the model after removing the MA surveys to determine their effect on abundance and exploitation estimates. Abundance and exploitation estimates from the sensitivity analysis were nearly identical to the preliminary basecase estimates (Table 6.3.1.3 and Figures 6.3.1.2-6.3.1.3).

A robust log Cauchy distribution was used for all basecase runs because it seemed to reduce residual patterns and effects of outliers in preliminary runs; ASMFC (2009) used a robust log normal distribution. The effect of this change was evaluated by rerunning the model using the robust log normal log likelihood. There was almost no effect on assessment results for GOM (Table 6.3.1.3 and Figures 6.3.1.2-6.3.1.3).

The model consistently under-predicted proportions of large lobsters (>100 mm CL) in NEFSC spring and fall surveys (Appendix 3 Figures 132-135). One of the standard sensitivity runs used the growth transition matrix from ASMFC (2009) that leads to faster growth, but this did not resolve the issue (Table 6.3.1.3 and Figures 6.3.1.2-6.3.1.3). We hypothesize that one or more issues relative to these large lobsters may be occurring. Growth may still be mischaracterized for large 100+ mm CL lobsters, which are poorly represented in growth increment data, or natural mortality rates may be overestimated, preventing sufficient lobsters from reaching these larger sizes in the model. Additionally, movements of large lobsters between the areas covered by inshore surveys, the area covered by the offshore survey, and specifically Georges Bank (immigration and emigration), may contribute to the problem with model fit.

The annual number of days with optimal sea surface temperatures (12°-18° C at Boothbay Harbor, Maine) was used as a recruit covariate in one sensitivity run. Results were similar to the basecase results, although the overall log likelihood indicated a slightly better fit for the basecase than the sensitivity run(76 units lower for the basecase run) (Table 6.3.1.3 and Figures 6.3.1.2-6.3.1.3).

Uncertainty in reference abundance and effective exploitation estimates for the GOM lobster stock is presented in Table 6.3.1.3 and Figures 6.3.1.2-6.3.1.3 as the differences in the various runs when compared to the basecase run. There appears to be less uncertainty in estimated trends than in estimated scale.

6.3.2 GBK Basecase Results, Sensitivity Analysis & Discussion

GBK basecase model

The University of Maine assessment model for GBK did not fit survey trends (Appendix 4 Figures 40-55), landings (Appendix 4 Figures 60-63) or survey length data (Appendix 4 Figures 72-75). Fishing mortality rate estimates were sometimes very high (F=10), implying that abundance estimates were too low (Appendix 4 Figure 119). Additionally, there is compelling evidence that GBK is not a closed population (see Section 2.9). As a result, the model was not accepted by the American Lobster Technical Committee as a basis for management advice for the GBK stock. An alternative empirical basecase approach was used instead, which is very similar to stock indicators presented elsewhere in this assessment.

Empirical basecase results

Trends in reference abundance and effective exploitation, along with associated reference points, were calculated based on survey and landings data. Reference abundance was measured as the average of spring and fall NEFSC survey catch rates (mean number per tow) for female and male lobster 78+ mm in each year. Fishing pressure (effective exploitation) was measured as the ratio of landings in weight and reference abundance in each year. Current reference point definitions are compatible with these measures because percentiles of the estimates during the reference period (1982-2003) can be calculated. Spring and fall survey data were averaged to dampen variability in the reference abundance measure and because it was not clear which seasonal survey better measures abundance of "true" GBK lobster.

Results indicate that total stock abundance is high but effective exploitation is near the threshold level (Table 6.3.2.1 and Figure 6.3.2.1). There are noteworthy differences between estimated abundance trends for females and males during recent years, with males at lower abundance and higher exploitation levels (Table 6.3.2.1 and Figure 6.3.2.2).

University of Maine Model results (not accepted)

Although the model was not accepted, University of Maine Model results for GBK may be of interest for diagnostic purposes. Abundance trends for the GBK basecase model generally show females increasing throughout the time series with rapid increases after 2004 and variable but stable male abundances (Figure 6.3.2.3). Effective exploitation rates trend downward throughout the time series for both sexes, with female exploitation rates higher than males early in the time series but lower than males at the end of the time series (Figure 6.3.2.3). The abundance estimates from the University of Maine model are higher than the estimates from the previous assessment before 1993 but similar from 1993-2007 (Figure 6.3.2.3). See Appendix 4 for a complete set of plots showing input data, biological assumptions and estimates, model diagnostics and population estimates.

The model converged with a maximum gradient < 10^{-6} and an invertible Hessian. There are strong residual patterns for survey trends, particularly for the spring and fall females and fall males, indicating poor model fit (Appendix 4 Figures 40-55). The model and the NMFS surveys both indicate a rapid rise in the female population around 2002 but the model predicts a proportionally larger population increase (Appendix 4 Figures 40 and 42). Conversely, model dynamics for males are generally stable across the time series while the fall survey exhibits a decline to relatively low levels after 2004 (Appendix 4 Figure 43).

The estimated size composition of new recruits, estimated as a beta distribution for each sex, has a mode for females > 80 mm CL and substantial male recruitment above 80 mm CL (Appendix 4 Figure 16). Such sizes at recruitment are too large to represent growth by molting from sizes less than 50 mm CL and indicate migration of large individuals from an outside source, probably GOM.

Similarly, spring and fall survey selectivity curves for each sex are very different for spring and fall surveys (Appendix 4 Figure 38). These differences suggest a seasonal shift in the availability of the modeled population or a need to "manufacture" lobsters present in the landings that are not observed in the survey and cannot be accounted for by recruitment.

Model fit to the landings is generally fair for quarters 1 and 2 but the model estimates higher landings than were observed for portions of quarter 3 and 4 for both sexes (Appendix 4 Figures 60-63). Additionally, estimated fishing mortalities often hit bounds (F=10) and were unreasonably high, indicating implausibly low abundance estimates (Appendix 4 Figure 119).

Uncertainty and sensitivity analyses

Likelihood profile analysis from GBK with runs that had fixed average log recruitments at +/- 20% indicate that abundances below the original estimates are supported by commercial catch and length data and by female survey trends. Abundances above the original estimates are supported by male survey trends and most survey length data (Table 6.3.2.2).

Sensitivity analysis for GBK included the standard set (without the run assuming all linear surveys because only linear surveys were used) and one additional stock-specific run. Average reference abundance for 2011-2013 ranged from -19% lower to 50% higher than the original estimates, though most sensitivity runs had similar estimates (Table 6.3.2.3 and Figures 6.3.2.4-6.3.2.5). Similarly, reference exploitation ranged from 34% lower to 23% higher than in the original run. The sensitivity runs most different from the basecase involved shifting the gear selectivity to the right and removing recruit covariates.

Because the model had difficulty fitting the survey trends, an additional sensitivity run was conducted where the likelihood weights on the spring and fall female and fall male survey trends were set to 20 so that the model fit the data better but without tracking apparent noise (Table 6.3.2.3). Forced to fit the survey trend, the model estimated much higher landings earlier in the time series for both sexes (Figure 6.3.2.6).

6.3.3 GOM/GBK Basecase Results, Sensitivity Analysis & Discussion

GOM/GBK basecase model

Trends from the GOM/GBK basecase model were similar to trends from the GOM basecase model, as would be expected given that survey data show most of the abundance is in GOM. Reference abundance estimates increased after 1979 and at an accelerated pace after 2007 (Table 6.3.3.1, Figure 6.3.3.1). Effective exploitation estimates declined after 1979 until the mid-1990's and then remained stable with higher exploitation on males than females. Basecase estimates for GOM/GBK were slightly higher than the sum of GOM and GBK estimates from the previous assessment (ASMFC 2009, Figure 6.3.3.1). See Appendix 5 for a complete set of plots showing input data, biological assumptions and estimates, model diagnostics and population estimates.

The basecase model converged with a maximum absolute gradient of 0.0002 and an invertible Hessian. Deviance residuals for survey trends showed noticeable patterns that ranged from weak to strong (Appendix 5 Figures 56-111). As with GOM, the model had trouble fitting length data from NEFSC offshore surveys for lobster 100+ mm CL (Appendix 5 Figures 132-135). The fit to landings data was reasonably good (Appendix 5 Figures 118-121).

As for GOM, the basecase GOM/GBK model had trouble fitting the trend in the MA surveys which do not show the sharp increases in recent years evident in the other surveys. Like the GOM model, the GOM/GBK model accounts for this by estimating a flat saturation relationship between the population and survey index (Appendix 5 Figures 55, 62-65, 76-79).

Uncertainty and sensitivity analyses

Likelihood profile analysis for GOM/GBK with runs that had average log recruitments fixed at +/- 20% of basecase estimates indicates some disagreement between the commercial catch/length and survey length data. The commercial data support abundance estimates lower than basecase estimates while survey length data support higher levels of abundance (Table 6.3.3.2).

Sensitivity analyses for GOM/GBK included the standard set and two stock-specific cases (Table 6.3.3.3 and Figures 6.3.3.2-6.3.3.3). The standard set of sensitivity analyses for GOM/GBK did not include a run with conservation selectivity assumptions from the last assessment because ASMFC (2009) did not fit models for GOM/GBK. The first additional run assumed linear catchability relationships for all surveys and did not use recruitment covariates. The second assumed that all size selectivity curves for NEFSC offshore surveys were increasing logistic curves (females had a strongly domed pattern in the basecase run, Appendix 5 Figure 52).

Average reference abundance estimates for 2011 - 2013 from sensitivity analyses ranged from -4% smaller to 19% larger than the basecase estimates while average exploitation estimates ranged from -25% lower to 10% higher (Table 6.3.3.3 and Figures 6.3.3.2-6.3.3.3). The sensitivity run with the strongest effect on model estimates shifted gear selectivity towards larger lobsters ("Gear selectivity shift right" scenario) so that traps were assumed to be less efficient at retaining small lobsters near the minimum legal limit.

Uncertainty in reference abundance and effective exploitation estimates for the GOM/GBK lobster stock is presented in Table 6.3.3.3 and Figures 6.3.3.2-6.3.3.3 as the differences in the various runs when compared to the basecase run. There appears to be less uncertainty in estimated trends then in estimated scale.

6.3.4 SNE Basecase Results, Sensitivity Analysis & Discussion

SNE basecase model

Basecase model reference abundance estimates for SNE lobster increased from the early 1980's, peaked during the late 1990's, then declined steeply through the early 2000's to a record low level in 2013 (Table 6.3.4.1 and Figure 6.3.4.1). Basecase estimates for recent recruitments are near zero and the lowest on record. Effective exploitation trended down in the early 2000's and remained at relatively low average levels during 2011-2013 (Table 6.3.4.1 and Figure 6.3.4.1). Trends in basecase estimates from this assessment are similar to trends from the previous assessment, but abundance is higher due in part to assuming higher natural mortality in the model (M was increased from 0.15 to 0.29 starting in 1998, Figure 6.3.4.1).

M=0.29 in the basecase model during 1998-2014 is a crude estimate and an attempt to capture effects of recent warm water conditions in the inshore portions of SNE. Sensitivity analysis in the last assessment showed that the model fit better with M=0.225 during 1998-2007 (ASMFC 2009), and likelihood profile analysis between this and the last assessment indicated that the model fit best with M=0.285 after 1998 (see Section 2.3, Natural Mortality). Sensitivity analyses indicate that reference abundance estimates with different assumptions about M were -9% to -1% smaller than basecase estimates and effective exploitation estimates were 4%-12% larger (Table 6.3.4.3). Natural mortality in SNE lobster is an important area for additional research.

See Appendix 6 for a complete set of plots showing input data, biological assumptions and estimates, model diagnostics and population estimates.

Uncertainty and sensitivity analyses

The basecase model was updated after sensitivity and retrospective analyses were completed by switching from a cubic to quadratic recruit covariate relationship, adding the 2014 spring and fall NEAMAP surveys, using nonlinear catchability relationships for all four CT surveys and increasing M during 1998-2007 from M=0.225 to 0.285. Mean 2011-2013 abundance and exploitation estimates from the preliminary and final basecase run varied by -2% and 4% (Table 6.3.4.3 and Figures 6.3.4.2-6.3.4.3). All profile and sensitivity runs described below are based on the preliminary model but results are applicable to the final basecase.

The basecase model converged with the maximum absolute gradient < 0.00005 and an invertible Hessian. Deviance residuals for survey trends showed noticeable patterns that ranged from weak to moderate (Appendix 6 Figures 60-123). The model estimated exponential catchability relationships for Connecticut surveys and saturating relationships for ventless trap surveys (Appendix 6 Figures 58-59). Model fit was acceptable for landings data (Appendix 6 Figures 132-135) and commercial lengths (Appendix 6 Figures 136-143).

As in other stock areas, the basecase model under-predicted length composition data for large lobsters (80-125 mm CL) in offshore NEFSC surveys and for females in the NJ spring survey but fit other survey length data reasonably well (Appendix 6 Figures 144-159). One of the standard sensitivity runs used the growth transition matrix from ASMFC (2009), which leads to faster growth, but the issue with the fit to size data for larger lobsters was not resolved.

Likelihood profile analysis for SNE with runs that had average log recruitment fixed at +/- 20% of the basecase estimate did not indicate pathological patterns (Table 6.3.4.2).

Sensitivity analyses for SNE included the standard set plus two runs with different assumptions about recent natural mortality, a run using sub-surface temperature data (see section 2.3) as a recruitment covariate, and a run in which the model was fit to spring and fall swept-area abundance data as surveys (Table 6.3.4.3). Average reference abundance estimates during 2011-2013 from sensitivity runs ranged from -11% smaller to 15% larger than basecase estimates, while average effective exploitation estimates during the same period ranged from -7% smaller to 12% larger (Table 6.3.4.3 and Figures 6.3.4.2-6.3.4.3). The largest percent changes from basecase were in runs assuming constant natural mortality M=0.15, using temperature as a recruit covariate, and runs with the swept-area abundance surveys. Overall, the sensitivity analyses indicate that estimates and trends from the basecase model for SNE are reasonably robust.

The first natural mortality sensitivity analysis assumed M=0.15 in all years. The second used a ramp function rather than an abrupt step function to increase natural mortality gradually from 0.15 to 0.25 during 1994-1997. Based on negative log likelihood, the preliminary basecase model fit better than both sensitivity runs (see table below) but differences were hard to detect in diagnostic plots (Table 6.3.4.3 and Figures 6.3.4.2-6.3.4.3).

The temperature recruit covariate run was meant to investigate whether the recent decline in recruitment might be attributed to recent increases in water temperature along coastal SNE. To examine this, the number of days with sub-surface temperature above 20° C at the Millstone Power Station in southeast Connecticut on Long Island Sound was used as a recruitment covariate. The following equation was used to create the covariate:

$$K_t = 1 + \left(\frac{D_t - \bar{D}}{\bar{D}}\right)$$

where K_t is the covariate in year t, D_t is the annual number of days above 20° C and $\bar{D}$ is the mean number of days. Based on negative log likelihoods, the basecase model fit the data better than the alternatives (see table below).

Run	**-Log likelihood**	**N parameters for expected recruitment**
Basecase	0	4
M ramp 94-97	9.1	2
M=0.15 all years	19.1	1
Days>20°C	37.3	2

However, log likelihood is an imperfect basis for comparing these sensitivity runs because differences in the number of recruitment covariate parameters are not considered. An AIC-type approach would provide a more reliable basis for comparison. Recruitment covariates in the model are used to calculate expected recruitment, which may be the ideal approach when expected recruitment is a smooth function of time. However, temperature would probably be better used as a recruitment “survey” tracking interannual variability in recruit deviations. This is a topic for future research.

The basecase model for SNE is complicated by differences in trend and length composition data among surveys which are conducted in different areas of SNE and by possible migration effects. A sensitivity run was conducted using a single spring and fall survey swept-area abundance index for each sex to potentially minimize effects of the multiple conflicting survey trends and other issues in SNE (i.e. using spring and fall swept-area abundance estimates from CT, RI, MA and NEFSC surveys as the only abundance indices). This approach adjusts swept-area abundance for differences in area surveyed and area swept, but assumes all survey bottom trawls have the same selectivity and capture efficiency for lobsters in the path of the net. The most important advantage is swept-area abundance and abundance-at-length observations from each survey are weighted automatically in proportion to the apparent abundance of lobster in the area covered by the survey.

Swept-Area abundance and size composition during 1984-2014 were calculated for each sex and season based on CT, MA, NEFSC, and RI survey program data (Table 6.3.4.4):

$$N_{p,s,y} = I_{p,s,y}\frac{A_p}{a_p}$$

where $N_{p,s,y}$ is swept-area abundance for survey program p (e.g. CT spring) and sex s in year y, $I_{p,s,y}$ is a survey mean number per tow for sizes 50+ mm CL, A_p is the area covered by the survey and a_p is the area swept by the net during a tow. Swept-area abundance for each program was multiplied by the proportions-at-length in the same survey to determine the swept-area abundance-at-length. Total swept-area abundance and abundance-at-length in each year were calculated by summing the estimates for each survey program. For simplicity, recruitment covariates were turned off, the fall and spring swept-area abundance estimates were assumed to have linear catchability functions, and the swept-area survey was assumed to have the same selectivity for all lobsters 50+ mm CL. Missing survey data for the CT survey in the fall of 2010 were ignored.

Reference abundance estimates from the swept-area survey sensitivity run were 15% larger, and effective exploitation estimates were -7% smaller (Table 6.3.4.3 and Figures 6.3.4.2-6.3.4.3). Estimated trends during 1984-2011 were similar but swept-area survey estimates were substantially higher for 2012-2014, probably because the offshore areas where stock conditions are better were emphasized in the swept-area abundance survey in recent years run due to declines inshore (Figure 6.3.4.4).

Uncertainty in reference abundance and effective exploitation estimates for the SNE lobster stock is presented in Table 6.3.4.3 and Figures 6.3.4.2-6.3.4.3 as the differences in the various runs when compared to the basecase run. There appears to be less uncertainty in estimated trends then in estimated scale.

6.4 UNCERTAINTY

6.4.1 Asymptotic and MCMC intervals

Confidence intervals and MCMC credibility intervals from basecase models were narrow in absolute terms and much narrower than the range of estimates from sensitivity analysis (Table 6.4.1.1). These results indicate that both types of interval grossly understate true uncertainty in basecase results.

Fishery selectivity, natural mortality and growth parameters were not estimated in the model and this probably contributes to underestimation of uncertainty in model results. However, an analysis of likelihood profile results presented during the assessment peer review (June 8-11, 2015, Woods Hole, MA) strongly suggests that conflict between landings and length composition data stemming from problems with growth estimates are important. Profile results for the mean log recruitment parameter presented at the review for the GOM, GOM/GBK and SNE stocks were reanalyzed by comparing the summed likelihoods for all survey trends, the summed likelihoods for all length data and the summed likelihoods for all landings data (Tables 6.3.1.2, 6.3.2.2, 6 and 6.3.4.2). Results showed that landings data are informative for each stock and fit best in models with relatively low abundance and high exploitation estimates (Figure 6.4.1.1 - 6.4.1.3). In contrast, length composition data fit best in models with relatively high abundance and low exploitation estimates because low exploitation indices allow more large lobsters to survive and grow to large size so that the fit to size data for large lobsters improves. The lowest total log likelihoods in basecase models occur at intermediate abundance levels where the right hand side of the likelihood for landings and the left hand side of the likelihood for length data are steep and combine to form an artificially narrow "V" shaped valley (see Figures 6.4.1.1 - 6.4.1.3). Basecase model results appear precise because the valley is steep and sharp but the geometry of the valley is due to conflict between landings and length that arises due to difficulties predicting the proportions of large lobsters in size data. Inaccurate growth assumptions are the most likely cause of the problems in fitting size composition data for large lobsters. Thus, the apparent certainty in model results appears to be a geometric side effect of errors in growth assumptions. These results suggest that growth is the most important uncertainty in using the University of Maine assessment model for lobsters.

6.4.2 Retrospective Pattern Analyses

Retrospective analysis for basecase models

Basecase reference abundance and effective exploitation estimates in this assessment and estimates from ASMFC (2009) were compared to evaluate the historical stability of assessment estimates over time. Stability in scale (the level of estimated abundance and exploitation) and trend (changes over time) were evaluated, although only trends are used for status determination. To quantify historical changes in scale, we computed the mean ratio N_{new}/N_{old} where N_{new} is a basecase estimate from this assessment and N_{old} is from ASMFC (2009). We used the correlation between N_{new} and N_{old} to quantify similarity in historical estimated trends (Table 6.4.2.1).

Analytical retrospective analysis
We reran basecase models sequentially omitting one year of data to evaluate the stability of basecase models. The basecase estimates through 2013 were based on data through 2014. We omitted data for 2014 and ran the model through 2013 to estimate stock size in 2012, and so on. In the last retrospective run, we omitted data through 2008 to estimate stock size in 2007 (7 "peels").

Mohn's (2009) rho statistic and standard plots were used to quantify retrospective patterns in reference abundance and effective exploitation estimates from basecase models:

$$\rho = \left(\sum_{r=1}^{7} \frac{x_{2013-r-1,r} - R_{2013-r-1}}{R_{2013-r-1}} \right) \Big/ 7$$

where $x_{Y-r-1,r}$ is the estimate for the year Y-r-1 in retrospective run r with terminal year Y-r, and R_{Y-r} is the same estimate from the basecase model. Mohn's rho measures the average relative difference between basecase estimates and terminal estimates for the same year from a retrospective run.

Plots and retrospective scores indicate mild retrospective patterns in all basecase models, suggesting that the estimated trends and scale for recent years are stable (Table 6.4.2.2 and Figures 6.4.2.1-6.4.2.8).

7.0 REFERENCE POINTS

7.1 CURRENT REFERENCE POINT DEFINITIONS

"Reference abundance" and "effective exploitation" are the primary descriptors of annual abundance and annual fishing pressure (N and F reference points). Reference abundance is the number of lobsters 78+ mm carapace length (CL) on January 1 plus the number that will molt and recruit to the 78+ CL group during the year. The 78 mm CL size was chosen because it is the lower end of the model size group that contains the lowest minimum legal size (81 mm or 3 ¼ inches) in all three stocks. Effective exploitation is the annual catch in number divided by the reference abundance.

7.1.1 Abundance Reference Point

GOM and GBK Stocks:
A stock is considered below the limit reference point (threshold), and overfished, if model abundance is less than the 25th percentile relative to the 1982-2003 reference period (Figure 7.1.1.1). Immediate action would be required if stock abundance were to fall below the 25th percentile. If the stock abundance is at or above the 75th percentile (green), a stock is considered in favorable condition.

SNE Stock:
The SNE stock is considered below the limit reference point (threshold), and overfished, if model abundance is less than the 25th percentile relative to the 1984-2003 reference period (Figure 7.1.1.2). Immediate action would be required if stock abundance were to fall below the

25^{th} percentile. If the stock abundance is at or above the 50^{th} percentile (green), a stock is considered in favorable condition.

7.1.2 Exploitation Reference Point

The exploitation reference point is designed to be a conditional target as exploitation has remained relatively stable in all areas over a wide range of abundance during the reference periods. The exploitation reference point is the same for all three stocks (or two if GOM and GBK are combined). A stock is considered above the limit reference point (threshold), and overfishing is occurring, if exploitation is greater than the 75^{th} percentile relative to the reference period (GOM and GBK: 1982-2003; SNE: 1984-2003) (Figure 7.1.1.3). Immediate action would be required if exploitation were to exceed the 75^{th} percentile. If the stock exploitation is at or below the 25^{th} percentile (green), a stock is considered in favorable condition.

7.2 BACKGROUND

In the last assessment (ASMFC 2009) revised reference points were developed which intended to more clearly depict the current and historical status of the three lobster stocks. A goal of the 2009 assessment was to alleviate problems created by the use of annual instantaneous fishing mortality rates applied to a model-estimated fishable abundance. Changes in the minimum legal size, gear regulations and v-notching have changed the selectivity patterns of the various fisheries at differing times and have undermined the reliability of the model estimates of fishable abundance for each stock.

The main disadvantage of effective exploitation rates is that they depend on both recruitment and fishing pressure. In particular, effective exploitation rates will increase or decrease with recruitment and the abundance of lobsters between 78 mm CL and the minimum legal size. An increase in effective exploitation accurately reflects deteriorating conditions for the stock but may be due to low recruitment instead of increased fishing pressure, and vice-versa. Although variability in recruitment may make effective exploitation rates highly variable, status determinations are based on percentile distributions which are much less variable than estimates for individual years. In addition, the relationship between the effective exploitation rate and instantaneous fishing mortality rate will differ between the sexes because management measures differentially affect fishery selectivity and fishable abundance by sex (i.e. discard of v-notched or ovigerous females). The relationship will change over time as new management measures affecting fishery selectivity are introduced or as natural mortality varies. Exploitation rates for combined sexes may exclude important information about stock status for lobster, specifically very high exploitation rates on males. In all cases, however, the effective exploitation rate measures the practical effects of fishing pressure in a consistent manner using a summary statistic that ranges from zero to one.

Point estimates of effective exploitation and reference abundance from the University of Maine (UM) assessment model are more reliable as trend indicators than as estimates in absolute terms. For example, a change in effective exploitation from 0.2 to 0.4 would indicate that the variable in question doubled but would not necessarily indicate that either 0.2 or 0.4 was a reasonable estimate of the underlying true values. Uncertainties in estimates and/or reference points stem from several sources including growth parameters, natural mortality and recruitment dynamics at low or high stock sizes.

This assessment explored several analyses to better characterize the inherent variance in growth and natural mortality rates which affect abundance and mortality estimates. In view of these issues, the UM model was used to evaluate stock status relative to trends during a reference period for each stock, but not relative to absolute abundance or exploitation-based reference points (e.g. B_{msy} or $F_{10\%}$). The trend based reference points for lobster have proven robust over a wide range of assumptions about natural mortality and do not depend on the estimated scale of model estimates. However, the disadvantage of using trend based reference points is that there is no guarantee that percentile conditions in the early 1980s through 2003 are equally optimal threshold and target values for all three lobster stocks. The reference period used in this assessment (1982-2003 for GOM and GBK; 1984-2003 for SNE) is a relatively short time series and may not reflect an optimal and sustainable production range for each stock.

7.3 RESULTS

7.3.1 – Gulf of Maine

The Gulf of Maine stock is not depleted. The reference 2011 to 2013 abundance for the GOM was 247 million lobsters which is well above the threshold abundance of 52 million lobsters (Table 7.3.1 and Figure 7.3.1). In fact the reference abundance was above the target abundance (75th percentile) of 103 million lobsters. Overfishing is not occurring in the GOM stock. The reference effective exploitation (2011-2013) was 0.48, which is below the threshold of 0.54 (Table 7.3.1 and Figure 7.3.1.1).

In general, both University of Maine model estimates and model-free stock indicators suggest that abundance and spawning stock biomass are high in GOM and the stock appears to be healthy at present. However, assessment results suggest careful consideration of key issues:

1. The model results indicate a dramatic overall stock abundance increase since the late 1980s, and abundance has been above the reference period median since 1995. The rate of increase has accelerated since 2005. These combined results overshadow more localized abundance trends that vary. For example, Statistical Area 514 has no clear trend in abundance, while Areas such as 511 and 512 have recorded stepped increases.
2. The lobster distribution as described by survey encounter rate was positive over the last 5 years. In particular the federal survey has demonstrated a dramatically increasing trend in percent positive occurrence over the time series, indicating that lobster in GOM were generally more available in offshore areas compared to the early part of the time series.
3. Exploitation rate is below the reference point threshold. Exploitation levels have varied, largely without trend since the early 1990s. Model free exploitation indicators for the combined GOM stock are neutral. One of the more remarkable patterns presented in this assessment is the stability of exploitation rates while stock abundance has increased since the late 1980s with even more dramatic increase since 2005.

4. Model free indicators point to the average spawning stock, full recruit and recruit abundance above the 75th percentile in most surveys since the last assessment.
5. Record high landings have been supported by a long period of excellent recruitment in the GOM. However, settlement indices have shown a downward trend since the last assessment, with relatively low levels of settlement throughout the GOM during this time period (2008-2013). Furthermore, four of the five regions in the GOM reported settlement that was below the median for the time series in the terminal year of 2013, and three of those were below the 25th percentile. This recent pattern of low settlement indicates a potential for declines in recruitment to the fishery in future years.

7.3.2 – Georges Bank

The UM Assessment Model for GBK was not accepted by the ASMFC Lobster Technical Committee for management and an empirical approach based on survey and landings data was used instead. The empirical approach estimated trends in reference abundance by averaging mean numbers of lobster per tow (73+ mm CL) in the NEFSC spring and fall surveys during each year and estimated trends in effective exploitation using annual catch weight divided by reference abundance (then multiplied by 0.001 for convenience in plotting). Based on this method, the Georges Bank stock is not depleted. The reference 2011 to 2013 abundance for GBK was 1.57 million, which is well above threshold abundance of 0.8 million (Table 7.3.1 and Figure 7.3.2). Overfishing is not occurring in the GBK stock. The reference relative exploitation (2011-2013) was 1.54 which, is below the threshold of 1.83 (Table 7.3.1 and Figure 7.3.2.1).

In general, model-free stock indicators suggest that abundance and spawning stock biomass are high in GBK and the stock appears to be healthy at present. However, assessment results suggest careful consideration of key issues:

1. Recruit abundance for both the spring and fall survey NEFSC indices was neutral for the 2008-2013 reference period, with 4 out of the last 6 years below the 25th percentile in the fall. It is not known to what degree this stock relies on local production as compared to subsidies from GOM. This trend in recruitment should be carefully monitored.
2. The increase in abundance of large female lobsters on GB appears to be the result of management measures put into place in the GOM (LCMA1) in the late 1990's. Steps should be taken to ensure that these large females continue to be protected. These females are highly fecund, have highly viable eggs and likely represent a very important component of the spawning stock for the Gulf of Maine and Georges Bank.

7.3.3 – Gulf of Maine/Georges Bank

The newly suggested GOM/GBK stock is not depleted. The reference 2011 to 2013 abundance for the GOM was 248 million lobsters which is well above the threshold abundance of 66 million lobsters (Table 7.3.1 and Figure 7.3.3). In fact the reference abundance was above the target (75th percentile) abundance of 107 million lobsters. Overfishing is not occurring in the GOM/GBK stock. The reference effective exploitation (2011-2013) was 0.48, which is below the threshold of 0.50 (Table 7.3.1 and Figure 7.3.3.1).

In general, both University of Maine model estimates and model-free stock indicators suggest that abundance and spawning stock biomass are high in GOM/GBK and the stock appears to be healthy at present. However, assessment results suggest careful consideration of key issues:

1. The model results indicate a dramatic overall stock abundance increase since the late 1980s, and abundance has been above the reference period median since 1995. The rate of increase has accelerated since 2005. These combined results overshadow localized abundance trends that vary. For example, Statistical Area 514 has no clear trend in abundance, while Areas such as 511 and 512 have recorded stepped increases.
2. The lobster distribution as described by survey encounter rate was positive over the last 5 years. In particular the federal survey has demonstrated a dramatic increasing trend in percent positive occurrence over the time series, indicating that lobster in GOM/GB were generally more available in offshore areas compared to the early part of the time series.
3. Exploitation rate is below the reference point threshold. Exploitation levels have varied, largely without trend since the early 1990s. Model free exploitation indicators for the combined GOM/GBK stock are mixed, with fall being negative while spring is positive. One of the more remarkable patterns presented in this assessment is the stability of exploitation rates while stock abundance has increased since the late 1980s with even more dramatic increase since 2005.
4. Model free indicators point to the average spawning stock, full recruit and recruit abundance above the 75th percentile since the last assessment. In contrast, the Young of Year (YOY) indicator is neutral or negative. Four of the five regions in the GOM reported settlement that was below the median for the time series in the terminal year of 2013, and three of those were below the 25th percentile. YOY estimates for all regions are trending down in recent years. This indicates a potential for declines in recruitment and is a pattern to pay particular attention to in coming years.

7.3.4 – Southern New England

The SNE stock is depleted. The reference 2011 to 2013 abundance for the SNE was 10 million lobsters which is well below the threshold abundance of 24 million lobsters (Table 7.3.1 and Figure 7.3.4.1). Overfishing is not occurring in the SNE stock. The reference effective exploitation (2011-2013) was 0.27, which is below the threshold of 0.41 (Table 7.3.1 and Figure 7.3.4.1).

In general, University of Maine model estimates and non-model based stock indicators suggest that abundance, spawning stock biomass, and recruitment are at historic low levels in SNE. Four of the six inshore spawning stock abundance indicators and both offshore indicators are negative. The stock has not rebuilt since the last assessment and is in very poor condition. Assessment results suggest careful consideration of key issues:

1. All recruitment indices indicate that the stock is not rebuilding and is in recruitment failure. Since 2008, nine of the twelve indicators for Rhode Island and Massachusetts young-of-year have been below their 25th percentile. Since 2011 all of the available LIS larval indices have been below their 25th percentile.
2. The lobster distribution as described by survey encounter rate was negative in all six inshore indices over the 2008-2013 period. The offshore indicators are neutral but at or below the median. This highlights the contraction of the inshore component of the SNE resource in comparison to the more stable trend in the offshore component.
3. The estimated upturn in abundance and spawning stock biomass in 2000-2005 was short-lived and could probably be attributed to the RI v-notch program. A longer and more geographically widespread harvest moratorium would be necessary to increase spawning stock abundance enough to boost recruitment and allow the stock to rebuild.
4. The total SNE landings have remained below the 25th percentile for the past twelve years, with the lowest value on record in 2013.
5. The lower level of landings observed over the last six years was produced by moderate-sized year classes (Table 5.2.3.2D) that settled between 2003 and 2007. The extremely poor year classes that have settled since 2008 have yet to recruit to the fishery. These poor year classes will recruit to the fishery starting in 2015. It is possible, if not likely, that landings in the immediate future will continue to decline.

7.4. BIOLOGICAL REFERENCE POINTS

The Technical Committee considered a suite of standard and often-used biological reference points for lobster. These included $F_{5\%}$, $F_{10\%}$, $F_{15\%}$, $F_{20\%}$, F_{MAX}, and $F_{0.1}$ which were calculated using the UM model (see Table 7.4.1). These per-recruit reference points assume equilibrium conditions such as a constant rate of growth and a constant rate of natural mortality.

The current rate of exploitation in the Gulf of Maine stock and the Gulf of Maine/Georges Bank combined stock are above threshold levels for the entire suite of per-recruit reference points estimated (Table 7.4.1). By these metrics, overfishing is occurring in both the GOM and GOM/GBK stock. This seems implausible given the record abundance and recruitment observed in this stock over the last 20 years. Per-recruit reference points were not calculated for GBK because the model used to calculate them was not accepted for management use.

It was not possible to calculate percent spawning biomass per-recruit reference points ($F_{5\%}$, $F_{10\%}$, $F_{15\%}$ or $F_{20\%}$) for the SNE stock. Relatively high assumed natural mortality, early sexual maturation (100% mature prior to recruiting to the fishery), and recent shifts in fishery selectivity towards larger lobsters (via increased minimum size regulations) make it impossible, based on the calculations, to fish hard enough to reduce mean lifetime egg production per-recruit to even 20% of the virgin level, let alone more liberal levels. Similarly, F_{MAX} was not calculated for SNE because the yield curve did not have a maximum at effective exploitation levels ≤ 0.4, which corresponds to annual full recruit fishing mortality levels of approximately F=8. Effective exploitation is small relative to full F for SNE because a large proportion of the stock in per-recruit calculations was smaller than the current minimum legal size and not harvestable. Thus, these unusual results for SNE are due to recent environmental changes which have reduced longevity and management actions which protect the remaining stock.

Uncertainty about the scale of fishing mortality estimates makes the use of absolute overfishing reference points problematic. This assessment has demonstrated a strong relationship between annual recruitment and temperature thresholds defining optimal and stressful environmental conditions. These temperature regimes have undergone substantial systematic changes which directly affect natural mortality, rate of maturation, and rate of growth. Climate projections for the Northeast shelf predict that a continuation of environmental variability is a reasonable expectation. Therefore reference points that are based on hypothetical equilibrium conditions become unrealistic and unreliable management tools. An estimate of 100%MSP based on past data has little relevance to current or future conditions. As such the TC does not recommend the use of any of the biological based reference points.

7.5 – PROJECTIONS

Projection runs using the basecase model runs for GOM, GOM/GBK and SNE and one hypothetical scenario are used to demonstrate analyses that can be carried out using the University of Maine assessment model, although projection results are not used elsewhere in this assessment. Projections are not shown for GBK because the assessment model for GBK was not accepted by the Lobster Technical Committee. The demonstration runs address the question of what lobster stocks might look like in the future if fishing mortality, fishery selectivity, natural mortality, recruitment, etc. remained constant at current levels with no variability due to environmental conditions. The projections should not be viewed as estimates of future stock size in any particular year and are meant only to give readers a feeling for average potential stock productivity in a hypothetical world where factors affecting lobster dynamics are near current average levels with no variability.

Commercial selectivity and natural mortality were the same as in the terminal year (2014) because this assumption is hardwired in the model and difficult to change. Recruitment and fishing mortality used in projections were fixed at 2009-2013 average levels. The year 2014 was ignored in calculating recruitment and fishing mortality because estimates for 2014 were unreliable and not suitable as a basis for projection. Therefore, short-term projected increases or decreases in stock size during 2014 to about 2020 should be ignored. Only the equilibrium levels calculated for years after 2020 are of interest. Projection runs were for years 2015-2039 (25 y). Legal abundance (sexes combined) on July 1 (immediately after the major molt), female spawning biomass on July 1, and landings in weight were calculated for each projected year.

Results suggest that stock abundance and productivity would decline but remain relatively high after 2013 under the assumed conditions for GOM and GOM/GBK (Figures 7.5.1-7.5.2). Projections for GOM and GOM/GBK through 2017 are affected by the unusually high recruitment estimates for 2011-2014. Projections for SNE indicate that productivity would increase slightly but remain low overall under the conditions assumed (Figure 7.5.3).

8.0 RESEARCH RECOMMENDATIONS

Research Recommendations
Responses to the 2009 Peer Review Research Recommendations and the 2010 CIE Review of the TC Report on SNE Recruitment Failure are presented in Appendix 2.

Model Recommendations
Examine the use of a hierarchical modeling technique (Conn, 2010) to aggregate survey information for the different stock areas as an alternative to internally weighting indices in the model or using area-swept information.

Program Research
New research and expansion of existing monitoring programs in the following areas would provide information needed to improve future stock assessments.

8.1 FISHERY-DEPENDENT INFORMATION

a. Accurate and comparable landings are the principal data needed to assess the impact of fishing on lobster populations. The quality of landings data has not been consistent spatially or temporally. Limited funding, and in some cases, elimination of sea sampling and port sampling programs will negatively affect our ability to characterize catch and conservation discards, limiting the ability of the model to accurately describe landings and stock conditions. It is imperative that funding for critical monitoring programs continues, and increased monitoring efforts for offshore areas, particularly those from which a large portion of landings originate, are necessary. These types of programs are essential for accurate lobster assessments and must have dedicated funding.

b. There are some indications that lobster harvest may be under-reported and this under-reporting may be significant during some periods in the time series examined for this assessment. It is recommended that future research examine this potential under-reporting, and this examination should include simulation testing of these potential periods of under-reporting. One particular area that can be examined is the period prior to the implementation of the 100/500 possession rule for non-pot gear, as landings by non-pot gear may have been a significant source of under-reporting.

c. A thorough investigation of methods for determining optimal biological sampling intensity based on variability in catch and spatial/temporal landings information should be undertaken. This investigation should explore other metrics that may be more variable than length composition (i.e. conservation discards, sex ratio, legal proportions), as well as an examination of the importance of the different Statistical Areas to the assessment and how this may interplay with the needed level of sampling from those areas.

8.2 FISHERY-INDEPENDENT INFORMATION

Ventless Trap Survey

a. (***High priority***) Calibration work to determine how catch in the ventless trap surveys relates to catch in the bottom trawl surveys would be a useful topic of research. It is likely that at low densities, when trawl survey indices have dropped to near zero, ventless trap surveys will still catch lobsters due to the attractive nature of the gear and the ability to fish the gear over all habitat types. Conversely, it is possible that trawl surveys may be able to detect very high levels of lobster abundance, if trap saturation limits the capacity of the ventless traps. Ventless traps may be limited in their ability to differentiate between moderately high and extremely high abundance, and calibration with bottom trawl surveys may help to clarify how q might change with changes in lobster density.

b. Now that funding for long-term ventless trap surveys appears to be more secure, there are some outstanding questions regarding this survey method that would benefit from further research. Namely, understanding trap saturation, in terms of high lobster densities and the capacity of the traps, along with the ensuing behavioral interactions that affect trapping of particular individuals, is a prime topic of interest to understand how density might impact the segment of the population represented in the survey catch. Also, the efficiency of the standardize survey gear could be explored in relation to effective fishing circles.

8.3 MATURITY AND GROWTH

(***High priority***) Increases in water temperatures over the past several decades (see Section 2.2) have likely resulted in changes to size at maturity and growth patterns, since temperature has such a strong influence on these vital processes (see Section 2.1). Maturity data used in this assessment are more than 20 years old, making it likely that changes have since occurred. Evidence to suggest that decreases in the size at which females reach maturity exists in both the GOM stock (see Pugh et al. 2013) and the SNE stock (see DNC 2013, Landers et al. 2001). Changes in sizes at maturity will subsequently affect growth, since female molting frequency decrease after reaching sexual maturity. Additionally, growth is directly influenced by water temperatures, and evidence exists in SNE for increased molt frequency and decreased molt increments (DNC 2013). It is critical to collect updated information on maturity and growth in order to appropriately assign molt probabilities to lobsters in the U. Maine length-based model.

8.4 AGE

a. If a definitive age-length relationship can be developed, a research recommendation will be to confirm the transition matrices used in the University of Maine model and improve the current assessment.

b. In 2013 the Maine Department of Marine Resources contracted with the University of Maine for a five year $250,000 project designed to apply Kilada et al.'s (2012) approach to ageing for lobster. This work will focus on lobsters ranging in size from newly settled lobsters to fully recruited sizes. Regional temperature regimes will be tested as well as differences between laboratory and field scenarios. Anticipated deliverables should be directly applicable to future assessment and will include size-at-age estimates, molt increments and molt frequency.

8.5 ENVIRONMENTAL INFLUENCE ON LOBSTER LIFE HISTORY PROCESSES

a. Examine methods for determining age- or length-varying natural mortality, as well as looking at more rigorous ways of determining time-varying natural mortality for lobster, which may be driven by climactic shifts and changing predator fields. Additionally, interplay between natural mortality and the potential for underreported harvest should be examined to determine how these factors may impact assessment outcomes.

b. Continue exploring relationships between environmental drivers (temperature) and recruitment. Develop techniques to enhance predictive capabilities of YOY indices used together with temperature time series. Improve methods to incorporate environmental data into population modeling.

c. Examine post-larval settlement dynamics in relation to movement/re-distribution of spawning stock. Develop habitat suitability models for spawning stock and settling post-larvae. Integrate climate projections into habitat suitability models for lobster.

d. The Maine Department of Marine Resources conducted a three year study (2010-2013) where settlement was measured in randomly selected sites, based on depth and substrate, and compared to standardized sentinel locations in Mid-Coast Maine. Mid-Coast Maine is the region with the longest time series for settlement, dating back to 1989. For this reason, it was important to investigate the patterns of settlement from fixed and randomly selected sites. Initial results indicate fixed and random stations have similar magnitude and trend with respect to settlement density for this region.

   In other regions in Maine, there may be evidence that thermal conditions may have changed, providing additional habitat for settlement. Annis et al. (2013) suggest that small differences in water temperature may shape settlement patterns through either behavioral avoidance of colder settlement sites or elevated post-settlement mortality of postlarvae settling at colder sites. Wahle et al. (2013) observed young-of-year lobsters as deep as 80 m. If available substrate has increased in eastern/northern Maine, simply as a result of increasing water temperatures, then fixed sentinel sites in shallow water may miss a broader pattern of settlement in the region. As such, deep water settlement should be investigated, using an appropriate number of passive settlement collectors (see Wahle et al. 2009) to detect anticipated settlement in conditions where the lack of thermal stratification would tend to distribute postlarvae evenly with depth.

e. With the high prevalence of shell disease in the SNE stock, particularly in ovigerous females, some exploration of the potential sub-lethal effects of disease should be examined. These effects could include negative impacts to larval quality, fecundity issues in females who need to re-direct physiological resources to dealing with the disease, and male sperm quality (see

Comeau and Benhalima 2009). Any sub-lethal effects of shell disease could further impede the potential for the SNE stock to rebuild.

8.6 POPULATION DYNAMICS AND MATING SUCCESS

With the SNE stock in such poor condition, questions arise regarding how the population functions at some basic levels. In particular, because of the nature of the American lobster mating system (wherein males establish mating shelters and females seek out and choose to mate with dominant males; see Atema 1986, Atema and Vogt 1995 for reviews), low population abundance may be causing a mate-finding Allee effect (Stephens et al. 1999, Gascoigne et al.2009). There is some evidence indicating that larger, presumably reproductively mature females have not mated in some inshore regions (Pugh et al. 2103, Pugh 2014). In order to understand the potential the SNE stock has to rebuild, it is important to know whether current stock conditions have disrupted the mating system. Additional work to examine female mating activity and success should be initiated.

Due to the continuation of female-skewed sex ratios observed in the GBK stock (on-going since the previous assessment), questions regarding the reproductive capacity of these large females should be considered. Recent laboratory work showed that females who mated with smaller males, or who mated under female-skewed sex ratios, did not have completely filled seminal receptacles, and may have been sperm-limited (Pugh 2014). As such, information regarding the location and timing of the female molt (thus mating) would be required to determine whether the skewed sex ratios and larger female size structure might impact female reproductive output. Additionally, sampling of the large females to determine whether they have mated would also be informative with regards to reproductive activity, as preliminary data indicated some large females had not mated (Goldstein et al. 2014).

8.7 STOCK CONNECTIVITY

(***High priority***) There is need for a comprehensive large scale tagging study to examine stock connectivity between the Gulf of Maine and Georges Bank. Historical tagging studies demonstrate movement from the inshore Gulf of Maine to locations east of Cape Cod in the inshore portions of Georges Bank, from the Scotian Shelf to Georges Bank, and from inshore areas east of Cape Cod to inshore Gulf of Maine (see Section 2.9). What is lacking is a tagging study of lobsters in the fall/winter on Georges Bank proper, prior to seasonal migrations which occur in the spring. This information would be extremely valuable to help complement other data used to justify the combination of the Gulf of Maine and Georges Bank stock and to confirm the connectivity of the Gulf of Maine and Georges Bank.

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10.0 TABLES

Table 1.2: A summary of management measures by LCMA.

Management Measure	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	OCC
Min Gauge Size	3-1/4"	3-3/8"	3-17/32"	3-3/8"	3-3/8"	3-3/8"	3-3/8"
Vent Rect.	1-15/16x 5-3/4"	2 x 5-3/4"	2-1/16 x 5-3/4"	2 x 5-3/4"	2 x 5-3/4"	2 x 5-3/4"	2 x 5-3/4"
Vent Cir.	2-7/16"	2-5/8"	2-11/16"	2-5/8"	2-5/8"	2-5/8"	2-5/8"
V-notch requirement	Mandatory for all eggers	Mandatory for all legal size eggers	Mandatory for all eggers above 42°30'	Mandatory for all eggers	None	None	None
V-Notch Definition (possession)	Zero Tolerance	1/8" with or w/out setal hairs[1]	1/8" with or w/out setal hairs[1]	1/8" with or w/out setal hairs[1]	1/8" with or w/out setal hairs[1]	1/8" with or w/out setal hairs[1]	State Permitted fisherman in state waters 1/4" without setal hairs Federal Permit holders 1/8" with or w/out setal hairs[1]
Max. Gauge (male & female)	5"	5 ¼"	6 3/4"	5 ¼"	5 ¼"	5 ¼"	State Waters none Federal Waters 6 3/4"
Season Closure				Feb 1- Mar 31	April 30-May 31	Sept 8-Nov 28	Feb 1-April 30

[1] A v-notched lobster is defined as any female lobster that bears a notch or indentation in the base of the flipper that is at least as deep as 1/8 inch, with or without setal hairs. It also means any female which is mutilated in a manner that could hide, obscure, or obliterate such a mark.

Table 2.1.1: A summary of key biological threshold values for *H. americanus*.

Category	Life-Stage	Threshold Value	Reference(s)
Temperature	Eggs	<5°C winter, 10-12°C hatching	1, 2
	Larvae	10-12°C	2
	Juveniles/Adults	5-18°C, preference ~ 16°C, 20.5°C stressed	3, 4, 5, 6
Salinity	Eggs/Larvae	< 17 ppt	7
	Juveniles/Adults	< 12 ppt	8
Dissolved Oxygen	Larvae	< 1 mgO_2/L	9
	Juveniles/Adults	< 2 ppm	10
pH	Larvae	< 7.7 (stages I – IV)	11
	Juveniles/Adults	n/a	

References: (1) Waddy and Aiken 1995; (2) MacKenzie 1988; (3) Reynolds and Casterlin 1979; (4) Crossin et al. 1998; (5) Dove et al. 2005; (6) Powers et al. 2004; (7) Charmantier et al. 2001; (8) Jury et al. 1994; (9) Ennis 1995; (10) Howell and Simpson 1994; (11) Keppel et al. 2012.

Table 2.3.1. SNE UMM difference in total unweighted negative log likelihood from the base run

Source	Sex	Type	Base	M_1.1	M_1.2	M_1.3	M_1.4	M_1.5	M_1.6	M_1.7	M_1.8	**M_1.9**	M_2
Commercial	Female	Prof.NLL.CPUE	0	0	0	0	0	0	0	0	0	**0**	0
Commercial	Male	Prof.NLL.CPUE	0	0	0	0	0	0	0	0	0	**0**	0
Survey.1	Female	Prof.NLL.SurveyTrend	0	0.034	0.144	-0.08	0.431	0.537	0.592	0.581	0.68	**0.459**	0.97
Survey.1	Male	Prof.NLL.SurveyTrend	0	-0.01	0.155	-0.24	0.422	0.478	0.494	0.224	0.434	**0.391**	1.511
Commercial	Female	Prof.NLL.LenComps	0	-1.58	-13.1	-16.2	-14.2	-14.5	-21.8	-12.6	-9.13	**-21.2**	-20.3
Commercial	Male	Prof.NLL.LenComps	0	0.05	1.9	5.13	10.79	10.24	12.94	10.2	2.62	**1.65**	10.33
Survey.1	Female	Prof.NLL.LenComps	0	-0.54	-2.75	5.94	-11.7	-14.6	-18.1	-14.4	-14.7	**-17.3**	-26.5
Survey.1	Male	Prof.NLL.LenComps	0	1.05	4.21	7.14	13.31	14.75	13.15	11.94	15.63	**11.94**	24.16
NA	NA	Prof.NLL.Priors	0	0	0	0	0	0	0	0	0	**0**	0
NA	NA	Prof.NLL.Rdevs	0	-0.17	-0.51	-1.03	-1.06	-1.3	-1.43	-1.24	-0.02	**-1.64**	-1.27
Survey.2	Female	Prof.NLL.LenComps	0	-0.68	4.572	-8.73	-5.87	-15.7	-23.4	-18.6	-37.2	**-16.4**	-36.4
Survey.2	Male	Prof.NLL.LenComps	0	-1.06	-7.34	-15.8	-23.3	-27.5	-21.9	-27.3	-11.7	**-28.6**	9.159
Survey.2	Female	Prof.NLL.SurveyTrend	0	-0.21	-0.11	0.163	-0.04	0.186	-0.04	-0.69	-0.88	**-0.43**	-1.05
Survey.2	Male	Prof.NLL.SurveyTrend	0	-0.26	-0.17	0.057	-0.19	-0.01	-0.36	-1.08	-1.29	**-0.84**	-1.64
Survey.3	Female	Prof.NLL.LenComps	0	-1.55	-0.6	-7.13	-8.22	-2.13	-4	-10.3	0.303	**-20.4**	-17.4
Survey.3	Male	Prof.NLL.LenComps	0	-0.86	-0.39	-3.52	6.396	2.326	2.522	-13.8	-10.2	**-14.4**	-1.82
Survey.3	Female	Prof.NLL.SurveyTrend	0	-0.05	-0.21	-0.47	-0.68	-0.98	-0.74	-0.62	-1.34	**-0.7**	-0.32
Survey.3	Male	Prof.NLL.SurveyTrend	0	-0.21	-0.42	-0.73	-0.92	-1.32	-1.27	-1.3	-1.99	**-1.62**	-1.34
Commercial	Female	Prof.NLL.Catch	0	-8.41	-22.3	-19.7	-31.7	-30.7	-29.1	-35.1	-38.8	**-40.2**	-47.7
Commercial	Male	Prof.NLL.Catch	0	2.172	2.134	-4.8	-9.39	-8.15	-11.7	-11.4	-12.9	**-4.91**	-18.2
NA	NA	of.NLL.XtraRecruitConstra	0	0	0	0	0	0	0	0	0	**0**	0
NA	NA	Prof.NLL.weighted.total											
		Total unweighted NLL	0	-12.3	-34.8	-59.9	-75.9	-88.4	-104	-125	-121	**-154**	-128
		M	0.15	0.165	0.18	0.195	0.21	0.225	0.24	0.255	0.27	**0.285**	0.3

Table 2.3.1 continued

Source	Sex	Type	M_2.1	M_2.2	M_2.3	M_2.4	M_2.5	M_2.6	M_2.7	M_2.8	M_2.9	M_3
Commercial	Female	Prof.NLL.CPUE	0	0	0	0	0	0	0	0	0	0
Commercial	Male	Prof.NLL.CPUE	0	0	0	0	0	0	0	0	0	0
Survey.1	Female	Prof.NLL.SurveyTrend	1.598	0.693	0.292	1.218	1.577	1.56	2.768	1.803	2.224	2.219
Survey.1	Male	Prof.NLL.SurveyTrend	1.476	1.057	1.026	2.273	1.642	1.666	3.007	2.946	3.851	4.52
Commercial	Female	Prof.NLL.LenComps	9.05	-24	-15.6	-70.7	-22.7	-35.5	-17.6	-11	-28.2	-25.8
Commercial	Male	Prof.NLL.LenComps	22.88	38.4	0.35	62.83	36.51	62.08	96.08	45.7	64.74	69.15
Survey.1	Female	Prof.NLL.LenComps	-17.4	27.13	4.28	-6.49	17.54	9.65	-3.09	19.43	-3.44	-1.08
Survey.1	Male	Prof.NLL.LenComps	22.03	5.08	6.56	5.63	-13.9	-8.23	5.95	-5.64	23.78	8.05
NA	NA	Prof.NLL.Priors	0	0	0	0	0	0	0	0	0	0
NA	NA	Prof.NLL.Rdevs	5.394	2.793	3.522	0.588	9.929	0.88	7.126	6.507	10.28	10.79
Survey.2	Female	Prof.NLL.LenComps	-29.5	3.901	7.317	-14	-4.45	-0.51	-20.5	-5.54	11.12	34.95
Survey.2	Male	Prof.NLL.LenComps	11.86	17.07	45.7	37.24	39.93	10.55	12.99	52.92	19.15	41.84
Survey.2	Female	Prof.NLL.SurveyTrend	-2.44	-2.29	-2.74	-2.79	-1.58	-0.01	-1.07	-2.52	-2.93	-3.16
Survey.2	Male	Prof.NLL.SurveyTrend	-3.04	-2.67	-3.35	-3.57	-2.19	-0.47	-1.6	-3.29	-3.69	-4.07
Survey.3	Female	Prof.NLL.LenComps	19.03	-1.2	-1.63	-18.5	-3.34	30.7	7.509	54.84	20.38	31.26
Survey.3	Male	Prof.NLL.LenComps	-27.1	-2.62	-4.75	14.7	1.875	-63.5	-36.1	-25.6	-31.3	-14
Survey.3	Female	Prof.NLL.SurveyTrend	-0.34	0.752	1.974	2.974	0.359	0.047	0.194	3.457	3.373	6.275
Survey.3	Male	Prof.NLL.SurveyTrend	-1.56	0.068	1.021	1.857	-0.43	-0.62	0.372	2.717	2.534	5.011
Commercial	Female	Prof.NLL.Catch	-61.8	-60.5	-64	-73.6	-75.1	-73.8	-68.5	-107	-62.4	-83.3
Commercial	Male	Prof.NLL.Catch	2.075	8.219	-9.81	-5.83	-13.1	-9.52	-5.34	-39.6	-29.6	-24.4
NA	NA	of.NLL.XtraRecruitConstra	0	0	0	0	0	0	0	0	0	0
NA	NA	Prof.NLL.weighted.total										
		Total unweighted NLL	-47.8	11.93	-29.8	-66.1	-27.4	-75	-17.7	-9.41	-0.03	58.21
		M	0.315	0.33	0.345	0.36	0.375	0.39	0.405	0.42	0.435	0.45

Table 2.3.2: Annual days with average temperature above 20° C recorded at Millstone Power Station (DNC 2013 and personal communication). Daily averages are computed from continuous 15-minute readings taken at the intakes 1-2 m off bottom (4.6-7.6 m depth).

Year	Total Days in Year	Avg>20C	Deviation from Avg Days>20C 1979-2014	Recruitment covariate weight factor (1+(dev from avg/avg))
1976	366	8		
1977	365	34		
1978	365	17		
1979	365	48	-4.36	0.92
1980	366	42	-10.36	0.80
1981	365	59	6.64	1.13
1982	365	42	-10.36	0.80
1983	365	31	-21.36	0.59
1984	366	35	-17.36	0.67
1985	365	50	-2.36	0.95
1986	365	35	-17.36	0.67
1987	365	33	-19.36	0.63
1988	366	17	-35.36	0.32
1989	365	40	-12.36	0.76
1990	365	46	-6.36	0.88
1991	365	51	-1.36	0.97
1992	366	14	-38.36	0.27
1993	365	49	-3.36	0.94
1994	365	43	-9.36	0.82
1995	365	59	6.64	1.13
1996	366	13	-39.36	0.25
1997	365	7	-45.36	0.13
1998	365	55	2.64	1.05
1999	365	76	23.64	1.45
2000	366	71	18.64	1.36
2001	365	66	13.64	1.26
2002	365	76	23.64	1.45
2003	365	63	10.64	1.20
2004	366	57	4.64	1.09
2005	365	65	12.64	1.24
2006	365	69	16.64	1.32
2007	365	69	16.64	1.32
2008	366	73	20.64	1.39
2009	365	44	-8.36	0.84
2010	365	75	22.64	1.43
2011	365	63	10.64	1.20
2012	366	94	41.64	1.80
2013	365	77	24.64	1.47
2014	365	78	25.64	1.49
Average: 1976 - 2014		52.36		1.00

Table 2.3.1.1. Total numbers of lobster observed in stomach samples collected during NEFSC winter, spring and fall bottom trawl surveys between Cape Hatteras and Canada from 1982-2013, by predator..

Predator species	N Lobster Observed
Atlantic cod	69
Spiny dogfish	45
Smooth dogfish	37
Little skate	25
Longhorn sculpin	16
Red hake	12
Haddock	8
Barndoor skate	7
White hake	7
Thorny skate	7
Winter skate	6
Sea raven	6
Goosefish	4
Smooth skate	3
Silver hake	3
Black sea bass	2
Spotted hake	1
Atlantic halibut	1
Fourspot flounder	1
Winter flounder	1
Atlantic croaker	1
Atlantic wolffish	1
Ocean pout	1

Table 2.3.1.2. Mean percent stomach contents by weight for lobster in the top five predators based on NEAMAP stomach samples. Mean stomach weight is calculated over tows weighted by predator catch to accommodate cluster sampling. The rank for lobster as prey for each predator is calculated by assigning rank=1 to the most common prey species by weight. Thus, rank=92 for black sea bass samples means that 91 prey items were more common than lobster by weight.

Predator	Lobster percent weight	Rank for percent weight
Winter skate	0.10%	60
Smooth dogfish	0.09%	60
Black sea bass	0.05%	92
Tautog	0.05%	45
Spiny dogfish	< 0.01%	111

Table 2.4.1. Annual shell disease prevalence in lobsters observed during commercial trap sampling by state and NMFS statistical area.

State:	New York	Connecticut & New York	Rhode Island		Massachusetts			New Hampshire	Maine			
Area:	**612-613**	**611**	**616**	**539**	**537-538**	**521**	**514**	**513**	**513**	**512**	**511**	**467**
1992		0.6%										
1993		0.5%										
1994		1.0%										
1995		1.0%										
1996		1.6%	0%	0.3%								
1997		2.3%	0%	4.3%								
1998		2.1%	0.2%	19.0%								
1999		3.9%	0.8%	20.3%								
2000		4.6%	2.2%	21.8%	9.4%	0%	3.7%					
2001		5.9%	2.2%	22.6%	11.6%	2.2%	6.5%					
2002		9.7%	3.1%	30.6%	25.9%	0.4%	5.5%	0.2%				
2003		13.0%	3.1%	24.9%	29.0%	0.9%	3.9%	0.3%	<0.05%	<0.05%	<0.05%	0%
2004	19.4%	6.2%	2.6%	27.9%	11.5%	0.5%	2.3%	0.2%	<0.05%	<0.05%	<0.05%	0%
2005	*5.8%	8.7%	2.3%	26.2%	14.3%	0.4%	2.3%	0.1%	<0.05%	<0.05%	<0.05%	0%
2006	na	na	1.7%	27.6%	23.9%	0%	1.2%	0.1%	<0.05%	<0.05%	<0.05%	0%
2007	na	9.1%	5.1%	21.8%	24.6%	0.6%	3.7%	0.1%	<0.05%	<0.05%	<0.05%	0%
2008	0%	7.9%	1.6%	**28.9%	26.7%	0.2%	2.4%	0.1%	<0.05%	<0.05%	<0.05%	0%
2009	*8.2%	14.3%	na	**28.5%	32.7%	0.2%	1.1%	0.1%	<0.05%	<0.05%	<0.05%	0%
2010	*31.1%	8.2%	na	33.9%	21.9%	0.3%	2.6%	0.1%	0.1%	<0.05%	<0.05%	0%
2011	26.9%	15.0%	na	29.5%	37.7%	0.2%	4.2%	0.3%	0.2%	<0.05%	<0.05%	0%
2012	0%	5.2%	na	34.0%	18.6%	0.6%	3.1%	0.5%	0.3%	<0.05%	<0.05%	0%
2013	na	na	na	†14.5%	37.2%	0.9%	5.5%		0.6%	0.1%	<0.05%	<0.05%

2004-2008 Ave	9.7%	8.0%	2.7%	25.9%	20.2%	0.3%	2.4%	0.1%	0.3%	<0.05%	<0.05%	0.0%
2009-2013 Ave	13.5%	10.7%	na	32.5%	29.6%	0.4%	3.3%	0.3%	0.3%	0.1%	<0.05%	0.0%

*sample N<100

**2008-09: 2-4% of sample taken in SA 537

†2013: 60% of sample taken in SA 537

Table 2.6.1.1.1. Parameters for logistic molt probability curves for American lobster. GBK parameters are from Fogarty and Idoine (1988). Parameters for GOM and SNE are from ASMFC (2009). Parameters for the GOM&GBK area are from fitting logistic curves to average curves for GOM and GBK using average numbers caught per tow during NMFS spring and fall bottom trawl surveys in the two areas as weights for each length group.

Stock Area	a	b
GBK females	-6.867	0.058
GBK males	-6.886	0.052
GOM females	-8.081	0.07654
GOM&GBK	-6.571	0.05901
GOM&GBK	-6.834	0.06046
SNE female	-9.72	0.1032

Table 2.6.1.1.2. Assumed double molting probabilities for lobsters used in calculating growth matrices for the University of Maine stock assessment model.

CL	GOM & GBK	SNE	CL	GOM & GBK	SNE
50	0.45	0.46	67	0.22	0.03
51	0.44	0.41	68	0.2	0.02
52	0.42	0.37	69	0.19	0.01
53	0.41	0.34	70	0.18	0.01
54	0.39	0.3	71	0.16	0
55	0.38	0.27	72	0.15	0
56	0.37	0.24	73	0.14	0
57	0.35	0.21	74	0.12	0
58	0.34	0.18	75	0.11	0
59	0.33	0.15	76	0.1	0
60	0.31	0.13	77	0.08	0
61	0.3	0.11	78	0.07	0
62	0.29	0.09	79	0.05	0
63	0.27	0.07	80	0.04	0
64	0.26	0.06	81	0.03	0
65	0.25	0.05	82	0.01	0
66	0.23	0.03	83	0	0

Table 2.6.1.2.1. Sample size, pre-molt size range and mean molt increment model parameters used to estimate lobster growth for the GOM, GBK, and combined GOM/GBK stock areas in this assessment and in ASMFC (2006; 2009).

Sex	N	Size range	Inflection	Asymptotic increment	Residual standard deviation	Intercept	Slope
New GOM&GBK							
Female	554	50-151	76	13	2.1	-3.9	0.22
Male	438	50-171	86	15	2.5	-4.51	0.23
ASMFC (2006) -GOM							
Female	201	25-80	82	12	2	1.23	0.13
Male	289	25-79	95	14	2.2	1.22	0.13
ASMFC (2006) -GBK							
Female	106	68-140	75	14	1.7	0.97	0.17
Male	63	63-115	87	18	2.1	0.83	0.19

Table 2.6.1.2.2. Sample size, pre-molt size range and mean molt increment model parameters used to estimate lobster growth for the SNE stock assessment in this assessment and in ASMFC (2006; 2009).

Sex	N	Size range	Inflection	Asymptotic increment	Residual standard deviation	Intercept	Slope
New SNE							
Female	1255	50-102	na	8	2.2	na	na
Male	955	51-98	na	11	2.4	na	na
ASMFC (2009)							
Female	293	30-94	64	9	2.3	na	na
Male	482	53-98	74	11	2.3	na	na

Table 2.6.1.2.3. Minimum and maximum molt increment and growth rate criteria used to exclude lobsters from growth calculations that did not molt or had molted more than once.

Dataset	*Females*				*Males*				Note
	Increments		Growth rates		Increments		Growth rates		
	Min	Max	Min	Max	Min	Max	Min	Max	
GOM									
Krause	-	-	-	-	-	-	-	-	Pre-cleaned
Wahle	5	16		0.25	5	16	-	0.25	
DMR	-	-	0.1	0.22	-	-	0.1	0.22	
DFO	7	20	-	0.25	7	20	-	0.25	
GBK									
Uzzman	10	20	-	-	10	22	-	-	
SNE									
Castro	5	15	-	-	5	20	-	-	
RI	5	15	-	-	5	20	-	-	
CT	5	15	-	-	5	20	-	-	
NY	5	15	-	-	5	20	-	-	

Table 2.9.1 Assignment of surveys to stock regions used in modeling

Stock region	Surveys	Strata
GOM	NEFSC - GOM, Spring, Fall	NEFSC survey strata 01260-01300, 01340, 01351, 01360-01400, 03590- 03610, 03640-03660
	MA_DMF - GOM, Spring, Fall	MA_DMF Strata 25-29, 31-36
	ME_DMR, Spring, Fall	ME_DMR survey strata 1-3
	Ventless Trap – ME, NH, MA	ME_DMR 0-40m, NH_DFW 0-40m, MA_DMF 0-60m
GBK	NEFSC - GBK, Spring, Fall	NEFSC survey strata 01090-01250
SNE	NEFSC - SNE, Spring, Fall	NEFSC survey strata 01010-01080, 01610-01760, 0320-03440 offshore, 03450, 03460, 03480, 03550
	CD_DEP - Spring, Fall	See CTDEP (2004, p 63 and Fig. 2.1)
	RI_DMF - Spring, Fall	RI_DMF survey strata 1-11
	MA_DMF - SNE, Spring, Fall	MA_DMF Strata 11-14
	NEAMAP, Spring, Fall	NEAMAP Regions 1-15, RI, and BI
	Ventless Trap –MA, RI	MA_DMF 0-40m, RI_DFW 0-40m

Table 2.9.2. Assignment of statistical areas for landings data to stock regions used in modeling.

Stock region-survey area	Statistical Reporting Areas for Landings
GOM	464, 465, 511, 512, 513, 514, 515
GBK	521, 522, 523, 524, 525, 526, 541, 542, 543, 561, 562
GOM/GBK	464, 465, 511, 512, 513, 514, 515, 521, 522, 523, 524, 525, 526, 541, 542, 543, 561, 562
SNE	533, 534, 537, 538, 539, 611, 612, 613, 614, 615, 616, 621, 622, 623, 624, 625, 626, 627, 631, 632, 635, 701

Table 3.2. Number of commercial lobster licenses issued by jurisdiction, 1981 to 2013.

Year	CT	MA	ME	NH	NJ	NY	RI	NMFS	Total
1981	659	1,515	8,548	302	*NA*	393	*NA*	*NA*	11,417
1982	678	1,538	8,891	323	*NA*	380	*NA*	*NA*	11,810
1983	649	1,609	8,895	337	*NA*	446	*NA*	*NA*	11,936
1984	642	1,679	8,730	307	*NA*	521	*NA*	*NA*	11,879
1985	693	1,744	7,879	302	*NA*	556	*NA*	*NA*	11,174
1986	623	1,803	6,875	332	*NA*	559	*NA*	*NA*	10,192
1987	578	1,877	6,730	313	*NA*	551	*NA*	1,919	10,049
1988	612	1,832	6,804	318	*NA*	959	*NA*	2,712	10,525
1989	595	1,782	7,215	327	*NA*	945	*NA*	2,783	10,864
1990	606	1,727	6,706	299	*NA*	994	1,177	3,017	11,509
1991	611	1,682	6,940	286	*NA*	1,067	1,270	3,402	11,856
1992	547	1,647	6,162	267	*NA*	1,171	1,394	3,731	11,188
1993	544	1,627	6,176	263	*NA*	1,211	1,007	3,666	10,828
1994	499	1,612	6,503	287	*NA*	1,265	980	3,801	11,146
1995	513	1,609	7,690	311	*NA*	995	1,317	2,833	12,435
1996	445	1,598	7,158	310	*NA*	932	1,075	3,465	11,518
1997	427	1,591	6,392	303	*NA*	888	1,089	3,414	10,690
1998	441	1,570	6,175	311	*NA*	761	1,597	3,196	10,855
1999	419	1,549	5,930	297	*NA*	746	1,087	3,313	10,028
2000	389	1,541	5,950	309	87	657	1,487	3,254	10,420
2001	352	1,540	5,933	325	95	600	1,512	3,269	10,357
2002	345	1,531	5,894	339	109	554	1,398	3,311	10,170
2003	286	1,504	5,867	349	109	506	1,302	3,324	9,923
2004	293	1,464	5,849	356	109	477	1,239	3,381	9,787
2005	276	1,428	5,830	374	109	458	1,168	3,353	9,643
2006	274	1,401	5,763	373	109	428	1,103	3,393	9,451
2007	255	1,361	5,693	362	109	412	1,050	3,287	9,242
2008	228	1,333	5,539	377	109	384	1,010	3,214	8,980
2009	220	1,314	5,376	365	109	375	979	3,176	8,738
2010	206	1,278	5,226	347	109	360	948	3,141	8,474
2011	180	1,245	5,155	333	109	344	922	3,119	8,288
2012	161	1,214	5,079	334	109	334	905	3,003	8,136
2013	142	1,188	4,979	322	109	326	874	2,963	7,940

Table 3.2.1.1. Gulf of Maine landings in metric tons by state from 1981 to 2013.

Year	ME	NH	MA	RI	Total
1981	10,266	360	4,152	0	14,777
1982	10,310	366	3,992	0	14,669
1983	9,836	594	4,638	0	15,069
1984	8,866	712	4,219	0	13,797
1985	9,129	539	4,890	0	14,558
1986	8,935	427	4,454	0	13,816
1987	8,958	570	4,425	0	13,952
1988	9,861	508	4,328	0	14,696
1989	10,600	649	5,459	0	16,708
1990	12,732	752	5,761	0	19,245
1991	13,966	817	5,420	13	20,216
1992	12,170	694	4,875	0	17,738
1993	13,575	673	4,554	1	18,802
1994	17,667	596	5,392	0	23,655
1995	16,878	710	5,375	0	22,962
1996	16,367	628	5,127	0	22,122
1997	21,330	544	4,750	0	26,624
1998	21,336	460	3,973	0	25,769
1999	24,265	525	5,115	0	29,905
2000	25,924	658	5,208	0	31,797
2001	22,053	780	3,664	0	26,497
2002	28,860	781	4,158	0	33,800
2003	24,935	682	3,506	6	29,129
2004	32,466	968	3,553	34	37,021
2005	31,176	622	3,227	33	35,058
2006	32,961	680	3,573	83	37,297
2007	28,645	720	3,266	69	32,700
2008	31,710	831	3,656	55	36,252
2009	36,828	1,049	4,052	78	42,008
2010	43,654	1,225	4,153	75	49,107
2011	47,590	1,381	4,458	91	53,521
2012	57,446	1,554	4,828	108	63,936
2013	57,797	1,213	5,031	45	64,087
1981 to 2007 mean	17,928	630	4,483	9	23,051
2008 to 2013 mean	45,837	1,209	4,363	75	51,485
6 yr. % change from mean	155.67%	91.85%	-2.68%	753.12%	123.35%

Table 3.2.1.2. Number of traps reported fished by state in the Gulf of Maine stock unit.

Year	Maine	New Hampshire	Massachusetts	Total
1982	2,143,000	NA	247,415	2,390,415
1983	2,340,000	NA	259,642	2,599,642
1984	2,175,000	NA	275,165	2,450,165
1985	1,766,000	NA	313,758	2,079,758
1986	1,595,000	NA	331,713	1,926,713
1987	1,909,000	NA	356,169	2,265,169
1988	2,053,000	NA	356,689	2,409,689
1989	2,001,000	NA	351,584	2,352,584
1990	2,130,000	NA	378,703	2,508,703
1991	2,015,000	NA	399,010	2,414,010
1992	2,012,000	NA	388,415	2,400,415
1993	1,806,000	NA	370,641	2,176,641
1994	2,785,000	NA	372,014	3,157,014
1995	2,408,000	NA	375,177	2,783,177
1996	2,605,000	NA	387,526	2,992,526
1997	2,532,479	NA	381,361	2,913,840
1998	2,742,571	NA	388,073	3,130,644
1999	2,925,622	NA	377,691	3,303,313
2000	2,650,718	NA	381,775	3,032,493
2001	2,840,765	NA	373,114	3,213,879
2002	2,961,698	NA	390,535	3,352,233
2003	3,067,057	NA	378,891	3,445,948
2004	3,100,875	67,895	356,121	3,524,891
2005	3,155,722	72,880	342,659	3,571,261
2006	3,154,845	73,127	339,104	3,567,076
2007	3,146,175	72,089	338,506	3,556,770
2008	3,090,129	70,840	323,037	3,484,006
2009	3,019,110	70,647	308,408	3,398,165
2010	2,948,935	71,415	297,142	3,317,492
2011	2,916,583	70,783	369,132	3,356,498
2012	2,902,867	73,516	357,887	3,334,270
2013	2,864,423	70,089	345,568	3,280,080

Table 3.2.2.1 Georges Bank landings in metric tons by state from 1981 to 2013.

Year	ME	NH	MA	RI	CT	NY	Total
1981	0	0	596	543	0	25	1,165
1982	0	0	590	710	0	1	1,301
1983	0	0	591	852	0	0	1,447
1984	0	0	749	747	0	0	1,496
1985	0	3	746	740	0	0	1,489
1986	3	0	624	616	0	0	1,243
1987	0	0	828	488	0	0	1,316
1988	0	0	931	391	0	95	1,417
1989	0	0	964	362	0	0	1,326
1990	0	0	1,026	397	0	7	1,431
1991	0	0	936	644	0	0	1,580
1992	0	0	1,131	572	0	0	1,703
1993	0	95	1,124	326	0	0	1,545
1994	0	153	1,013	180	0	0	1,346
1995	0	122	925	167	0	0	1,214
1996	0	112	864	165	1	0	1,141
1997	0	97	937	180	1	0	1,215
1998	0	82	938	175	1	0	1,196
1999	0	102	1,112	227	0	0	1,441
2000	0	117	871	192	4	0	1,184
2001	0	139	1,140	124	4	0	1,407
2002	0	139	1,315	107	2	0	1,563
2003	0	206	1,214	365	1	0	1,787
2004	0	326	1,310	333	3	8	1,979
2005	0	537	1,461	390	1	4	2,394
2006	0	502	1,369	363	1	5	2,240
2007	0	387	1,298	359	11	8	2,064
2008	0	334	1,365	256	5	3	1,962
2009	0	305	1,474	264	1	0	2,046
2010	0	429	1,595	340	5	1	2,370
2011	0	396	1,626	347	1	0	2,371
2012	0	351	1,636	344	1	0	2,331
2013	0	516	1,547	268	0	0	2,332
1981 to 2007 mean	N/A	116	985	397	1	6	1,505
2008 to 2013 mean	N/A	389	1,541	303	2	1	2,235
6 yr. % change from mean	N/A	236.37%	56.34%	-23.57%	93.14%	-86.63%	48.55%

Table 3.2.2.2. Number of traps reported fished by state in the Georges Bank stock unit.

Year	New Hampshire	Massachusetts	Rhode Island	Total
1982	NA	27,560		27,560
1983	NA	28,922		28,922
1984	NA	30,651		30,651
1985	NA	34,950		34,950
1986	NA	36,950		36,950
1987	NA	39,674		39,674
1988	NA	39,732		39,732
1989	NA	39,163		39,163
1990	NA	35,891		35,891
1991	NA	36,784		36,784
1992	NA	38,745		38,745
1993	NA	43,041		43,041
1994	NA	47,894		47,894
1995	NA	44,480		44,480
1996	NA	42,008		42,008
1997	NA	40,974		40,974
1998	NA	45,327		45,327
1999	NA	47,941		47,941
2000	NA	41,464		41,464
2001	NA	40,899	12,355	53,254
2002	NA	47,387	10,800	58,187
2003	NA	42,834	12,630	55,464
2004	NA	43,922	13,690	57,612
2005	NA	40,694	12,598	53,292
2006	NA	40,175	8,223	48,398
2007	NA	42,307	30,735	73,042
2008	NA	41,477	11,870	53,347
2009	NA	39,251	16,892	56,143
2010	NA	58,607	16,631	75,238
2011	NA	51,096	9,134	60,230
2012	NA	53,349	12,598	65,947
2013	NA	53,250	10,679	63,929

Table 3.2.3.1. Southern New England landings in metric tons by state from 1981 to 2013.

Year	MA	RI	CT	NY	NJ & South	Total
1981	432	340	366	379	324	1,842
1982	527	788	399	508	457	2,680
1983	608	1,468	750	548	414	3,788
1984	678	1,638	815	593	530	4,254
1985	579	1,592	626	563	600	3,961
1986	590	1,955	569	643	627	4,383
1987	578	1,924	713	520	722	4,457
1988	628	1,768	872	713	771	4,752
1989	674	2,263	942	1,064	997	5,940
1990	909	2,895	1,200	1,549	1,066	7,620
1991	934	2,721	1,213	1,419	799	7,086
1992	813	2,496	1,149	1,203	573	6,233
1993	868	2,499	987	1,210	445	6,008
1994	979	2,757	974	1,794	271	6,774
1995	980	2,553	1,153	3,018	301	8,004
1996	976	2,521	1,310	4,268	313	9,388
1997	1,168	2,761	1,573	4,027	406	9,935
1998	1,098	2,675	1,684	3,582	338	9,376
1999	989	3,473	1,177	2,927	447	9,013
2000	739	2,941	629	1,308	456	6,073
2001	748	1,896	600	931	291	4,465
2002	750	1,633	482	653	133	3,652
2003	465	1,244	303	429	113	2,554
2004	449	1,021	290	531	193	2,484
2005	507	1,018	323	556	198	2,601
2006	544	1,256	358	590	240	2,989
2007	386	1,053	247	403	345	2,435
2008	341	951	189	320	363	2,165
2009	403	947	186	331	388	2,255
2010	346	913	196	368	366	2,189
2011	249	811	89	156	341	1,645
2012	289	767	109	125	450	1,740
2013	316	665	58	112	359	1,509
1981 to 2007 mean	726	1,968	804	1,331	458	5,287
2008 to 2013 mean	324	842	138	235	378	1,917
6 yr. % change from mean	-55.36%	-57.21%	-82.88%	-82.31%	-17.53%	-63.74%

Table 3.2.3.2. Number of traps reported fished by state in the Southern New England stock unit.

Year	Massachusetts	Rhode Island	Connecticut	New York	Total
1981	41,395	NA		48,295	89,690
1982	44,123	NA		43,977	88,100
1983	46,303	NA		59,808	106,111
1984	49,072	NA	66,709	77,599	193,380
1985	55,954	NA	65,262	88,332	209,548
1986	59,156	NA	65,826	77,429	202,411
1987	63,518	NA	70,646	76,729	210,893
1988	63,610	NA	79,154	101,790	244,554
1989	62,700	NA	83,915	143,320	289,935
1990	53,768	NA	100,360	137,504	291,632
1991	59,922	NA	101,290	155,276	316,488
1992	58,406	NA	107,668	187,661	353,735
1993	62,615	NA	115,224	237,117	414,956
1994	71,472	NA	110,805	269,419	451,696
1995	71,269	NA	119,983	252,581	443,833
1996	71,830	NA	130,360	314,297	516,487
1997	76,717	NA	133,770	335,860	546,347
1998	83,166	NA	158,527	346,729	588,422
1999	83,394	NA	162,149	332,323	577,865
2000	68,162	NA	122,386	212,767	403,314
2001	65,225	173,133	121,501	191,853	551,712
2002	78,965	152,021	117,731	157,747	506,464
2003	63,444	133,687	85,048	101,207	383,386
2004	55,191	128,081	84,071	102,351	369,694
2005	47,779	117,610	83,946	85,817	335,152
2006	52,990	120,242	90,421	89,301	352,954
2007	49,722	130,556	81,792	92,368	354,438
2008	42,934	104,440	56,355	90,909	294,638
2009	40,237	105,414	63,824	51,173	260,648
2010	48,558	111,509	53,516	70,350	283,933
2011	58,783	78,849	39,518	49,779	226,929
2012	54,102	76,826	29,353	29,678	189,959
2013	49,319	63,089	18,435	21,127	151,970

Table 4.1.3.3.1. Gulf of Maine. Results of a sampling intensity analysis, showing NMFS Statistical Areas (Area) sampled by year and quarter, existing power of the sample, existing number of samples, and samples needed to reach a power of 0.9 and a significance level of 0.1. NaN = not enough data for the power analysis; NS = not sampled at all in the year. Needed samples categories: ++ (need more than 50% additional samples); + (more samples are needed but not more than 50%); -- (fewer samples are needed by more than 50%); - (fewer samples are needed but not more than 50% fewer).

		2008			2009			2010			2011			2012		
Area	Quarter	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples
464	1	1	NaN	++	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0
464	2	4	0.16	++	4	0.18	++	4	0.18	++	4	0.14	++	13	0.49	- -
464	3	4	0.23	++	3	0.14	++	5	0.27	++	6	0.23	++	6	0.24	- -
464	4	2	0.09	++	4	0.15	++	4	0.15	++	5	0.23	++	5	0.34	- -
465	1	NS	NS	NS	1	NaN	++	NS	NS	NS	NS	NS	NS	NS	NS	NS
465	2	NS	NS	NS	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
465	3	NS	NS	NS	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
465	4	NS	NS	NS	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
467	1	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	3	0.10	- -
467	2	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	7	0.37	- -
467	3	1	NaN	++	1	NaN	++	0	0.00	0	1	NaN	++	8	0.54	- -
467	4	0	0.00	0	0	0.00	0	1	NaN	++	0	0.00	0	5	0.30	- -
511	1	3	0.12	++	2	0.12	++	1	NaN	++	1	NaN	++	3	0.16	- -
511	2	8	0.88	+	10	1.00	-	11	0.97	-	9	0.61	++	18	0.80	- -
511	3	13	0.97	-	11	0.84	+	15	0.99	-	13	0.89	+	23	0.98	- -
511	4	7	0.67	++	7	0.92	-	4	0.31	++	13	0.86	+	15	0.91	- -
512	1	6	0.39	++	5	0.27	++	4	0.33	++	1	NaN	++	3	0.19	- -
512	2	26	0.99	-	24	1.00	- -	26	1.00	- -	25	1.00	- -	30	1.00	- -
512	3	36	1.00	- -	38	1.00	- -	36	1.00	- -	37	1.00	- -	43	1.00	- -
512	4	24	1.00	- -	23	1.00	- -	24	1.00	- -	19	0.99	-	35	1.00	- -
513	1	3	0.24	++	5	0.16	++	6	0.68	++	3	0.29	++	0	0.00	0
513	2	37	1.00	- -	34	1.00	- -	32	1.00	- -	32	1.00	- -	16	0.91	- -
513	3	47	1.00	- -	50	1.00	- -	50	1.00	- -	53	1.00	- -	25	0.71	- -
513	4	35	1.00	- -	35	1.00	- -	30	1.00	- -	35	1.00	- -	16	0.81	- -
514	1	0	0.00	0	2	0.07	++	0	0.00	0	0	0.00	0	0	0.00	0
514	2	16	0.73	++	17	0.80	+	17	0.77	+	13	0.80	+	3	0.13	- -
514	3	26	0.80	+	20	0.68	++	22	0.72	++	23	0.79	+	0	0.00	0
514	4	16	0.75	++	15	0.82	+	15	0.78	+	15	0.79	+	2	0.18	- -
515	1	3	0.26	++	4	0.28	++	2	0.12	++	NS	NS	NS	NS	NS	NS
515	2	3	0.16	++	4	0.08	++	2	0.07	++	NS	NS	NS	NS	NS	NS
515	3	2	0.07	++	1	NaN	++	1	NaN	++	NS	NS	NS	NS	NS	NS
515	4	1	NaN	++	1	NaN	++	0	0.00	0	NS	NS	NS	NS	NS	NS

Table 4.1.3.3.2. Georges Bank. Results of a sampling intensity analysis, showing NMFS Statistical Area (Area) sampled by year and quarter, existing power of the sample, existing number of samples, and samples needed to reach a power of 0.9 and a significance level of 0.1. NaN = not enough data for the power analysis; NS = not sampled at all in the year. Needed samples categories: ++ (need more than 50% additional samples); + (more samples are needed but not more than 50%); -- (fewer samples are needed by more than 50%); - (fewer samples are needed but not more than 50% fewer).

		2008			2009			2010			2011			2012		
Area	**Quarter**	**Existing Sample Size**	**Existing Power**	**Needed Samples**	**Existing Sample Size**	**Existing Power**	**Needed Samples**	**Existing Sample Size**	**Existing Power**	**Needed Samples**	**Existing Sample Size**	**Existing Power**	**Needed Samples**	**Existing Sample Size**	**Existing Power**	**Needed Samples**
521	1	1	NaN	++	1	NaN	++	1	NaN	++	0	0.00	0	2	0.09	++
521	2	7	0.27	++	7	0.45	++	7	0.49	++	6	0.50	++	9	0.64	++
521	3	10	0.24	++	11	0.30	++	7	0.26	++	7	0.27	++	18	0.37	++
521	4	7	0.22	++	4	0.18	++	5	0.27	++	4	0.19	++	5	0.26	++
522	1	2	0.07	++	1	NaN	++	2	0.11	++	2	0.13	++	2	0.17	++
522	2	2	0.10	++	4	0.14	++	3	0.15	++	1	NaN	++	0	0.00	0
522	3	16	0.27	++	11	0.28	++	7	0.44	++	0	0.00	0	0	0.00	0
522	4	2	0.08	++	1	NaN	++	3	0.15	++	0	0.00	0	2	0.13	++
525	1	4	0.13	++	2	0.09	++	2	0.10	++	0	0.00	0	2	0.09	++
525	2	4	0.13	++	10	0.19	++	6	0.17	++	6	0.17	++	3	0.09	++
525	3	9	0.11	++	4	0.12	++	6	0.20	++	6	0.20	++	6	0.23	++
525	4	4	0.17	++	4	0.19	++	3	0.16	++	5	0.25	++	10	0.34	++
526	1	3	0.17	++	5	0.24	++	4	0.19	++	5	0.17	++	2	0.09	++
526	2	4	0.69	+	5	0.45	++	5	0.64	++	6	0.85	+	4	0.24	++
526	3	5	0.41	++	5	0.56	++	4	0.35	++	4	0.60	++	0	0.00	0
526	4	5	0.32	++	4	0.29	++	4	0.38	++	4	0.37	++	3	0.37	++
561	1	1	NaN	++	4	0.20	++	NS	NS	NS	0	0.00	0	3	0.25	++
561	2	0	0.00	0	1	NaN	++	NS	NS	NS	4	0.28	++	0	0.00	0
561	3	9	0.18	++	1	NaN	++	NS	NS	NS	0	0.00	0	4	0.21	++
561	4	3	0.26	++	0	0.00	0	NS	NS	NS	0	0.00	0	1	NaN	++
562	1	4	0.15	++	3	0.12	++	1	NaN	++	NS	NS	NS	0	0.00	0
562	2	1	NaN	++	2	0.06	++	0	0.00	0	NS	NS	NS	1	NaN	++
562	3	2	0.07	++	4	0.13	++	0	0.00	0	NS	NS	NS	8	0.21	++
562	4	4	0.10	++	2	0.08	++	2	0.10	++	NS	NS	NS	4	0.16	++

Table 4.1.3.3.3. Southern New England. Results of a sampling intensity analysis, showing NMFS Statistical Area (Area) sampled by year and quarter, existing power of the sample, existing number of samples, and samples needed to reach a power of 0.9 and a significance level of 0.1. NaN = not enough data for the power analysis; NS = not sampled at all in the year. Needed samples categories: ++ (need more than 50% additional samples); + (more samples are needed but not more than 50%); -- (fewer samples are needed by more than 50%); - (fewer samples are needed but not more than 50% fewer).

		2008			2009			2010			2011			2012		
Area	Quarter	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples
533	1	NS	NS	NS	0	0.00	0	0	0.00	0	NS	NS	NS	NS	NS	NS
533	2	NS	NS	NS	1	NaN	++	0	0.00	0	NS	NS	NS	NS	NS	NS
533	3	NS	NS	NS	0	0.00	0	0	0.00	0	NS	NS	NS	NS	NS	NS
533	4	NS	NS	NS	0	0.00	0	1	NaN	++	NS	NS	NS	NS	NS	NS
537	1	3	0.43	++	4	0.32	++	4	0.53	++	3	0.51	++	1	NaN	++
537	2	6	1.00	-	10	1.00	--	9	1.00	--	8	1.00	--	7	0.91	-
537	3	11	1.00	-	15	1.00	--	9	1.00	--	5	1.00	-	4	0.46	++
537	4	9	0.94	-	8	0.99	-	7	0.90	+	4	0.75	+	2	0.19	++
538	1	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0
538	2	3	0.24	++	0	0.00	0	0	0.00	0	0	0.00	0	3	0.74	-
538	3	3	0.86	+	1	NaN	++	4	0.59	++	2	0.27	++	1	NaN	++
538	4	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0
539	1	6	0.93	-	8	0.99	-	10	1.00	--	10	1.00	--	5	0.84	+
539	2	7	0.98	-	10	0.97	-	10	1.00	--	8	1.00	--	3	0.90	-
539	3	6	0.92	-	9	1.00	-	7	0.99	-	7	1.00	-	5	0.85	+
539	4	7	0.77	+	9	0.92	-	8	0.97	-	6	0.88	+	2	0.14	++
611	1	6	0.78	+	7	1.00	--	0	0.00	0	4	0.28	++	0	0.00	0
611	2	3	0.45	++	10	0.84	+	14	1.00	--	5	0.55	++	1	NaN	++
611	3	14	1.00	-	21	1.00	--	13	0.99	-	5	0.80	+	4	0.36	++
611	4	7	0.82	+	5	0.54	++	7	0.38	++	3	0.35	++	4	0.34	++
612	1	2	0.19	++	1	NaN	++	0	0.00	0	2	0.19	++	3	0.35	++
612	2	5	0.95	-	8	1.00	--	2	0.20	++	7	0.80	+	5	0.36	++
612	3	5	0.12	++	7	0.96	-	6	0.55	++	3	0.23	++	5	0.21	++
612	4	2	0.14	++	3	0.57	++	3	0.15	++	1	NaN	++	1	NaN	++
613	1	0	0.00	0	0	0.00	0	1	NaN	++	1	NaN	++	NS	NS	NS
613	2	1	NaN	++	0	0.00	0	2	0.08	++	0	0.00	0	NS	NS	NS
613	3	1	NaN	++	7	0.33	++	10	0.74	++	6	0.28	++	NS	NS	NS
613	4	0	0.00	0	2	0.26	++	1	NaN	++	0	0.00	0	NS	NS	NS
614	1	NS	NS	NS	1	NaN	++	NS	NS	NS	NS	NS	NS	NS	NS	NS
614	2	NS	NS	NS	1	NaN	++	NS	NS	NS	NS	NS	NS	NS	NS	NS
614	3	NS	NS	NS	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
614	4	NS	NS	NS	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
615	1	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	2	0.20	++
615	2	0	0.00	0	1	NaN	++	0	0.00	0	0	0.00	0	2	0.13	++
615	3	1	NaN	++	0	0.00	0	0	0.00	0	1	NaN	++	1	NaN	++
615	4	0	0.00	0	1	NaN	++	1	NaN	++	2	0.13	++	3	0.15	++

Table 4.1.3.3.3. continued.

		2008			2009			2010			2011			2012		
Area	Quarter	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples	Existing Sample Size	Existing Power	Needed Samples
616	1	6	0.90	+	4	0.97	-	1	NaN	++	0	0.00	0	5	0.26	++
616	2	6	0.99	-	6	1.00	-	4	1.00	-	3	0.67	+	2	0.46	++
616	3	8	1.00	-	8	1.00	- -	5	1.00	-	5	0.98	-	4	0.88	+
616	4	6	0.93	-	6	0.96	-	5	0.94	-	7	0.86	+	1	NaN	++
621	1	0	0.00	0	0	0.00	0	NS	NS	NS	NS	NS	NS	0	0.00	0
621	2	0	0.00	0	0	0.00	0	NS	NS	NS	NS	NS	NS	1	NaN	++
621	3	0	0.00	0	1	NaN	++	NS	NS	NS	NS	NS	NS	0	0.00	0
621	4	2	0.10	++	2	0.09	++	NS	NS	NS	NS	NS	NS	0	0.00	0
622	1	0	0.00	0	1	NaN	++	1	NaN	++	0	0.00	0	1	NaN	++
622	2	6	0.28	++	4	0.27	++	1	NaN	++	1	NaN	++	0	0.00	0
622	3	0	0.00	0	2	0.26	++	0	0.00	0	0	0.00	0	2	0.20	++
622	4	1	NaN	++	3	0.18	++	3	0.17	++	2	0.12	++	2	0.16	++
623	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	0	0.00	0	NS	NS	NS
623	2	NS	NS	NS	NS	NS	NS	NS	NS	NS	0	0.00	0	NS	NS	NS
623	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	2	0.25	++	NS	NS	NS
623	4	NS	NS	NS	NS	NS	NS	NS	NS	NS	0	0.00	0	NS	NS	NS
624	1	NS	NS	NS	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
624	2	NS	NS	NS	1	NaN	++	NS	NS	NS	NS	NS	NS	NS	NS	NS
624	3	NS	NS	NS	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
624	4	NS	NS	NS	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS
626	1	5	0.10	++	0	0.00	0	1	NaN	++	1	NaN	++	NS	NS	NS
626	2	1	NaN	++	1	NaN	++	1	NaN	++	1	NaN	++	NS	NS	NS
626	3	0	0.00	0	0	0.00	0	0	0.00	0	0	0.00	0	NS	NS	NS
626	4	0	0.00	0	2	0.09	++	0	0.00	0	0	0.00	0	NS	NS	NS
632	1	0	0.00	0	2	0.07	++	0	0.00	0	NS	NS	NS	NS	NS	NS
632	2	1	NaN	++	0	0.00	0	1	NaN	++	NS	NS	NS	NS	NS	NS
632	3	0	0.00	0	0	0.00	0	1	NaN	++	NS	NS	NS	NS	NS	NS
632	4	0	0.00	0	0	0.00	0	0	0.00	0	NS	NS	NS	NS	NS	NS
636	1	1	NaN	++	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
636	2	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
636	3	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
636	4	0	0.00	0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.1.4.1. Minimum and maximum legal size (CL, mm) weighted by landings, used for legal selectivity.

Year	Minimum Size			Maximum Size		
	GOM	GBK	SNE	GOM	GBK	SNE
1981	81	81	81	128	None	None
1982	81	81	81	128	None	None
1983	81	81	81	128	None	None
1984	81	81	81	128	None	None
1985	81	81	81	128	None	None
1986	81	81	81	128	None	None
1987	81	81	81	128	None	None
1988	82	82	82	128	None	None
1989	83	83	83	128	None	None
1990	83	83	83	128	None	None
1991	83	83	83	128	None	None
1992	83	83	83	128	None	None
1993	83	83	83	128	None	None
1994	83	83	83	128	None	None
1995	83	83	83	128	None	None
1996	83	83	83	128	None	None
1997	83	83	83	128	None	None
1998	83	83	83	128	None	None
1999	83	83	83	128	None	None
2000	83	83	83	128	None	None
2001	83	83	83	128	None	None
2002	83	84	83	128	None	None
2003	83	85	83	128	None	None
2004	83	86	83	128	None	None
2005	83	87	83	128	None	None
2006	83	87	84	128	None	None
2007	83	86	84	128	None	None
2008	83	86	84	128	None	140
2009	83	86	84	128	None	140
2010	83	86	86	128	None	140
2011	83	86	86	128	None	140
2012	83	86	86	128	None	140
2013	83	86	86	128	None	140
2014	83	86	86	128	None	140

Table 4.1.4.3.1. Parameter estimates for the length-weight analysis on log transformed data. Note, all parameter estimates were significantly different from 0. SNE = Southern New England; GBK = Georges Bank; GOM = Gulf of Maine.

	Combined Sex		Male		Female	
	Intercept	Slope	Intercept	Slope	Intercept	Slope
SNE	-13.793545	2.936657	-14.21495489	3.029413622	-13.42273645	2.853801849
GBK	-13.701596	2.921227	-14.31577123	3.052918322	-13.33875913	2.84556492
GOM	-14.192657	3.020978	-14.46794173	3.078127279	-13.9586538	2.971572176

Table 4.1.4.3.2. Back transformed parameter estimates for the length-weight equation. Note, all parameter estimates were significantly different from 0. SNE = Southern New England; GBK = Georges Bank; GOM = Gulf of Maine.

	Combined Sex		Male		Female	
	Intercept	Slope	Intercept	Slope	Intercept	Slope
SNE	1.02221E-06	2.936657	6.70693E-07	3.029413622	1.48108E-06	2.853801849
GBK	1.12066E-06	2.921227	6.06373E-07	3.052918322	1.61083E-06	2.84556492
GOM	6.85816E-07	3.020978	5.20778E-07	3.078127279	8.6663E-07	2.971572176

Table 4.2.1.1 Sampling seasons, strata, and survey coverage (total survey area and actual area swept) for fishery-independent trawl surveys incorporated into assessment models.

Survey (yrs)	Seasons	Strata (# Divisions)	Total Survey Area (km^2)	Area swept (km^2)
NMFS (1979-present)	Spring (March-April) Fall (Sept. - Oct.)	Region (13) Depth (5)	70,990 (GOM) 70,391.6 (GB) 91,010.7 (SNE)	0.034
Maine (2000-present)	Spring (May) Fall (Oct. - Nov.)	Region (5) Depth (4)	11699.8 (GOM)	0.016
Massachusetts (1981-present)	Spring (May) Fall (Sept.)	Region (5) Depth (6)	2,718 (GOM) 2,671 (SNE)	0.013
Rhode Island (1979-present)	Spring (May) Fall (Sept.)	Region (3) Depth (11)	898 (SNE)	0.026
Connecticut (1984-present)	Spring (April-June) Fall (Sept. - Oct.)	Depth (4) Bottom Type (3)	3373.8 (SNE)	0.03
New Jersey (1988-present)	Spring (April and June) Fall (Oct.)	Region (5) Depth (3)	4640.5 (SNE)	0.02
NEAMAP (2007 - present)	Spring (April - May) Fall (Sept. - Oct.)	Depth (4)	2321.9 (SNE)	0.025

Table 4.2.1.1.1. Size-based calibration coefficients (r) and CVs for lobsters in NEFSC bottom trawl surveys (Jacobson and Miller (2012).

CL (cm)	r	CV	CL (cm)	r	CV	CL (cm)	r	CV	CL (cm)	r	CV	CL (cm)	r	CV	CL (cm)	r	CV
2.6	17.272	0.48	6.1	3.784	0.13	9.6	1.45	0.07	13.1	1.185	0.08	16.6	1.237	0.18	20.1	1.564	0.52
2.7	16.735	0.47	6.2	3.64	0.12	9.7	1.443	0.07	13.2	1.186	0.08	16.7	1.247	0.18	20.2	1.562	0.53
2.8	16.198	0.45	6.3	3.504	0.12	9.8	1.436	0.07	13.3	1.188	0.09	16.8	1.259	0.19	20.3	1.559	0.54
2.9	15.661	0.44	6.4	3.376	0.12	9.9	1.431	0.07	13.4	1.191	0.09	16.9	1.271	0.19	20.4	1.556	0.56
3	15.127	0.43	6.5	3.255	0.11	10	1.426	0.07	13.5	1.195	0.09	17	1.285	0.2	20.5	1.552	0.57
3.1	14.594	0.41	6.6	3.141	0.11	10.1	1.422	0.07	13.6	1.198	0.09	17.1	1.299	0.2	20.6	1.548	0.58
3.2	14.065	0.4	6.7	3.032	0.11	10.2	1.418	0.07	13.7	1.202	0.09	17.2	1.314	0.21	20.7	1.544	0.6
3.3	13.539	0.38	6.8	2.928	0.11	10.3	1.413	0.07	13.8	1.206	0.09	17.3	1.329	0.22	20.8	1.54	0.61
3.4	13.018	0.37	6.9	2.828	0.1	10.4	1.409	0.07	13.9	1.21	0.1	17.4	1.345	0.23	20.9	1.536	0.62
3.5	12.502	0.36	7	2.733	0.1	10.5	1.403	0.07	14	1.213	0.1	17.5	1.36	0.23			
3.6	11.994	0.34	7.1	2.641	0.1	10.6	1.397	0.07	14.1	1.216	0.1	17.6	1.376	0.24			
3.7	11.493	0.33	7.2	2.553	0.1	10.7	1.39	0.07	14.2	1.218	0.1	17.7	1.391	0.25			
3.8	11.002	0.32	7.3	2.468	0.1	10.8	1.383	0.07	14.3	1.22	0.1	17.8	1.407	0.26			
3.9	10.521	0.3	7.4	2.386	0.09	10.9	1.374	0.07	14.4	1.221	0.11	17.9	1.422	0.27			
4	10.051	0.29	7.5	2.308	0.09	11	1.364	0.07	14.5	1.222	0.11	18	1.436	0.28			
4.1	9.594	0.28	7.6	2.233	0.09	11.1	1.354	0.07	14.6	1.221	0.11	18.1	1.45	0.28			
4.2	9.151	0.27	7.7	2.16	0.09	11.2	1.343	0.07	14.7	1.22	0.11	18.2	1.463	0.29			
4.3	8.722	0.26	7.8	2.091	0.09	11.3	1.331	0.07	14.8	1.219	0.12	18.3	1.476	0.3			
4.4	8.309	0.25	7.9	2.026	0.09	11.4	1.319	0.07	14.9	1.217	0.12	18.4	1.487	0.31			
4.5	7.911	0.24	8	1.963	0.09	11.5	1.306	0.07	15	1.214	0.12	18.5	1.499	0.32			
4.6	7.53	0.23	8.1	1.905	0.08	11.6	1.293	0.07	15.1	1.212	0.12	18.6	1.509	0.34			
4.7	7.167	0.22	8.2	1.849	0.08	11.7	1.28	0.07	15.2	1.209	0.13	18.7	1.519	0.35			
4.8	6.821	0.21	8.3	1.798	0.08	11.8	1.267	0.07	15.3	1.206	0.13	18.8	1.528	0.36			
4.9	6.492	0.2	8.4	1.75	0.08	11.9	1.255	0.07	15.4	1.203	0.13	18.9	1.536	0.37			
5	6.181	0.19	8.5	1.706	0.08	12	1.243	0.07	15.5	1.201	0.13	19	1.543	0.38			
5.1	5.887	0.18	8.6	1.666	0.08	12.1	1.232	0.07	15.6	1.199	0.14	19.1	1.549	0.39			
5.2	5.611	0.17	8.7	1.629	0.08	12.2	1.222	0.07	15.7	1.198	0.14	19.2	1.555	0.4			
5.3	5.351	0.17	8.8	1.597	0.08	12.3	1.213	0.08	15.8	1.198	0.14	19.3	1.559	0.42			
5.4	5.107	0.16	8.9	1.568	0.08	12.4	1.205	0.08	15.9	1.199	0.15	19.4	1.563	0.43			
5.5	4.878	0.16	9	1.542	0.07	12.5	1.199	0.08	16	1.2	0.15	19.5	1.565	0.44			
5.6	4.664	0.15	9.1	1.52	0.07	12.6	1.193	0.08	16.1	1.203	0.15	19.6	1.567	0.45			
5.7	4.464	0.14	9.2	1.501	0.07	12.7	1.189	0.08	16.2	1.207	0.16	19.7	1.568	0.47			
5.8	4.276	0.14	9.3	1.485	0.07	12.8	1.186	0.08	16.3	1.213	0.16	19.8	1.568	0.48			
5.9	4.101	0.13	9.4	1.471	0.07	12.9	1.185	0.08	16.4	1.219	0.17	19.9	1.567	0.49			
6	3.938	0.13	9.5	1.46	0.07	13	1.184	0.08	16.5	1.227	0.17	20	1.566	0.5			

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Table 4.2.1.2.1. Gulf of Maine. Coefficients of variation (CV) for the Maine-New Hampshire, Massachusetts, and NMFS NEFSC bottom trawl surveys by season and lobster sex.

	Spring Trawl Survey-Females			Spring Trawl Survey-Males			Fall Trawl Survey-Females			Fall Trawl Survey-Males		
Year	ME/NH CV	MA CV	NMFS CV	ME/NH CV	MA CV	NMFS CV	ME/NH CV	MA CV	NMFS CV	ME/NH CV	MA CV	NMFS CV
1978	*	0.291	*	*	0.245	*	*	0.368	*	*	0.353	*
1979	*	0.546	0.398	*	0.463	0.430	*	0.444	0.324	*	0.511	0.282
1980	*	0.243	0.290	*	0.381	0.253	*	0.129	0.290	*	0.113	0.326
1981	*	0.544	0.344	*	0.564	0.523	*	0.365	0.298	*	0.338	0.398
1982	*	0.739	0.287	*	0.721	0.245	*	0.332	0.491	*	0.341	0.455
1983	*	0.332	0.207	*	0.205	0.259	*	0.399	0.245	*	0.340	0.306
1984	*	0.234	0.539	*	0.205	0.338	*	0.427	0.250	*	0.453	0.273
1985	*	0.321	0.656	*	0.311	0.297	*	0.584	0.205	*	0.515	0.183
1986	*	0.285	0.270	*	0.210	0.295	*	0.285	0.125	*	0.230	0.086
1987	*	0.329	0.267	*	0.342	0.353	*	0.345	0.320	*	0.396	0.474
1988	*	0.283	0.200	*	0.300	0.187	*	0.075	0.407	*	0.090	0.355
1989	*	0.326	0.383	*	0.346	0.615	*	0.043	0.251	*	0.055	0.294
1990	*	0.355	0.220	*	0.353	0.312	*	0.506	0.264	*	0.467	0.284
1991	*	0.312	0.302	*	0.301	0.371	*	0.462	0.438	*	0.425	0.461
1992	*	0.269	0.224	*	0.235	0.297	*	0.234	0.305	*	0.205	0.308
1993	*	0.266	0.321	*	0.291	0.348	*	0.269	0.272	*	0.287	0.239
1994	*	0.332	0.189	*	0.279	0.337	*	0.357	0.252	*	0.315	0.292
1995	*	0.340	0.205	*	0.230	0.236	*	0.441	0.362	*	0.386	0.528
1996	*	0.238	0.226	*	0.210	0.191	*	0.344	0.234	*	0.293	0.219
1997	*	0.164	0.167	*	0.169	0.251	*	0.152	0.165	*	0.152	0.204
1998	*	0.501	0.164	*	0.331	0.243	*	0.667	0.197	*	0.637	0.171
1999	*	0.243	0.194	*	0.248	0.238	*	0.312	0.156	*	0.308	0.229
2000	*	0.181	0.257	*	0.181	0.357	0.378	0.375	0.195	0.380	0.283	0.252
2001	0.313	0.217	0.289	0.354	0.158	0.252	0.275	0.354	0.271	0.288	0.314	0.284
2002	0.336	0.279	0.166	0.354	0.245	0.215	0.217	0.326	0.206	0.230	0.254	0.228
2003	0.315	0.231	0.279	0.312	0.200	0.247	0.155	0.281	0.352	0.143	0.188	0.444
2004	0.274	0.253	0.132	0.232	0.219	0.192	0.310	0.632	0.493	0.353	0.403	0.555
2005	0.367	0.219	0.144	0.358	0.153	0.194	0.329	0.425	0.172	0.333	0.388	0.228
2006	0.407	0.217	0.166	0.443	0.200	0.216	0.324	0.409	0.186	0.304	0.397	0.277
2007	0.272	0.256	0.149	0.262	0.232	0.185	0.283	0.398	0.332	0.281	0.322	0.365
2008	0.517	0.171	0.202	0.503	0.140	0.234	0.260	0.401	0.148	0.308	0.412	0.198
2009	0.371	0.215	0.133	0.411	0.147	0.252	0.306	0.307	0.157	0.251	0.227	0.274
2010	0.231	0.184	0.119	0.229	0.148	0.187	0.219	0.319	0.165	0.271	0.287	0.204
2011	0.281	0.179	0.123	0.245	0.200	0.162	0.227	0.293	0.141	0.230	0.249	0.210
2012	0.244	0.158	0.106	0.241	0.113	0.111	0.195	0.225	0.130	0.208	0.188	0.147
2013	0.245	0.145	0.201	0.238	0.120	0.186	0.197	0.176	0.214	0.188	0.171	0.133

Table 4.2.1.2.2. Georges Bank. Coefficients of variation (CV) for NMFS NEFSC bottom trawl survey by season and lobster sex.

Year	Spring Trawl Survey-Females	Spring Trawl Survey-Males	Fall Trawl Survey-Females	Fall Trawl Survey-Males
1979	0.447	0.364	0.224	0.181
1980	0.410	0.346	0.207	0.217
1981	0.327	0.296	0.167	0.257
1982	0.393	0.399	0.199	0.201
1983	0.425	0.474	0.154	0.198
1984	0.485	0.619	0.213	0.190
1985	0.364	0.281	0.282	0.250
1986	0.322	0.485	0.317	0.291
1987	0.465	0.495	0.304	0.294
1988	0.546	0.717	0.256	0.265
1989	0.577	0.681	0.317	0.207
1990	0.405	0.615	0.210	0.219
1991	0.470	0.543	0.206	0.192
1992	0.365	0.324	0.243	0.258
1993	0.384	0.407	0.230	0.294
1994	0.531	0.497	0.185	0.292
1995	0.561	0.591	0.227	0.387
1996	0.476	0.575	0.221	0.357
1997	0.409	0.735	0.216	0.318
1998	0.409	0.518	0.227	0.272
1999	0.559	0.417	0.204	0.261
2000	0.511	0.827	0.208	0.310
2001	0.397	0.376	0.208	0.499
2002	0.283	0.359	0.160	0.287
2003	0.482	0.465	0.228	0.375
2004	0.348	0.441	0.289	0.251
2005	0.460	0.382	0.178	0.299
2006	0.278	0.287	0.178	0.291
2007	0.260	0.378	0.173	0.294
2008	0.722	0.591	0.391	0.269
2009	0.458	0.259	0.309	0.319
2010	0.209	0.288	0.157	0.225
2011	0.294	0.439	0.220	0.199
2012	0.333	0.290	0.167	0.196
2013	0.304	0.293	0.173	0.204

Table 4.2.1.2.3. Southern New England. Coefficients of variation (CV) for the Massachusetts, Rhode Island, Connecticut, New Jersey, Northeast Area Monitoring Assessment Program (NEAMAP), and NMFS NEFSC bottom trawl surveys by season and lobster sex. *The NJ Ocean Trawl Survey incorporates a random stratified design. CV is therefore calculated as SE/arithmetic mean since all the survey strata have a standard error.

	Spring Trawl Survey-Females						Spring Trawl Survey-Males						Fall Trawl Survey-Females						Fall Trawl Survey-Males					
Year	MA-CV	RI CV	CT CV	NJ CV *	NEAMAP-CV	NMFS CV	MA-CV	RI CV	CT CV	NJ CV	NEAMAP CV	NMFS CV	MA-CV	RI CV	CT CV	NJ CV	NEAMAP-CV	NMFS CV	MA-CV	RI CV	CT CV	NJ CV	NEAMAP CV	NMFS CV
1978	0.457	*	*	*	*	*	0.376	*		*	*	*	0.522	*	*	*	*	*	0.709	*	*	*	*	*
1979	0.694	*	*	*	*	0.408	0.463	*		*	*	0.497	1.000	*	*	*	*	0.159	1.000	*	*	*	*	0.217
1980	0.539	*	*	*	*	0.278	0.543	*		*	*	0.212	0.750	*	*	*	*	0.243	0.708	*	*	*	*	0.357
1981	0.479	0.342	*	*	*	0.355	0.396	0.325		*	*	0.559	0.491	0.425	*	*	*	0.505	0.581	0.444	*	*	*	0.615
1982	0.386	0.335	*	*	*	0.274	0.439	0.273		*	*	0.390	0.550	0.316	*	*	*	0.339	0.504	0.285	*	*	*	0.276
1983	0.472	0.332	*	*	*	0.406	0.608	0.233		*	*	0.638	1.000	0.373	*	*	*	0.327	0.516	0.305	*	*	*	0.326
1984	0.424	0.400	0.289	*	*	0.331	0.393	0.399	0.318	*	*	0.472	1.000	0.386	0.289	*	*	0.427	0.430	0.418	0.309	*	*	0.507
1985	0.448	0.371	0.295	*	*	0.866	0.363	0.472	0.330	*	*	0.690	1.000	0.308	0.247	*	*	0.433	0.494	0.311	0.221	*	*	0.407
1986	0.380	0.287	0.180	*	*	0.388	0.488	0.306	0.161	*	*	0.372	0.319	0.452	0.191	*	*	0.457	0.521	0.546	0.189	*	*	0.597
1987	0.525	0.423	0.202	*	*	1.117	0.560	0.496	0.211	*	*	1.069	0.479	0.418	0.222	*	*	0.364	0.598	0.349	0.203	*	*	0.189
1988	0.573	0.323	0.184	*	*	0.434	0.410	0.276	0.198	*	*	0.401	0.551	0.493	0.321	0.371	*	0.295	0.563	0.539	0.322	0.448	*	0.266
1989	0.578	0.455	0.255	0.652	*	0.427	0.878	0.551	0.247	0.720	*	0.543	0.592	0.369	0.283	0.401	*	0.348	0.663	0.344	0.254	0.282	*	0.414
1990	0.563	0.379	0.260	0.821	*	0.505	0.601	0.405	0.190	0.673	*	0.464	0.408	0.384	0.217	0.000	*	0.319	0.393	0.370	0.179	0.000	*	0.448
1991	0.400	0.272	0.165	0.626	*	0.511	0.453	0.248	0.190	0.311	*	0.481	0.742	0.364	0.207	0.569	*	0.259	0.710	0.274	0.202	0.564	*	0.251
1992	0.412	0.403	0.208	0.464	*	0.393	0.313	0.336	0.239	0.630	*	0.394	0.588	0.337	0.268	0.397	*	0.339	0.495	0.307	0.245	0.323	*	0.286
1993	0.459	0.499	0.211	0.604	*	0.504	0.273	0.479	0.197	0.668	*	0.469	0.445	0.808	0.212	0.489	*	0.333	0.442	0.790	0.185	0.750	*	0.445
1994	0.348	0.348	0.228	0.655	*	0.632	0.356	0.275	0.218	0.646	*	0.476	0.683	0.406	0.183	0.068	*	0.366	0.695	0.380	0.177	0.099	*	0.254
1995	0.672	0.298	0.274	0.098	*	0.631	0.543	0.276	0.222	0.693	*	0.729	0.506	0.390	0.235	0.462	*	0.256	0.707	0.240	0.256	0.000	*	0.271
1996	0.505	0.268	0.247	0.483	*	0.667	0.536	0.262	0.215	0.308	*	0.611	0.501	0.423	0.239	0.612	*	0.501	0.546	0.305	0.195	0.588	*	0.405
1997	0.524	0.425	0.205	0.319	*	0.982	0.451	0.394	0.198	0.459	*	0.758	0.461	0.399	0.217	0.604	*	0.395	0.494	0.317	0.194	0.536	*	0.367
1998	0.648	0.392	0.212	0.555	*	0.637	0.565	0.309	0.191	0.208	*	0.551	0.541	0.462	0.212	0.453	*	0.235	0.616	0.377	0.166	0.637	*	0.285
1999	0.560	0.306	0.197	0.687	*	0.824	0.758	0.205	0.174	0.709	*	0.720	0.671	0.443	0.224	0.927	*	0.244	0.422	0.467	0.190	0.821	*	0.223
2000	0.441	0.291	0.238	0.584	*	0.549	0.571	0.257	0.207	0.308	*	0.596	0.530	0.682	0.199	0.817	*	0.465	0.696	0.487	0.189	0.812	*	0.278
2001	0.511	0.284	0.180	0.765	*	0.465	0.431	0.280	0.147	0.696	*	0.346	0.589	0.390	0.172	1.000	*	0.415	0.553	0.332	0.194	0.551	*	0.398
2002	0.393	0.318	0.209	0.642	*	0.510	0.390	0.343	0.171	0.917	*	0.443	0.000	0.587	0.211	0.577	*	0.261	1.000	0.351	0.203	0.572	*	0.308
2003	0.708	0.264	0.221	1.000	*	0.782	0.558	0.295	0.213	1.000	*	0.964	0.000	0.449	0.249	1.000	*	0.319	1.000	0.389	0.185	0.873	*	0.276
2004	0.502	0.374	0.229	0.645	*	0.432	0.423	0.300	0.204	1.000	*	0.451	1.000	0.336	0.211	0.555	*	0.338	0.000	0.289	0.171	0.430	*	0.522
2005	0.427	0.304	0.221	0.818	*	0.548	0.341	0.338	0.212	0.655	*	0.620	0.578	0.703	0.237	0.496	*	0.349	1.000	0.523	0.167	0.354	*	0.283
2006	0.620	0.403	0.343	0.721	*	0.477	0.316	0.284	0.246	0.885	*	0.547	0.000	0.536	0.379	0.000	*	0.418	1.000	0.270	0.328	0.788	*	0.251
2007	0.709	0.378	0.250	0.579	*	0.545	0.337	0.291	0.213	0.564	*	0.429	0.598	0.357	0.256	0.764	1.122	0.344	1.000	0.359	0.225	1.000	1.166	0.428
2008	0.405	0.320	0.152	0.904	0.834	0.599	0.442	0.294	0.140	1.000	0.918	0.373	0.000	0.378	0.283	0.594	1.226	0.309	0.810	0.351	0.256	1.000	1.000	0.306
2009	0.493	0.365	0.194	0.876	0.678	0.303	0.262	0.301	0.178	0.745	0.673	0.367	1.000	0.406	0.206	0.053	1.025	0.219	1.000	0.324	0.211	0.594	1.017	0.186
2010	0.460	0.446	0.295	0.734	1.296	0.393	0.400	0.322	0.222	1.000	1.296	0.441	0.571	0.418	*	0.000	1.499	0.144	0.848	0.423	*	0.000	1.315	0.179
2011	0.621	0.348	0.367	1.000	0.720	0.439	0.646	0.343	0.295	1.000	0.735	0.579	0.708	0.511	0.404	0.724	1.094	0.217	1.000	0.480	0.241	0.000	1.135	0.203
2012	0.731	0.521	0.218	0.932	0.733	0.346	0.397	0.409	0.204	0.684	0.751	0.417	0.563	0.440	0.413	0.662	1.577	0.318	0.322	0.499	0.355	0.665	1.744	0.279
2013	0.323	0.465	0.270	0.931	0.539	0.570	0.362	0.600	0.261	0.705	0.600	0.649	0.707	0.698	0.363	0.658	1.367	0.284	1.000	0.699	0.452	0.776	1.401	0.235

Table 5.2.1.1. GOM Mortality Indicators categorized based on quartile rankings (see Section 5.1) as positive (white), neutral (grey), or negative (black).

EXPLOITATION RATE (landings / survey ref. pop'n)						
Landings (lbs) by area / Reference pop'n (survey weights (lbs) > 77						
Survey	*NESFC*		*ME/NH*		*MA 514*	
	fall	*spring*	*fall*	*spring*	*fall*	*spring*
1981						
1982	3.40	2.15				
1983	1.39	2.12				
1984	1.64	1.14				
1985	0.65	0.26				
1986	0.60	0.99				
1987	1.53	0.94				
1988	1.37	1.27				
1989	0.85	2.94				
1990	1.05	1.47			0.40	0.80
1991	1.04	1.12			0.62	1.41
1992	1.21	1.34			0.71	0.78
1993	1.06	1.64			1.71	0.74
1994	0.74	1.23			0.47	0.77
1995	0.69	1.05			0.59	1.18
1996	0.42	0.78			0.54	1.30
1997	0.82	0.71			0.76	0.95
1998	0.87	0.79			1.10	0.90
1999	0.49	1.29			0.76	0.96
2000	0.90	0.53	0.89		0.69	0.83
2001	1.05	0.66	1.15	1.44	1.81	0.78
2002	0.50	0.61	1.20	0.80	1.06	1.01
2003	0.93	0.45	0.87	1.18	2.83	1.48
2004	0.79	0.55	1.51	2.11	2.69	0.81
2005	1.51	0.68	0.86	0.85	1.81	0.46
2006	1.15	0.64	1.18	0.87	0.91	0.51
2007	1.65	0.68	1.04	0.85	1.65	1.90
2008	0.91	0.61	0.73	0.93	0.63	0.81
2009	0.69	0.70	0.71	0.72	0.58	0.89
2010	0.54	0.68	0.81	0.97	0.41	1.41
2011	0.44	0.67	0.74	0.58	0.35	0.79
2012	0.63	0.57	1.19	0.71	0.47	1.70
2013	0.49	0.72	1.12	0.78	0.43	0.83
2008 - 2013 ave	**0.62**	**0.66**	**0.88**	**0.78**	**0.48**	**1.07**

25th	0.70	0.73	0.89	0.99	0.60	0.78
median	0.92	1.09	1.02	1.18	0.73	0.92
75th	1.17	1.33	1.16	1.31	1.09	1.14

Table 5.2.1.2. GOM Abundance Indicators A through E.

Table 5.2.1.2. A.

SPAWNING STOCK ABUNDANCE						
Mean weight (g) per tow of mature females						
Survey	NESFC		ME/NH		MA 514	
	fall	spring	fall	spring	fall	spring
1981	127.57	303.66			342.80	251.36
1982	20.19	78.56			404.26	90.43
1983	118.43	176.40			537.29	32.40
1984	159.77	347.71			336.33	78.90
1985	311.91	2189.79			563.45	32.32
1986	155.64	375.38			135.10	50.24
1987	29.47	356.77			146.15	82.80
1988	106.70	173.52			94.55	42.74
1989	205.15	169.48			123.19	114.57
1990	116.49	368.43			538.08	100.27
1991	131.02	301.70			142.51	101.77
1992	115.27	304.54			262.54	110.74
1993	167.68	337.77			53.48	117.58
1994	233.02	521.60			376.55	132.17
1995	284.29	252.38			222.57	91.04
1996	422.24	601.51			262.89	72.61
1997	354.21	757.88			87.30	49.64
1998	216.98	832.32			113.80	81.44
1999	931.76	572.69			178.35	194.17
2000	318.65	875.14	3425.58		287.35	133.73
2001	312.96	1058.84	1858.63	462.60	105.26	151.41
2002	1247.40	1450.71	3707.47	967.67	163.87	105.74
2003	675.87	1688.03	3988.26	847.68	101.81	45.15
2004	411.40	1988.81	3497.55	682.69	86.24	189.23
2005	288.34	1163.74	4062.27	1505.13	167.88	358.32
2006	457.21	1298.00	2909.52	885.80	118.39	290.44
2007	291.48	1094.86	3010.80	735.09	138.01	91.86
2008	497.90	1357.83	3423.42	712.51	354.40	222.36
2009	1111.88	1332.23	5525.54	1138.18	396.60	135.71
2010	1796.57	1720.01	3879.74	1322.90	1176.34	157.93
2011	1334.21	1387.80	4446.97	868.71	782.58	151.85
2012	1964.23	2372.91	2964.59	1190.50	524.55	68.82
2013	2010.87	1672.97	4144.70	671.93	761.16	187.97
2008 - 2013 ave	1452.61	1640.62	4064.16	984.12	665.94	154.11
25th	121.58	302.41	3033.84	655.14	116.15	55.84
median	211.06	371.91	3566.52	847.68	171.11	90.73
75th	317.23	813.71	3777.66	907.67	324.09	113.62

Table 5.2.1.2. B.

FULL RECRUIT ABUNDANCE (SURVEY)						
Abundance of lobsters > 82 mm CL (sexes combined)						
Survey	NEFSC		ME/NH		MA 514	
	fall	spring	fall	spring	fall	spring
1981	0.24	0.36			1.91	1.83
1982	0.05	0.21			2.80	0.57
1983	0.21	0.20			3.08	0.51
1984	0.29	0.34			4.09	0.49
1985	0.55	1.81			3.94	0.50
1986	0.45	0.55			1.71	0.54
1987	0.15	0.44			0.53	0.56
1988	0.14	0.27			1.51	0.56
1989	0.38	0.28			2.27	0.79
1990	0.25	0.44			4.92	0.97
1991	0.35	0.46			3.18	0.69
1992	0.22	0.36			2.35	0.87
1993	0.40	0.47			0.63	1.00
1994	0.50	0.70			3.15	0.76
1995	0.98	0.47			2.50	0.58
1996	0.89	0.99			2.50	0.33
1997	0.70	1.02			1.69	0.62
1998	0.45	0.96			0.88	0.49
1999	1.55	0.51			1.93	0.72
2000	0.61	1.35	14.22		2.20	0.97
2001	0.62	1.50	9.83	2.25	0.72	0.53
2002	1.89	1.81	12.57	3.40	1.02	0.43
2003	1.14	2.38	16.65	3.08	0.42	0.22
2004	1.18	2.55	16.18	3.14	0.33	0.78
2005	0.62	1.64	21.09	6.53	0.56	0.95
2006	0.83	1.67	14.85	5.33	1.03	0.68
2007	0.51	1.50	14.13	4.19	0.48	0.32
2008	0.90	1.94	20.72	3.06	1.55	0.67
2009	1.82	1.66	30.48	6.32	1.70	0.54
2010	3.06	2.61	21.42	6.29	2.30	0.40
2011	3.15	2.14	23.83	5.14	3.80	0.55
2012	3.35	3.38	16.51	5.94	3.18	0.31
2013	3.29	2.43	21.45	4.50	3.74	0.87
2008 - 2013 ave	2.60	2.36	22.40	5.21	2.71	0.55
25th	0.26	0.38	11.88	2.67	1.14	0.50
median	0.45	0.49	13.39	3.08	2.24	0.56
75th	0.68	1.01	14.83	3.24	3.01	0.75

Table 5.2.1.2. C.

RECRUIT ABUNDANCE (SURVEY)						
Abundance of lobsters 71 - 80 mm CL (sexes combined)						
Survey	NEFSC		ME/NH		MA 514	
	fall	spring	fall	spring	fall	spring
1981	0.03	0.06			4.84	6.38
1982	0.16	0.13			3.85	2.74
1983	0.37	0.13			9.76	1.76
1984	0.12	0.08			6.13	2.15
1985	0.61	0.10			9.60	4.48
1986	0.47	0.09			3.80	3.01
1987	0.27	0.22			1.16	2.47
1988	0.48	0.23			4.12	2.52
1989	0.56	0.00			7.51	4.48
1990	0.88	0.19			15.40	6.11
1991	0.70	0.27			7.55	2.73
1992	0.53	0.24			8.95	4.31
1993	0.44	0.10			3.19	5.12
1994	1.06	0.09			13.80	7.59
1995	0.73	0.74			12.10	4.54
1996	1.96	0.32			12.10	3.09
1997	0.82	0.88			6.41	4.57
1998	0.91	0.70			7.47	4.50
1999	1.26	0.57			8.73	4.26
2000	1.18	1.64	23.82		8.86	4.24
2001	0.60	0.55	17.53	9.16	1.58	4.30
2002	0.67	0.70	22.12	22.63	5.00	3.43
2003	0.19	0.60	23.78	13.71	0.66	1.96
2004	1.01	0.39	15.96	9.69	1.30	2.46
2005	0.35	0.27	30.88	23.85	2.11	4.35
2006	0.56	1.09	23.27	23.15	5.30	6.09
2007	0.32	0.70	21.62	20.24	1.61	0.75
2008	0.96	0.45	40.45	22.90	6.12	2.54
2009	1.06	0.93	41.84	31.77	8.88	3.18
2010	1.36	0.68	46.24	22.40	9.39	2.22
2011	2.49	1.85	58.53	47.39	15.00	5.24
2012	1.49	2.20	47.28	44.81	11.30	3.03
2013	2.99	1.90	48.24	39.71	12.20	4.83
2008 - 2013 ave	1.73	1.34	47.10	34.83	10.48	3.51
25th	0.45	0.11	20.97	11.43	3.92	2.73
median	0.60	0.24	22.95	13.71	7.49	4.25
75th	0.87	0.59	23.79	18.17	9.44	4.50

Table 5.2.1.2. D.

YOUNG-OF-YEAR INDICES					
	YOY	YOY	YOY	YOY	YOY
Survey	ME 511	ME 512	ME 513 East	ME 513 West	MA 514
1981					
1982					
1983					
1984					
1985					
1986					
1987					
1988					
1989			1.64		
1990			0.77		
1991			1.54		
1992			1.30		
1993			0.45		
1994			1.61		
1995		0.02	0.66		0.56
1996		0.05	0.47		0.00
1997		0.05	0.46		0.17
1998		0.00	0.14		0.02
1999		0.04	0.65		0.36
2000		0.10	0.13	0.17	0.19
2001		0.43	2.08	1.17	0.38
2002	0.13	0.29	1.38	0.85	0.89
2003	0.22	0.27	1.75	1.22	0.68
2004	0.18	0.36	1.75	0.67	1.20
2005	1.59	1.36	1.77	0.82	0.82
2006	0.58	1.13	0.84	0.82	0.32
2007	0.84	1.34	2.01	1.27	1.22
2008	0.42	0.83	1.08	0.97	0.24
2009	0.69	0.48	1.25	0.45	0.13
2010	0.28	0.72	0.80	0.47	0.45
2011	0.41	1.10	2.33	0.67	0.63
2012	0.53	0.73	1.06	0.22	0.21
2013	0.10	0.20	0.48	0.12	0.09
2008 - 2013 ave	0.40	0.68	1.17	0.48	0.29
25th	0.15	0.04	0.47	0.68	0.17
median	0.17	0.05	0.77	1.01	0.36
75th	0.19	0.27	1.57	1.18	0.56

Table 5.2.1.2. E.

SURVEY LOBSTER ENCOUNTER RATE						
Proportion of postive tows						
Survey	*NEFSC*		*ME/NH*		*MA 514*	
	fall	*spring*	*fall*	*spring*	*fall*	*spring*
1981					0.73	0.86
1982	0.18	0.36			0.70	0.50
1983	0.33	0.26			0.76	0.76
1984	0.36	0.28			0.76	0.76
1985	0.49	0.38			0.67	0.71
1986	0.47	0.33			0.83	0.68
1987	0.24	0.43			0.54	0.85
1988	0.30	0.31			0.58	0.76
1989	0.36	0.19			0.95	0.78
1990	0.32	0.42			0.95	0.86
1991	0.32	0.42			0.94	0.87
1992	0.25	0.40			0.77	0.93
1993	0.39	0.41			0.82	0.97
1994	0.40	0.45			0.93	1.00
1995	0.36	0.41			0.93	0.93
1996	0.54	0.54			0.95	0.91
1997	0.35	0.64			0.86	0.93
1998	0.40	0.52			0.69	0.76
1999	0.43	0.51			0.91	0.73
2000	0.42	0.61	0.94		0.98	0.93
2001	0.40	0.57	0.86	0.88	0.72	0.93
2002	0.53	0.75	0.95	0.94	0.73	0.91
2003	0.44	0.69	0.85	0.92	0.55	0.82
2004	0.31	0.87	0.86	0.89	0.56	0.84
2005	0.36	0.77	0.91	0.95	0.67	0.95
2006	0.60	0.72	0.93	0.93	0.88	0.91
2007	0.43	0.72	0.85	0.97	0.54	0.51
2008	0.49	0.84	0.86	0.92	0.75	0.83
2009	0.63	0.82	0.92	0.98	0.87	0.89
2010	0.75	0.85	0.93	0.98	0.98	0.87
2011	0.74	0.83	0.96	0.99	0.85	0.89
2012	0.78	0.86	0.98	0.98	0.95	0.91
2013	0.73	0.87	0.93	1.00	0.95	0.96
2008 - 2013 ave	**0.69**	**0.85**	**0.93**	**0.98**	**0.89**	**0.89**

25th	0.32	0.37	0.86	0.90	0.70	0.76
median	0.37	0.42	0.90	0.92	0.79	0.85
75th	0.42	0.53	0.94	0.93	0.93	0.93

Table 5.2.1.3. GOM Fishery Performance Indicators

	EFFORT	TOTAL GOM LANDINGS	PARTIAL LANDINGS	GROSS CPUE	SET OVER DAYS		PRICE PER POUND		REVENUE		REVENUE PER TRAP	
Description	# Traps	Pounds (all sources)	Pounds from jurisdictions with effort data	Landings / Traps	Average Soak Time of Traps		Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI
Jurisdiction	*ME & MA*	*All*	*ME & MA*	*ME & MA*	*ME*	*MA*			*All*	*All*	*ME & MA*	*ME & MA*
1981		32,578,614	31,785,206		3.0		$2.19	$3.01	$71,377,063	$97,951,448		
1982	2,390,415	32,339,635	31,532,227	13.2	3.3		$2.31	$2.69	$74,644,962	$86,926,240	$30	$35
1983	2,599,642	33,221,681	31,911,107	12.3	3.4		$2.42	$2.55	$80,408,962	$84,722,110	$30	$31
1984	2,450,165	30,417,950	28,846,643	11.8	3.5		$2.69	$2.39	$81,835,621	$72,547,392	$32	$28
1985	2,079,758	32,094,641	30,906,547	14.9	3.7		$2.49	$2.35	$79,903,369	$75,277,238	$37	$35
1986	1,926,713	30,459,613	29,518,503	15.3	4.0		$2.62	$2.15	$79,762,626	$65,550,757	$40	$33
1987	2,265,169	30,759,273	29,503,090	13.0	3.6		$3.09	$1.92	$95,193,400	$59,055,970	$40	$25
1988	2,409,089	32,399,147	31,280,235	13.0	3.8		$2.99	$1.81	$96,726,018	$58,565,032	$39	$23
1989	2,352,584	36,834,226	35,403,664	15.0	4.1		$2.80	$1.88	$103,156,883	$69,284,342	$42	$28
1990	2,508,703	42,427,201	40,768,834	16.3	4.0	2.9	$2.48	$1.83	$105,251,398	$77,473,352	$40	$30
1991	2,414,010	44,567,828	42,737,613	17.7	3.8	2.8	$2.59	$1.80	$115,438,249	$80,130,168	$46	$32
1992	2,400,416	39,106,504	37,577,196	15.7	4.3	2.8	$2.90	$1.72	$113,604,009	$67,338,256	$45	$27
1993	2,176,641	41,452,052	39,966,109	18.4	4.5	3.0	$2.77	$1.72	$114,617,859	$71,194,668	$51	$32
1994	3,157,014	52,150,181	50,835,959	16.1	3.8	3.2	$2.96	$1.67	$154,466,477	$86,849,649	$48	$27
1995	2,783,177	50,622,884	49,057,796	17.6	3.4	3.2	$3.06	$1.57	$155,132,041	$79,666,327	$54	$28
1996	2,992,526	48,771,586	47,386,030	15.8	4.5	3.5	$3.39	$1.62	$165,130,906	$79,019,862	$54	$26
1997	2,913,040	58,695,042	57,495,064	19.7	4.6	3.6	$3.29	$1.51	$193,036,317	$88,583,590	$65	$30
1998	3,130,044	56,810,399	55,796,661	17.8	4.5	3.7	$3.19	$1.47	$180,944,396	$83,417,583	$57	$20
1999	3,303,313	65,929,041	64,772,528	19.6	4.8	3.5	$3.70	$1.41	$243,852,201	$92,859,919	$72	$28
2000	3,032,493	70,101,064	68,834,176	22.6	4.8	3.6	$3.61	$1.38	$253,390,890	$95,116,511	$82	$31
2001	3,213,879	58,416,229	56,695,581	17.6	5.1	3.8	$3.50	$1.41	$204,731,439	$82,294,522	$62	$25
2002	3,352,233	74,516,504	72,794,017	21.7	5.0	3.7	$3.54	$1.41	$263,577,803	$104,756,350	$77	$31
2003	3,445,948	64,218,671	62,700,875	18.2	5.2	3.9	$3.96	$1.38	$253,993,533	$88,384,242	$72	$25
2004	3,456,996	81,618,424	79,409,137	23.0	4.8	3.9	$4.16	$1.30	$339,168,829	$106,341,108	$95	$30
2005	3,498,381	77,289,836	75,844,526	21.7	5.4	4.1	$4.73	$1.21	$365,653,191	$93,328,732	$103	$26
2006	3,493,949	82,225,833	80,544,638	23.1	5.1	4.1	$4.21	$1.15	$345,943,285	$94,418,390	$97	$26
2007	3,484,681	72,092,245	70,352,226	20.2	5.2	4.1	$4.55	$1.16	$327,840,079	$83,492,916	$92	$23
2008	3,413,166	79,921,993	77,968,874	22.8	5.2	4.5	$3.71	$1.10	$296,121,686	$87,997,734	$85	$25
2009	3,327,518	92,611,675	90,125,814	27.1	4.9	4.6	$3.09	$1.27	$285,977,939	$117,531,283	$84	$34
2010	3,246,077	108,263,011	105,395,976	32.5	5.2	4.6	$3.44	$1.15	$372,051,827	$124,706,360	$112	$37
2011	3,285,715	117,994,600	114,747,727	34.9	4.9	4.4	$3.35	$1.17	$395,228,598	$138,610,757	$117	$41
2012	3,260,754	140,953,999	137,289,101	42.1	NA	4.2	$2.87	$1.16	$404,616,188	$163,554,946	$121	$49
2013	3,209,991	141,287,060	138,512,831	43.2	NA	4.4	$2.89	$1.00	$408,319,604	$141,287,060	$125	$43
2008 - 2013 ave	3,290,537	113,505,390	110,673,387	33.6	5.1	4.5	$3.22	$1.14	$360,385,974	$128,948,023	$107	$38
25th	2,392,915	32,604,780	31,626,947	14.9	3.7	3.1	$2.64	$1.48	$95,576,555	$71,532,849	$40	$26
median	2,554,173	43,497,515	41,753,223	16.2	4.1	3.5	$2.97	$1.72	$115,028,054	$79,898,247	$47	$28
75th	3,106,106	58,014,772	56,470,851	18.1	4.6	3.7	$3.36	$1.91	$190,013,337	$86,907,092	$61	$31

Table 5.2.2.1. GBK Mortality Indicators

EXPLOITATION RATE (landings / survey ref. pop'n)		
Landings (numbers) by area / Reference pop'n (survey lengths > 77 mm, sexes combined)		
Survey	*NESFC*	
	fall	*spring*
1981		
1982	0.97	0.66
1983	0.99	1.23
1984	1.57	3.47
1985	1.71	1.59
1986	0.92	0.45
1987	1.17	1.04
1988	0.93	0.29
1989	0.74	0.73
1990	1.16	1.02
1991	1.17	1.21
1992	1.31	1.00
1993	1.56	0.68
1994	1.12	3.11
1995	1.05	1.90
1996	0.87	0.41
1997	0.88	3.30
1998	0.83	2.10
1999	0.74	0.46
2000	0.92	0.80
2001	0.66	0.46
2002	0.51	0.56
2003	1.30	0.35
2004	1.14	1.04
2005	1.55	0.87
2006	1.02	0.81
2007	0.99	0.49
2008	0.60	0.21
2009	0.54	0.31
2010	1.05	0.36
2011	0.47	0.43
2012	0.75	0.31
2013	0.80	0.34
2008 - 2013 ave	**0.70**	**0.33**

25th	0.87	0.49
median	0.98	0.90
75th	1.17	1.50

Table 5.2.2.2. GBK Abundance Indicators A through D.

Table 5.2.2.2. A

SPAWNING STOCK ABUNDANCE		
Mean weight (g) per tow of mature females		
Survey	NESFC	
	fall	spring
1981	491.28	35.84
1982	438.48	69.86
1983	419.35	71.77
1984	221.61	19.94
1985	345.21	22.28
1986	260.02	191.52
1987	345.02	70.47
1988	451.51	195.65
1989	624.96	89.30
1990	480.53	59.08
1991	542.93	96.84
1992	489.66	90.59
1993	397.36	50.43
1994	500.49	15.84
1995	634.74	21.41
1996	700.78	315.81
1997	446.10	28.19
1998	678.70	31.56
1999	927.74	238.22
2000	610.24	60.00
2001	1162.15	151.11
2002	1463.52	190.11
2003	728.49	540.30
2004	1047.89	191.92
2005	925.37	325.08
2006	1534.94	280.99
2007	1260.32	490.01
2008	2113.99	1271.28
2009	2595.35	925.63
2010	1514.98	723.68
2011	3182.30	676.37
2012	1849.56	954.20
2013	1676.45	929.70
2008 - 2013 ave	2155.44	913.48
25th	424.14	36.28
median	495.08	71.12
75th	667.71	180.36

Table 5.2.2.2. B

FULL RECRUIT ABUNDANCE		
Abundance of lobsters ≥ 90 mm CL (sexes combined)		
Survey	NESFC	
	fall	spring
1981	0.62	0.09
1982	0.61	0.20
1983	0.57	0.17
1984	0.49	0.05
1985	0.50	0.12
1986	0.59	0.28
1987	0.38	0.11
1988	0.68	0.40
1989	0.86	0.22
1990	0.58	0.08
1991	0.75	0.16
1992	0.58	0.27
1993	0.53	0.21
1994	0.64	0.06
1995	0.57	0.07
1996	0.70	0.40
1997	0.77	0.06
1998	0.62	0.06
1999	0.97	0.45
2000	0.75	0.19
2001	1.21	0.32
2002	1.55	0.40
2003	0.68	0.65
2004	1.16	0.24
2005	0.92	0.39
2006	1.16	0.40
2007	1.21	0.53
2008	1.91	1.12
2009	1.97	0.84
2010	1.15	0.91
2011	2.67	0.77
2012	1.57	1.12
2013	1.68	0.72
2008 - 2013 ave	1.82	0.91
25th	0.57	0.09
median	0.63	0.20
75th	0.75	0.31

Table 5.2.2.2. C

RECRUIT ABUNDANCE (SURVEY)		
Abundance of lobsters 71 - 80 mm CL (sexes combined)		
Survey	NESFC	
	fall	spring
1981	0.20	0.03
1982	0.22	0.13
1983	0.15	0.06
1984	0.24	0.08
1985	0.08	0.11
1986	0.29	0.17
1987	0.23	0.09
1988	0.17	0.49
1989	0.05	0.13
1990	0.14	0.14
1991	0.14	0.07
1992	0.29	0.06
1993	0.16	0.31
1994	0.08	0.04
1995	0.13	0.01
1996	0.17	0.03
1997	0.26	0.00
1998	0.16	0.01
1999	0.09	0.12
2000	0.22	0.17
2001	0.29	0.31
2002	0.24	0.03
2003	0.26	0.11
2004	0.08	0.07
2005	0.10	0.03
2006	0.05	0.09
2007	0.16	0.03
2008	0.06	0.06
2009	0.15	0.07
2010	0.04	0.06
2011	0.15	0.01
2012	0.06	0.03
2013	0.06	0.04
2008 - 2013 ave	0.09	0.04
25th	0.14	0.05
median	0.17	0.10
75th	0.24	0.14

Table 5.2.2.2. D

SURVEY LOBSTER ENCOUNTER RATE		
Proportion of postive tows		
Survey	NESFC	
	fall	spring
1981		
1982	0.44	0.24
1983	0.44	0.18
1984	0.41	0.10
1985	0.37	0.20
1986	0.37	0.24
1987	0.33	0.18
1988	0.40	0.34
1989	0.42	0.17
1990	0.44	0.19
1991	0.49	0.18
1992	0.48	0.24
1993	0.38	0.25
1994	0.42	0.11
1995	0.42	0.12
1996	0.36	0.17
1997	0.48	0.11
1998	0.43	0.12
1999	0.53	0.21
2000	0.42	0.21
2001	0.47	0.25
2002	0.57	0.27
2003	0.44	0.26
2004	0.51	0.18
2005	0.54	0.16
2006	0.53	0.25
2007	0.46	0.23
2008	0.52	0.27
2009	0.55	0.33
2010	0.63	0.38
2011	0.70	0.30
2012	0.58	0.33
2013	0.66	0.31
2008 - 2013 ave	0.61	0.32
25th	0.40	0.17
median	0.43	0.20
75th	0.46	0.24

Table 5.2.2.3. GBK Fishery Performance Indicators

	EFFORT	TOTAL GBK LANDINGS	PARTIAL LANDINGS	GROSS CPUE	SET OVER DAYS	PRICE PER POUND		REVENUE		REVENUE PER TRAP	
Description	Traps	Pounds (all sources)	Pounds from jurisdictions with effort data	Landings / Traps	Average Soak Time of Traps	Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI
Jurisdiction	*MA*	*All*	*MA*	*MA*	*MA*			*All*	*All*	*MA*	*MA*
1981		2,567,862	1,314,735			$2.19	$3.01	$5,625,974	$7,720,580		
1982	27,560	2,869,179	1,301,287	47.2		$2.31	$2.69	$6,622,516	$7,712,113	$109	$127
1983	28,922	3,190,519	1,301,857	45.0		$2.42	$2.55	$7,722,257	$8,136,480	$109	$115
1984	30,651	3,297,873	1,650,172	53.8		$2.69	$2.39	$8,872,508	$7,865,491	$145	$120
1985	34,950	3,281,638	1,644,564	47.1		$2.49	$2.35	$8,170,025	$7,697,009	$117	$110
1986	36,950	2,739,754	1,375,309	37.2		$2.62	$2.15	$7,174,418	$5,896,100	$97	$80
1987	39,674	2,901,630	1,826,294	46.0		$3.09	$1.92	$8,979,928	$5,570,957	$142	$88
1988	39,732	3,123,164	2,052,993	51.7		$2.99	$1.81	$9,324,047	$5,645,463	$154	$93
1989	39,163	2,923,852	2,126,052	54.3		$2.80	$1.88	$8,188,455	$5,499,698	$152	$102
1990	35,891	3,153,726	2,262,055	63.0	6.8	$2.48	$1.83	$7,823,615	$5,758,799	$158	$115
1991	36,784	3,483,213	2,063,952	56.1	6.7	$2.59	$1.80	$9,022,113	$6,262,599	$145	$101
1992	38,745	3,754,377	2,493,492	64.4	6.8	$2.90	$1.72	$10,906,428	$6,464,735	$167	$111
1993	43,041	3,405,884	2,478,804	57.6	6.8	$2.77	$1.72	$9,417,511	$5,849,869	$159	$99
1994	47,894	2,967,382	2,234,087	46.6	6.9	$2.96	$1.67	$8,790,503	$4,941,806	$138	$78
1995	44,480	2,676,978	2,039,871	45.9	7.0	$3.06	$1.57	$8,203,504	$4,212,818	$141	$72
1996	42,008	2,516,081	1,904,847	45.3	6.6	$3.39	$1.62	$8,518,952	$4,076,562	$154	$73
1997	40,974	2,677,613	2,064,850	50.4	8.3	$3.29	$1.51	$8,806,136	$4,041,101	$166	$76
1998	45,327	2,635,930	2,067,469	45.6	6.8	$3.19	$1.47	$8,395,591	$3,870,470	$145	$67
1999	47,941	3,176,902	2,452,283	51.2	7.1	$3.70	$1.41	$11,741,014	$4,474,697	$189	$72
2000	41,464	2,610,913	1,920,883	46.3	7.1	$3.61	$1.36	$9,437,540	$3,542,613	$187	$63
2001	40,899	3,101,798	2,514,054	61.5	7.1	$3.50	$1.41	$10,870,877	$4,369,693	$215	$87
2002	47,387	3,444,830	2,898,174	61.2	6.7	$3.54	$1.41	$12,184,961	$4,842,790	$216	$86
2003	42,834	3,938,924	2,675,731	62.5	7.1	$3.96	$1.38	$15,578,976	$5,421,146	$247	$86
2004	43,922	4,362,874	2,887,586	65.7	7.6	$4.16	$1.30	$18,130,107	$5,684,413	$273	$86
2005	40,694	5,276,968	3,221,845	79.2	7.9	$4.73	$1.21	$24,964,995	$6,372,025	$375	$96
2006	40,175	4,939,026	3,018,471	75.1	7.7	$4.21	$1.15	$20,779,637	$5,671,392	$316	$86
2007	42,307	4,550,686	2,862,517	67.7	7.4	$4.55	$1.16	$20,694,284	$5,270,332	$308	$78
2008	41,477	4,324,556	3,008,867	72.5	8.9	$3.71	$1.10	$16,023,060	$4,761,532	$269	$80
2009	39,251	4,510,495	3,250,592	82.8	6.5	$3.09	$1.27	$13,928,070	$5,724,162	$256	$105
2010	58,607	5,224,723	3,516,248	60.0	6.3	$3.44	$1.15	$17,955,048	$6,018,271	$206	$69
2011	51,096	5,227,574	3,585,289	70.2	5.8	$3.35	$1.17	$17,510,011	$6,140,942	$235	$82
2012	53,349	5,139,781	3,605,923	67.6	6.2	$2.87	$1.16	$14,754,024	$5,963,908	$194	$78
2013	53,250	5,140,880	3,410,887	64.1	6.4	$2.89	$1.00	$14,857,143	$5,140,880	$185	$64
2008 - 2013 ave	49,505	4,928,001	3,396,301	69.5	6.3	$3.22	$1.14	$15,837,893	$5,624,949	$224	$80
25th	36,826	2,772,110	1,845,932	46.1	6.8	$2.64	$1.48	$8,192,217	$4,395,944	$141	$76
median	40,316	3,112,481	2,084,401	50.8	6.8	$2.97	$1.72	$8,839,322	$5,535,328	$153	$87
75th	42,989	3,293,815	2,404,726	57.2	7.1	$3.36	$1.91	$9,432,533	$6,170,974	$167	$108

Table 5.2.3.1. SNE Mortality Indicators

EXPLOITATION RATE (landings / survey ref. pop'n)								
Landings (numbers) by area / Reference pop'n (survey lengths > 77 mm, sexes								
Survey	NESFC		MA		RI		CT/NY LIS	
	fall	spring	fall	spring	fall	spring	fall	spring
1981								
1982	0.41	0.21			0.85	1.56		
1983	0.88	0.78			2.39	1.04		
1984	0.57	1.17			0.84	0.68	0.32	
1985	0.65	0.16			1.09	1.94	0.64	1.00
1986	1.02	0.67			1.05	1.07	0.29	1.33
1987	1.22	0.28			0.57	1.27	0.35	0.92
1988	1.11	0.76			0.27	2.39	0.74	1.99
1989	0.81	1.23			0.58	1.22	0.85	1.02
1990	0.90	0.69	0.43	0.31	1.51	0.66	0.54	0.83
1991	1.15	1.16	0.11	0.20	0.69	0.32	0.50	0.50
1992	0.82	0.91	0.11	0.59	0.88	2.28	0.42	0.58
1993	1.40	0.54	0.23	2.50	0.28	0.14	0.35	0.90
1994	3.31	1.77	0.21	0.53	0.63	2.43	0.43	2.27
1995	1.45	10.78	7.00	0.66	0.72	1.73	0.76	1.13
1996	0.61	2.05	0.46	1.28	0.49	1.09	1.22	1.51
1997	1.00	0.38	1.30	0.46	0.56	0.87	0.49	0.77
1998	1.18	1.14	1.08	0.53	1.03	1.18	1.05	0.58
1999	2.43	0.37	2.22	0.65	2.07	1.59	0.74	0.49
2000	0.93	0.47	0.51	0.47	2.10	1.52	0.52	0.40
2001	0.82	0.59	0.56	1.91	1.03	0.54	0.50	0.32
2002	1.40	0.17	3.32	1.07	2.98	0.50	1.36	0.40
2003	1.00	0.34		1.00	0.43	0.96	0.39	0.90
2004	0.65	0.51	0.55		0.39	0.21	0.75	1.17
2005	0.69	0.69	0.22	1.59	0.23	0.41	1.05	1.72
2006	0.89	0.38		0.35	0.38	0.17	3.03	1.70
2007	0.50	0.40	0.53	4.18	0.22	0.56	1.62	0.97
2008	0.70	0.30	1.29	1.11	0.20	0.50	0.86	0.47
2009	1.13	0.93		0.68	0.40	0.43	0.71	0.81
2010	0.66	0.59	0.10	0.54	0.57	0.59	NA	1.16
2011	0.62	0.78	0.14	1.34	0.40	0.51	2.78	1.09
2012	0.42	0.46	0.33	0.62	1.70	0.77	4.08	1.36
2013	0.66	0.36	0.32	0.44	4.51	0.87	1.65	0.70
2008 - 2013 ave	**0.70**	**0.57**	**0.43**	**0.79**	**1.30**	**0.61**	**2.02**	**0.93**
25th	0.82	0.38	0.23	0.49	0.56	0.67	0.41	0.54
median	1.01	0.68	0.51	0.62	0.78	1.13	0.51	0.90
75th	1.27	1.16	1.30	1.05	1.06	1.63	0.75	1.07

Table 5.2.3.2. SNE Abundance Indicators A through E.

Table 5.2.3.2. A.

SPAWNING STOCK ABUNDANCE Mean weight (g) per tow of mature females								
Survey	*NESFC*		*MA*		*RI*		*CT*	
	Fall	*spring*	*fall*	*spring*	*Fall*	*spring*	*Fall*	*spring*
1981	198.93	15.71	9.21	99.78	161.55	111.57		
1982	156.07	118.29	50.04	26.42	53.52	43.52		
1983	120.20	35.51	0.72	59.62	87.86	141.69		
1984	192.38	44.50	4.04	51.67	203.58	259.91	2331.33	
1985	132.96	138.13	1.88	36.90	125.09	60.22	1040.42	1155.01
1986	59.83	61.35	87.60	19.06	128.49	136.78	1548.94	751.75
1987	143.76	67.33	44.51	35.12	475.51	86.13	1869.91	932.49
1988	122.36	121.34	13.16	46.33	662.07	100.75	1081.60	639.82
1989	124.57	44.65	233.88	70.68	363.92	151.06	853.74	1193.87
1990	175.83	75.87	59.02	150.21	230.17	258.72	1818.59	2369.93
1991	160.99	53.14	125.79	236.11	367.25	698.35	2185.29	2692.42
1992	178.88	61.38	179.80	47.84	321.95	117.18	1905.99	3598.02
1993	139.25	71.48	99.33	25.59	1286.74	1595.77	3335.55	2320.25
1994	54.70	36.40	126.00	82.42	359.96	164.37	3402.43	1170.49
1995	145.39	10.18	10.89	92.76	410.53	153.14	2253.58	3302.56
1996	227.08	32.01	59.61	54.16	861.32	353.55	3018.00	3882.27
1997	121.74	137.20	29.11	225.15	654.91	439.93	7173.56	5994.27
1998	161.20	44.97	52.73	138.81	251.53	286.59	2573.44	7738.30
1999	69.56	122.59	24.53	81.12	171.54	324.62	2546.24	8261.90
2000	95.66	60.02	20.08	142.78	268.99	303.32	1744.69	4430.68
2001	95.78	36.43	21.28	16.61	267.62	535.45	1513.56	3363.78
2002	85.56	146.86	0.00	44.75	35.68	572.35	365.12	2044.42
2003	52.83	31.71	0.00	5.97	205.85	110.43	1187.14	698.04
2004	47.10	47.01	37.18	3.58	288.49	591.60	626.96	522.99
2005	110.36	42.31	101.87	23.02	353.53	243.36	473.26	479.71
2006	65.03	90.62	0.00	60.77	465.26	788.63	219.99	465.37
2007	44.60	34.20	41.79	10.32	350.43	206.96	188.98	595.89
2008	25.90	58.14	0.00	19.67	401.73	194.57	248.63	760.88
2009	36.92	24.49	3.95	31.29	184.35	250.00	305.31	371.95
2010	101.74	46.39	130.73	32.09	166.07	177.64	na	361.72
2011	89.95	22.79	36.96	8.55	148.47	152.43	30.24	64.00
2012	205.12	39.64	14.13	9.93	31.16	118.13	6.28	88.85
2013	52.95	42.05	23.96	35.49	2.02	67.76	24.56	39.81
2008 - 2013 ave	**85.43**	**38.92**	**34.96**	**22.84**	**155.63**	**160.09**	**123.00**	**281.20**
25th	93.14	42.48	12.59	36.45	205.28	131.88	1431.95	1162.75
median	128.76	60.69	36.81	52.92	295.47	259.32	1887.95	2369.93
75th	161.04	87.24	90.53	104.27	426.78	375.15	2553.04	3740.14

Table 5.2.3.2. B.

FULL RECRUIT ABUNDANCE (SURVEY) Abundance of lobsters > 85 mm CL (sexes combined)								
Survey	*NEFSC*		*MA*		*RI*		*CT*	
	Fall	*spring*	*fall*	*spring*	*Fall*	*spring*	*Fall*	*spring*
1981	0.24	0.03	0.00	0.02	0.01	0.03		
1982	0.17	0.13	0.07	0.02	0.04	0.03		
1983	0.13	0.03	0.00	0.07	0.13	0.08		
1984	0.24	0.04	0.07	0.03	0.16	0.31	2.67	
1985	0.12	0.07	0.00	0.00	0.10	0.07	0.81	1.06
1986	0.06	0.12	0.05	0.00	0.08	0.11	2.73	0.63
1987	0.19	0.05	0.05	0.05	0.31	0.04	1.62	0.99
1988	0.15	0.04	0.00	0.03	0.83	0.09	1.26	0.82
1989	0.20	0.07	0.20	0.07	0.24	0.05	1.00	1.41
1990	0.19	0.05	0.05	0.05	0.38	0.10	2.39	1.35
1991	0.20	0.04	0.23	0.19	0.44	0.37	1.34	3.26
1992	0.20	0.07	0.22	0.05	0.34	0.10	2.37	1.44
1993	0.14	0.10	0.12	0.02	1.12	1.42	1.55	0.68
1994	0.08	0.03	0.00	0.00	0.55	0.10	3.75	0.50
1995	0.16	0.01	0.01	0.05	0.33	0.07	2.20	1.85
1996	0.22	0.02	0.06	0.08	0.82	0.19	1.97	1.96
1997	0.11	0.19	0.02	0.10	0.98	0.08	4.00	4.44
1998	0.25	0.00	0.04	0.00	0.17	0.17	1.48	4.10
1999	0.08	0.07	0.00	0.16	0.27	0.26	1.70	3.27
2000	0.08	0.09	0.08	0.08	0.30	0.32	0.95	2.44
2001	0.10	0.07	0.02	0.03	0.10	0.32	0.35	2.47
2002	0.08	0.08	0.00	0.08	0.00	0.20	0.03	1.35
2003	0.08	0.05	0.00	0.06	0.29	0.07	0.62	0.35
2004	0.07	0.04	0.04	0.00	0.26	0.41	0.27	0.30
2005	0.12	0.07	0.06	0.00	0.30	0.33	0.21	0.25
2006	0.11	0.06	0.00	0.14	0.24	0.65	0.03	0.20
2007	0.07	0.03	0.05	0.01	0.32	0.15	0.03	0.24
2008	0.07	0.06	0.00	0.02	0.74	0.12	0.19	0.66
2009	0.07	0.03	0.00	0.01	0.17	0.19	0.24	0.32
2010	0.11	0.05	0.15	0.07	0.07	0.12	na	0.26
2011	0.10	0.04	0.07	0.00	0.14	0.16	0.01	0.07
2012	0.19	0.05	0.03	0.02	0.02	0.09	0.03	0.06
2013	0.08	0.09	0.03	0.07	0.00	0.02	0.03	0.07
2008 - 2013 ave	**0.10**	**0.05**	**0.05**	**0.03**	**0.19**	**0.12**	**0.10**	**0.24**
25th	0.08	0.04	0.00	0.03	0.17	0.07	0.99	0.91
median	0.14	0.06	0.04	0.05	0.31	0.10	1.59	1.41
75th	0.20	0.08	0.07	0.08	0.46	0.28	2.38	2.46

Table 5.2.3.2. C.

RECRUIT ABUNDANCE (SURVEY)								
Abundance of lobsters 71 - 80 mm CL (sexes combined)								
Survey	*NEFSC*		*MA*		*RI*		*CT*	
	Fall	*spring*	*fall*	*spring*	*Fall*	*spring*	*Fall*	*spring*
1981	0.40	0.05	0.07	0.65	1.31	0.89		
1982	0.24	0.23	0.04	0.10	0.62	0.26		
1983	0.28	0.13	0.04	0.09	0.43	0.94		
1984	0.17	0.04	0.01	0.42	1.21	1.03	8.62	
1985	0.32	0.77	0.09	0.34	0.97	0.26	5.03	4.73
1986	0.12	0.09	0.20	0.17	1.30	0.75	8.22	3.45
1987	0.18	0.33	0.17	0.27	2.53	0.79	9.46	3.90
1988	0.22	0.07	0.16	0.24	4.14	0.42	4.82	2.16
1989	0.52	0.04	0.43	0.14	3.26	0.93	6.32	5.51
1990	0.35	0.29	0.31	2.29	1.38	2.17	10.31	9.53
1991	0.22	0.18	0.87	1.18	3.05	4.77	14.23	15.39
1992	0.36	0.06	0.57	0.10	1.97	0.67	12.25	16.55
1993	0.17	0.27	0.52	0.25	8.29	7.81	21.46	10.69
1994	0.10	0.10	0.42	0.95	3.64	1.00	18.87	5.90
1995	0.27	0.00	0.03	1.14	4.48	1.36	15.30	16.31
1996	0.75	0.12	0.32	0.40	6.42	1.60	14.91	16.30
1997	0.53	0.59	0.12	1.45	6.10	2.58	40.43	25.49
1998	0.43	0.36	0.11	1.09	3.38	1.63	18.61	37.56
1999	0.20	0.89	0.19	0.75	2.10	1.64	20.22	40.84
2000	0.40	0.30	0.13	0.54	1.83	1.54	12.71	20.72
2001	0.16	0.13	0.03	0.18	2.21	3.03	11.94	19.12
2002	0.16	0.62	0.00	0.34	0.75	2.73	3.52	11.44
2003	0.12	0.21	0.00	0.07	1.00	0.29	5.56	4.58
2004	0.12	0.11	0.00	0.05	1.48	1.86	4.52	2.92
2005	0.07	0.04	0.00	0.08	2.48	1.02	2.14	2.67
2006	0.10	0.12	0.03	0.08	2.26	3.63	1.38	2.12
2007	0.10	0.10	0.00	0.08	2.76	0.73	1.35	2.86
2008	0.12	0.09	0.01	0.16	2.98	0.64	1.43	3.10
2009	0.04	0.05	0.05	0.16	1.36	1.14	1.72	1.55
2010	0.13	0.05	0.18	0.06	1.21	0.44	na	1.41
2011	0.11	0.03	0.00	0.18	1.02	0.42	0.19	0.42
2012	0.14	0.04	0.21	0.07	0.27	0.61	0.14	0.50
2013	0.08	0.02	0.04	0.11	0.02	0.18	0.06	0.23
2008 - 2013 ave	**0.10**	**0.05**	**0.08**	**0.12**	**1.14**	**0.57**	**0.70**	**1.20**
25th	0.17	0.09	0.08	0.23	1.36	0.78	7.74	5.12
median	0.22	0.19	0.17	0.37	2.37	1.45	12.09	11.44
75th	0.37	0.34	0.35	0.99	3.77	2.27	16.13	17.84

Table 5.2.3.2. D.

YOUNG-OF-YEAR INDICES				
	YOY	YOY	Larvae	Postlarvae
Survey	*MA*	*RI*	*CT / ELIS* Summer	*CT_NY / WLIS* Summer
1981				
1982				
1983				14.48
1984			0.43	6.89
1985			0.53	66.75
1986			0.90	4.58
1987			0.78	18.98
1988			0.74	49.27
1989			0.74	5.88
1990		1.31	0.81	19.66
1991		1.49	0.55	9.97
1992		0.63	1.44	14.12
1993		0.51	1.19	26.23
1994		1.23	0.98	96.52
1995	0.17	0.33	1.46	18.20
1996	0.00	0.15	0.31	12.07
1997	0.09	0.99	0.21	13.69
1998	0.20	0.57	0.55	4.85
1999	0.03	0.92	2.83	39.70
2000	0.33	0.34	0.78	14.28
2001	0.10	0.75	0.32	9.46
2002	0.10	0.25	0.64	1.99
2003	0.03	0.79	0.25	2.60
2004	0.03	0.42	0.45	6.10
2005	0.13	0.53	0.49	6.90
2006	0.17	0.44	0.71	1.70
2007	0.10	0.36	0.37	18.10
2008	0.00	0.14	0.37	8.10
2009	0.03	0.08	0.19	7.62
2010	0.00	0.11	0.35	9.91
2011	0.03	0.00	0.26	5.90
2012	0.00	0.09	0.12	2.77
2013	0.20	0.22	0.16	NA
2008 - 2013 ave	**0.04**	**0.11**	**0.24**	**6.86**
25th	0.03	0.39	0.50	6.64
median	0.10	0.69	0.74	13.91
75th	0.17	0.97	0.92	21.30

Table 5.2.3.2. E.

SURVEY LOBSTER ENCOUNTER RATE								
Proportion of postive tows								
Survey	***NEFSC***		***MA***		***RI***		***CT***	
	Fall	***spring***	***fall***	***spring***	***Fall***	***spring***	***Fall***	***spring***
1981			0.15	0.38	0.54	0.49		
1982	0.34	0.24	0.21	0.28	0.59	0.30		
1983	0.22	0.14	0.16	0.21	0.36	0.45		
1984	0.27	0.09	0.18	0.40	0.45	0.59	0.76	0.72
1985	0.30	0.20	0.22	0.51	0.50	0.31	0.69	0.57
1986	0.25	0.19	0.38	0.39	0.43	0.64	0.61	0.67
1987	0.23	0.13	0.18	0.28	0.47	0.33	0.76	0.63
1988	0.27	0.08	0.21	0.39	0.59	0.49	0.66	0.65
1989	0.37	0.11	0.33	0.50	0.55	0.52	0.63	0.75
1990	0.43	0.14	0.44	0.66	0.54	0.66	0.76	0.73
1991	0.29	0.13	0.39	0.41	0.69	0.77	0.78	0.81
1992	0.31	0.23	0.23	0.51	0.57	0.41	0.69	0.78
1993	0.26	0.09	0.26	0.54	0.73	0.50	0.77	0.74
1994	0.23	0.09	0.20	0.51	0.57	0.56	0.74	0.73
1995	0.33	0.06	0.13	0.44	0.67	0.55	0.68	0.77
1996	0.41	0.08	0.16	0.30	0.76	0.79	0.78	0.68
1997	0.28	0.24	0.21	0.45	0.71	0.75	0.81	0.71
1998	0.30	0.11	0.13	0.54	0.55	0.59	0.71	0.83
1999	0.29	0.18	0.21	0.41	0.59	0.76	0.79	0.78
2000	0.30	0.13	0.15	0.45	0.63	0.68	0.73	0.82
2001	0.24	0.18	0.18	0.28	0.61	0.64	0.58	0.77
2002	0.21	0.19	0.03	0.28	0.45	0.63	0.59	0.73
2003	0.25	0.11	0.03	0.14	0.40	0.53	0.63	0.71
2004	0.20	0.10	0.03	0.28	0.50	0.54	0.66	0.61
2005	0.20	0.08	0.15	0.34	0.45	0.50	0.55	0.63
2006	0.23	0.13	0.03	0.43	0.61	0.81	0.53	0.61
2007	0.19	0.15	0.10	0.34	0.54	0.43	0.53	0.70
2008	0.24	0.11	0.10	0.33	0.52	0.55	0.65	0.63
2009	0.28	0.16	0.05	0.50	0.40	0.57	0.55	0.49
2010	0.30	0.09	0.24	0.23	0.45	0.47	NA	0.54
2011	0.32	0.11	0.05	0.18	0.23	0.29	0.28	0.46
2012	0.32	0.12	0.15	0.18	0.16	0.29	0.20	0.44
2013	0.24	0.09	0.08	0.18	0.09	0.20	0.15	0.28
2008 - 2013 ave	**0.28**	**0.11**	**0.11**	**0.26**	**0.31**	**0.39**	**0.37**	**0.47**

25th	0.25	0.09	0.16	0.37	0.49	0.52	0.65	0.70
median	0.29	0.13	0.20	0.42	0.57	0.59	0.72	0.73
75th	0.31	0.18	0.24	0.51	0.64	0.66	0.76	0.77

Table 5.2.3.3. SNE Fishery Performance Indicators

	EFFORT	TOTAL SNE LANDINGS	PARTIAL LANDINGS	GROSS CPUE	SET OVER DAYS		PRICE PER POUND		REVENUE		REVENUE PER TRAP	
Description	Traps	Pounds (all sources)	Pounds from jurisdictions with effort data	Landings / Traps	Average Soak Time of Traps		Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI
Jurisdiction	*MA, CT, NY*	*all*	*MA, CT, NY*	*MA, CT, NY*	*MA*	*CT*			*All*	*All*	*MA, CT, NY*	*MA, CT, NY*
1981		4,060,297	2,595,413			3.4	$2.19	$3.01	$8,895,777	$12,207,763		
1982		5,907,454	3,162,734			3.3	$2.31	$2.69	$13,635,332	$15,878,742		
1983		8,350,636	4,201,326			3.1	$2.42	$2.55	$20,211,680	$21,295,837		
1984	193,380	9,379,497	4,600,248	23.8		4.0	$2.69	$2.39	$25,234,342	$22,370,279	$64	$57
1985	209,548	8,731,427	3,899,105	18.6		4.2	$2.49	$2.35	$21,737,911	$20,479,360	$46	$44
1986	202,411	9,663,892	3,971,304	19.6		4.3	$2.62	$2.15	$25,306,211	$20,797,225	$51	$42
1987	210,893	9,826,820	3,993,476	18.9		4.5	$3.09	$1.92	$30,411,914	$18,866,907	$59	$36
1988	244,554	10,475,714	4,878,141	19.9		4.6	$2.99	$1.81	$31,274,716	$18,936,009	$60	$36
1989	289,935	13,095,008	5,906,893	20.4		4.7	$2.80	$1.88	$36,673,499	$24,631,408	$57	$38
1990	291,632	16,798,605	8,065,523	27.7	4.9	4.9	$2.48	$1.83	$41,673,186	$30,674,760	$69	$51
1991	316,488	15,621,005	7,861,069	24.8	4.4	5.1	$2.59	$1.80	$40,461,058	$28,085,590	$64	$45
1992	353,735	13,742,002	6,977,429	19.7	5.0	5.4	$2.90	$1.72	$39,920,379	$23,662,622	$57	$34
1993	414,956	13,246,216	6,757,241	16.3	4.8	5.5	$2.77	$1.72	$36,626,725	$22,750,621	$45	$28
1994	451,696	14,934,767	8,258,793	18.3	3.8	5.5	$2.96	$1.67	$44,242,404	$24,871,999	$54	$30
1995	443,633	17,646,733	11,355,614	25.6	5.2	5.9	$3.06	$1.57	$54,077,790	$27,771,045	$78	$40
1996	516,487	20,697,168	14,448,223	28.0	4.8	6.3	$3.39	$1.62	$70,076,501	$33,533,610	$95	$45
1997	546,347	21,902,392	14,920,913	27.3	5.1	6.2	$3.29	$1.51	$72,032,611	$33,055,476	$90	$41
1998	588,422	20,671,210	14,030,667	23.8	5.2	6.2	$3.19	$1.47	$65,838,994	$30,352,583	$76	$35
1999	577,865	19,870,895	11,228,721	19.4	5.2	6.7	$3.70	$1.41	$73,436,339	$27,987,814	$72	$27
2000	403,314	13,387,841	5,897,836	14.6	5.6	7.1	$3.61	$1.36	$48,392,373	$18,165,269	$53	$20
2001	551,712	9,844,660	5,024,534	9.1	6.1	7.0	$3.50	$1.41	$34,502,592	$13,868,775	$32	$13
2002	506,464	8,050,419	4,157,018	8.2	5.8	7.3	$3.54	$1.41	$28,475,730	$11,317,393	$29	$12
2003	383,386	5,630,900	2,637,818	6.9	6.4	7.7	$3.96	$1.38	$22,270,973	$7,749,816	$27	$9
2004	369,684	5,477,212	2,800,898	7.6	6.4	7.6	$4.16	$1.30	$22,760,787	$7,136,291	$31	$10
2005	335,152	5,733,586	3,053,909	9.1	6.9	7.4	$4.73	$1.21	$27,125,225	$6,923,399	$43	$11
2006	352,954	6,588,980	3,290,888	9.3	7.1	7.5	$4.21	$1.15	$27,721,379	$7,566,003	$39	$11
2007	354,438	5,367,227	2,283,672	6.4	7.2	8.7	$4.55	$1.16	$24,407,511	$6,216,001	$29	$7
2008	294,638	6,069,202	1,875,050	6.4	5.6	NA	$3.71	$1.10	$22,487,205	$6,682,466	$24	$7
2009	260,648	6,203,080	2,028,765	7.8	6.4	9.7	$3.09	$1.27	$19,164,648	$7,872,182	$24	$10
2010	283,933	6,031,530	2,005,660	7.1	4.5	9.7	$3.44	$1.15	$20,727,687	$6,947,619	$24	$8
2011	226,929	4,663,070	1,087,632	4.8	4.0	10.2	$3.35	$1.17	$15,619,178	$5,477,807	$16	$6
2012	189,959	4,535,915	1,152,468	6.1	3.8	10.5	$2.87	$1.16	$13,020,594	$5,263,216	$17	$7
2013	151,970	3,327,197	1,070,293	7.0	4.1	10.2	$2.89	$1.00	$9,615,600	$3,327,197	$20	$7
2008 - 2013 ave	234,679	5,138,332	1,536,645	6.5	4.8	10.1	$3.22	$1.14	$16,770,819	$5,928,415	$21	$7
25th	278,590	9,786,088	4,489,440	17.8	4.8	4.7	$2.75	$1.45	$29,927,868	$18,918,734	$50	$28
median	393,350	13,317,028	6,332,087	19.7	5.1	5.5	$3.02	$1.69	$38,296,939	$23,206,622	$58	$36
75th	508,970	17,010,637	9,001,275	24.1	5.5	6.4	$3.42	$1.84	$49,813,727	$28,012,258	$69	$43

Table 5.2.4.1. GOM / GBK Combined Mortality Indicators

EXPLOITATION RATE (landings / survey ref. pop'n)						
Landings (lbs) by area / Reference pop'n (survey weights (lbs) > 77						
Survey	NESFC		ME/NH		MA 514	
	fall	spring	fall	spring	fall	spring
1981						
1982	1.42	1.29				
1983	1.18	1.56				
1984	1.07	1.90				
1985	0.94	0.97				
1986	0.62	0.73				
1987	0.73	0.92				
1988	0.95	0.62				
1989	0.81	0.82				
1990	0.85	1.67			0.40	0.80
1991	0.97	1.41			0.62	1.41
1992	0.90	1.19			0.71	0.78
1993	1.07	1.22			1.71	0.74
1994	1.02	1.76			0.47	0.77
1995	0.86	1.43			0.59	1.18
1996	0.64	0.97			0.54	1.30
1997	0.70	0.91			0.76	0.95
1998	0.89	0.84			1.10	0.90
1999	0.85	1.07			0.76	0.96
2000	0.80	0.64	0.89		0.69	0.83
2001	0.85	0.49	1.15	1.44	1.81	0.78
2002	0.96	0.86	1.20	0.80	1.06	1.01
2003	0.92	0.65	0.87	1.18	2.83	1.48
2004	1.37	0.81	1.51	2.11	2.69	0.81
2005	1.35	1.00	0.86	0.85	1.81	0.46
2006	1.79	0.94	1.18	0.87	0.91	0.51
2007	1.59	0.73	1.04	0.85	1.65	1.90
2008	1.35	0.82	0.73	0.93	0.63	0.81
2009	1.05	0.83	0.71	0.72	0.58	0.89
2010	1.01	0.90	0.81	0.97	0.41	1.41
2011	0.79	0.76	0.74	0.58	0.35	0.79
2012	0.88	0.66	1.19	0.71	0.47	1.70
2013	0.81	0.63	1.12	0.78	0.43	0.83
2008 - 2013 ave	0.982	0.766	0.88	0.78	0.48	1.07

25th	0.82	0.83	0.89	0.99	0.60	0.78
median	0.90	0.97	1.02	1.18	0.73	0.92
75th	0.97	1.38	1.16	1.31	1.09	1.14

Table 5.2.4.2. GOM / GBK Combined Abundance Indicators – A through E.

Table 5.2.4.2.A

SPAWNING STOCK ABUNDANCE						
Mean weight (g) per tow of mature females						
Survey	NESFC		ME/NH		MA 514	
	fall	spring	fall	spring	fall	spring
1981	304.27	173.98			342.80	251.36
1982	223.09	74.35			404.26	90.43
1983	264.22	125.99			537.29	32.40
1984	189.82	188.73			336.33	78.90
1985	328.01	1138.49			563.45	32.32
1986	206.27	286.30			135.10	50.24
1987	179.30	219.81			146.15	82.80
1988	271.72	184.18			94.55	42.74
1989	407.16	130.78			123.19	114.57
1990	289.98	220.91			538.08	100.27
1991	326.86	204.07			142.51	101.77
1992	293.28	202.01			282.54	110.74
1993	277.73	200.30			53.48	117.58
1994	360.16	280.51			376.55	132.17
1995	452.00	141.92			222.57	91.04
1996	555.40	465.08			262.89	72.61
1997	398.24	410.45			87.30	49.64
1998	438.12	449.94			113.80	81.44
1999	929.85	411.02			178.35	194.17
2000	457.89	484.73	3425.58		287.35	133.73
2001	718.46	625.39	1858.63	462.60	105.26	151.41
2002	1350.72	849.37	3707.47	967.67	163.87	105.74
2003	701.10	1139.33	3988.26	847.68	101.81	45.15
2004	716.95	1141.16	3497.55	682.69	86.24	189.23
2005	593.44	762.80	4062.27	1505.13	167.88	358.32
2006	968.92	811.80	2909.52	685.80	118.39	290.44
2007	752.12	805.69	3010.80	735.09	138.01	91.66
2008	1270.51	1316.45	3423.42	712.51	354.40	222.36
2009	1811.80	1140.39	5526.54	1138.18	396.60	135.71
2010	1662.97	1249.92	3879.74	1322.90	1176.34	157.93
2011	2206.17	1053.94	4446.97	868.71	782.58	151.85
2012	1910.13	1703.54	2964.59	1190.50	524.55	88.82
2013	1853.09	1322.28	4144.70	671.93	761.16	187.97
2008 - 2013 ave	1785.78	1297.75	4064.16	984.12	665.94	154.11
25th	273.23	191.62	3033.84	655.14	116.15	55.84
median	344.08	250.71	3566.52	847.68	171.11	90.73
75th	456.42	461.30	3777.66	907.67	324.09	113.62

Table 5.2.4.2.B

FULL RECRUIT ABUNDANCE (SURVEY)						
Abundance of lobsters > 82 mm CL (sexes combined)						
Survey	NEFSC		ME/NH		MA 514	
	fall	spring	fall	spring	fall	spring
1981	0.42	0.23			1.91	1.83
1982	0.32	0.21			2.80	0.57
1983	0.38	0.18			3.08	0.51
1984	0.39	0.20			4.09	0.49
1985	0.52	0.99			3.94	0.50
1986	0.52	0.42			1.71	0.54
1987	0.26	0.28			0.53	0.56
1988	0.40	0.33			1.51	0.56
1989	0.61	0.25			2.27	0.79
1990	0.41	0.27			4.92	0.97
1991	0.54	0.32			3.18	0.69
1992	0.39	0.32			2.35	0.87
1993	0.46	0.35			0.63	1.00
1994	0.57	0.39			3.15	0.76
1995	0.78	0.28			2.50	0.58
1996	0.80	0.71			2.50	0.33
1997	0.74	0.56			1.69	0.62
1998	0.53	0.53			0.88	0.49
1999	1.27	0.48			1.93	0.72
2000	0.68	0.79	14.22		2.20	0.97
2001	0.90	0.94	9.83	2.25	0.72	0.53
2002	1.73	1.14	12.57	3.40	1.02	0.43
2003	0.92	1.55	16.65	3.08	0.42	0.22
2004	1.17	1.46	16.18	3.14	0.33	0.78
2005	0.77	1.04	21.09	6.53	0.56	0.95
2006	0.99	1.06	14.85	5.33	1.03	0.68
2007	0.84	1.04	14.13	4.19	0.48	0.32
2008	1.38	1.55	20.72	3.06	1.55	0.67
2009	1.89	1.27	30.48	6.32	1.70	0.54
2010	2.15	1.81	21.42	6.29	2.30	0.40
2011	2.93	1.50	23.83	5.14	3.80	0.55
2012	2.51	2.32	16.51	5.94	3.18	0.31
2013	2.53	1.62	21.45	4.50	3.74	0.87
2008 - 2013 ave	2.23	1.68	22.40	5.21	2.71	0.55
25th	0.40	0.28	11.88	2.67	1.14	0.50
median	0.53	0.37	13.39	3.08	2.24	0.56
75th	0.77	0.67	14.83	3.24	3.01	0.75

Table 5.2.4.2.C

RECRUIT ABUNDANCE (SURVEY)						
Abundance of lobsters 71 - 80 mm CL (sexes combined)						
Survey	NEFSC		ME/NH		MA 514	
	fall	spring	fall	spring	fall	spring
1981	0.11	0.05			4.84	6.38
1982	0.20	0.13			3.85	2.74
1983	0.31	0.10			9.76	1.76
1984	0.19	0.09			6.13	2.15
1985	0.40	0.10			9.60	4.48
1986	0.42	0.14			3.80	3.01
1987	0.26	0.17			1.16	2.47
1988	0.36	0.38			4.12	2.52
1989	0.37	0.07			7.51	4.48
1990	0.55	0.18			15.40	6.11
1991	0.46	0.19			7.55	2.73
1992	0.45	0.16			8.95	4.31
1993	0.35	0.22			3.19	5.12
1994	0.64	0.07			13.80	7.59
1995	0.46	0.41			12.10	4.54
1996	1.16	0.19			12.10	3.09
1997	0.58	0.50			6.41	4.57
1998	0.61	0.40			7.47	4.50
1999	0.76	0.37			8.73	4.26
2000	0.78	0.99	23.82		8.86	4.24
2001	0.50	0.45	17.53	9.16	1.58	4.30
2002	0.51	0.41	22.12	22.63	5.00	3.43
2003	0.25	0.37	23.78	13.71	0.66	1.96
2004	0.61	0.24	15.96	9.69	1.30	2.46
2005	0.25	0.17	30.88	23.85	2.11	4.35
2006	0.33	0.64	23.27	23.15	5.30	6.09
2007	0.29	0.39	21.62	20.24	1.61	0.75
2008	0.58	0.29	40.45	22.90	6.12	2.54
2009	0.70	0.55	41.84	31.77	8.88	3.18
2010	0.82	0.41	46.24	22.40	9.39	2.22
2011	1.50	1.05	58.53	47.39	15.00	5.24
2012	0.89	1.24	47.28	44.81	11.30	3.03
2013	1.74	1.06	48.24	39.71	12.20	4.83
2008 - 2013 ave	1.04	0.77	47.10	34.83	10.48	3.51
25th	0.35	0.13	20.97	11.43	3.92	2.73
median	0.45	0.19	22.95	13.71	7.49	4.25
75th	0.57	0.40	23.79	18.17	9.44	4.50

Table 5.2.4.2.D

YOUNG-OF-YEAR INDICES					
	YOY	YOY	YOY	YOY	YOY
Survey	ME	ME	ME	ME	MA
	511	512	513 East	513 West	514
1981					
1982					
1983					
1984					
1985					
1986					
1987					
1988					
1989			1.64		
1990			0.77		
1991			1.54		
1992			1.30		
1993			0.45		
1994			1.61		
1995		0.02	0.66		0.56
1996		0.05	0.47		0.00
1997		0.05	0.46		0.17
1998		0.00	0.14		0.02
1999		0.04	0.65		0.36
2000		0.10	0.13	0.17	0.19
2001		0.43	2.08	1.17	0.38
2002	0.13	0.29	1.38	0.85	0.89
2003	0.22	0.27	1.75	1.22	0.68
2004	0.18	0.36	1.75	0.67	1.20
2005	1.59	1.36	1.77	0.82	0.82
2006	0.58	1.13	0.84	0.82	0.32
2007	0.84	1.34	2.01	1.27	1.22
2008	0.42	0.83	1.08	0.97	0.24
2009	0.69	0.48	1.25	0.45	0.13
2010	0.28	0.72	0.80	0.47	0.45
2011	0.41	1.10	2.33	0.67	0.63
2012	0.53	0.73	1.06	0.22	0.21
2013	0.10	0.20	0.48	0.12	0.09
2008 - 2013 ave	0.40	0.68	1.17	0.48	0.29
25th	0.15	0.04	0.47	0.68	0.17
median	0.17	0.05	0.77	1.01	0.36
75th	0.19	0.27	1.57	1.18	0.56

Table 5.2.4.2.E

SURVEY LOBSTER ENCOUNTER RATE						
Proportion of postive tows						
Survey	NEFSC		ME/NH		MA 514	
	fall	spring	fall	spring	fall	spring
1981	0.40	0.34			0.73	0.86
1982	0.33	0.29			0.70	0.50
1983	0.40	0.22			0.76	0.76
1984	0.39	0.18			0.76	0.76
1985	0.43	0.28			0.67	0.71
1986	0.42	0.28			0.83	0.68
1987	0.29	0.28			0.54	0.85
1988	0.35	0.32			0.58	0.76
1989	0.39	0.18			0.95	0.78
1990	0.39	0.30			0.95	0.86
1991	0.41	0.28			0.94	0.87
1992	0.37	0.31			0.77	0.93
1993	0.38	0.32			0.82	0.97
1994	0.41	0.27			0.93	1.00
1995	0.39	0.26			0.93	0.93
1996	0.45	0.34			0.95	0.91
1997	0.42	0.36			0.86	0.93
1998	0.42	0.33			0.69	0.76
1999	0.47	0.34			0.91	0.73
2000	0.42	0.39	0.94		0.98	0.93
2001	0.44	0.39	0.86	0.88	0.72	0.93
2002	0.55	0.50	0.95	0.94	0.73	0.91
2003	0.44	0.46	0.85	0.92	0.55	0.82
2004	0.42	0.49	0.86	0.89	0.56	0.84
2005	0.46	0.44	0.91	0.95	0.67	0.95
2006	0.56	0.48	0.93	0.93	0.88	0.91
2007	0.45	0.44	0.85	0.97	0.54	0.51
2008	0.51	0.52	0.86	0.92	0.75	0.83
2009	0.58	0.57	0.92	0.98	0.87	0.89
2010	0.68	0.61	0.93	0.98	0.98	0.87
2011	0.72	0.54	0.96	0.99	0.85	0.89
2012	0.67	0.61	0.98	0.98	0.95	0.91
2013	0.70	0.58	0.93	1.00	0.95	0.96
2008 - 2013 ave	**0.64**	**0.57**	**0.93**	**0.98**	**0.89**	**0.89**

25th	0.39	0.28	0.86	0.90	0.70	0.76
median	0.41	0.31	0.90	0.92	0.79	0.85
75th	0.42	0.34	0.94	0.93	0.93	0.93

Table 5.2.4.3. GOM / GBK Combined Fishery Performance Indicators

	EFFORT	TOTAL GOM/GBK LANDINGS	PARTIAL LANDINGS	GROSS CPUE	SET OVER DAYS			PRICE PER POUND		REVENUE		REVENUE PER TRAP	
Description	Traps	Pounds (all sources)	Pounds from jurisdictions with effort data	Landings / Traps	Average Soak Time of Traps			Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI	Un-adjusted	Adjusted to Unprocessed Fish CPI
Jurisdiction	*ME & MA*	*All*	*ME & MA*	*ME & MA*	*ME GOM*	*MA GOM*	*MA GBK*			*All*	*All*	*ME & MA*	*ME & MA*
1981		35,146,476	33,099,940		3.0			$2.19	$3.01	$77,003,037	$105,672,027		
1982	2,417,975	35,208,814	32,833,514	13.6	3.3			$2.31	$2.69	$81,267,478	$94,638,353	$31	$36
1983	2,628,564	36,412,200	33,212,963	12.6	3.4			$2.42	$2.55	$88,131,219	$92,858,589	$31	$32
1984	2,480,816	33,715,824	30,496,815	12.3	3.5			$2.69	$2.39	$90,708,129	$80,412,883	$33	$29
1985	2,114,708	35,376,280	32,551,112	15.4	3.7			$2.49	$2.35	$88,073,394	$82,974,247	$38	$36
1986	1,963,663	33,199,366	30,893,812	15.7	4.0			$2.62	$2.15	$86,937,043	$71,446,857	$41	$34
1987	2,304,843	33,660,903	31,329,384	13.6	3.6			$3.09	$1.92	$104,173,328	$64,626,927	$42	$26
1988	2,449,421	35,522,311	33,333,229	13.6	3.8			$2.99	$1.81	$106,050,066	$64,210,494	$41	$25
1989	2,391,747	39,758,078	37,529,917	15.7	4.1			$2.80	$1.88	$111,345,338	$74,784,040	$44	$30
1990	2,544,594	45,580,927	43,030,889	16.9	4.0	2.9	6.8	$2.48	$1.83	$113,075,013	$83,232,151	$42	$31
1991	2,450,794	48,051,041	44,801,565	18.3	3.8	2.8	6.7	$2.59	$1.80	$124,460,362	$86,392,767	$47	$33
1992	2,439,160	42,860,881	40,070,688	16.4	4.3	2.8	6.8	$2.90	$1.72	$124,510,437	$73,802,991	$48	$28
1993	2,219,682	44,857,936	42,444,913	19.1	4.5	3.0	6.8	$2.77	$1.72	$124,035,370	$77,044,337	$53	$33
1994	3,204,908	55,117,563	53,070,047	16.6	3.8	3.2	6.9	$2.96	$1.67	$163,278,980	$91,791,455	$49	$28
1995	2,827,658	53,299,862	51,097,667	18.1	3.4	3.2	7.0	$3.06	$1.57	$163,335,545	$83,879,145	$55	$28
1996	3,034,534	51,287,667	49,290,877	16.2	4.5	3.5	6.8	$3.39	$1.62	$173,649,857	$83,096,424	$55	$26
1997	2,954,814	61,372,655	59,559,913	20.2	4.6	3.6	8.3	$3.29	$1.51	$201,842,453	$92,624,690	$66	$30
1998	3,175,971	59,446,330	57,864,129	18.2	4.5	3.7	6.8	$3.19	$1.47	$189,339,987	$87,288,053	$58	$27
1999	3,351,254	69,106,003	67,224,810	20.1	4.8	3.5	7.1	$3.70	$1.41	$255,393,216	$97,334,616	$74	$28
2000	3,073,957	72,711,978	70,555,059	23.0	4.8	3.6	7.1	$3.61	$1.36	$262,828,430	$98,659,124	$83	$31
2001	3,254,778	61,518,028	59,209,636	18.2	5.1	3.8	7.1	$3.50	$1.41	$215,602,316	$86,664,215	$64	$26
2002	3,399,620	77,961,334	75,692,191	22.3	5.0	3.7	6.7	$3.54	$1.41	$275,762,764	$109,599,140	$79	$31
2003	3,488,781	68,157,594	65,376,605	18.7	5.2	3.9	7.1	$3.96	$1.38	$269,572,509	$93,805,388	$74	$26
2004	3,500,918	85,981,298	82,296,703	23.5	4.8	3.9	7.6	$4.16	$1.30	$357,298,937	$112,025,521	$98	$31
2005	3,539,075	82,566,804	79,066,371	22.3	5.4	4.1	7.9	$4.73	$1.21	$390,618,186	$99,700,757	$106	$27
2006	3,534,125	87,164,859	83,563,109	23.6	5.1	4.1	7.7	$4.21	$1.15	$366,722,922	$100,089,782	$99	$27
2007	3,526,988	76,642,931	73,214,743	20.8	5.2	4.1	7.4	$4.55	$1.16	$348,534,363	$88,763,250	$94	$24
2008	3,454,643	84,246,549	80,977,742	23.4	5.2	4.5	6.9	$3.71	$1.10	$312,144,746	$92,759,267	$87	$26
2009	3,366,769	97,122,170	93,376,406	27.7	4.9	4.6	6.5	$3.09	$1.27	$299,906,010	$123,255,444	$86	$35
2010	3,304,684	113,487,733	108,912,224	33.0	5.2	4.6	6.3	$3.44	$1.15	$390,006,875	$130,724,631	$113	$38
2011	3,336,811	123,222,174	118,333,016	35.5	4.9	4.4	5.8	$3.35	$1.17	$412,738,609	$144,751,699	$119	$42
2012	3,314,103	146,093,780	140,895,025	42.5	NA	4.2	6.2	$2.87	$1.16	$419,370,212	$169,518,854	$122	$49
2013	3,263,241	146,427,940	141,923,718	43.5	NA	4.4	6.4	$2.89	$1.00	$423,176,747	$146,427,940	$126	$43
2008 - 2013 ave	**3,340,042**	**118,433,391**	**114,069,688**	**34.3**	**5.1**	**4.5**	**6.3**	**$3.22**	**$1.14**	**$376,223,866**	**$134,572,972**	**$109**	**$39**
25th	2,423,271	35,744,783	33,243,030	15.5	3.7	3.1	6.8	$2.64	$1.48	$104,642,513	$77,886,474	$41	$27
median	2,586,579	46,815,984	43,916,227	16.7	4.1	3.5	6.8	$2.97	$1.72	$124,485,400	$85,135,956	$48	$29
75th	3,150,468	60,891,074	58,873,259	18.6	4.6	3.7	7.1	$3.36	$1.91	$198,716,837	$92,800,115	$62	$32

Table 6.2.1. Configuration of basecase models for lobster in this assessment by stock area.

Item	GOM	GBK	GOMGBK	SNE
Model years	1979-2014 with quarterly time steps			
Sexes	Separate population dynamics (recruitment, growth, and mortality)			
Sizes	35 bins each 5 mm starting at 53 mm CL (i.e. 53-57, 58-62, …, 223+ mm CL)			
Recruitment	Log recruits independent normal			
Log expected value	Linear in year	Quadratic in year	Linear in year	Quadratic in year
Variance	Calculated internally from recruit dev parameters			
Proportion recruitment each season	Winter 0%; Spring 0%; Summer 66%; Winter 34%			
Size distribution recruits	Sex specific beta distributions with estimated shape and scale parameters over user-specified range of size bins (5 for GOM and SNE, 25 for GBK)			
Spawning season	Summer			
Age at recruitment for SR plots	5 y			
Natural mortality rate	M=0.15 y^{-1} all size groups, quarters and years			M=0.15 y^{-1} all size groups 1979-1997, then 0.285 y^{-1}
Maturity at length	ASMFC (2006), p. 9 (area specific)			
CL-weight parameters	Updated area- and sex specific			
Growth transition matrix	Updated using data for GOM and GBK			Updated using data for SNE
Initial abundance	Sex specific parameters estimated in model			
Landings data	Catch weight by quarter and sex			
Assumed errors	Normal distribution with CV=10%			
Commercial and survey length data	>=20 lobsters with >=90% of individuals sexed to qualify as a "trip"; year must have >= 10 trips (including trips from other years); offshore areas also require data from at least two years			
Plus groups for GOF	Dynamic binning (accumulate from above and below until proportions in first and last size group at least 0.01)			
Assumed errors	Robust likelihood from Fournier et al. (1990)			
Assumed sample sizes	Year specific. Tuned to match trend and scale of effective sample size from goodness of fit in preliminary run. Always <= 400.			
Commercial selectivity	Components for legal size regulations, gear regulations and conservation discards for v-notches and ovigerous females specified. Component for other selectivity not used.			
Survey data	Bottom trawl survey data are mean number per tow for one sex in one quarter. Ventless trap data are			
Survey catchability	Closed form MLE for lognormal surveys (median unbiased). Linear or nonlinear.			
Assumed errors	Assumed Cauchy distributed with constant log scale variance estimated internally or fixed (short time			
Survey selectivity	Double logistic (ascending, descending or domed variants), see Tables MC2-MC5.			
Priors	None			
Likelihood weights on all data and recruitment	Weights =1 in basecase runs			

Table 6.2.2. Survey data, selectivity and catchability configuration in the basecase model for GOM.

No.	Agency/Type/Season/Sex	Name in plots	Years	N years	Linear / nonlinear	Selectivity	N parameters estimated	Notes
1	Not used							
2								
3	Ventless traps, summer, females	VtsF3	2006-2012	7	Linear	Domed	4	
4	Ventless traps, summer, females	VtsM3	2006-2012	7	Linear	Domed	4	
5	NEFSC Albatross bottom trawl, spring females	NmfsF2	1979-2014	36	Exponential	Ascending	2	
6	NEFSC Albatross bottom trawl, spring males	NmfsM2	1979-2014	36	Exponential	Ascending	2	
7	NEFSC Albatross bottom trawl, fall females	NmfsF4	1979-2014	36	Exponential	Ascending	2	
8	NEFSC Albatross bottom trawl, fall males	NmfsM4	1979-2014	36	Saturation	Ascending	2	
9	MA bottom trawl, spring females	MaF2	1982-2014	33	Saturation	Domed	4	
10	MA bottom trawl, spring males	MaM2	1982-2014	33	Saturation	Domed	3	Ascending L50% fixed
11	MA bottom trawl, fall females	MaF4	1982-2014	33	Saturation	Descending	2	
12	MA bottom trawl, fall males	MaM4	1982-2014	33	Saturation	Descending	2	
13	MENH bottom trawl, spring females	MeF2	2001-2014	14	Linear	Descending	2	
14	MENH bottom trawl, spring females	MeM2	2001-2014	14	Linear	Descending	2	
15	MENH bottom trawl, fall females	MeF4	2000-2014	15	Linear	Descending	2	
16	MENH bottom trawl, fall females	MeM4	2000-2014	15	Linear	Descending	2	

Table 6.2.3. Survey data, selectivity and catchability configuration in the basecase model for GBK. This model was not accepted by the American Lobster Technical Committee, should not be used for management purposes, and the figures are provided for diagnostic purposes only

No.	Agency/Type/Season/Sex	Name in plots	Years	N years	Linear / nonlinear	Selectivity	N parameters estimated	Notes
1	NEFSC Albatross bottom trawl, spring females	NMFSF2	1979-2014	36	Linear	Domed	4	
2	NEFSC Albatross bottom trawl, spring males	NMFSM2	1979-2014	36	Linear	Ascending	1	Ascending L50 fixed
3	NEFSC Albatross bottom trawl, fall females	NMFSF4	1979-2014	36	Linear	Ascending	1	Ascending L50 fixed
4	NEFSC Albatross bottom trawl, fall males	NMFSM4	1979-2014	36	Linear	Ascending	1	Ascending slope fixed
5	Not used							

Table 6.2.4. Survey data, selectivity and catchability configuration in the basecase model for GOM/GBK.

No.	Agency/Type/Season/Sex	Name in plots	Years	N years	Linear/ nonlinear	Selectivity	N parameters estimated	Notes
1	Not used							
2								
3	Ventless traps, summer, females	VtsF3	2006-2012	7	Linear	Domed	3	Ascending L50 fixed
4	Ventless traps, summer, females	VtsM3	2006-2012	7	Linear	Domed	3	Ascending L50 fixed
5	NEFSC Albatross bottom trawl, spring females	NmfsF2	1979-2014	36	Exponential	Domed	4	
6	NEFSC Albatross bottom trawl, spring males	NmfsM2	1979-2014	36	Exponential	Ascending	2	
7	NEFSC Albatross bottom trawl, fall females	NmfsF4	1979-2014	36	Exponential	Domed	4	
8	NEFSC Albatross bottom trawl, fall males	NmfsM4	1979-2014	36	Linear	Ascending	2	
9	MA bottom trawl, spring females	MaF2	1982-2014	33	Saturation	Domed	3	Ascending L50 fixed
10	MA bottom trawl, spring males	MaM2	1982-2014	33	Saturation	Domed	4	
11	MA bottom trawl, fall females	MaF4	1982-2014	33	Saturation	Domed	3	Ascending L50 fixed
12	MA bottom trawl, fall males	MaM4	1982-2014	33	Saturation	Domed	3	Ascending slope fixed
13	MENH bottom trawl, spring females	MeF2	2001-2014	14	Linear	Domed	3	Ascending L50 fixed
14	MENH bottom trawl, spring females	MeM2	2001-2014	14	Linear	Domed	3	Descending slope fixed
15	MENH bottom trawl, fall females	MeF4	2000-2014	15	Linear	Domed	2	Descending slope & L50 fixed
16	MENH bottom trawl, fall females	MeM4	2000-2014	15	Linear	Domed	3	Descending L50 fixed

Table 6.2.5. Survey data, selectivity and catchability configuration in the basecase model for SNE.

No.	Agency/Type/Season/Sex	Name in plots	Years	N years	Linear/ nonlinear each sex	Selectivity	N parameters estimated	Notes
1	NEFSC Albatross bottom trawl, spring females and males	NfscQ2	1979-2014	36	Both linear	Ascending	2	
2	NEFSC Albatross bottom trawl, fall females	NfscFQ4	1979-2014	36	Linear	Ascending	2	
3	NEFSC Albatross bottom trawl, fall males	NfscMQ4	1979-2014	36	Linear	Ascending	2	
4	CT bottom trawl, spring, females and males	CTQ2	1984-2014	31	Both exponential	Descending	2	
5	CT bottom trawl , fall, females and males	CTQ4	1984-2009, 2011-2014	30	Both exponential	Descending	2	
6	RI bottom trawl, spring, females	RIFQ2	1982-2014	33	Linear	Descending	1	Descending L50 fixed
7	RI bottom trawl, spring, males	RIMQ2	1982-2014	33	Linear	Descending	2	
8	RI bottom trawl, fall, females	RIFQ4	1982-2014	33	Linear	Descending	2	
9	RI bottom trawl, fall, males	RIMQ4	1982-2014	33	Linear	Descending	2	
10	Ventless traps, summer, females and males	VTSQ3	2006-2012	7	Both saturate	Descending	2	
11	MA bottom trawl, spring, females and males	MAQ2	1979-2014	36	Linear	Descending	2	
12	NEAMAP bottom trawl, spring, females	NEAMAPFQ2	2008-2014	6	Both linear	Descending	2	2014 index only
13	NEAMAP bottom trawl, spring, males	NEAMAPMQ2	2008-2014	6	Both linear	Descending	2	2014 index only
14	NEAMAP bottom trawl , fall, females	NEAMAPFQ4	2007-2014	7	Both linear	Descending	1	2014 index only Descending slope fixed
15	NEAMAP bottom trawl, fall, males	NEAMAPMQ4	2007-2014	7	Both linear	Descending	2	2014 index only
16	NJ bottom trawl, spring, females and males	NJQ2	1989-2014	26	Both linear	Descending	2	

Table 6.3.1.1. Annual recruitment, reference abundance, effective exploitation and spawning biomass estimates generated by the GOM basecase model (1979-2013).

Year	Female				Male			Both sexes		
	Recruitment (millions)	Reference abundance (millions)	Effective exploitation	Spawning biomass (mt)	Recruitment (millions)	Reference abundance (millions)	Effective exploitation	Recruitment (millions)	Reference abundance (millions)	Effective exploitation
1979	9	27	0.42	3,712	6	23	0.53	15	49	0.47
1980	46	26	0.59	4,621	38	20	0.58	83	46	0.59
1981	12	24	0.58	2,393	13	21	0.59	25	45	0.59
1982	25	29	0.5	2,115	19	24	0.61	43	53	0.55
1983	13	29	0.48	3,122	15	23	0.55	28	52	0.51
1984	36	28	0.46	3,915	30	22	0.53	66	49	0.49
1985	10	28	0.57	4,426	17	24	0.61	27	52	0.59
1986	34	27	0.59	3,011	15	24	0.59	49	52	0.59
1987	12	26	0.48	2,513	14	23	0.56	26	48	0.52
1988	38	28	0.46	3,447	59	21	0.53	97	49	0.49
1989	23	31	0.44	4,082	24	30	0.48	47	61	0.46
1990	35	36	0.47	4,433	11	40	0.5	47	76	0.48
1991	42	38	0.53	4,757	32	38	0.59	74	76	0.56
1992	34	40	0.56	4,295	37	30	0.56	71	70	0.56
1993	32	43	0.5	3,821	19	33	0.47	51	75	0.49
1994	25	44	0.5	4,939	33	37	0.56	58	81	0.53
1995	63	42	0.52	5,769	35	35	0.52	99	77	0.52
1996	61	44	0.47	5,279	50	38	0.51	111	82	0.49
1997	46	59	0.49	6,465	22	45	0.55	67	104	0.52
1998	47	67	0.54	7,676	42	45	0.52	89	112	0.53
1999	28	63	0.5	7,291	51	45	0.49	79	108	0.5
2000	58	58	0.54	7,940	21	50	0.54	79	109	0.54
2001	40	52	0.45	6,802	76	49	0.49	116	102	0.46
2002	55	59	0.52	8,313	33	56	0.52	88	115	0.52
2003	40	59	0.47	7,271	66	61	0.48	105	120	0.48
2004	48	62	0.49	7,326	42	66	0.53	90	128	0.51
2005	48	60	0.51	7,740	45	65	0.53	93	125	0.52
2006	48	59	0.52	7,316	56	62	0.5	104	121	0.51
2007	73	60	0.47	7,768	70	63	0.46	143	123	0.47
2008	54	67	0.46	8,172	54	73	0.5	108	140	0.48
2009	99	77	0.44	9,948	118	78	0.47	217	155	0.46
2010	97	89	0.46	9,928	60	94	0.51	157	183	0.48
2011	125	106	0.48	13,777	138	104	0.45	264	210	0.47
2012	159	123	0.5	14,691	126	124	0.54	285	247	0.52
2013	161	147	0.37	17,042	87	136	0.52	249	283	0.44

Table 6.3.1.2. Likelihood profile over the mean log recruitment parameter in a preliminary GOM basecase assessment model run. "Less 20%", for example, is for the run with mean log recruitment fixed at log(exp(r_s)*0.8), where r_s is the estimate from the basecase model. Values shown are differences between the likelihood indicated and the smallest likelihood in the row. The lowest likelihoods with values of zero are highlighted.

Source	Sex	Type	Less 20%	Basecase	Plus 20%
NA	NA	NLL.weighted.total	73.47	***0***	150.42
Comm	Fem	NLL.Catch	***0***	15.74	136.75
Comm	Mal	NLL.Catch	***0***	2.05	87.9
cVtsF3	Fem	NLL.SurveyTrend	***0***	0.15	0.05
dVtsM3	Mal	NLL.SurveyTrend	0.2	0.5	***0***
eAlxF2	Fem	NLL.SurveyTrend	1.4	***0***	1.42
fAlxM2	Mal	NLL.SurveyTrend	2.69	0.98	***0***
gAlxF4	Fem	NLL.SurveyTrend	0.87	***0***	2.85
hAlxM4	Mal	NLL.SurveyTrend	1.88	0.34	***0***
iMaF2	Fem	NLL.SurveyTrend	***0***	0.14	0.34
jMaM2	Mal	NLL.SurveyTrend	***0***	0.14	0.09
kMaF4	Fem	NLL.SurveyTrend	0.74	***0***	0.08
lMaM4	Mal	NLL.SurveyTrend	***0***	0.32	0.64
mMeF2	Fem	NLL.SurveyTrend	***0***	0.26	0.11
nMeM2	Mal	NLL.SurveyTrend	2.02	1.52	***0***
oMeF4	Fem	NLL.SurveyTrend	***0***	0.29	1.04
pMeM4	Mal	NLL.SurveyTrend	***0***	0.14	1.31
Comm	Fem	NLL.LenComps	10.53	***0***	1.63
Comm	Mal	NLL.LenComps	***0***	16.45	17.28
cVtsF3	Fem	NLL.LenComps	***0***	2.9	1.98
dVtsM3	Mal	NLL.LenComps	3.93	***0***	6.11
eAlxF2	Fem	NLL.LenComps	24.22	20.55	***0***
fAlxM2	Mal	NLL.LenComps	9.03	3.45	***0***
gAlxF4	Fem	NLL.LenComps	16.66	24.41	***0***
hAlxM4	Mal	NLL.LenComps	14.02	***0***	4.88
iMaF2	Fem	NLL.LenComps	***0***	21.77	25.04
jMaM2	Mal	NLL.LenComps	0.7	0.04	***0***
kMaF4	Fem	NLL.LenComps	33.74	3.15	***0***
lMaM4	Mal	NLL.LenComps	13.94	3.5	***0***
mMeF2	Fem	NLL.LenComps	***0***	7.56	5.67
nMeM2	Mal	NLL.LenComps	***0***	5.81	2.32
oMeF4	Fem	NLL.LenComps	8.02	2.84	***0***
pMeM4	Mal	NLL.LenComps	4.5	1.62	***0***
NA	NA	NLL.XtraRecruitConstraint	33.18	4.85	0

Table 6.3.1.3. Mean (years 2011-2013) effective exploitation and reference abundance estimates for GOM lobster (sexes combined). From preliminary basecase and sensitivity runs. The basecase run is in the top row. “Relative to mean” is the ratio of the estimate shown to the mean in all years from the same model run and is meant to describe trends. “Compare to basecase” is the percent change from the basecase estimate on the first line (e.g. the comparison to basecase for exploitation in the M0.1 run is 0.50/0.48-1=5%).

Run	Exploitation	Relative to mean	Compare to	Abundance (millions)	Relative to mean	Compare to basecase
Basecase	0.48	0.94	0%	247	2.27	0%
M=0.1	0.5	0.93	5%	236	2.29	-4%
M=0.2	0.46	0.96	-3%	247	2.21	0%
No recruit covariates	0.47	0.92	-1%	258	2.29	5%
Old growth matrix	0.47	0.96	-1%	239	2.12	-3%
Gear Selectivity Shift Right	0.36	0.9	-24%	256	2.11	4%
Gear Selectivity Shift Left	0.51	0.94	7%	234	2.23	-5%
All surveys linear	0.47	0.94	-2%	243	2.24	-1%
Old conservation selectivity	0.46	0.9	-3%	249	2.3	1%
GOM stock specific sensitivity analyses						
Down weight all length data	0.5	0.97	5%	214	2.12	-13%
NEFSC fall survey trend weight=30	0.47	0.92	0%	217	1.84	-12%
NEFSC spring survey trend weight=30	0.5	0.98	6%	220	2.08	-11%
Drop Massachusetts surveys	0.48	0.94	0%	249	2.29	1%
No Cauchy	0.47	0.94	0%	249	2.28	1%
Days 12-18°C	0.47	0.92	0%	255	2.34	3%
Summary Minimum and Maximum - all runs						
Min	0.36	0.9	-24%	214	1.84	-13%
Max	0.51	0.98	7%	258	2.34	5%

Table 6.3.2.1. Annual reference abundance and effective exploitation estimates generated by the empirical basecase model for GBK (1979-2013).

Year	Female		Male		Both sexes	
	Reference abundance (n/tow)	Effective exploitation	Reference abundance (n/tow)	Effective exploitation	Reference abundance (n/tow)	Effective exploitation
1979	0.4	1.4	0.3	2.34	0.7	1.79
1980	0.3	1.86	0.4	1.82	0.7	1.84
1981	0.4	1.53	0.4	1.96	0.8	1.73
1982	0.5	1.25	0.5	1.53	0.9	1.39
1983	0.4	1.68	0.5	1.75	0.8	1.72
1984	0.3	2.1	0.3	2.57	0.6	2.33
1985	0.3	2.22	0.3	2.78	0.6	2.5
1986	0.6	1.02	0.6	1.14	1.1	1.08
1987	0.4	1.5	0.5	1.57	0.9	1.54
1988	0.8	0.75	0.9	0.84	1.8	0.8
1989	0.5	1.15	0.6	1.22	1.1	1.19
1990	0.5	1.29	0.5	1.74	0.9	1.52
1991	0.5	1.38	0.3	2.63	0.8	1.89
1992	0.6	1.31	0.3	2.85	0.9	1.87
1993	0.5	1.46	0.4	2.01	0.9	1.71
1994	0.3	2.12	0.3	1.93	0.6	2.02
1995	0.4	1.71	0.2	3.59	0.5	2.29
1996	0.4	1.45	0.3	1.78	0.7	1.58
1997	0.4	1.54	0.4	1.46	0.8	1.5
1998	0.4	1.57	0.3	1.7	0.8	1.63
1999	0.7	1.1	0.5	1.39	1.2	1.22
2000	0.5	1.37	0.5	1.2	1	1.29
2001	0.8	0.92	0.5	1.36	1.2	1.08
2002	0.9	0.98	0.5	1.28	1.4	1.09
2003	0.8	1.26	0.5	1.84	1.3	1.48
2004	0.6	2.04	0.2	4.29	0.8	2.62
2005	0.6	2.32	0.2	5.67	0.8	3.08
2006	0.8	1.97	0.2	4.45	1	2.45
2007	0.8	1.55	0.2	3.37	1	1.95
2008	1.4	0.93	0.2	2.82	1.6	1.22
2009	1.4	0.97	0.3	2.83	1.6	1.26
2010	0.9	1.67	0.2	3.82	1.1	2.07
2011	1.6	1.01	0.3	2.53	1.9	1.26
2012	1.2	1.27	0.2	3.04	1.5	1.56
2013	1.1	1.46	0.2	3.35	1.3	1.8

Table 6.3.2.2. Likelihood profile over the mean log recruitment parameter in the GBK University of Maine assessment model. "Less 20%", for example, is for the run with mean log recruitment fixed at log(exp(r_s)*0.8), where r_s is the estimate from the "best fit" model with the lowest unconstrained negative log likelihood. Values shown are differences between the likelihood indicated and the smallest likelihood in the row. The lowest likelihoods with values of zero are highlighted. The best fit model was not accepted by the American Lobster Technical Committee, should not be used for management purposes, and the tables are provided for diagnostic purposes only.

Source	Sex	Type	Less 20%	Best fit	Plus 20%
NA	NA	NLL.weighted.total	41.9	***0***	34.7
Comm	Fem	NLL.Catch	***0***	18.2	6.6
Comm	Mal	NLL.Catch	***0***	8.4	33.6
NMFSF2	Fem	NLL.SurveyTrend	***0***	6	14.8
NMFSM2	Mal	NLL.SurveyTrend	4.4	0.9	***0***
NMFSF4	Fem	NLL.SurveyTrend	***0***	3.8	12.1
NMFSM4	Mal	NLL.SurveyTrend	4.1	***0***	5
Comm	Fem	NLL.LenComps	***0***	3.3	2.9
Comm	Mal	NLL.LenComps	***0***	2.7	1.2
NMFSF2	Fem	NLL.LenComps	10.4	3.8	***0***
NMFSM2	Mal	NLL.LenComps	0.5	1.6	***0***
NMFSF4	Fem	NLL.LenComps	12.9	***0***	15.2
NMFSM4	Mal	NLL.LenComps	29.1	1.6	***0***
NA	NA	NLL.XtraRecruitConstraint	21.9	9.9	***0***

Table 6.3.2.3. Mean (years 2011-2013) effective exploitation and reference abundance estimates for GBK lobster (sexes combined). From University of Maine Model sensitivity analysis runs. The "best fit" run (with the default model configuration) is in the top row. "Relative to mean" is the ratio of the estimate shown to the mean in all years from the same model run. The best fit model was not accepted by the American Lobster Technical Committee, should not be used for management purposes and the figures are provided for diagnostic purposes only.

Run	Exploitation	Relative to mean	Compare to best fit	Abundance (millions)	Relative to mean	Compare to best fit
Best fit	0.34	0.53	0%	6	1.81	0%
M=0.1	0.34	0.51	1%	5.9	1.87	-1%
M=0.2	0.32	0.54	-4%	6.1	1.77	3%
No recruit covariates	0.41	0.63	23%	5.1	1.61	-15%
Old growth matrix	0.34	0.53	0%	6	1.81	0%
Gear selectivity shift right	0.22	0.43	-34%	8.9	2.22	50%
Gear selectivity shift left	0.32	0.49	-3%	6.5	1.96	9%
Old conservation selectivity	0.35	0.54	4%	5.9	1.79	-1%
GBK stock specific sensitivity analyses						
Force fit to trends	0.38	0.61	13%	4.8	1.22	-19%
Summary Minimum and Maximum - all runs						
Min	0.22	0.43	-34%	4.8	1.22	-19%
Max	0.41	0.63	23%	8.9	2.22	50%

Table 6.3.3.1. Annual recruitment, reference abundance, effective exploitation and spawning biomass estimates generated by the basecase GOM/GBK model (1979-2013).

Year	Female				Male			Both sexes		
	Recruitment (millions)	Reference abundance (millions)	Effective exploitation	Spawning biomass (mt)	Recruitment (millions)	Reference abundance (millions)	Effective exploitation	Recruitment (millions)	Reference abundance (millions)	Effective exploitation
1979	37	23	0.49	6,628	8	25	0.5	46	48	0.5
1980	33	23	0.55	4,086	45	22	0.55	78	45	0.55
1981	28	30	0.49	2,398	22	23	0.58	49	52	0.53
1982	10	36	0.51	3,415	19	30	0.48	29	66	0.5
1983	24	34	0.46	3,900	24	33	0.56	48	67	0.5
1984	27	29	0.49	4,877	18	28	0.56	45	58	0.53
1985	21	28	0.5	4,438	22	26	0.55	43	54	0.52
1986	27	30	0.53	3,936	25	25	0.55	52	55	0.54
1987	36	29	0.48	3,672	22	26	0.53	58	55	0.5
1988	32	33	0.38	4,223	28	28	0.5	59	60	0.44
1989	20	41	0.4	6,095	37	30	0.49	57	71	0.44
1990	34	43	0.46	7,110	30	34	0.47	64	77	0.46
1991	41	39	0.44	6,621	27	39	0.48	68	78	0.46
1992	33	42	0.38	6,876	25	40	0.52	58	82	0.45
1993	30	49	0.51	8,662	27	37	0.51	57	86	0.51
1994	46	45	0.47	6,722	36	35	0.53	82	80	0.49
1995	28	45	0.46	7,109	69	36	0.46	96	81	0.46
1996	47	48	0.44	7,263	36	47	0.51	83	95	0.47
1997	60	50	0.43	8,101	17	57	0.57	77	107	0.5
1998	62	56	0.44	8,906	62	50	0.51	124	106	0.48
1999	54	67	0.44	9,408	50	46	0.49	104	113	0.46
2000	45	75	0.45	11,024	36	54	0.48	81	129	0.46
2001	72	75	0.42	12,779	65	60	0.53	136	135	0.47
2002	62	76	0.45	14,205	26	58	0.5	88	134	0.47
2003	33	80	0.32	14,081	80	61	0.47	113	141	0.38
2004	47	90	0.47	18,212	39	63	0.48	87	153	0.47
2005	53	73	0.5	15,426	63	70	0.5	116	142	0.5
2006	54	63	0.4	11,520	62	69	0.53	116	133	0.47
2007	71	69	0.38	13,397	69	70	0.5	140	139	0.44
2008	78	78	0.44	14,700	74	76	0.51	152	154	0.47
2009	82	86	0.41	14,196	92	82	0.51	174	168	0.46
2010	100	99	0.44	16,122	94	91	0.52	193	190	0.48
2011	142	108	0.44	17,242	143	102	0.49	285	210	0.46
2012	74	126	0.44	17,861	133	122	0.52	207	248	0.48
2013	97	144	0.51	21,606	90	142	0.51	187	286	0.51

Table 6.3.3.2. Likelihood profile over the mean log recruitment parameter in the GOM/GBK basecase assessment model run. "Less 20%", for example, is for the run with mean log recruitment fixed at log(exp(r_s)*0.8), where r_s is the estimate from the basecase model. Values shown are differences between the likelihood indicated and the smallest likelihood in the row. The lowest likelihoods with values of zero are highlighted.

Source	Sex	Type	Less 20%	Basecase	Plus 20%
NA	NA	NLL.weighted.total	131	***0***	180.3
Comm	Fem	NLL.Catch	***0***	6.41	132.56
Comm	Mal	NLL.Catch	12.02	***0***	117.55
VtsF3	Fem	NLL.SurveyTrend	0.21	0.13	***0***
VtsM3	Mal	NLL.SurveyTrend	0.07	0.04	***0***
NmfsF2	Fem	NLL.SurveyTrend	2.8	1.71	***0***
NmfsM2	Mal	NLL.SurveyTrend	***0***	2.21	1.59
NmfsF4	Fem	NLL.SurveyTrend	1.17	2.19	***0***
NmfsM4	Mal	NLL.SurveyTrend	***0***	0.92	1.99
MaF2	Fem	NLL.SurveyTrend	***0***	0.25	0.46
MaM2	Mal	NLL.SurveyTrend	***0***	0.01	0.05
MaF4	Fem	NLL.SurveyTrend	***0***	0.34	0.3
MaM4	Mal	NLL.SurveyTrend	***0***	0.81	1.65
MeF2	Fem	NLL.SurveyTrend	1.28	1.07	***0***
MeM2	Mal	NLL.SurveyTrend	1.34	0.63	***0***
MeF4	Fem	NLL.SurveyTrend	3.43	2.68	***0***
MeM4	Mal	NLL.SurveyTrend	0.5	***0***	0.07
Comm	Fem	NLL.LenComps	***0***	22.95	17.61
Comm	Mal	NLL.LenComps	***0***	3.96	8.09
VtsF3	Fem	NLL.LenComps	1.53	0.32	***0***
VtsM3	Mal	NLL.LenComps	3.54	***0***	0.03
NmfsF2	Fem	NLL.LenComps	25.65	14.21	***0***
NmfsM2	Mal	NLL.LenComps	17.82	8.15	***0***
NmfsF4	Fem	NLL.LenComps	0.21	7.48	***0***
NmfsM4	Mal	NLL.LenComps	19.28	22.53	***0***
MaF2	Fem	NLL.LenComps	12.95	***0***	4.49
MaM2	Mal	NLL.LenComps	2.52	***0***	6.76
MaF4	Fem	NLL.LenComps	4.36	3.55	***0***
MaM4	Mal	NLL.LenComps	7.31	***0***	3.27
MeF2	Fem	NLL.LenComps	7.78	***0***	1.59
MeM2	Mal	NLL.LenComps	9.78	4.41	***0***
MeF4	Fem	NLL.LenComps	19.93	0.88	***0***
MeM4	Mal	NLL.LenComps	12.49	7.79	***0***
NA	NA	NLL.XtraRecruitConstraint	42.89	0.01	***0***

Table 6.3.3.3. Mean annual effective exploitation and reference abundance estimates for GOM/GBK lobster (sexes combined) during 2011-2013 from basecase and sensitivity runs. Relative estimates are the reference estimates divided by the mean in all years. Columns labeled "Relative to mean" are the average effective exploitation or abundance during 2011-2013 divided by the average for all years in the same model run. Columns labeled "Relative to basecase" are relative to the basecase model value in the same table. The basecase run is in the top row. The "Old conservation selectivity" run (with conservation selectivity data from the last assessment) is not applicable because the combined GOM/GBK area was not included in ASMFC (2009).

Run	Exploitation	Relative to mean	Compare to basecase	Abundance (millions)	Relative to mean	Compare to basecase
Basecase	0.48	1.01	0%	248	2.14	0%
M=0.1	0.5	0.99	4%	250	2.23	1%
M=0.2	0.46	1.02	-4%	266	2.19	7%
No recruit covariates	0.479	1	-1%	244	2.13	-2%
Old growth matrix	0.53	1.01	10%	247	2.27	-1%
Gear selectivity shift	0.36	0.94	-25%	294	2.27	19%
Gear selectivity shift	0.5	0.98	3%	245	2.16	-1%
All surveys linear	0.49	1.01	0%	244	2.11	-2%
Old conservation selectivity	NA					
GOMGBK stock specific sensitivity runs						
No covariates-all linear	0.48	1	0%	239	2.1	-4%
NMFS female logistic	0.48	1.01	1%	248	2.14	0%
Summary Minimum and Maximum - all runs						
Min	0.36	0.94	-25%	239	2.1	-4%
Max	0.53	1.02	10%	294	2.27	19%

Table 6.3.4.1. Annual recruitment, reference abundance, effective exploitation and spawning biomass estimates generated by the SNE basecase model (1979-2013).

Year	Female				Male			Both sexes		
	Recruitment (millions)	Reference abundance (millions)	Effective exploitation	Spawning biomass (mt)	Recruitment (millions)	Reference abundance (millions)	Effective exploitation	Recruitment (millions)	Reference abundance (millions)	Effective exploitation
1979	6	6	0.3	875	4	4	0.37	9	10	0.33
1980	8	6	0.32	869	5	4	0.43	12	11	0.36
1981	6	7	0.29	849	5	5	0.36	10	12	0.32
1982	16	8	0.33	866	7	6	0.45	22	15	0.38
1983	6	10	0.42	911	9	7	0.49	15	17	0.45
1984	11	12	0.39	750	7	8	0.49	18	20	0.43
1985	16	13	0.46	823	5	10	0.45	20	23	0.46
1986	15	13	0.36	762	12	10	0.53	27	22	0.43
1987	9	16	0.35	999	9	9	0.4	18	25	0.37
1988	10	18	0.32	1,224	10	12	0.44	20	31	0.37
1989	15	19	0.35	1,435	7	13	0.41	22	33	0.38
1990	15	18	0.37	1,367	10	14	0.42	25	32	0.39
1991	15	18	0.38	1,222	7	13	0.48	23	31	0.42
1992	28	19	0.36	1,345	14	12	0.41	42	32	0.38
1993	4	22	0.4	1,562	11	14	0.45	15	35	0.42
1994	30	24	0.34	1,319	11	15	0.42	41	39	0.37
1995	20	26	0.31	1,661	12	16	0.45	32	42	0.36
1996	20	28	0.38	2,173	22	16	0.44	42	44	0.4
1997	18	30	0.42	2,053	12	19	0.39	30	49	0.41
1998	12	29	0.35	1,500	13	23	0.4	24	52	0.37
1999	8	25	0.39	1,440	14	19	0.38	22	44	0.39
2000	13	19	0.42	1,095	7	17	0.39	20	36	0.4
2001	7	13	0.37	803	6	15	0.37	12	28	0.37
2002	6	11	0.31	632	7	11	0.32	13	23	0.31
2003	8	10	0.23	742	7	10	0.39	15	20	0.3
2004	9	10	0.28	887	6	9	0.27	16	18	0.28
2005	5	9	0.25	782	6	9	0.29	10	18	0.27
2006	16	9	0.28	678	6	9	0.3	22	17	0.29
2007	4	9	0.22	644	6	8	0.22	10	17	0.22
2008	4	10	0.19	802	5	9	0.26	9	19	0.22
2009	5	10	0.22	931	2	8	0.25	7	19	0.23
2010	2	9	0.27	922	3	7	0.34	5	16	0.3
2011	3	7	0.21	774	1	5	0.24	4	12	0.22
2012	2	6	0.23	688	2	4	0.34	3	10	0.28
2013	2	5	0.26	624	0	3	0.37	3	8	0.3

Table 6.3.4.2. **Likelihood profile over the mean log recruitment parameter in the SNE basecase assessment model run.** "Less 20%", for example, is for the run with mean log recruitment fixed at log(exp(r_s)*0.8), where r_s is the estimate from the basecase model. Values shown are differences between the likelihood indicated and the smallest likelihood in the row. The lowest likelihoods with values of zero are highlighted.

Source	Sex	Type	Less 20%	Basecase	Plus 20%
NA	NA	NLL.weighted.total	***0***	33.28	179.33
Comm	Fem	NLL.Catch	0.7	***0***	45.81
Comm	Mal	NLL.Catch	***0***	5.31	86.92
NfscQ2	Fem	NLL.SurveyTrend	0.28	0.27	***0***
NfscQ2	Mal	NLL.SurveyTrend	***0***	0.02	2.41
NfscFQ4	Fem	NLL.SurveyTrend	1.79	1.79	***0***
NfscMQ4	Mal	NLL.SurveyTrend	1.72	1.81	***0***
CTQ2	Fem	NLL.SurveyTrend	***0***	0.25	1.79
CTQ2	Mal	NLL.SurveyTrend	1.35	***0***	1.73
CTQ4	Fem	NLL.SurveyTrend	***0***	0.25	1.7
CTQ4	Mal	NLL.SurveyTrend	***0***	2.13	3.57
RIFQ2	Fem	NLL.SurveyTrend	1.15	1.31	***0***
RIMQ2	Mal	NLL.SurveyTrend	0.44	***0***	1.18
RIFQ4	Fem	NLL.SurveyTrend	0.6	0.57	***0***
RIMQ4	Mal	NLL.SurveyTrend	0.46	***0***	0.88
VTSQ3	Fem	NLL.SurveyTrend	0.01	0.01	***0***
VTSQ3	Mal	NLL.SurveyTrend	0.01	***0***	0.01
MAQ2	Fem	NLL.SurveyTrend	0.5	0.52	***0***
MAQ2	Mal	NLL.SurveyTrend	0.75	0.56	***0***
NEAMAPFQ2	Fem	NLL.SurveyTrend	***0***	0.01	0.2
NEAMAPMQ2	Mal	NLL.SurveyTrend	0.02	***0***	0.06
NEAMAPFQ4	Fem	NLL.SurveyTrend	***0***	0	1.58
NEAMAPMQ4	Mal	NLL.SurveyTrend	***0***	0.03	0.4
NJQ2	Fem	NLL.SurveyTrend	2.69	2.66	***0***
NJQ2	Mal	NLL.SurveyTrend	0.29	0.61	***0***
Comm	Fem	NLL.LenComps	***0***	6.5	5.95
Comm	Mal	NLL.LenComps	***0***	15.88	9.53
NfscQ2	Fem	NLL.LenComps	***0***	0.2	3.01
NfscQ2	Mal	NLL.LenComps	2.34	2.83	***0***
NfscFQ4	Fem	NLL.LenComps	6.97	7.35	***0***
NfscMQ4	Mal	NLL.LenComps	0.42	3.05	***0***
CTQ2	Fem	NLL.LenComps	3.4	2.58	***0***
CTQ2	Mal	NLL.LenComps	5.79	0.38	***0***
CTQ4	Fem	NLL.LenComps	***0***	0.65	13.31
CTQ4	Mal	NLL.LenComps	0.54	3.01	***0***
RIFQ2	Fem	NLL.LenComps	5.46	5.13	***0***
RIMQ2	Mal	NLL.LenComps	***0***	5.91	7.47
RIFQ4	Fem	NLL.LenComps	7.86	9.42	***0***
RIMQ4	Mal	NLL.LenComps	2.39	***0***	3.16
VTSQ3	Fem	NLL.LenComps	0.17	***0***	11
VTSQ3	Mal	NLL.LenComps	0.9	***0***	10.47
MAQ2	Fem	NLL.LenComps	***0***	2.01	6.8
MAQ2	Mal	NLL.LenComps	2.36	***0***	1.36
NEAMAPFQ2	Fem	NLL.LenComps	0.06	***0***	6.87
NEAMAPMQ2	Mal	NLL.LenComps	***0***	0.03	2.25
NEAMAPFQ4	Fem	NLL.LenComps	1.1	1.22	***0***
NEAMAPMQ4	Mal	NLL.LenComps	***0***	0.12	2.51
NJQ2	Fem	NLL.LenComps	1.12	***0***	2.02
NJQ2	Mal	NLL.LenComps	***0***	2.51	4.06
NA	NA	NLL.XtraRecruitConstraint	3.94	3.94	***0***

Table 6.3.4.3. Mean (years 2011-2013) effective exploitation and reference abundance estimates for SNE lobster (sexes combined) from the basecase and sensitivity analysis runs. The basecase run is in the top row. "Relative to mean" is the ratio of the estimate shown to the mean in all years from the same model run. "Compare to basecase" is the percent change from the basecase estimate on the first line (e.g. the comparison to basecase for exploitation in the M = 0.1 run is 0.30/0.27-1=12%).

Run	Exploitation	Relative to mean	Compare to basecase	Abundance (millions)	Relative to mean	Compare to basecase
Final Basecase	0.27	0.77	0%	10	0.41	0%
Preliminary basecase	0.28	0.78	4%	9.8	0.43	-2%
M=0.1	0.3	0.78	12%	8.9	0.44	-11%
M=0.2	0.27	0.79	0%	10.3	0.38	3%
No recruit covariates	0.3	0.82	12%	10.1	0.45	1%
Old growth matrix	0.28	0.77	4%	9.8	0.44	-2%
Gear selectivity shift right	0.27	0.94	0%	9.9	0.37	-1%
Gear selectivity shift Light	0.29	0.77	8%	9.5	0.42	-5%
All surveys linear	0.28	0.78	4%	9.8	0.43	-2%
Old conservation selectivity	0.28	0.78	4%	9.9	0.43	-1%
SNE stock specific sensitivity analyses						
M=0.15 all years	0.3	0.8	12%	9.1	0.44	-9%
M ramp prior to 1998	0.28	0.78	4%	9.9	0.43	-1%
Days > 20°C recruit covariate	0.3	0.8	12%	10	0.48	0%
Swept Area abundance surveys	0.25	0.72	-7%	11.5	0.46	15%
Summary Minimum and Maximum - all runs						
Min	0.25	0.72	-7%	8.9	0.37	-11%
Max	0.3	0.94	12%	11.5	0.48	15%

Table 6.3.4.4. Area swept (a; based on wing spread) and total area covered (A) for selected bottom trawl survey programs in SNE. Used to compute swept-area abundance survey data for sensitivity analyses.

Survey	a (km^2)	A (km^2)
CT	0.0302	3,370
MA	0.0132	2,671
NEFSC	0.034	91,011
RI	0.0259	898

Table 6.4.1.1. Asymptotic confidence and MCMC credibility intervals with 95% coverage for mean reference abundance and effective exploitation during 2011-2013. From basecase University of Maine assessment models in this assessment. Confidence intevals are the estimate ± 1.96 σ using standard errors σ from lobster6f3.std output files for each stock area. The credibility intervals were computed from 1000 MCMC samples (1 million draws, saving 1 out of every 1000) using the emp.hpd() function from the TeachingDemos library in R.

Type of interval	Abundance		Exploitation	
	Lo bound	Hi bound	Lo bound	Hi bound
	GOM			
Asymptotic	239	258	0.47	0.48
MCMC	231	255	0.49	0.51
	GOMGBK			
Asymptotic	239	257	0.48	0.49
MCMC	233	255	0.49	0.5
	SNE			
Asymptotic	9.6	10.3	0.26	0.28
MCMC	9.2	10.2	0.27	0.31

Table 6.4.2.1. Historical retrospective results for comparison of basecase reference abundance estimates for 1982-2007 in ASMFC (2009) and this assessment. The mean ratio N_{new}/N_{old} is the average ratio of the new and old estimates in each year. GOM/GBK estimates from ASMFC (2009) were calculated from their estimates for the GOM and GBK stock areas.

Stock	Mean N_{new}/N_{old} ratio	Correlation
GOM	1.06	0.98
GBK	1.17	0.84
GOMGBK	1.15	0.97
SNE	1.25	0.99

Table 6.4.2.2. Mohn's rho (ρ) retrospective scores for basecase models in this assessment.

Stock	Reference abundance	Effective exploitation
GOM	0.018	-0.019
GBK	0.058	-0.025
GOMGBK	-0.044	0.038
SNE	-0.074	0.053

Table 7.3.1. Current (2011-2013) reference estimates for each stock, and threshold and target abundance (millions) and effective exploitation for the GOM, GBK, GOM/GBK, and SNE stocks. Red shading indicates that the estimate exceeds the threshold reference point. Green shading indicates that the estimate exceeds the target reference point.

	GOM	GBK	GOM/GBK	SNE
Abundance (millions)	*Model*	*Empirical*	*Model*	*Model*
2011 - 2013 reference	247	1.57	248	***10***
Threshold (25th percentile)	52	0.8	66	24
Target (75th percentile GOM & GBK, 50th percentile SNE)	103	1.1	107	32

	GOM	GBK	GOM/GBK	SNE
Effective exploitation	*Model*	*Empirical*	*Model*	*Model*
2011 - 2013 reference	0.48	1.54	0.48	0.27
Threshold (75th percentile)	0.54	1.83	0.50	0.41
Target (25th percentile)	0.49	1.24	0.46	0.37

Table 7.4.1. Per-recruit mortality based reference points by stock. Red shading indicates that the reference estimate exceeds the threshold reference point. Green shading indicates that the reference estimate does not exceed the threshold reference point.

	GOM	GBK	GOM/GBK	SNE
2011 - 2013 Reference F	0.48	1.54	0.48	0.27
$F_{5\%}$	0.45	N/A	0.44	> 0.4
$F_{10\%}$	0.36		0.34	> 0.4
$F_{15\%}$	0.3		0.29	> 0.4
$F_{20\%}$	0.26		0.25	> 0.4
F_{MAX}	0.36		0.26	> 0.4
$F_{0.1}$	0.17		0.15	0.24

11.0 FIGURES

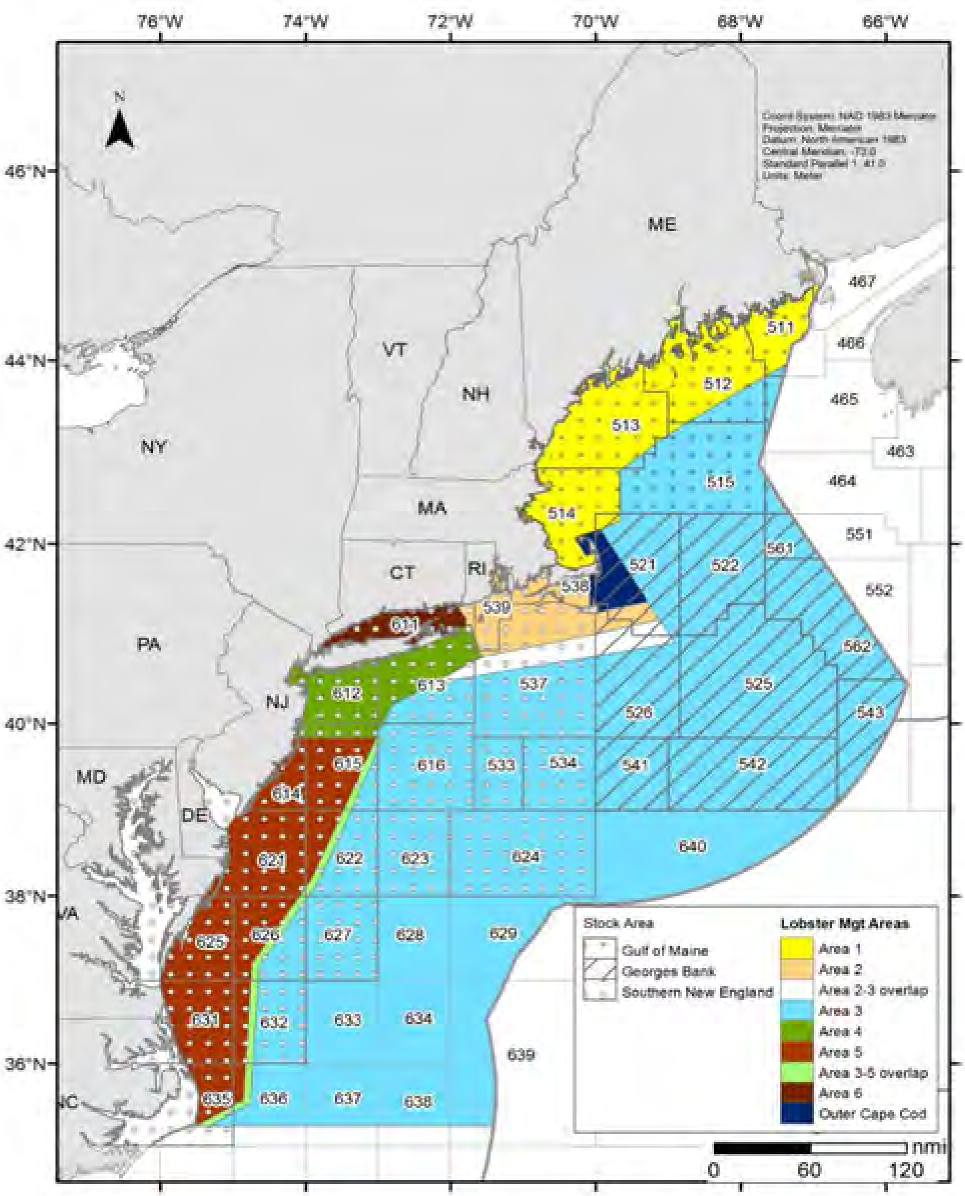


Figure 1.1. Statistical areas used to define the U.S. American lobster, *Homarus americanus,* stocks.

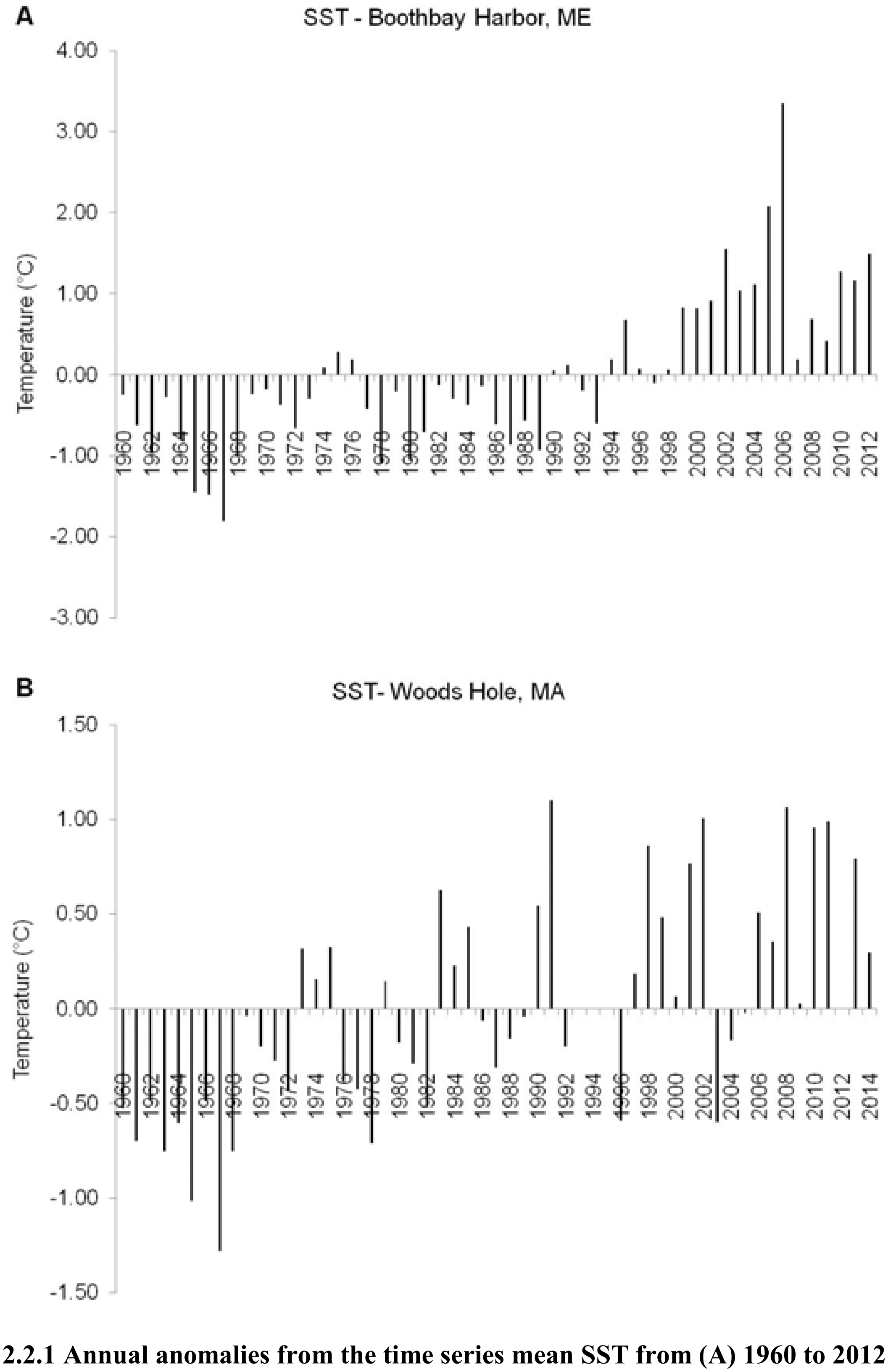


Figure 2.2.1 Annual anomalies from the time series mean SST from (A) 1960 to 2012 at Boothbay Harbor, ME and from (B) 1960 to 2014 at Woods Hole, MA.

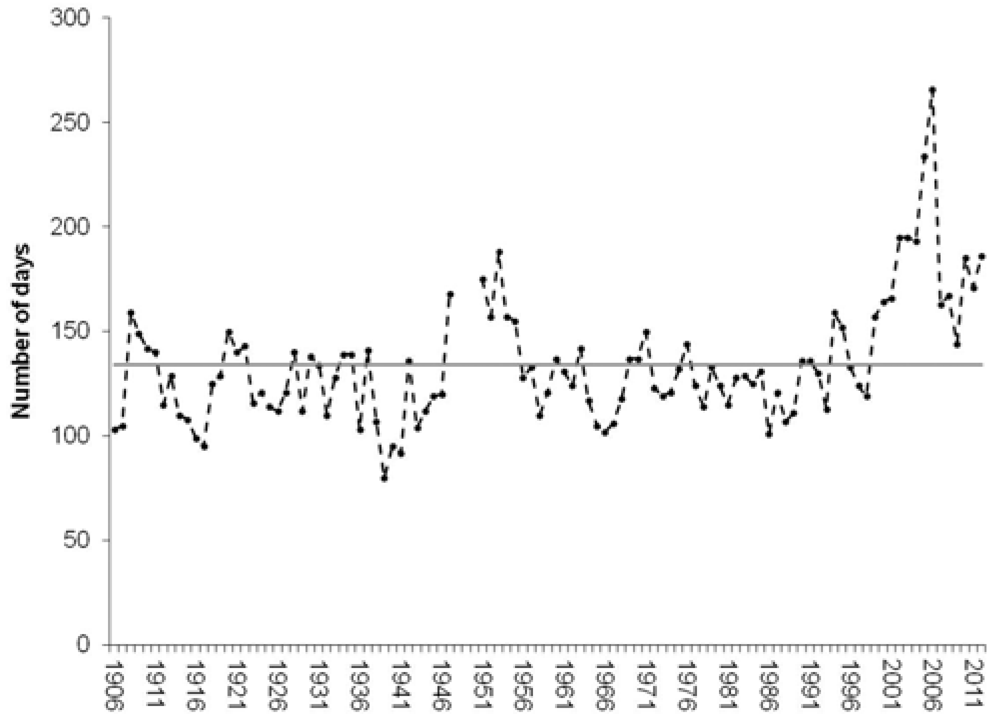


Figure 2.2.2. Number of days SST was within the optimal temperature range of 12° to 18° C at Boothbay Harbor, ME – 1906 to 2012. Solid line represents the time series mean.

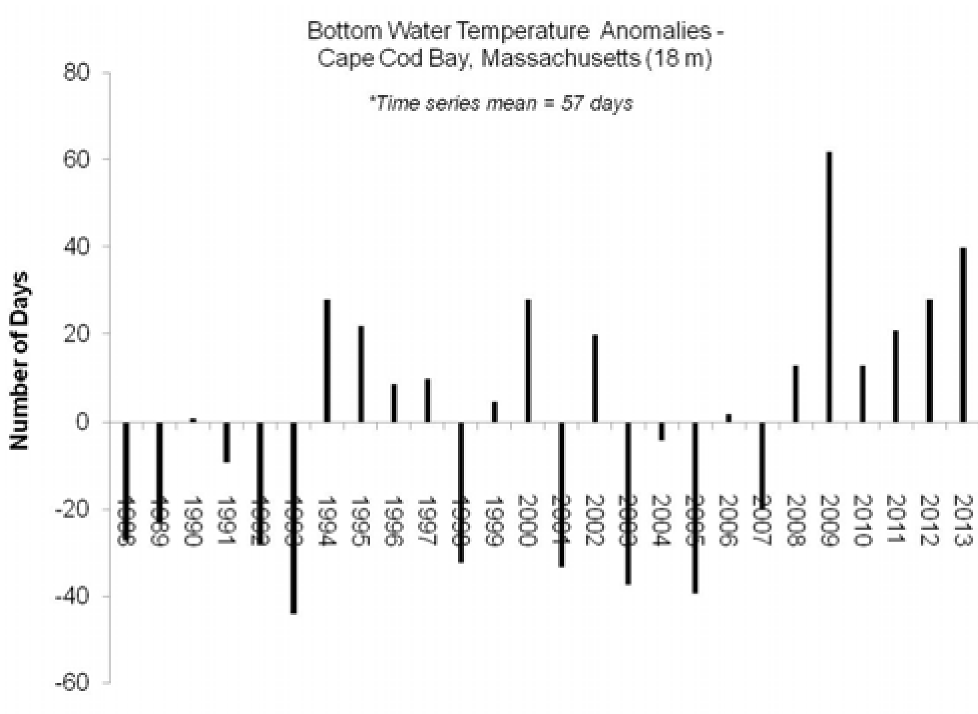


Figure 2.2.3. Anomalies from the time series mean number of days between 12° to 18° C at Manomet Point (depth = 18m) Cape Cod Bay, Massachusetts, 1988-2013.

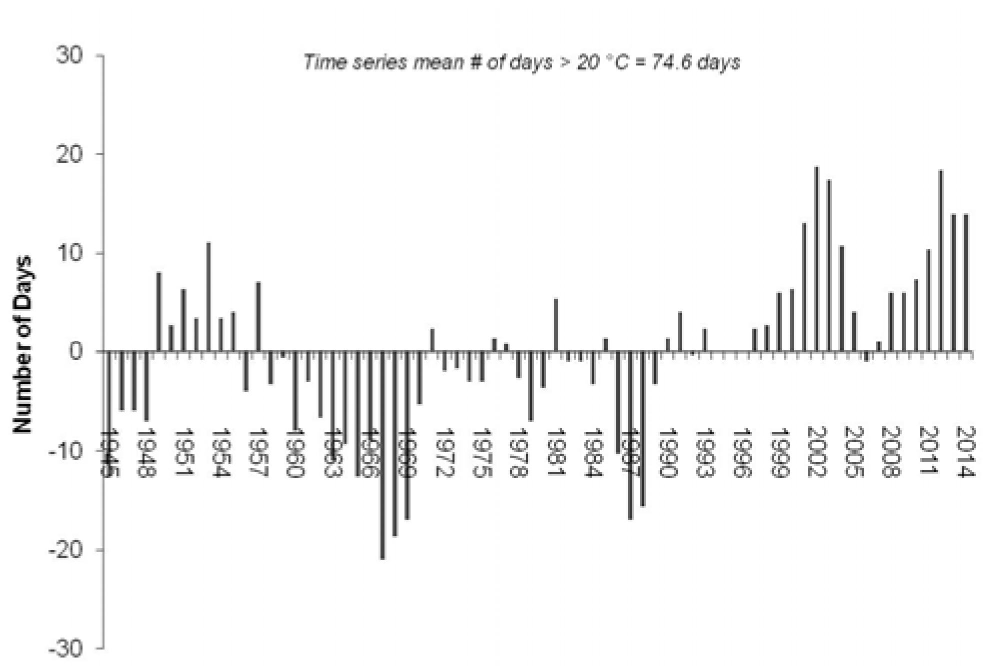


Figure 2.2.4 Sea surface temperature anomalies from the mean # of days > 20° C at Woods Hole, MA, 1945 to 2014.

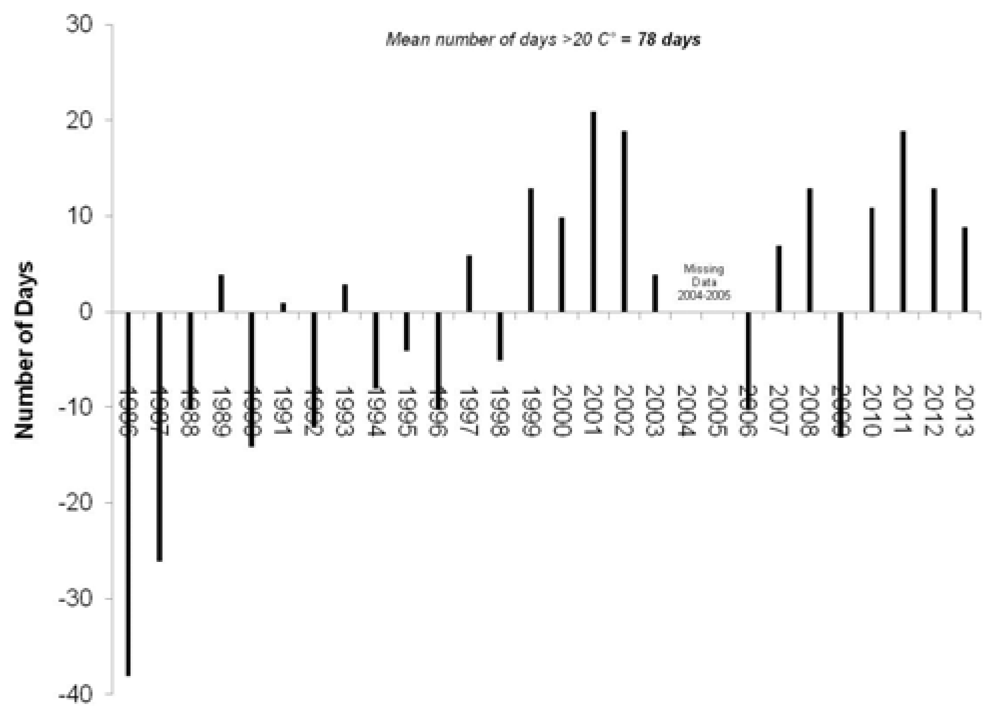


Figure 2.2.5. Bottom water (11 m) temperature anomalies from the mean number of days >20° C at Cleveland Ledge, Buzzards Bay, MA, 1986-2013.

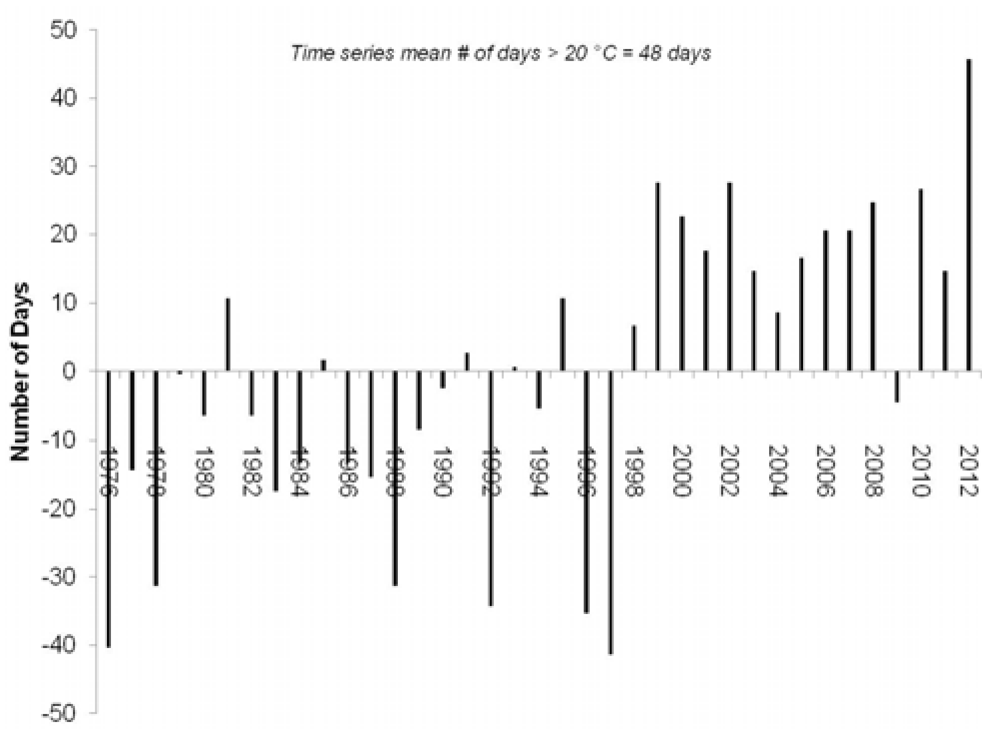


Figure 2.2.6. Bottom water (11 m) temperature anomalies from the mean number of days >20° C at Dominion Nuclear Power Station, eastern Long Island Sound, CT, 1976-2012.

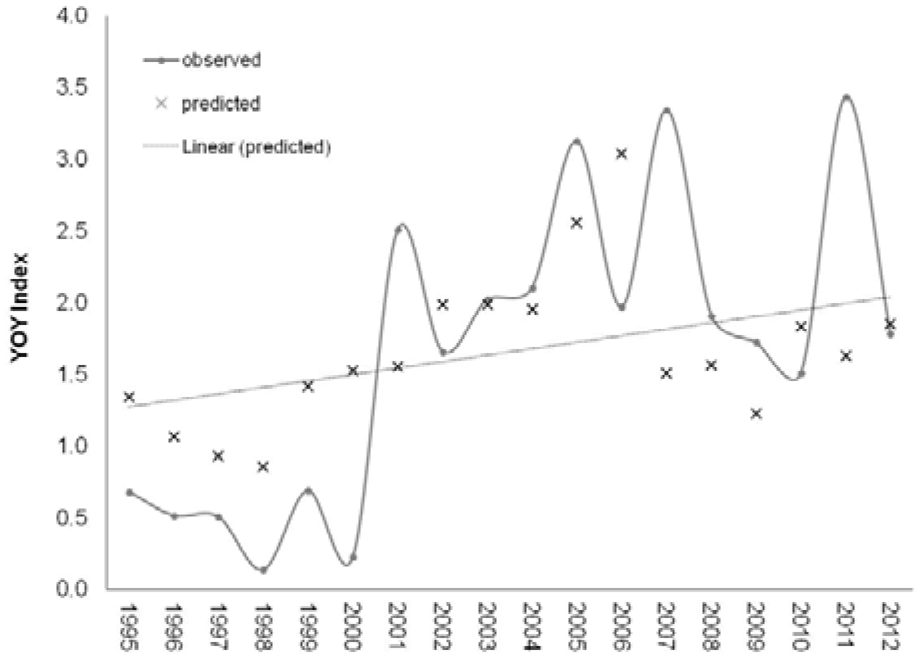


Figure 2.2.1.1. Observed summed indices of young-of-year (YOY) lobster surveyed on the southern coast of ME (statistical areas 512 and 513 east) compared to predicted YOY production based on total days each year with sea surface temperature 12°-18° C in Boothbay Harbor, 1995-2012.

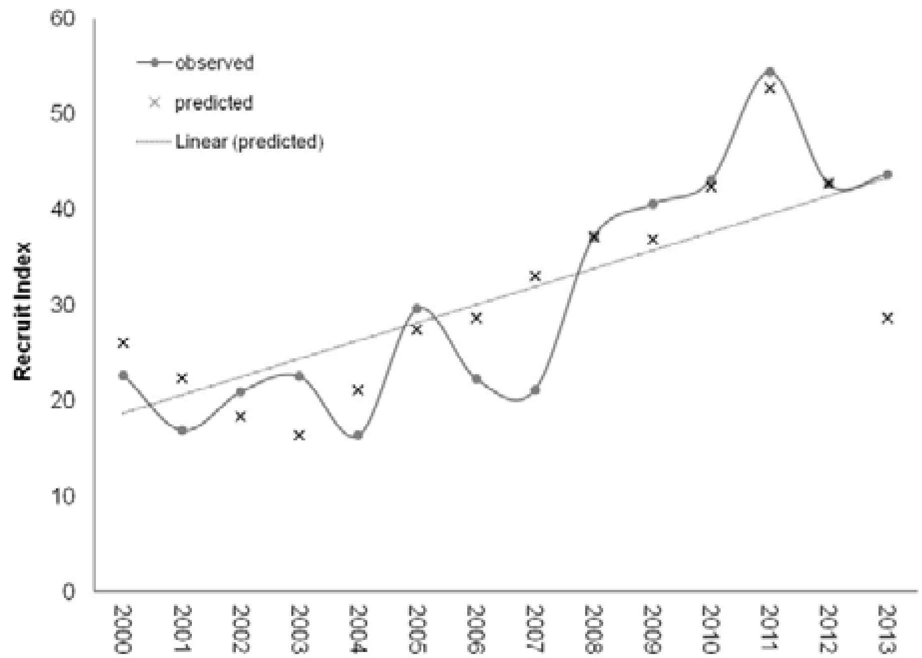


Figure 2.2.1.2. Observed recruit-size abundance indices generated from the ME Trawl Survey catches compared to predicted indices based on total days each year with sea surface temperature 12°-18° C in Boothbay Harbor, 2000-2013.

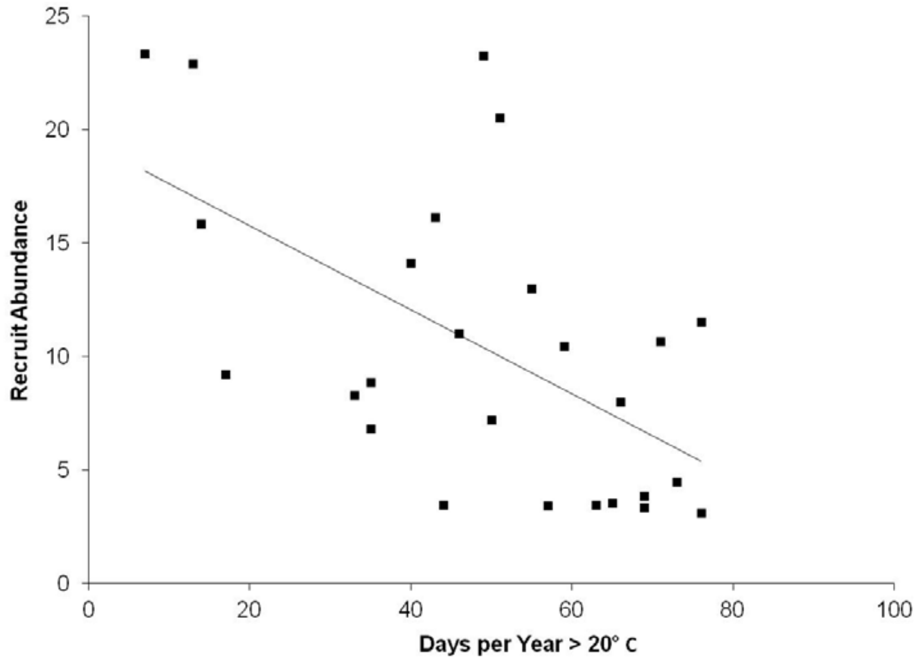


Figure 2.3.1. Annual relative abundance of recruit-size lobster versus the annual number of days with average temperature above 20° C. Recruit lobster abundance is the averaged catch index in four fall research surveys. Daily water temperature is the mean of continuous temperature recorded at the submerged intakes of Millstone Power Station.

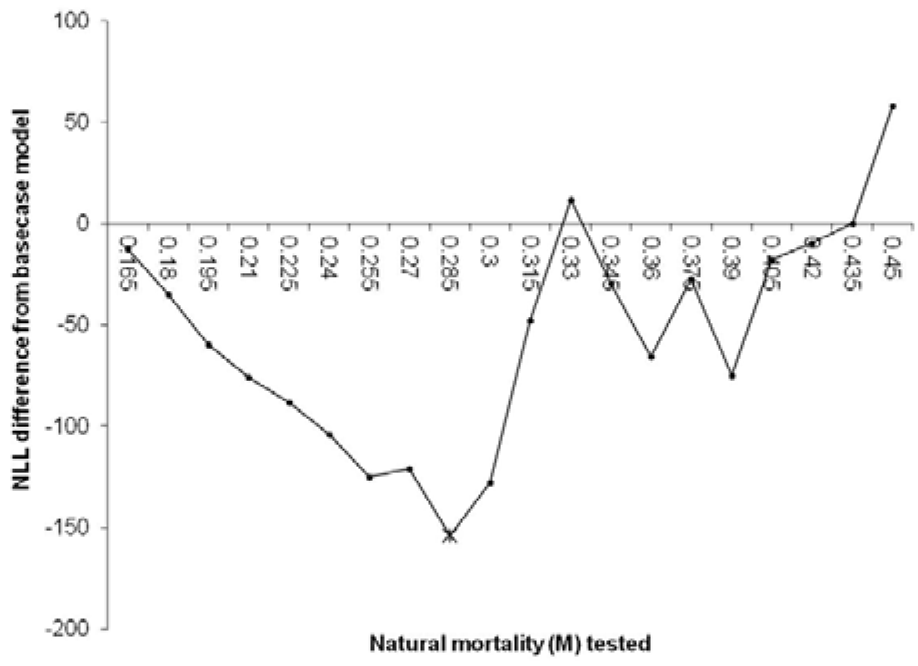


Figure 2.3.2. Difference in fit of alternative UMM model runs from ASMFC (2009) assuming different Ms during 1998 - 2007.

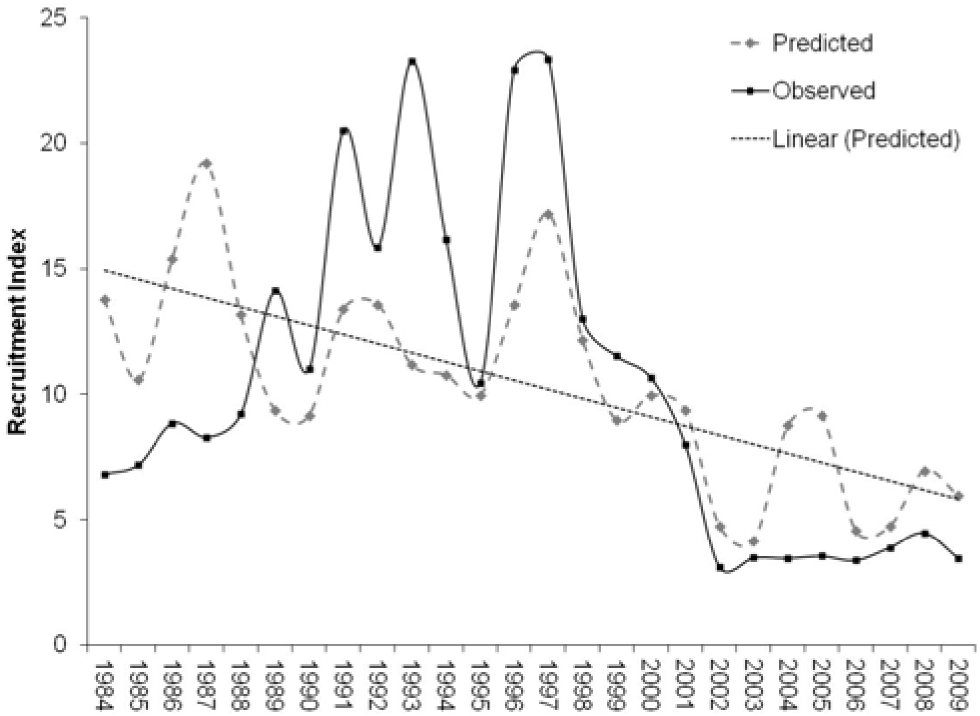


Figure 2.3.3. Rate of decline in predicted and observed recruitment based on water temperature pattern, 1984 - 2009. Recruit lobster abundance is the averaged catch index in four fall research surveys (MA, RI, CT, NMFS SNE surveys). Daily water temperature is the mean of continuous temperature recorded at the submerged intakes of Millstone Power Station.

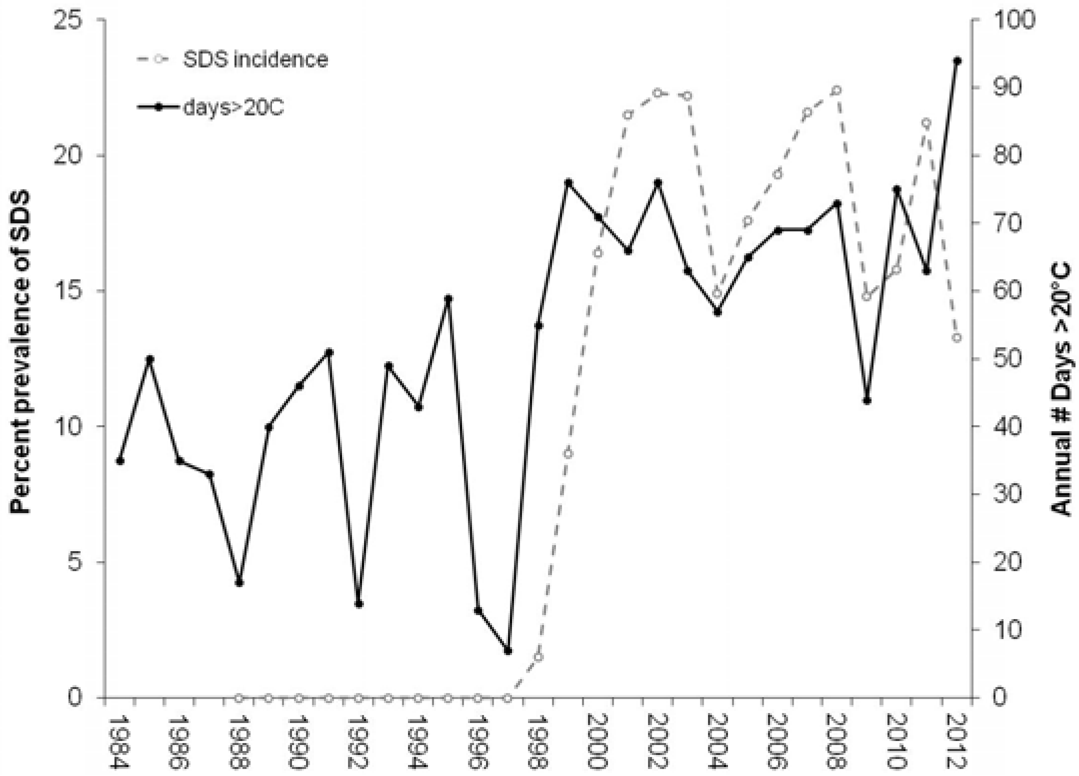


Figure 2.4.1. Annual shell disease prevalence in lobsters captured by the Millstone Power Plant ventless trap survey (see DNC 2013) and the number of days that bottom water temperatures exceeded 20° C. Catch and temperature data were recorded in research (ventless) lobster traps set in the vicinity of Millstone Power Station, Waterford CT, on 3-4 day sets May-November. Data provided by Donald Landers, Dominion Nuclear Connecticut.

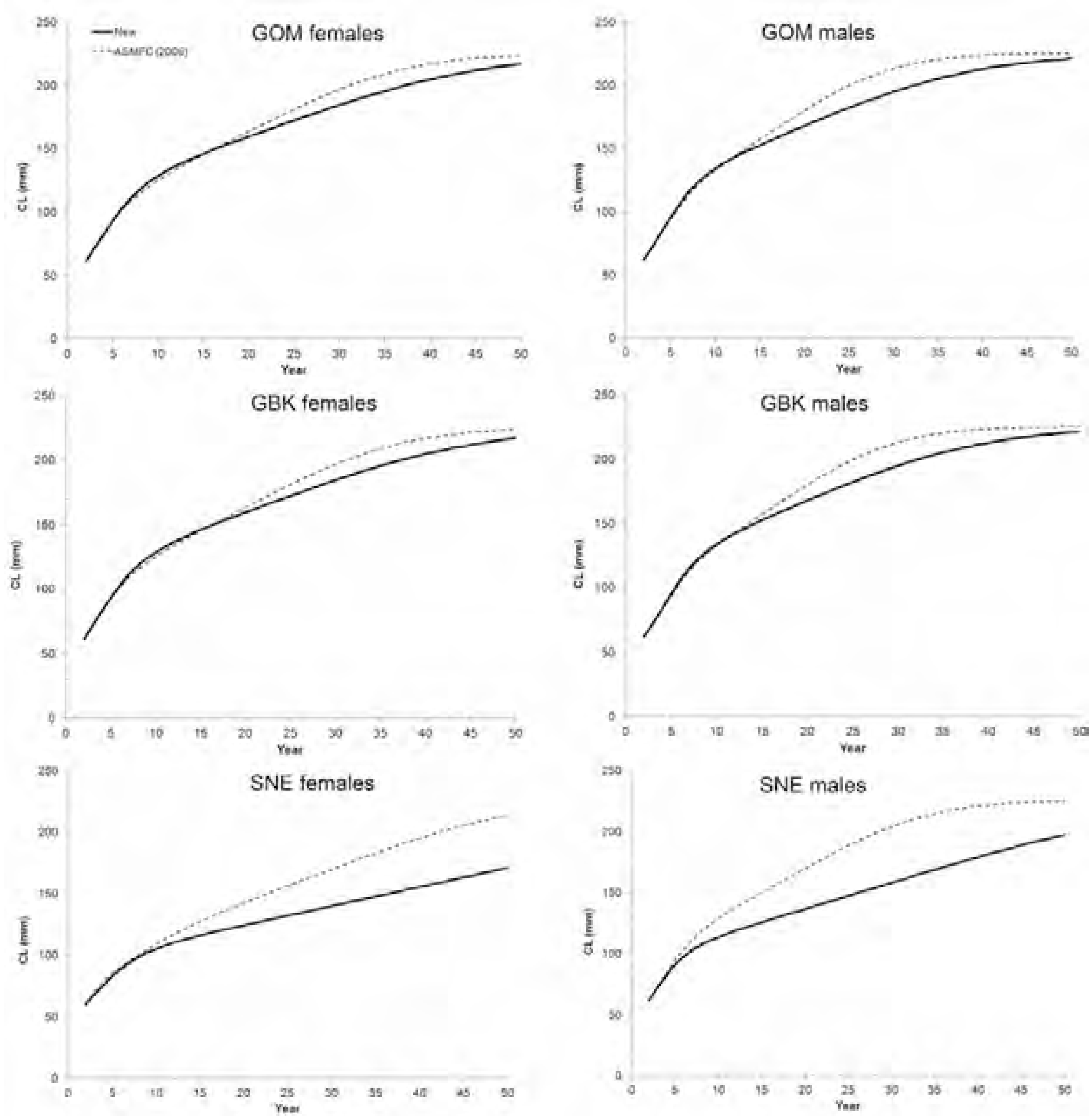


Figure 2.6.3.1. **Apparent growth of female and male lobsters in the three stock areas from preliminary UM assessment model runs using new updated growth transition matrices and matrices used in the last assessment (ASMFC 2009).** In the last assessment, GBK females and males used the same growth transition matrices because sexes were combined. In this assessment, GOM and GBK use growth transition matrices for the combined GOM&GBK stock area with different matrices for females and males.

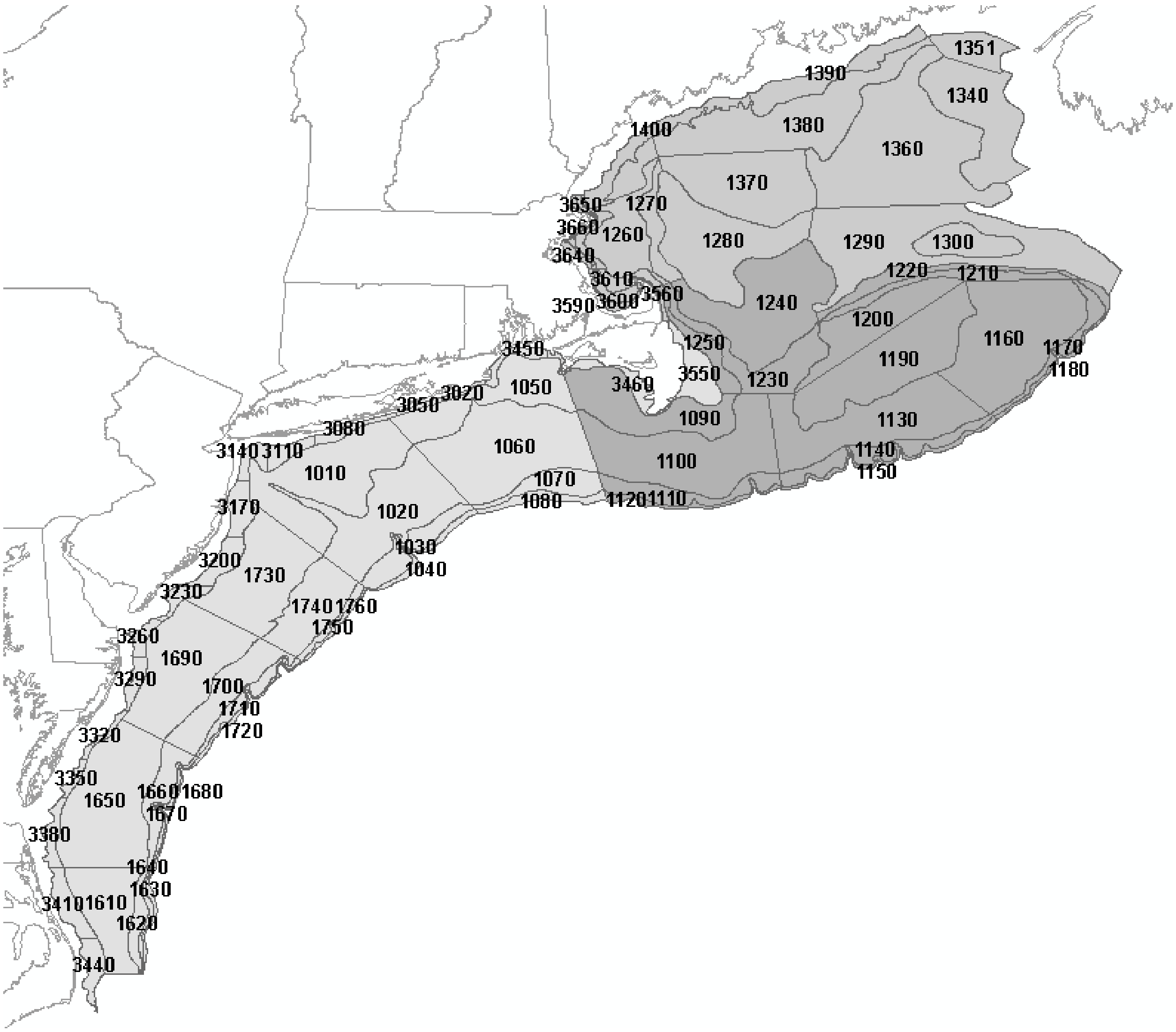


Figure 2.9.1. Stock definitions from NEFSC finfish survey strata for SNE (light gray), GOM (medium gray) and GBK (dark gray).

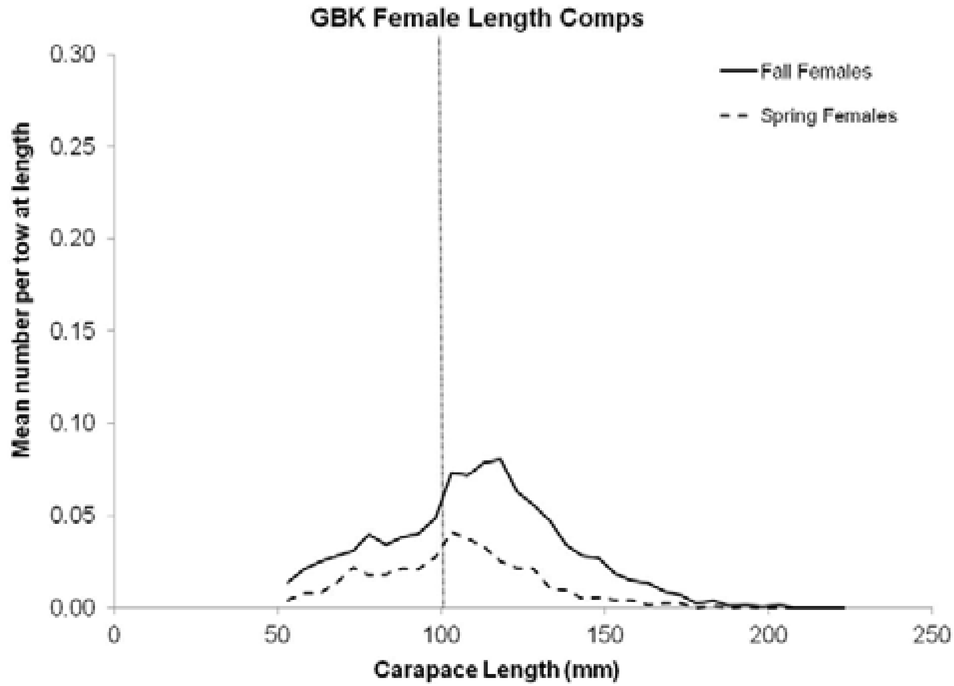


Figure 2.9.2. Mean catch per tow at length (mm) by season for GBK females in the NEFSC trawl survey 1982 – 2013

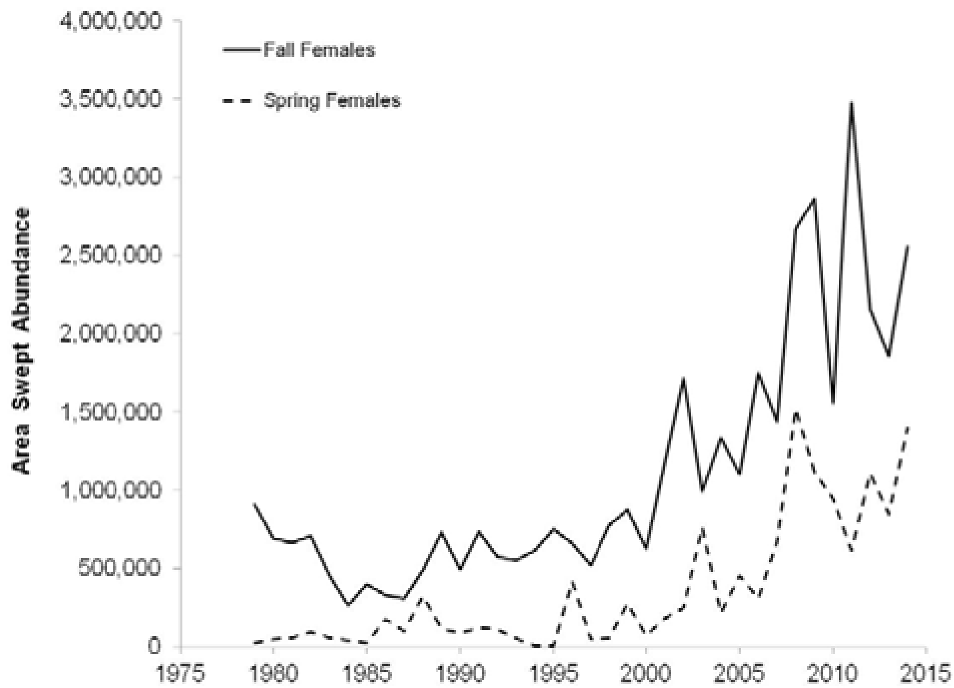


Figure 2.9.3. NEFSC trawl survey swept area abundance time series for GBK females >100mm CL.

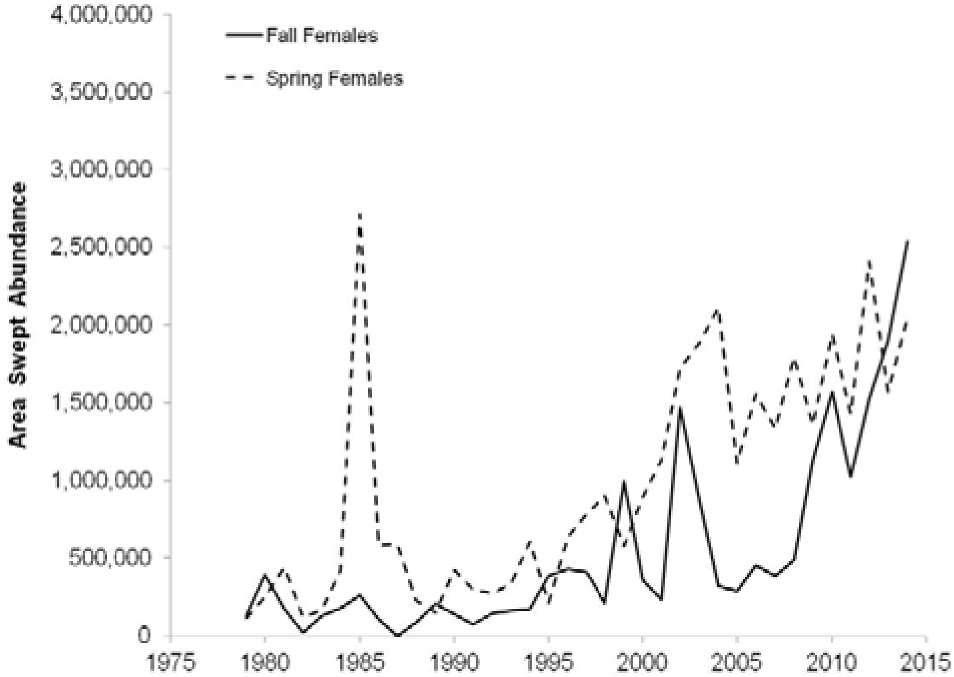


Figure 2.9.4. NEFSC trawl survey swept area abundance time series for GOM females >100mm CL.

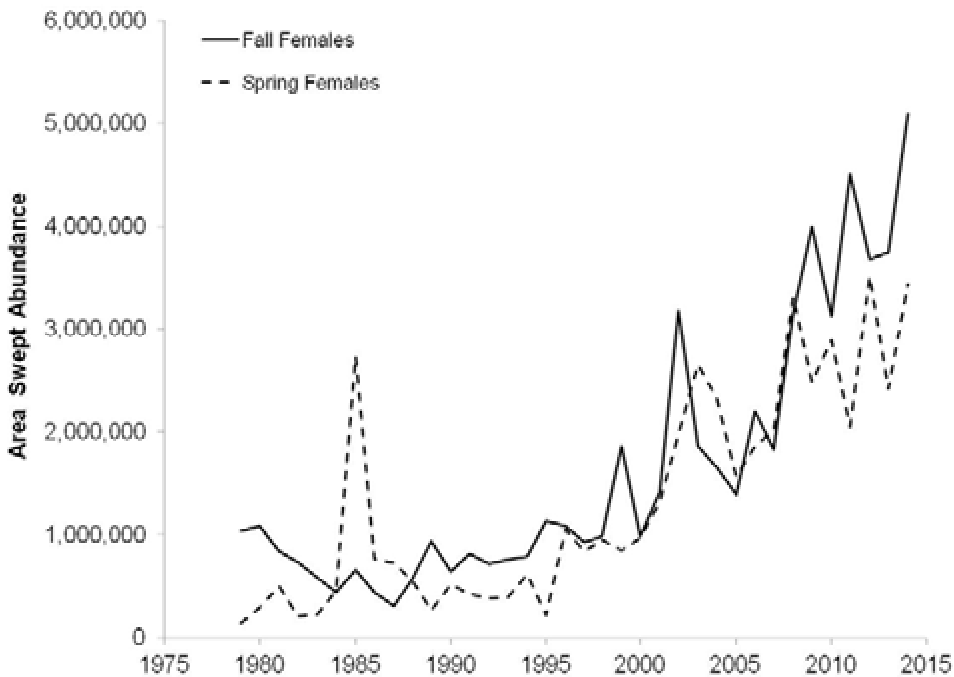


Figure 2.9.5. NEFSC trawl survey swept area abundance time series for combined GOM / GBK females >100mm CL.

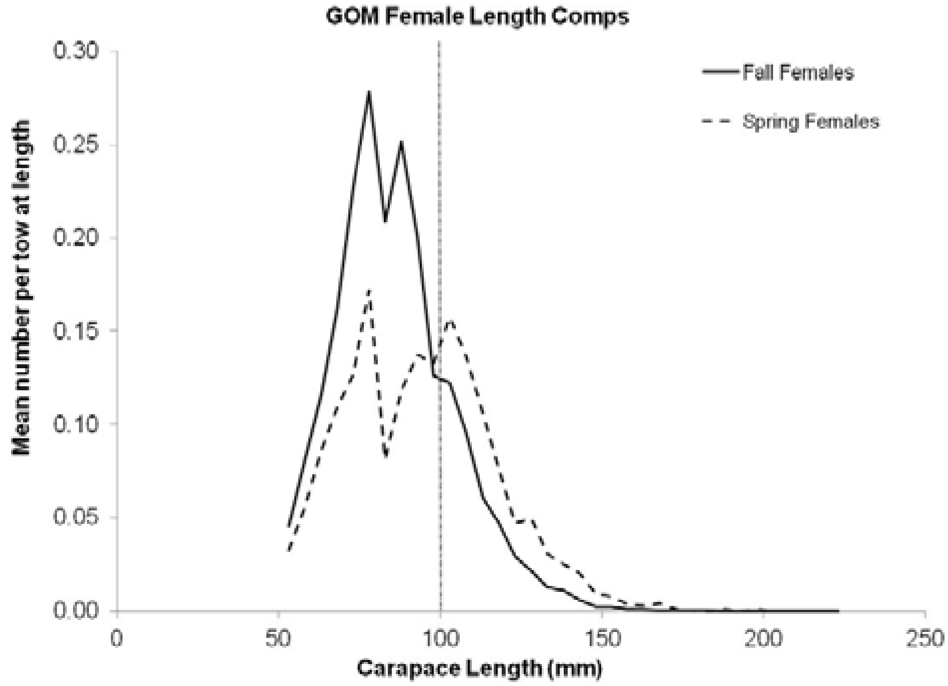


Figure 2.9.6. Mean catch per tow at length (mm) by season for GOM females in the NEFSC trawl survey 1982 – 2013.

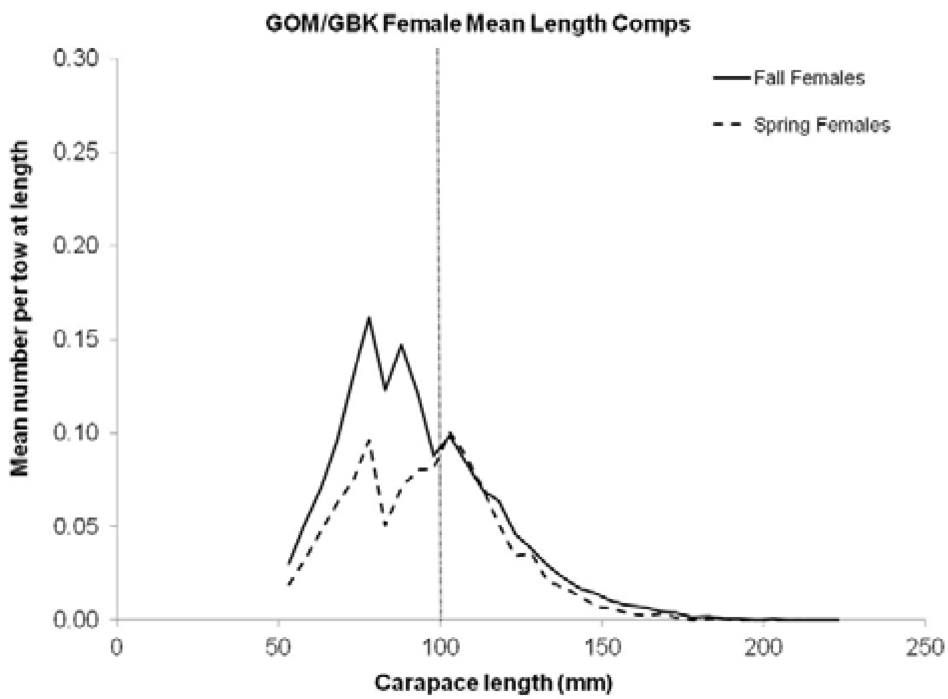


Figure 2.9.7. Mean catch per tow at length (mm) by season for the combined GOM / GBK females in the NEFSC trawl survey 1982 – 2013.

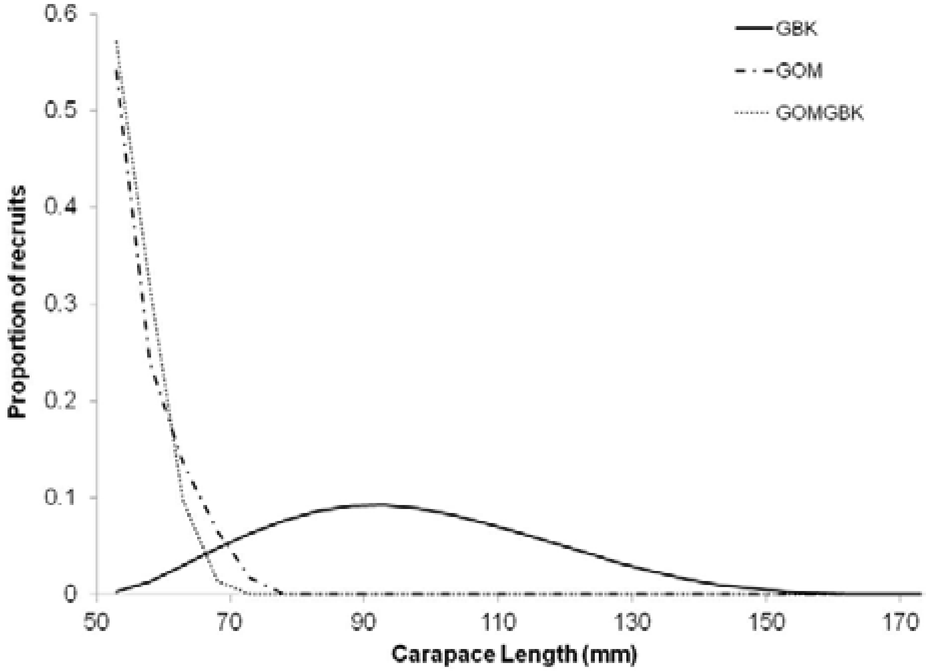


Figure 2.9.8. Model-estimated size composition of new female recruits by stock area from the basecase UMaine Model.

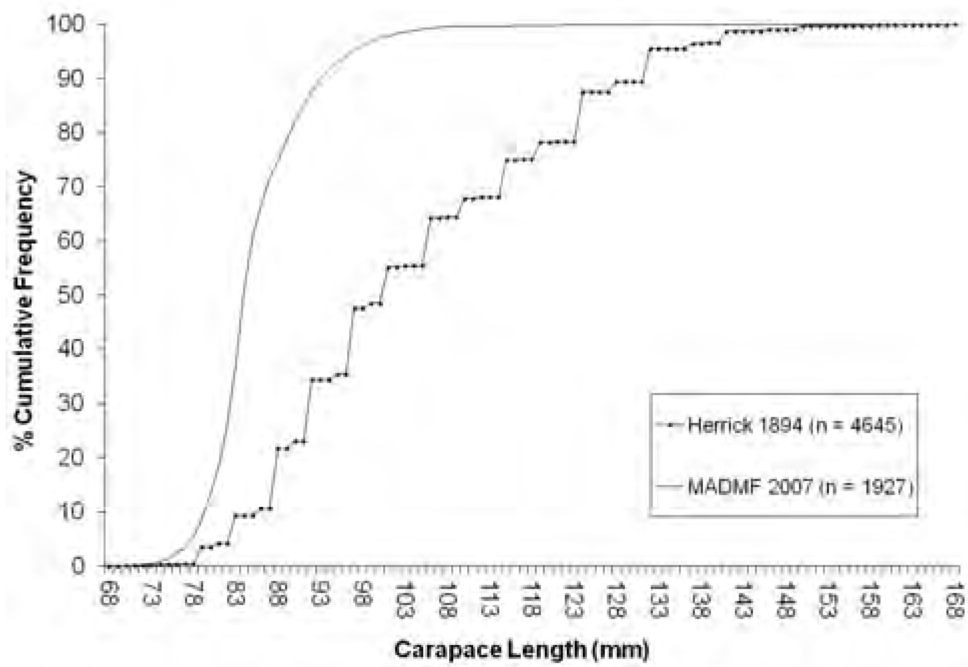


Figure 3.1.1. Comparison of cumulative length distribution of egg-bearing female lobsters from Buzzards Bay, MA (2007)/Cox Ledge, MA (1894).

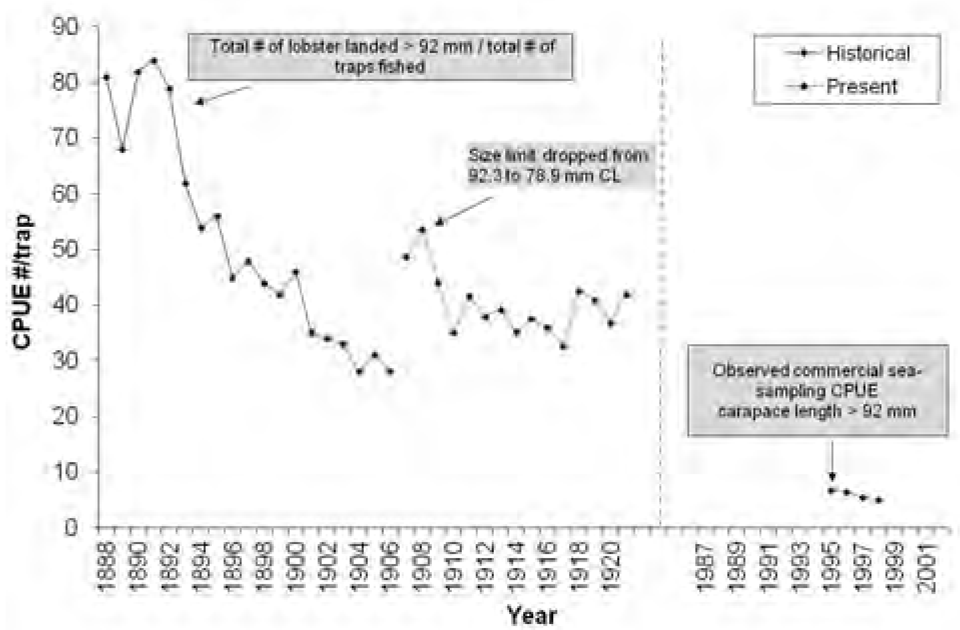


Figure 3.1.2. Annual CPUE (total # landed / total # traps) of lobsters >92 mm, 1880-1921, and 1995-1998 in Massachusetts coastal waters. Vertical dashed line indicates break in x-axis time line.

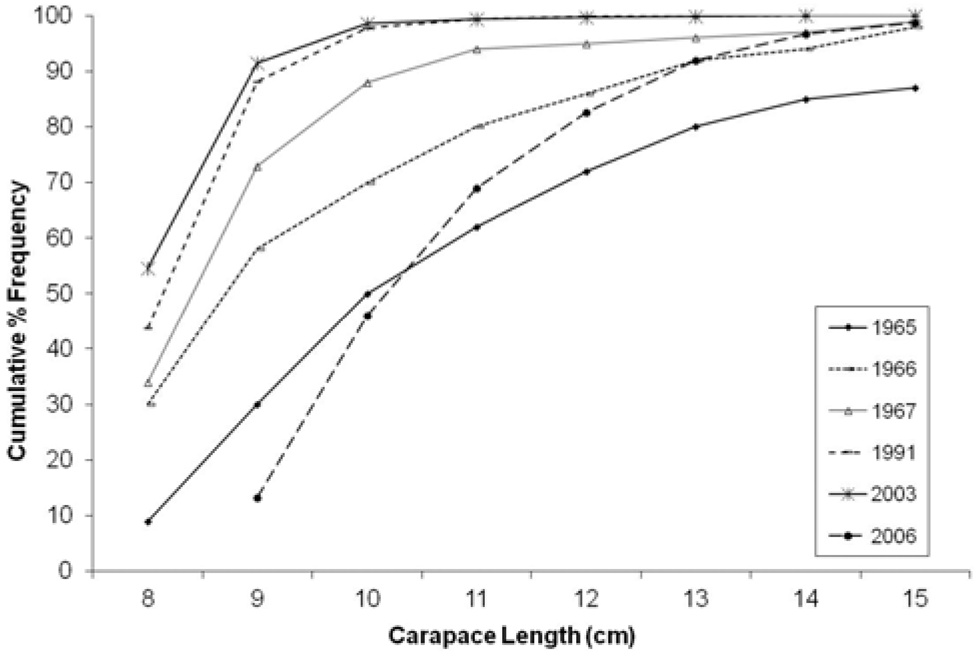


Figure 3.1.3. Comparison of cumulative length distribution of egg-bearing female lobsters from the Hudson Canyon from the 1960s, 1990s, and 2000s.

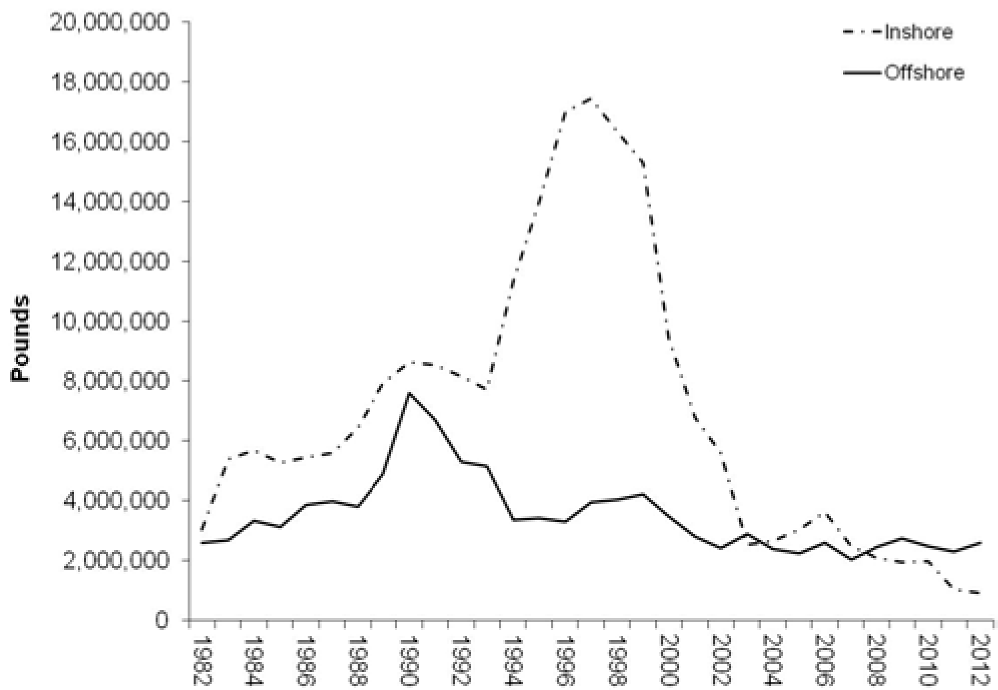


Figure 3.2.3.1. Commercial lobster landings in the Southern New England stock unit 1982 to 2012 from inshore (SA 538, 539, 611; dashed) and offshore/nearshore (SA 537, 612, 613, 615, 616; solid) regions.

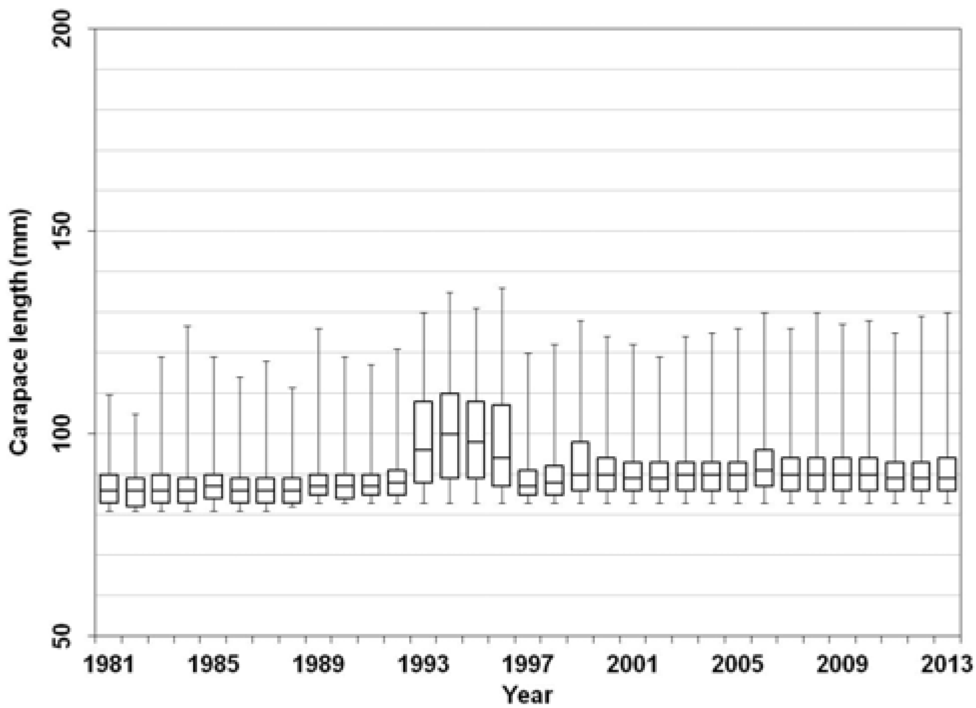


Figure 4.1.3.2.1. Size structure of the GOM female commercial catch. Box plots show the median and quartiles, while whiskers represent the minimum and 99th percentiles.

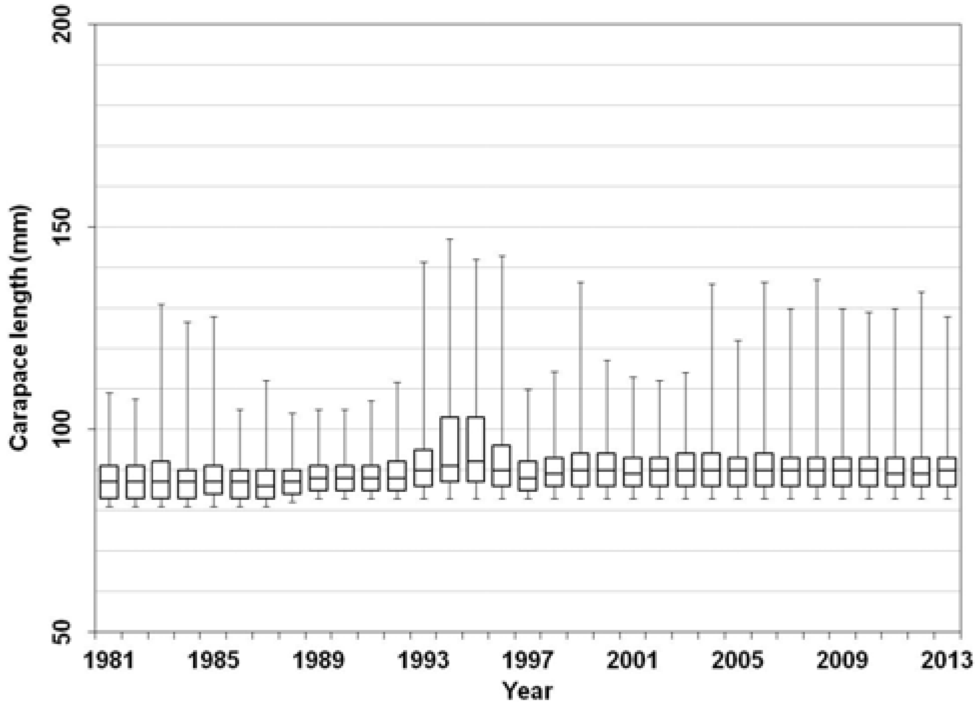


Figure 4.1.3.2.2. Size structure of the GOM male commercial catch. Box plots show the median and quartiles, while whiskers represent the minimum and 99th percentiles.

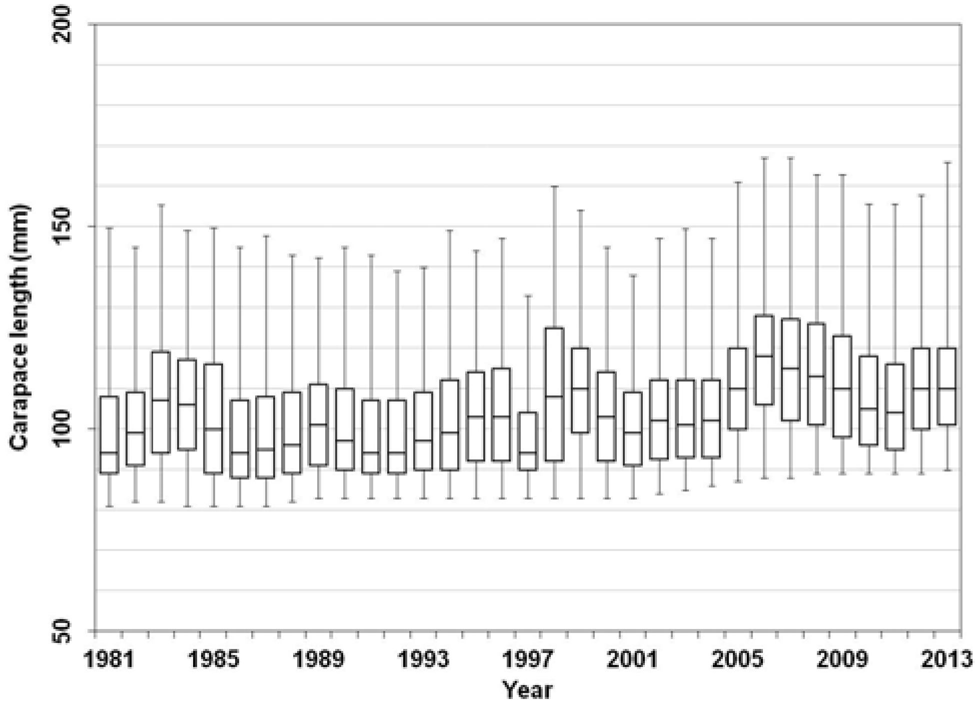


Figure 4.1.3.2.3. Size structure of the GBK female commercial catch. Box plots show the median and quartiles, while whiskers represent the minimum and 99th percentiles.

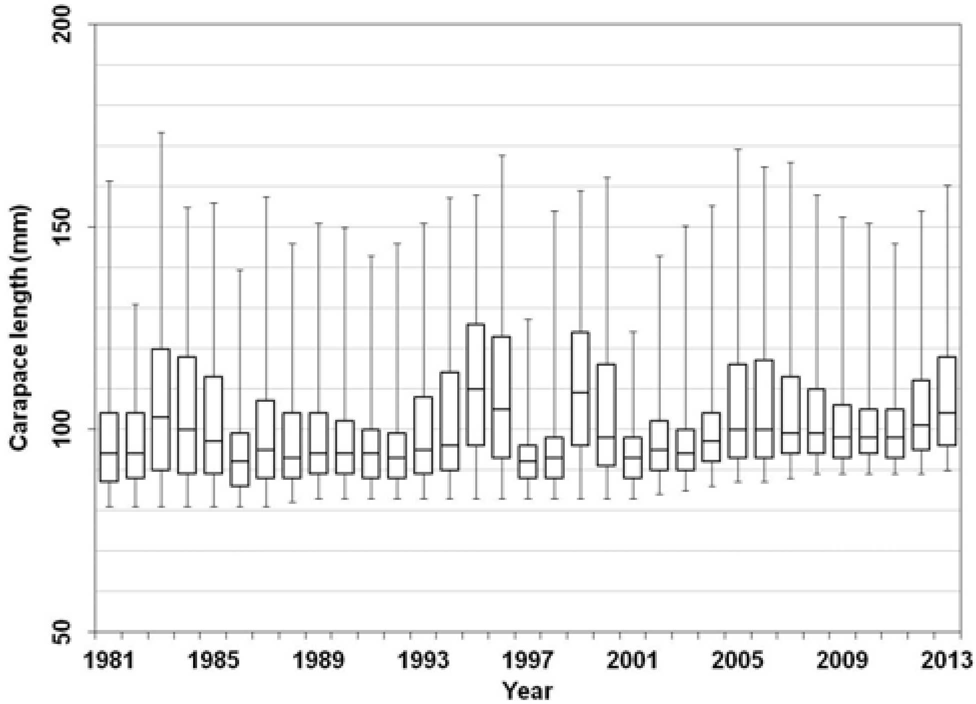


Figure 4.1.3.2.4. Size structure of the GBK male commercial catch. Box plots show the median and quartiles, while whiskers represent the minimum and 99th percentiles.

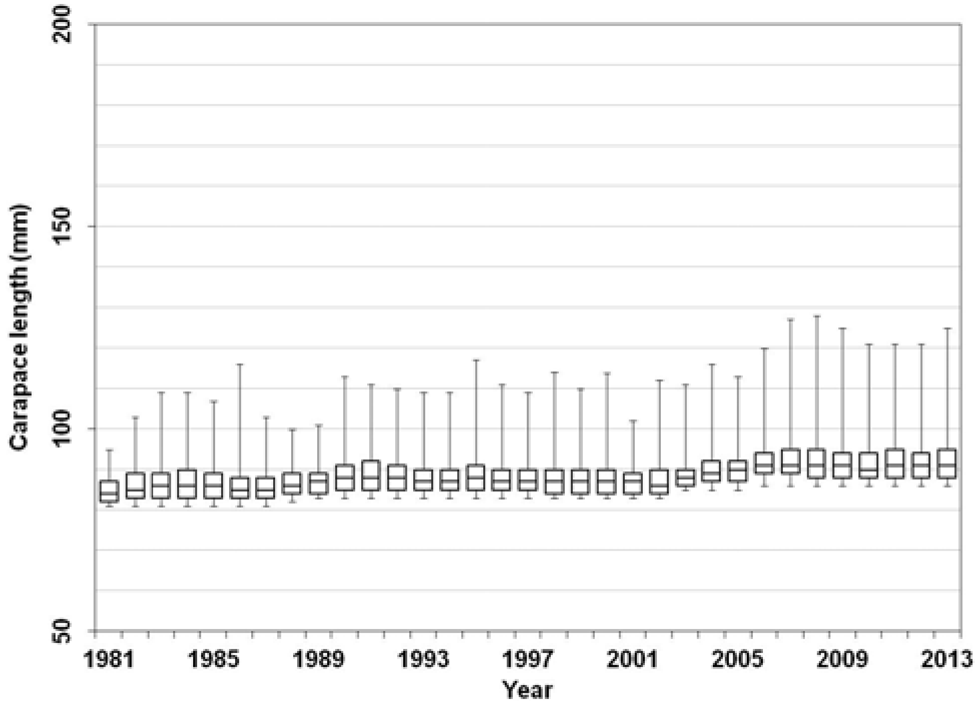


Figure 4.1.3.2.5. **Size structure of the SNE female commercial catch.** Box plots show the median and quartiles, while whiskers represent the minimum and 99th percentiles.

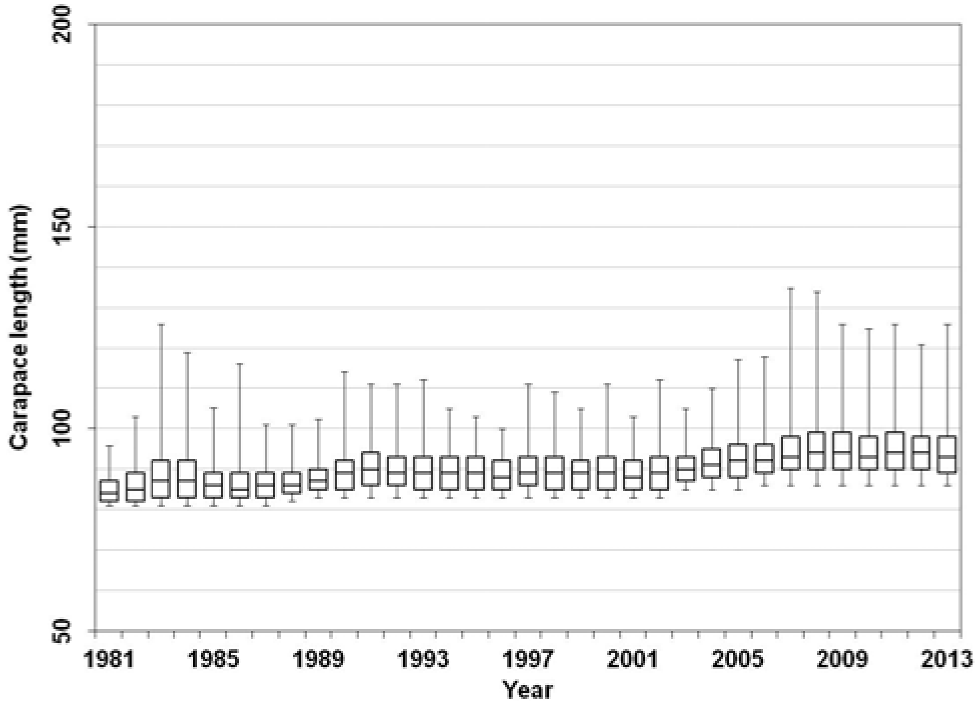


Figure 4.1.3.2.6. **Size structure of the SNE male commercial catch.** Box plots show the median and quartiles, while whiskers represent the minimum and 99th percentiles.

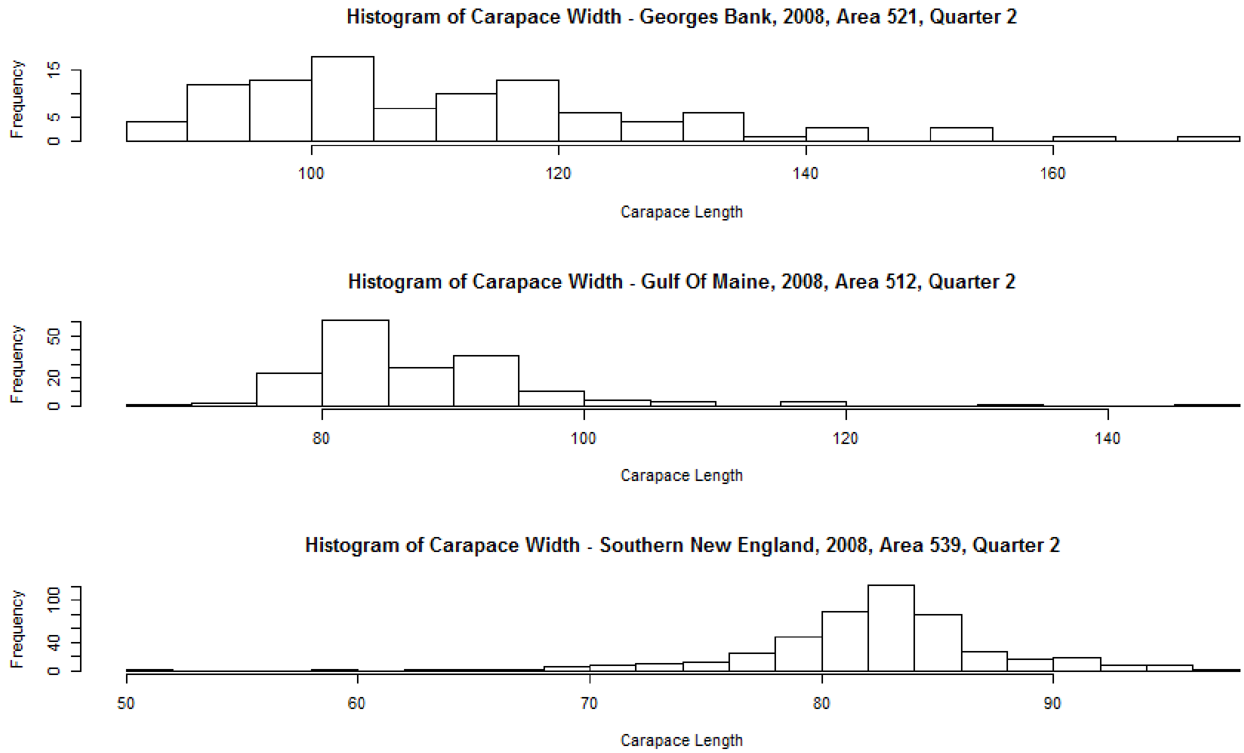


Figure 4.1.3.3.1 Examples of the length frequency distributions of the carapace length for example statistical areas in 2008. The plots indicate a generally normal distribution when the sample size is adequate.

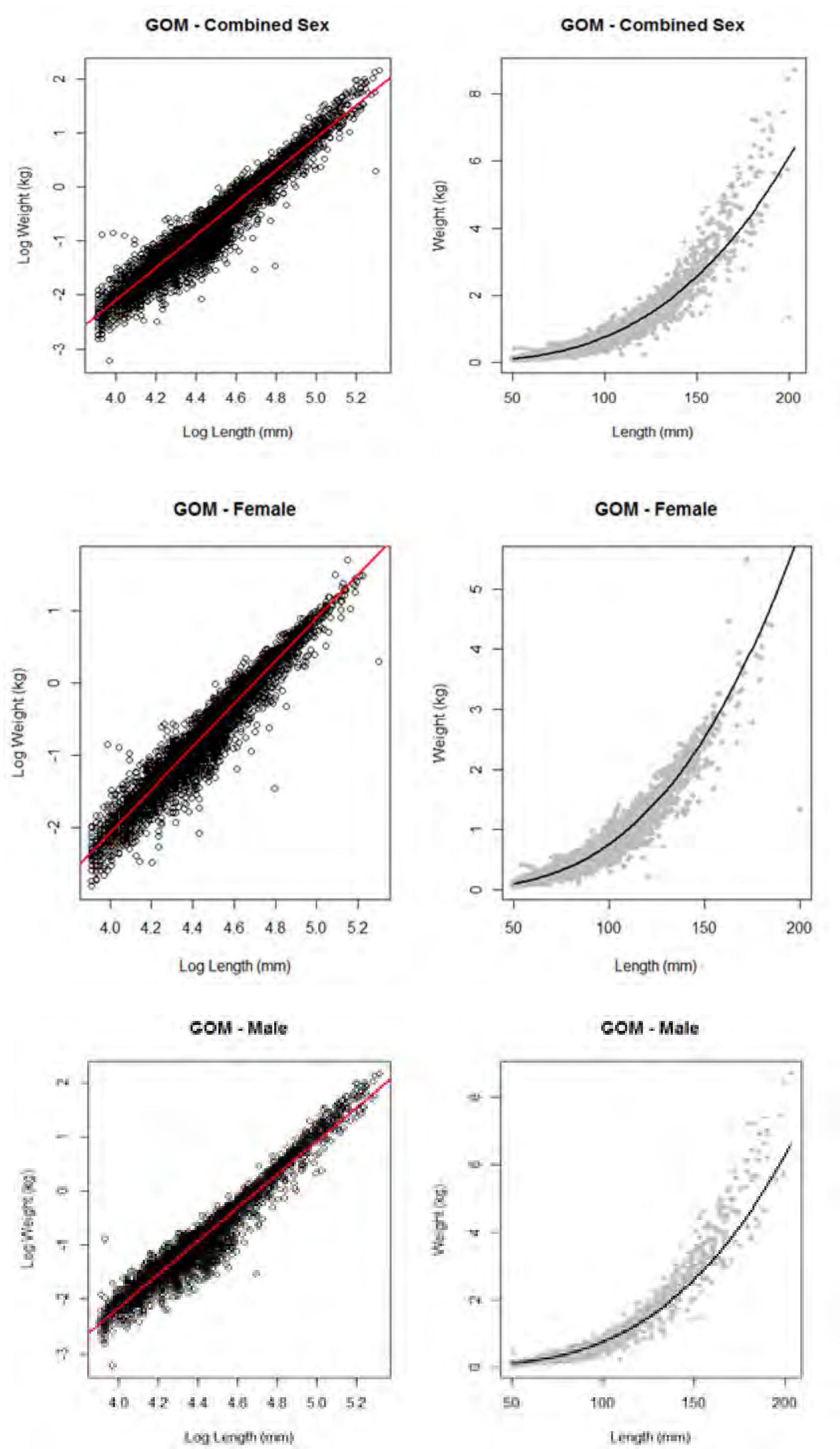


Figure 4.1.4.3 A. Model fits to the combined sex, female, and male data for Gulf of Maine. Left hand panel shows the linear regression fit to the log transformed observed data. Right hand panel shows the back transformed parameter fit to the untransformed data.

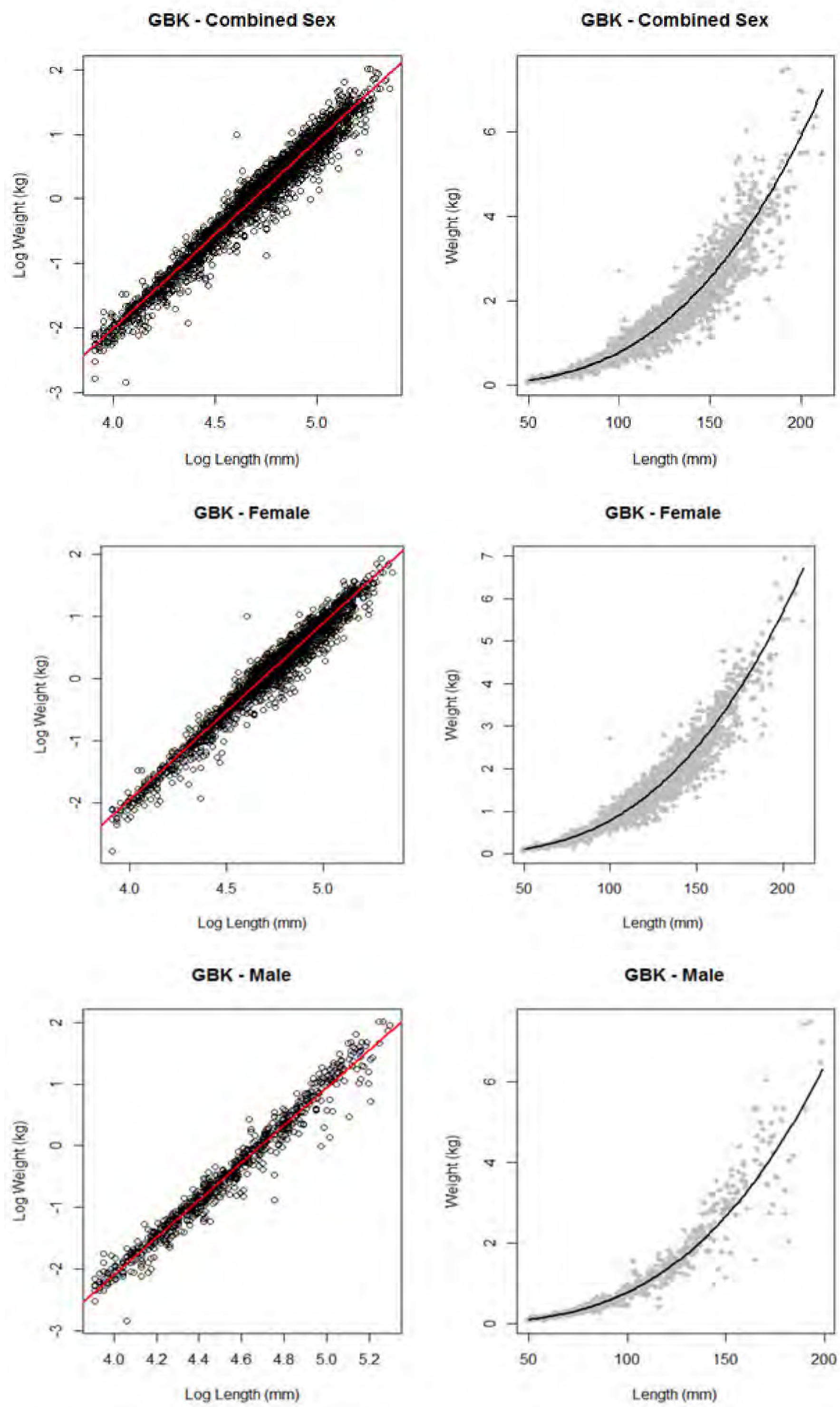


Figure 4.1.4.3 B. Model fits to the combined sex, female, and male data for Georges Bank. Left hand panel shows the linear regression fit to the log transformed observed data. Right hand panel shows the back transformed parameter fit to the untransformed data.

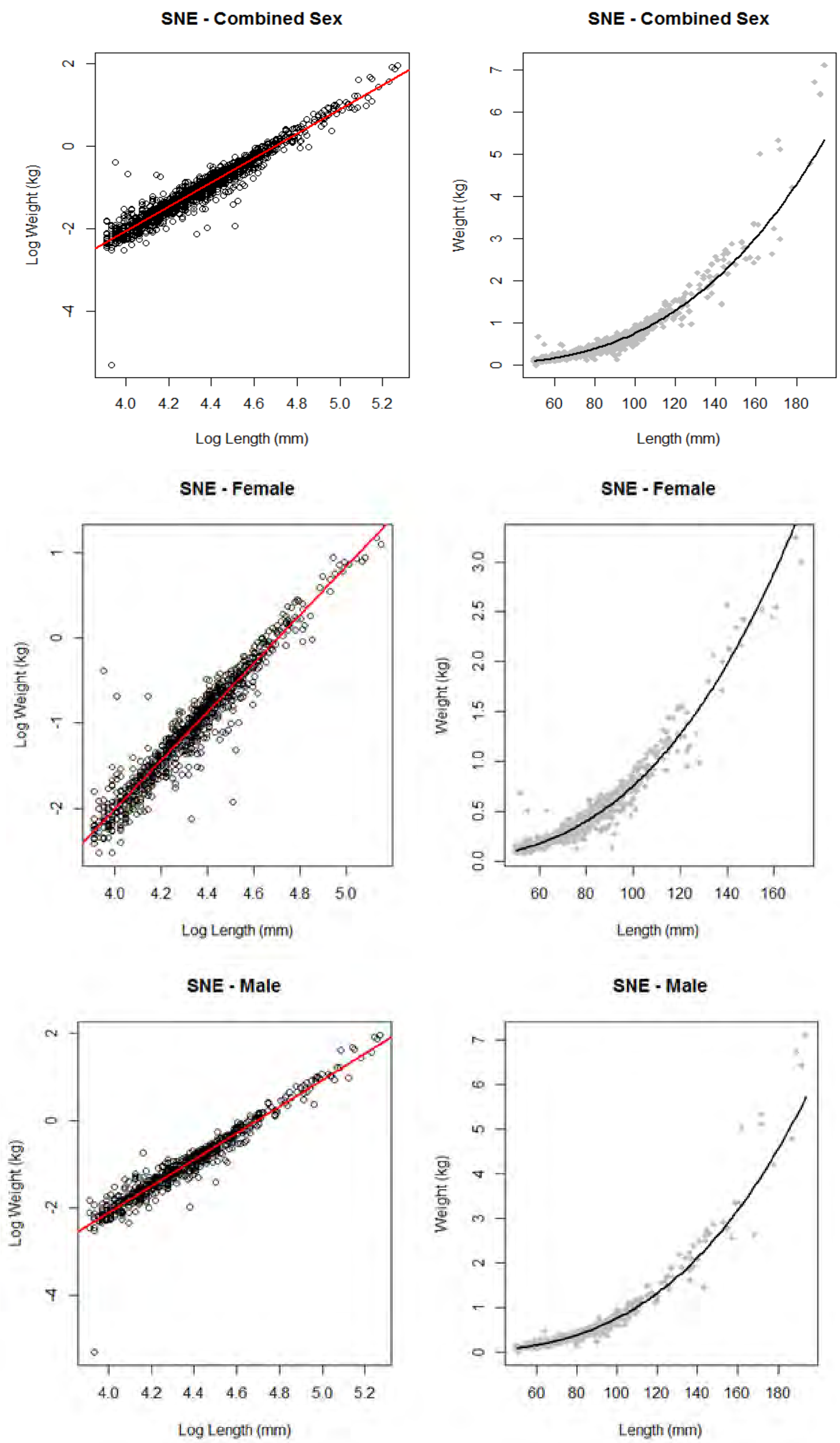


Figure 4.1.4.3 C. Model fits to the combined sex, female, and male data for Southern New England. Left hand panel shows the linear regression fit to the log transformed observed data. Right hand panel shows the back transformed parameter fit to the untransformed data.

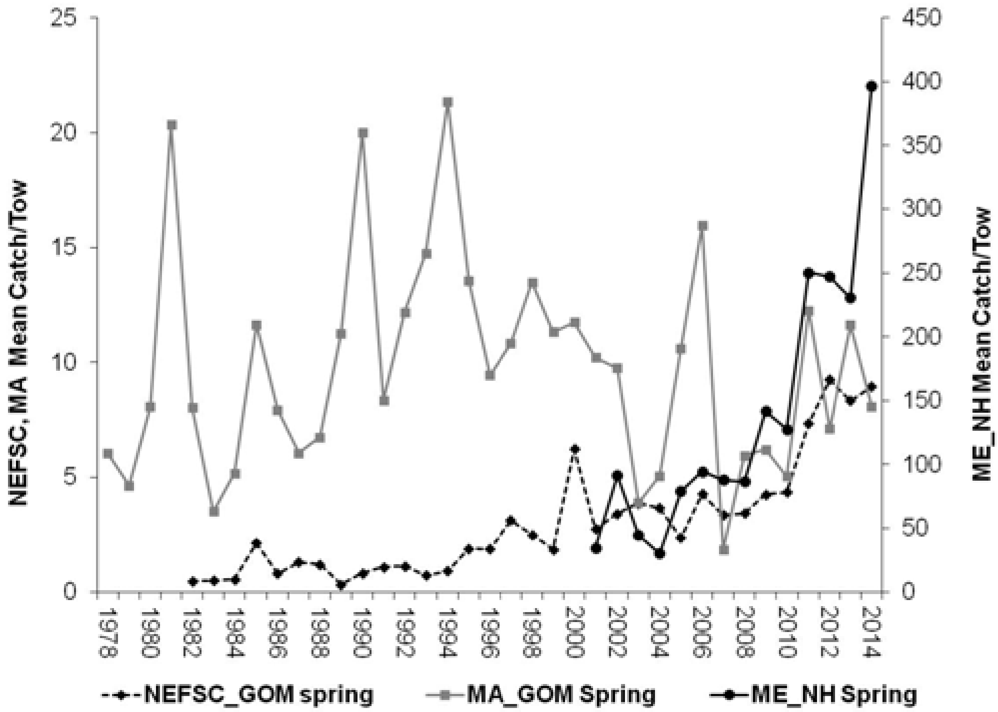


Figure 4.2.1.2.1.1. Gulf of Maine spring trawl survey indices for the NEFSC, MADMF, and ME-NH surveys, sexes combined.

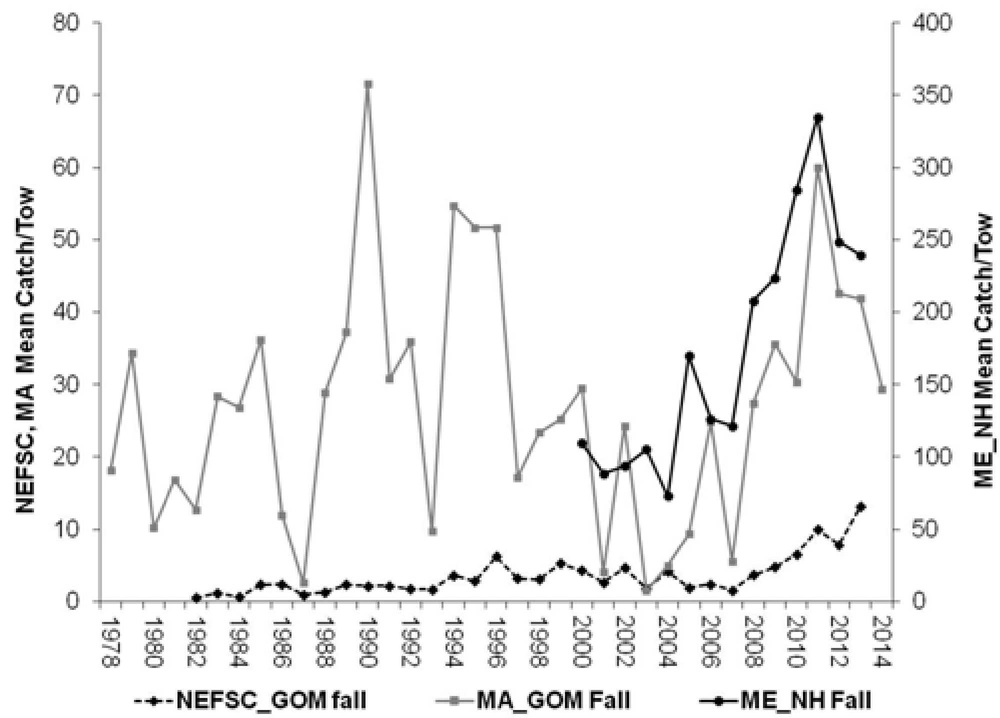


Figure 4.2.1.2.1.2. Gulf of Maine fall trawl survey indices for the NEFSC, MADMF, and ME-NH surveys, sexes combined.

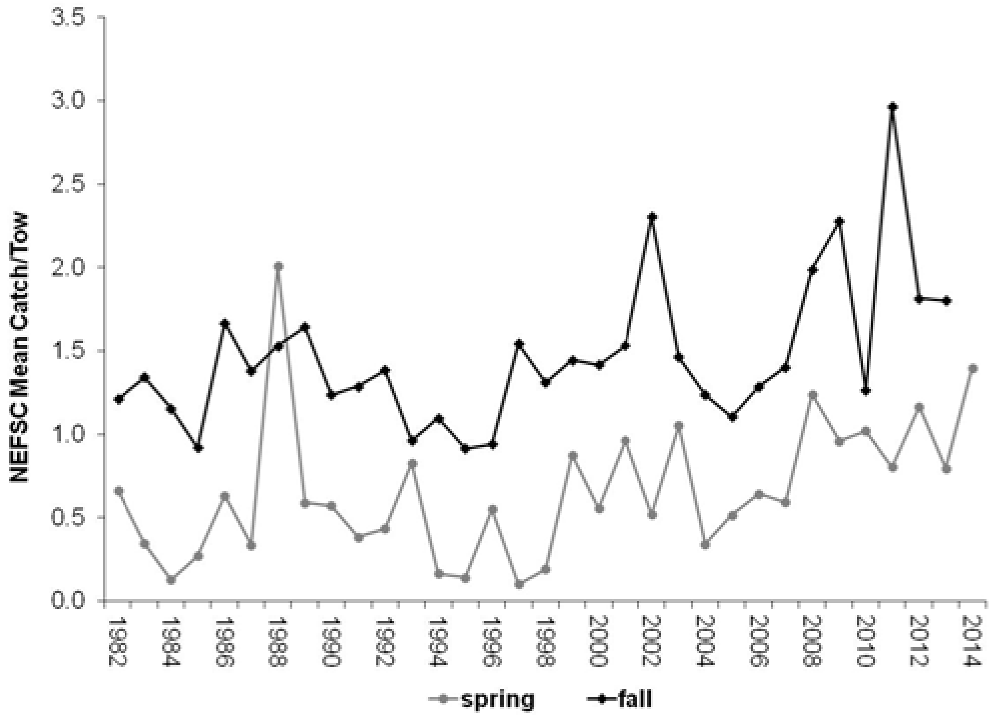


Figure 4.2.1.2.1.3. Georges Bank spring and fall trawl survey indices for the NEFSC survey, sexes combined.

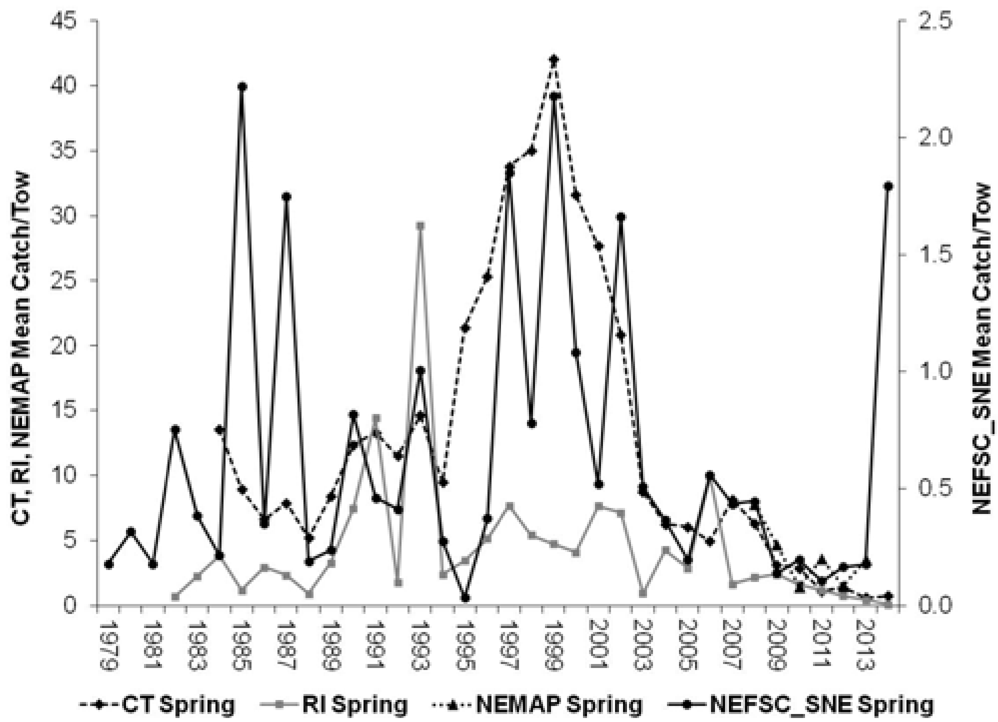


Figure 4.2.1.2.1.4. Southern New England spring trawl survey indices for the Connecticut, Rhode Island, NEMAP, and NEFSC surveys, sexes combined.

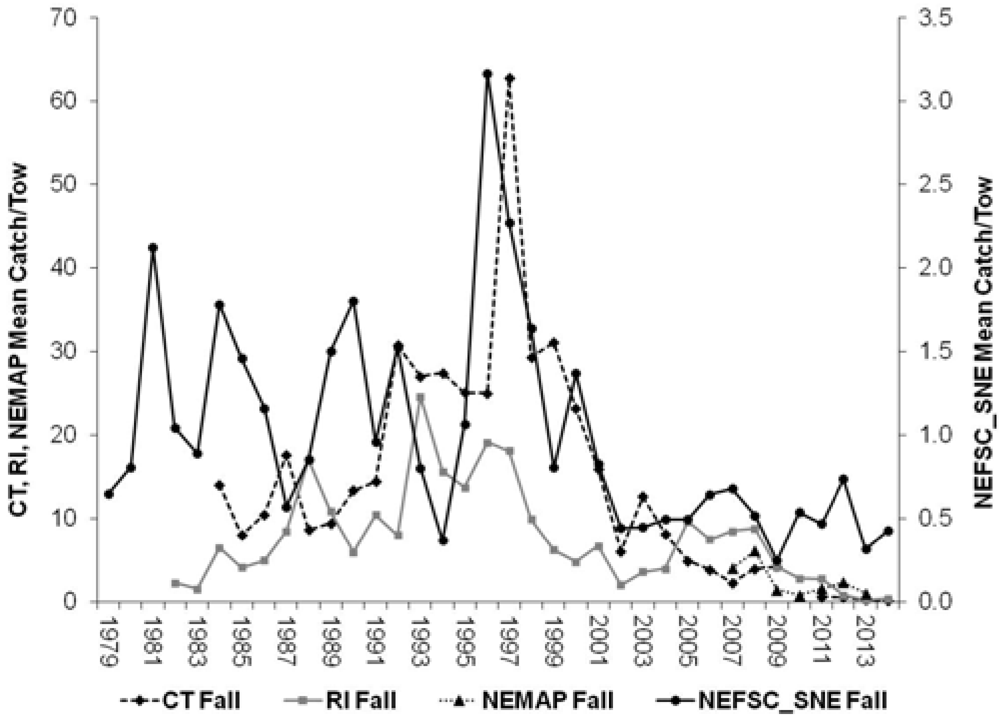


Figure 4.2.1.2.1.5. Southern New England fall trawl survey indices for the Connecticut, Rhode Island, NEMAP, and NEFSC surveys, sexes combined.

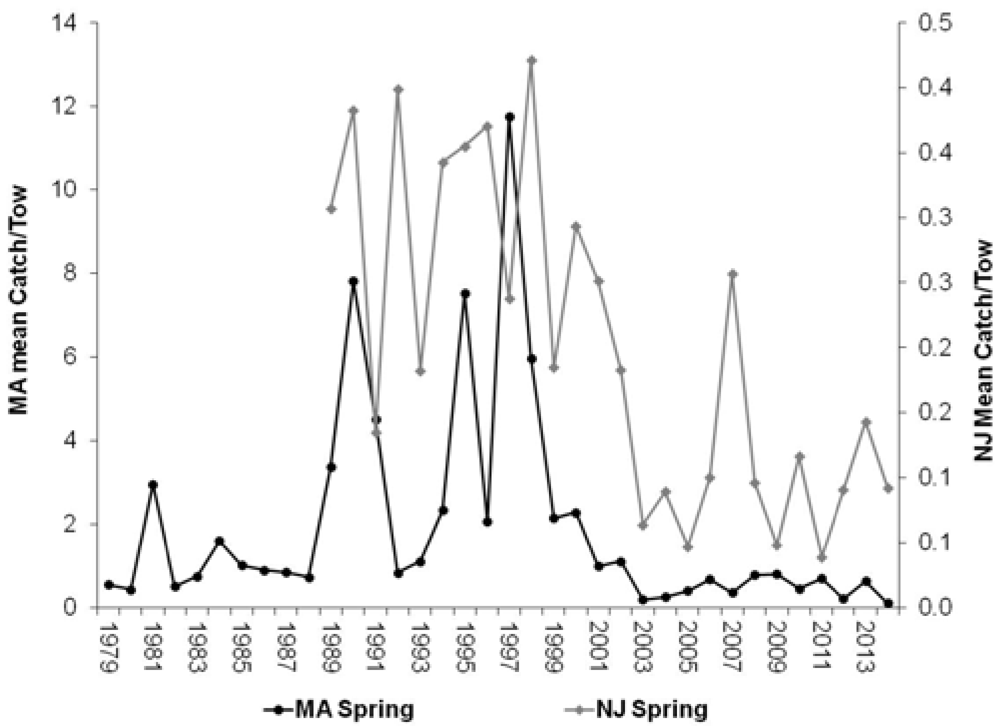


Figure 4.2.1.2.1.6. Southern New England spring trawl survey indices for the Massachusetts and New Jersey surveys, sexes combined.

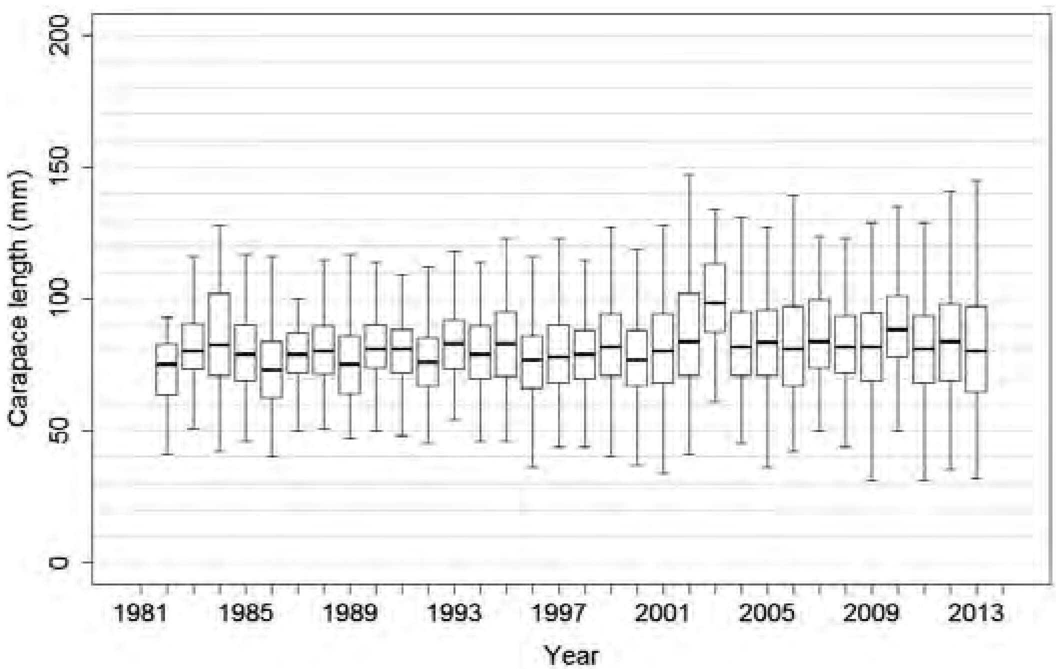


Figure 4.2.1.2.2.1. Gulf of Maine NMFS NEFSC fall survey annual female length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

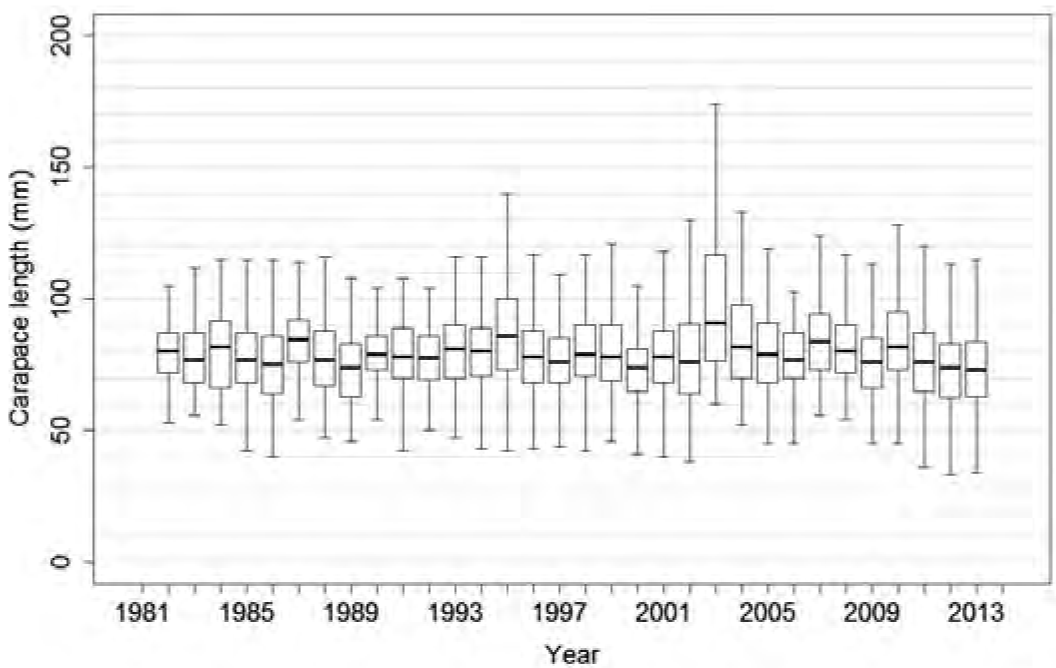


Figure 4.2.1.2.2.2. Gulf of Maine NMFS NEFSC fall survey annual male length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

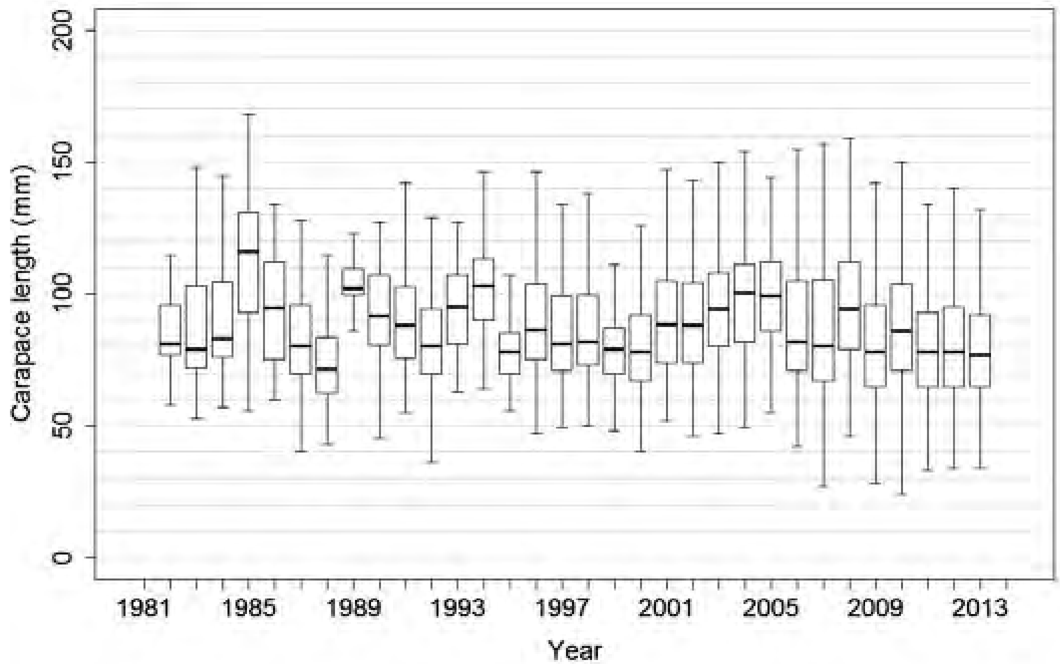


Figure 4.2.1.2.2.3. **Gulf of Maine NMFS NEFSC spring survey annual female length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

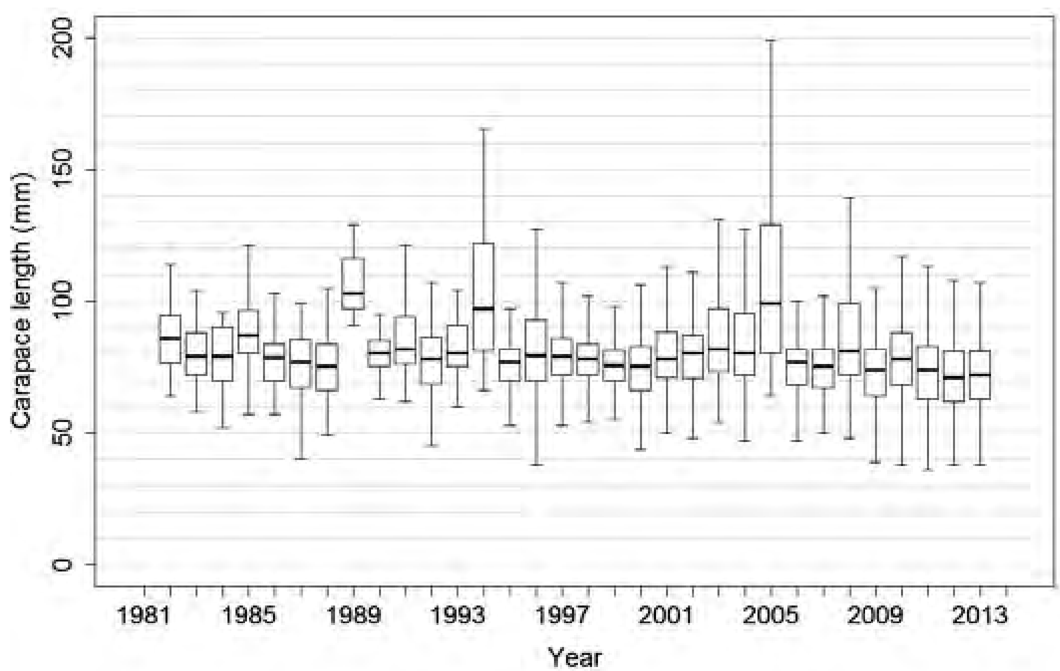


Figure 4.2.1.2.2.4. Gulf of Maine NMFS NEFSC spring survey annual male length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

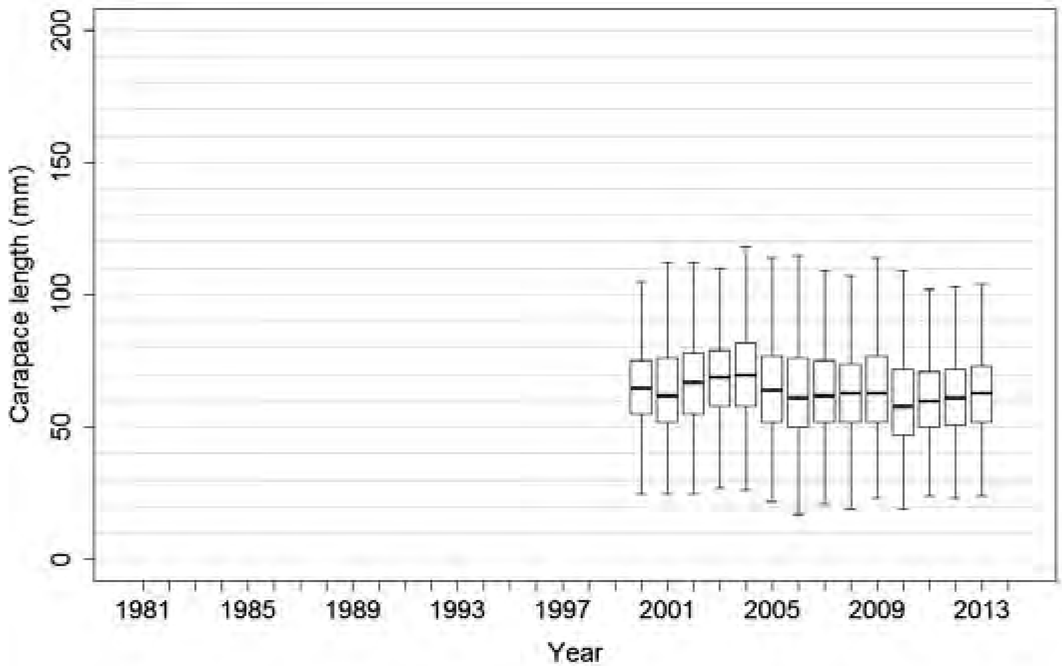


Figure 4.2.1.2.2.5. Gulf of Maine ME/NH fall survey annual female length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

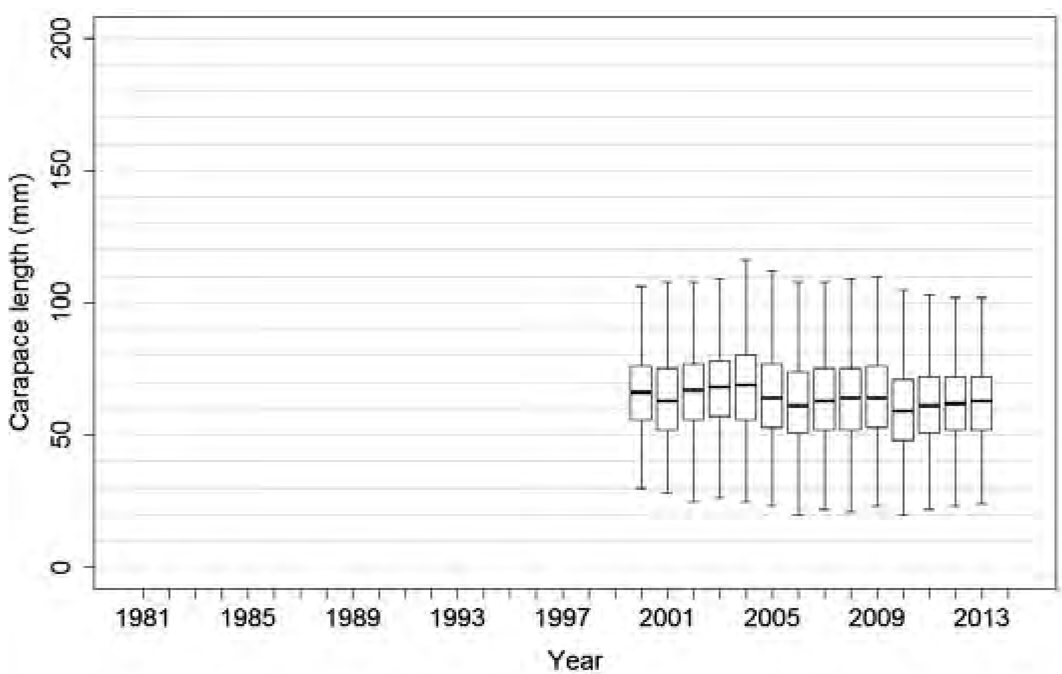


Figure 4.2.1.2.2.6. Gulf of Maine ME/NH fall survey annual male length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

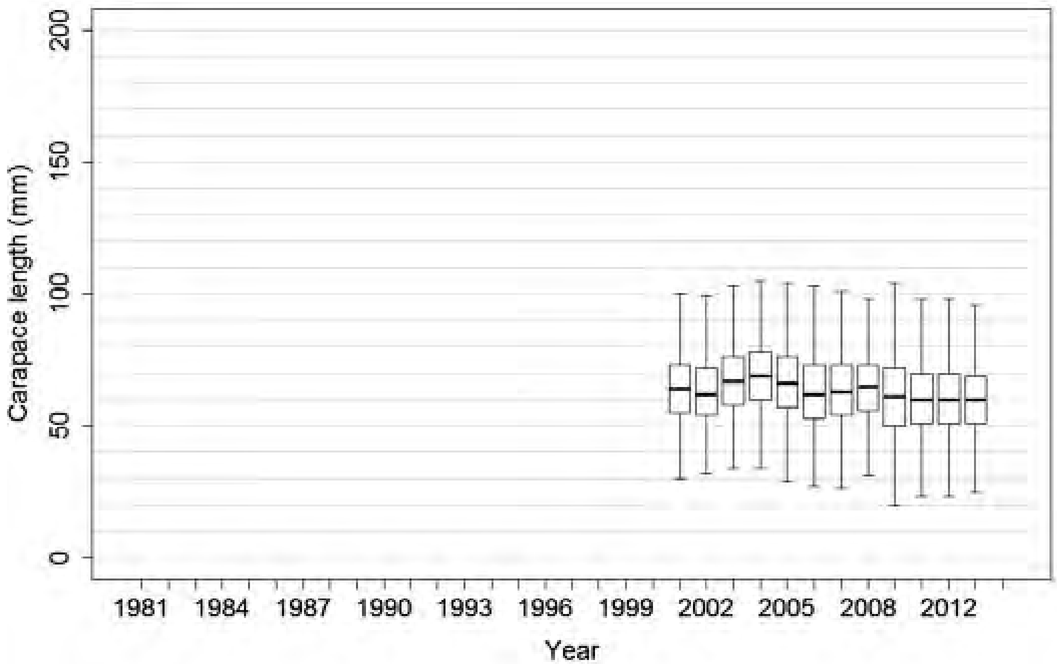


Figure 4.2.1.2.2.7. Gulf of Maine ME/NH spring survey annual female length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

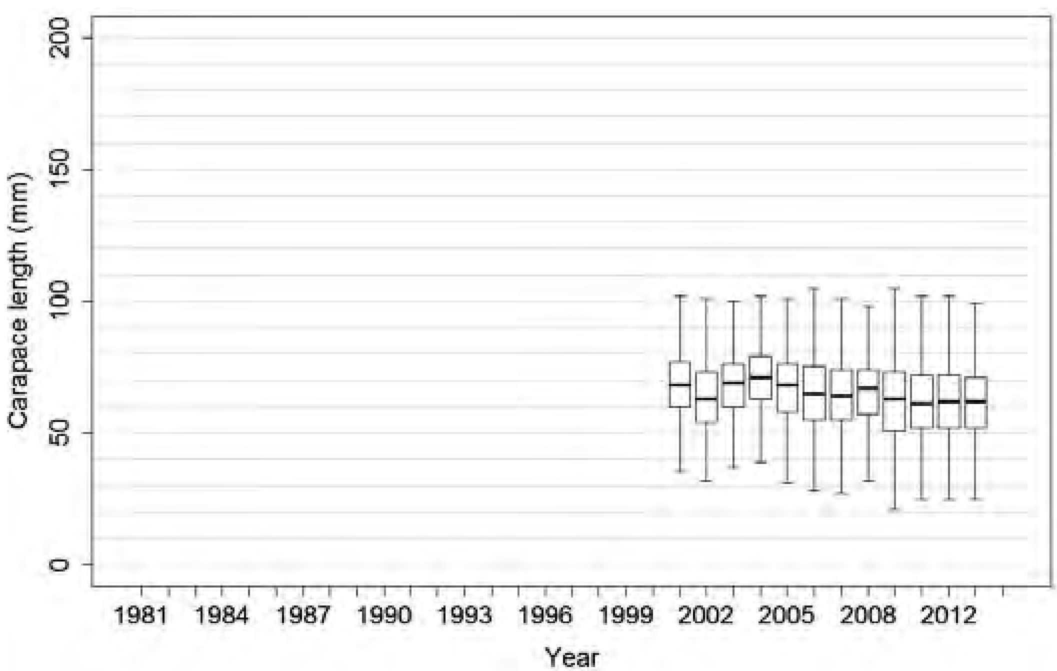


Figure 4.2.1.2.2.8. Gulf of Maine ME/NH spring survey annual male length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

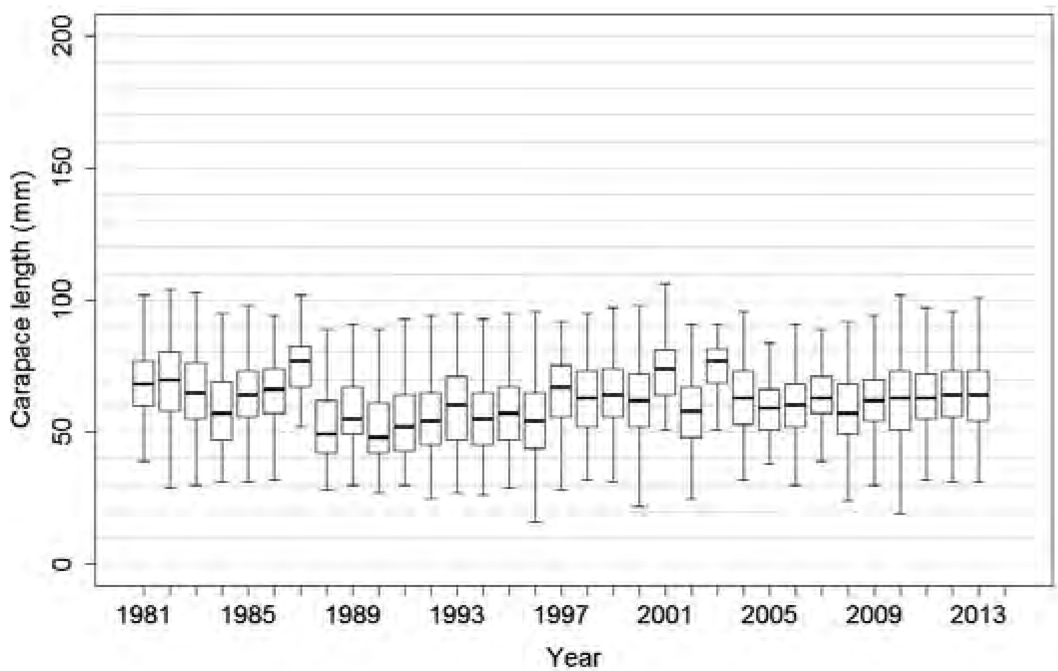


Figure 4.2.1.2.2.9. Gulf of Maine MA fall survey annual female length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

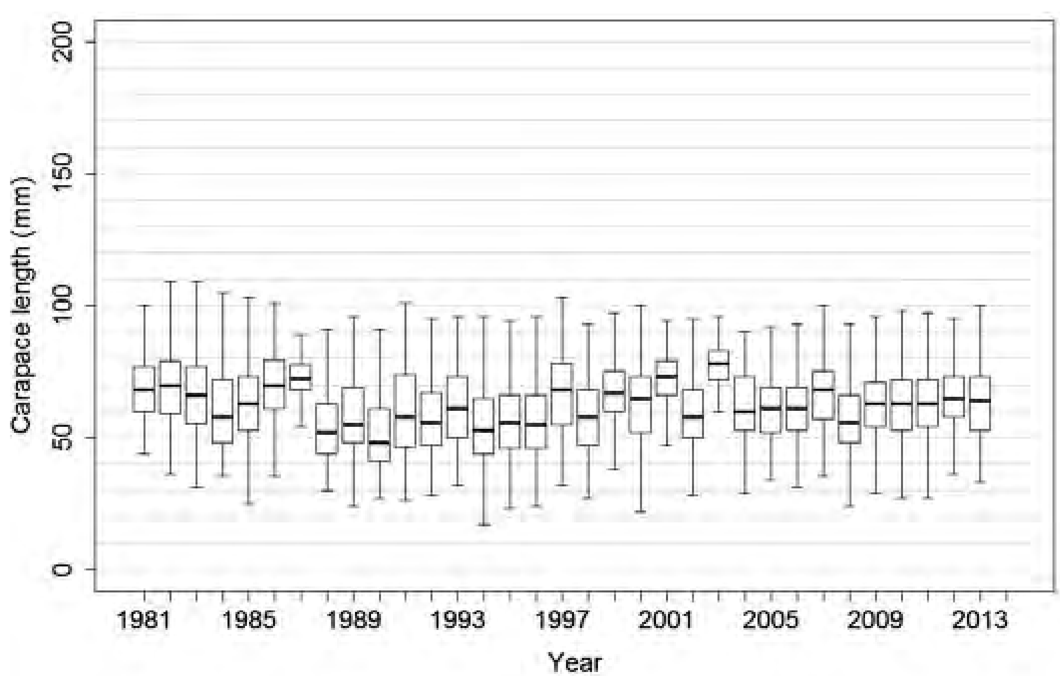


Figure 4.2.1.2.2.10. **Gulf of Maine MA fall survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

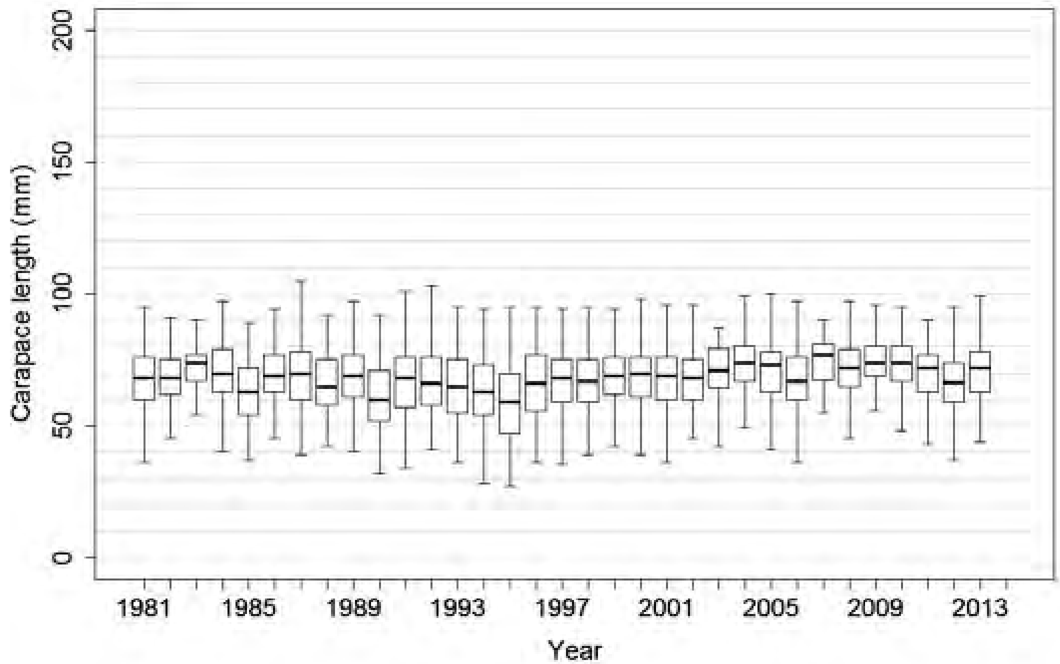


Figure 4.2.1.2.2.11. **Gulf of Maine MA spring survey annual female length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

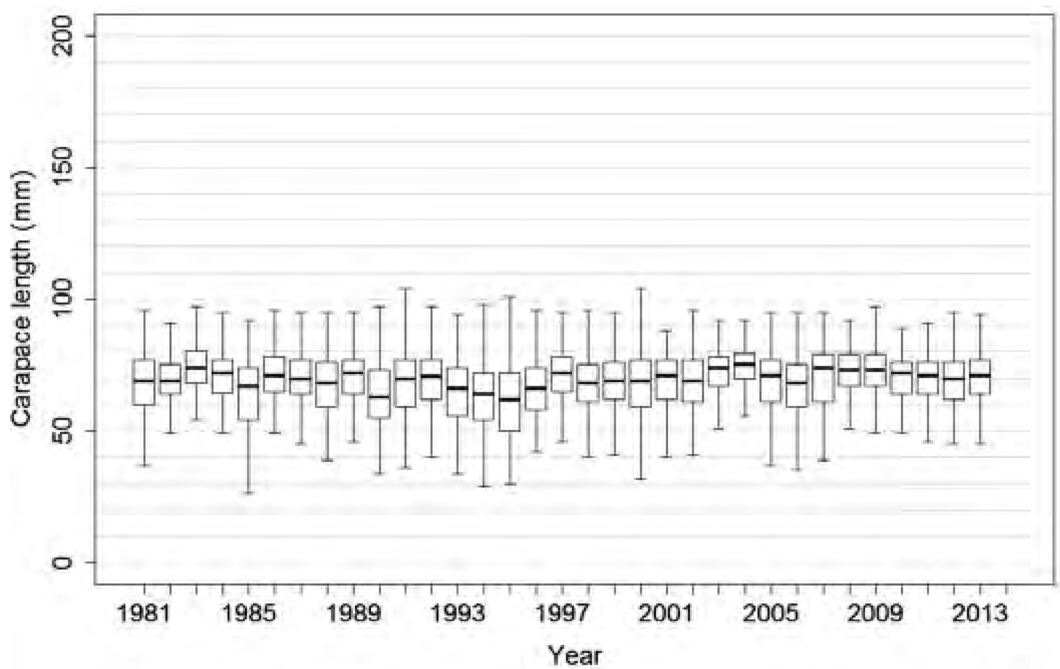


Figure 4.2.1.2.2.12. **Gulf of Maine MA spring survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

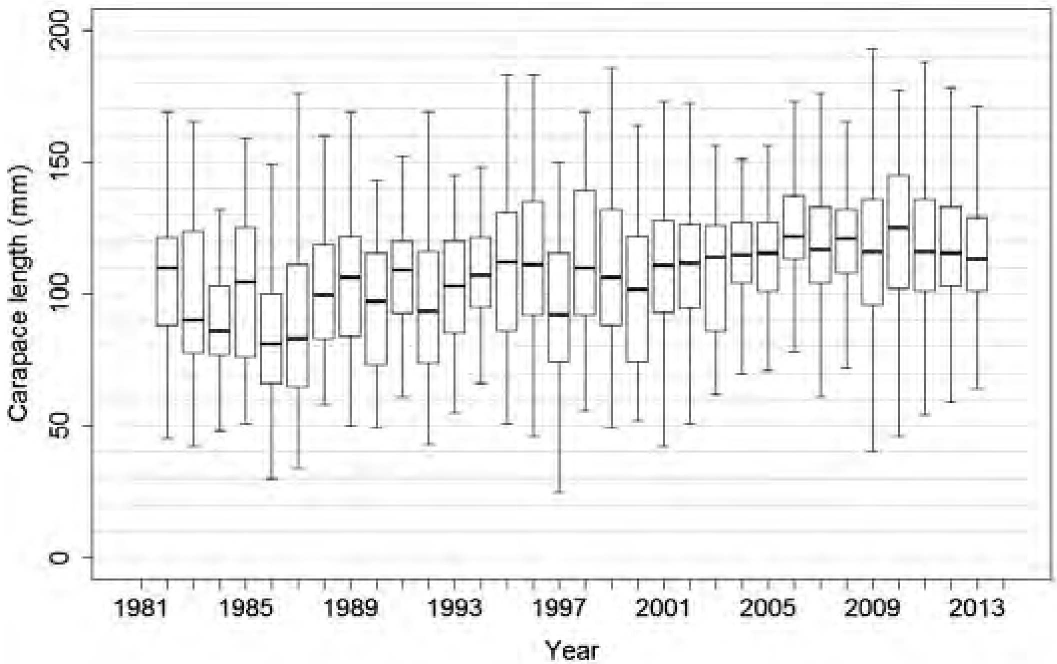


Figure 4.2.1.2.2.13. Georges Bank NMFS NEFSC fall survey annual female length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

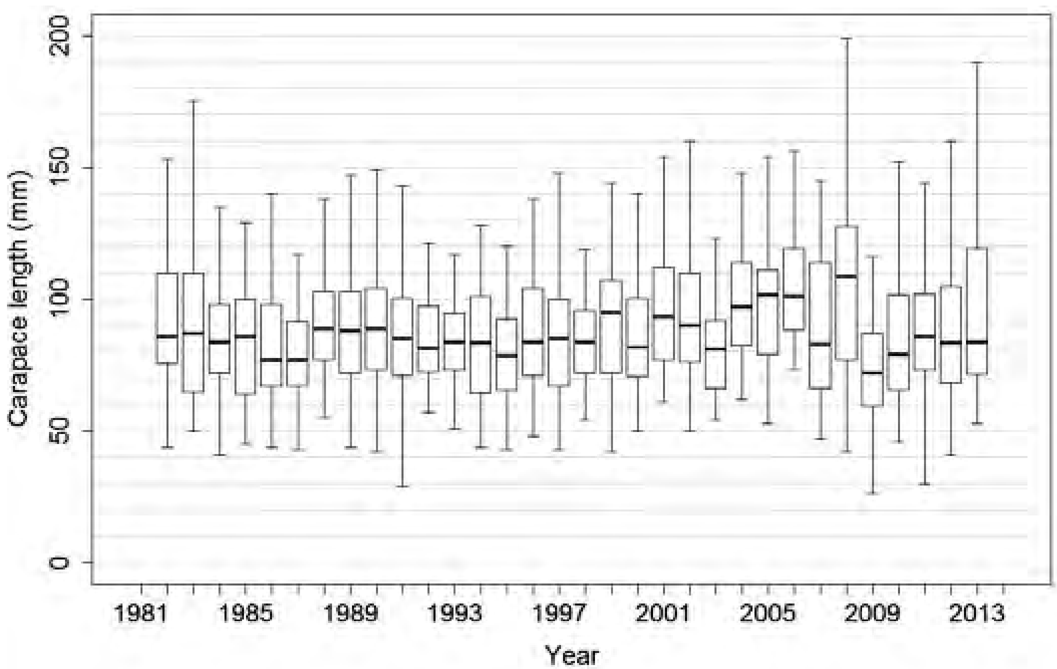


Figure 4.2.1.2.2.14. **Georges Bank NMFS NEFSC fall survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

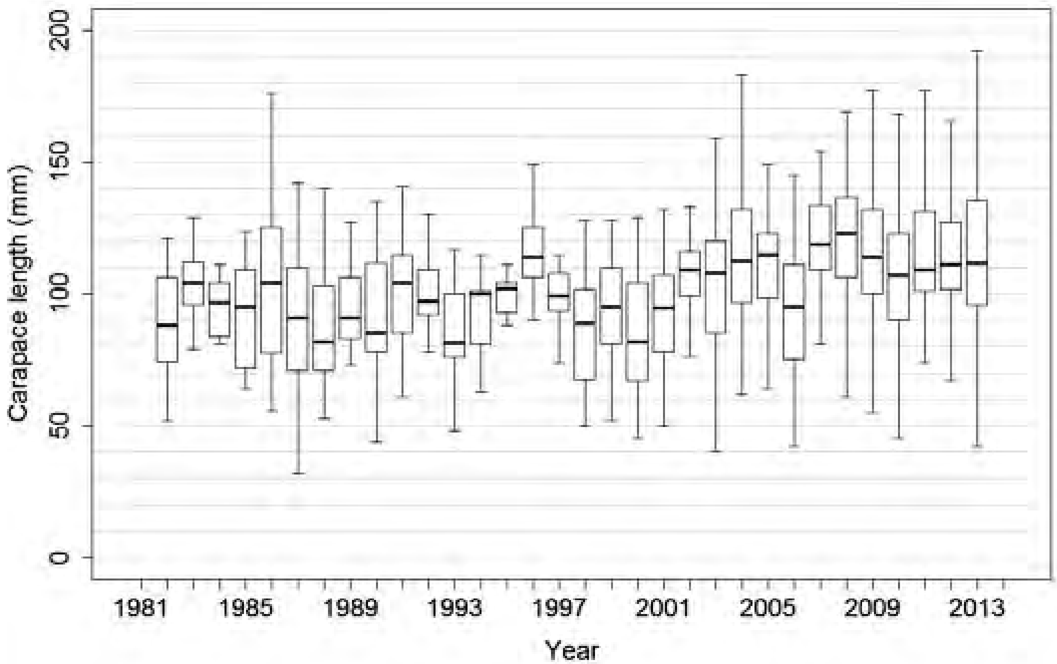


Figure 4.2.1.2.2.15. Georges Bank NMFS NEFSC spring survey annual female length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

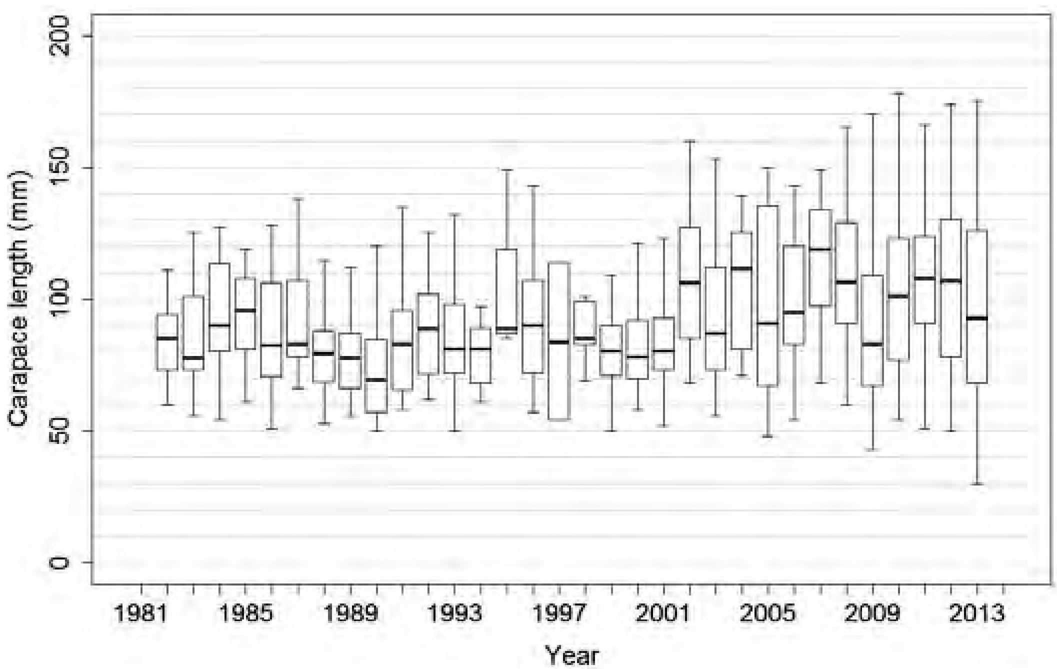


Figure 4.2.1.2.2.16. Georges Bank NMFS NEFSC spring survey annual male length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

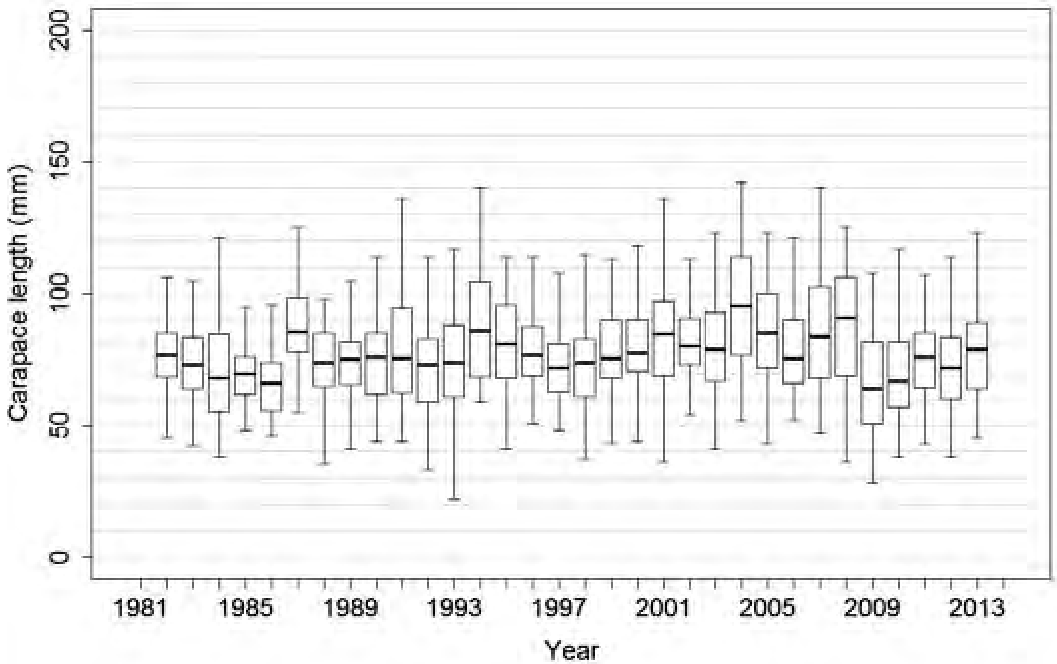


Figure 4.2.1.2.2.17. Southern New England NMFS NEFSC fall survey annual female length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

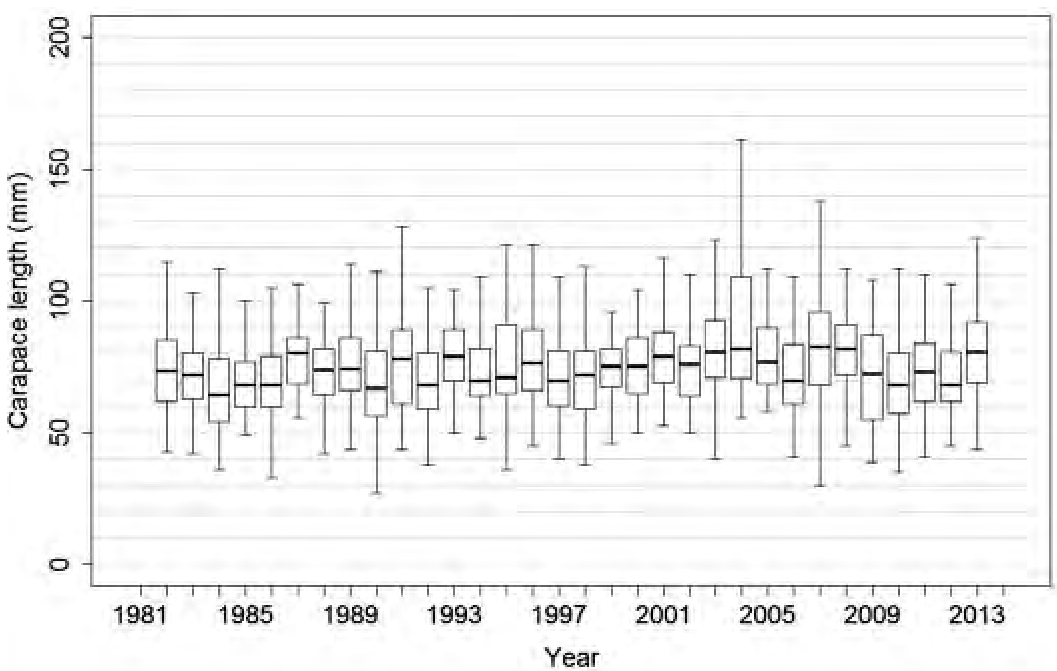


Figure 4.2.1.2.2.18. Southern New England NMFS NEFSC fall survey annual male length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

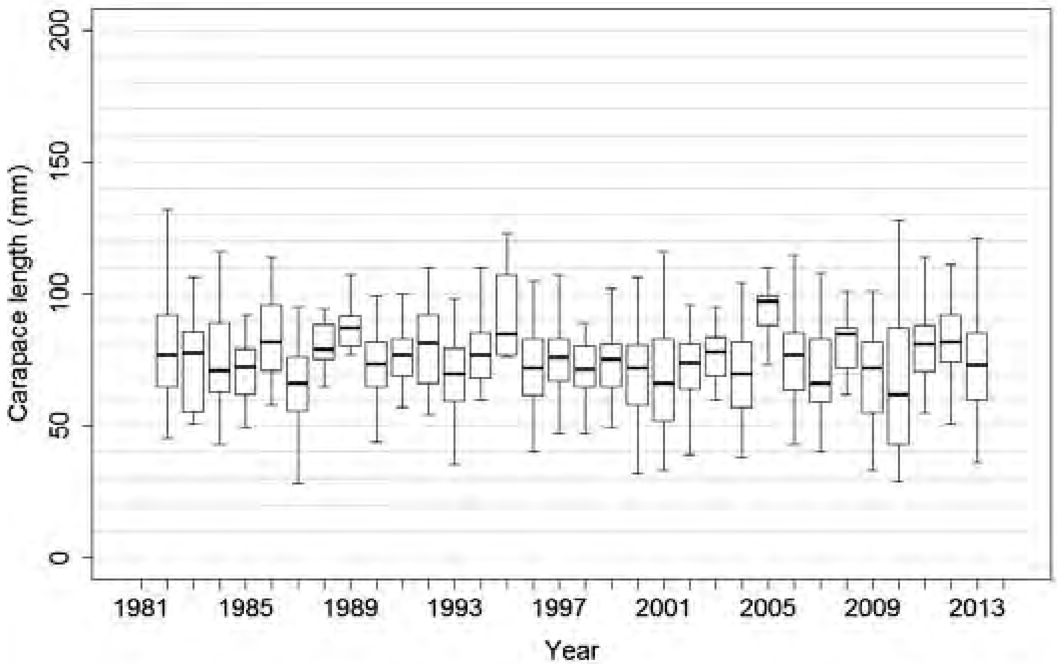


Figure 4.2.1.2.2.19. Southern New England NMFS NEFSC spring survey annual female length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

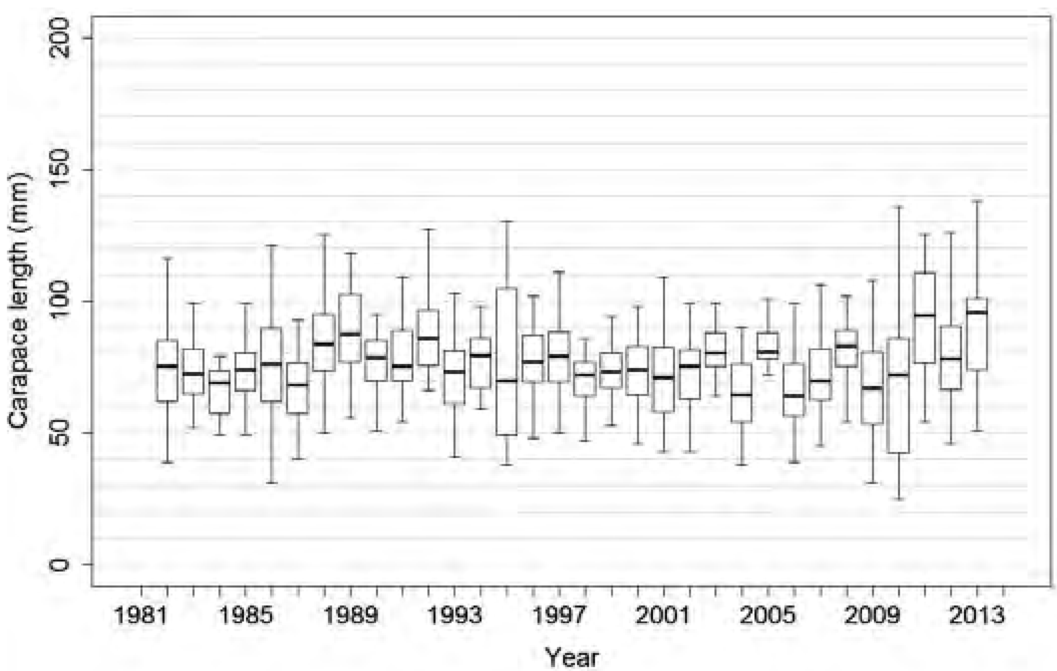


Figure 4.2.1.2.2.20. Southern New England NMFS NEFSC spring survey annual male length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

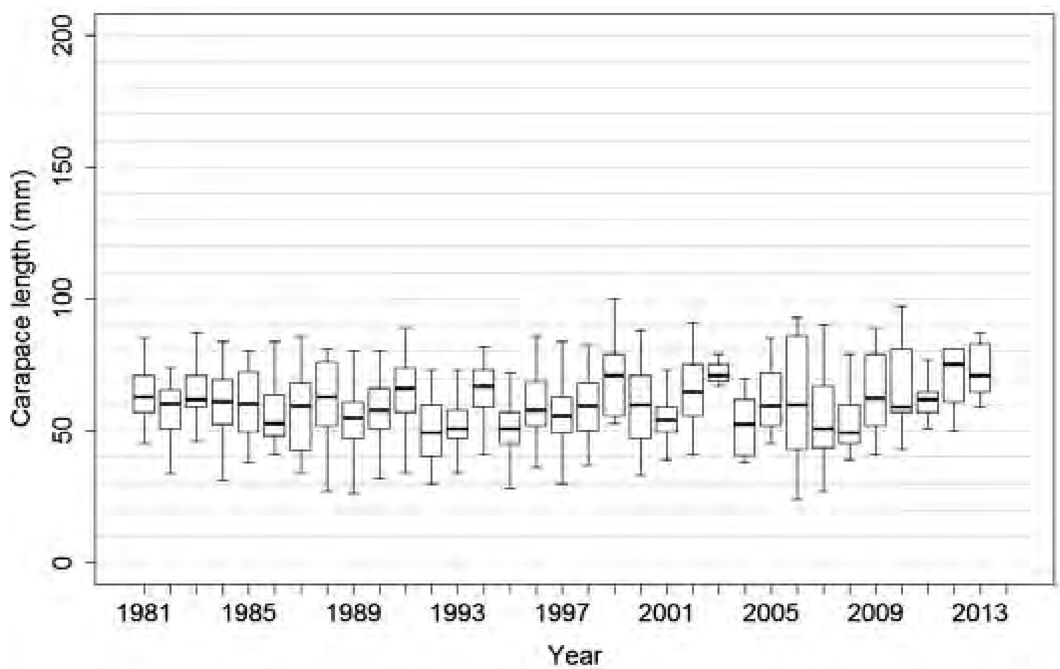


Figure 4.2.1.2.2.21. **Southern New England MA spring survey annual female length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

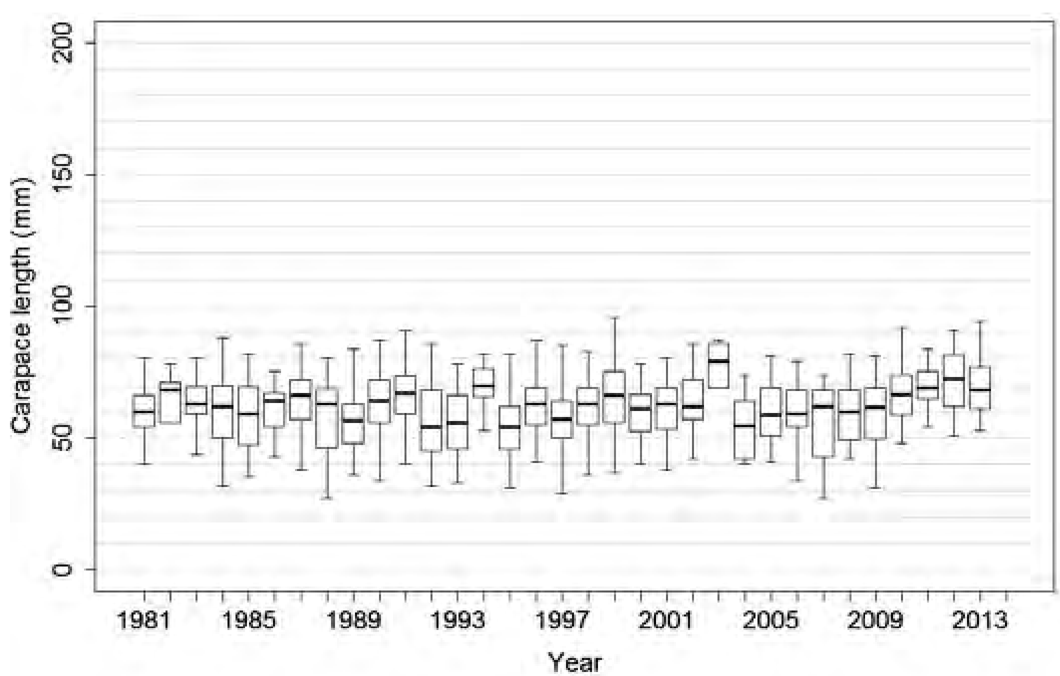


Figure 4.2.1.2.2.22. **Southern New England MA spring survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

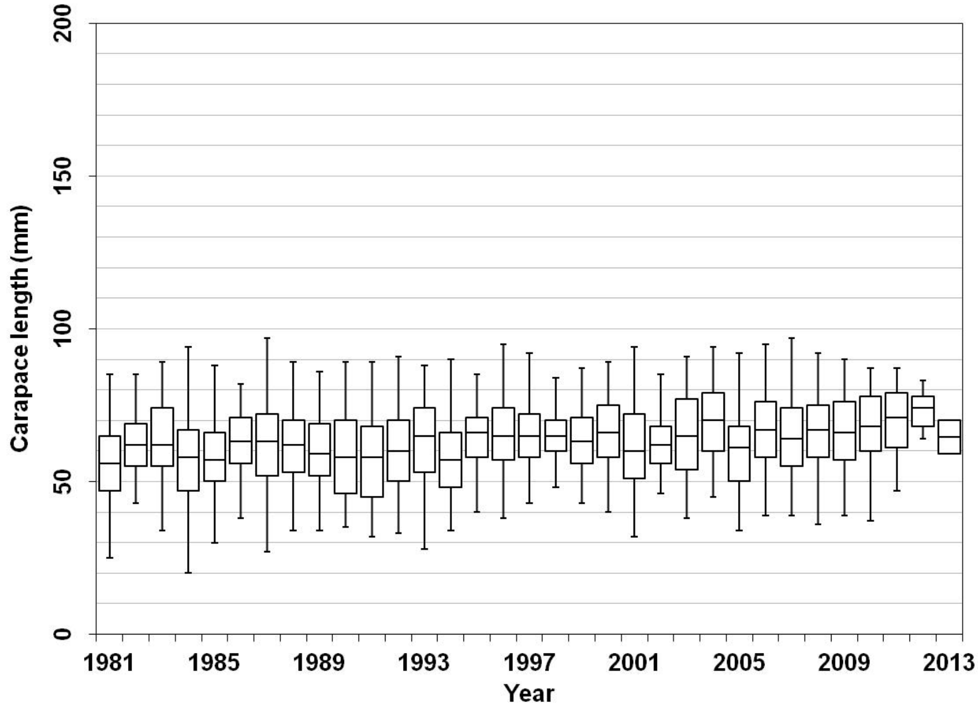


Figure 4.2.1.2.2.23. **Southern New England RI fall survey annual female length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

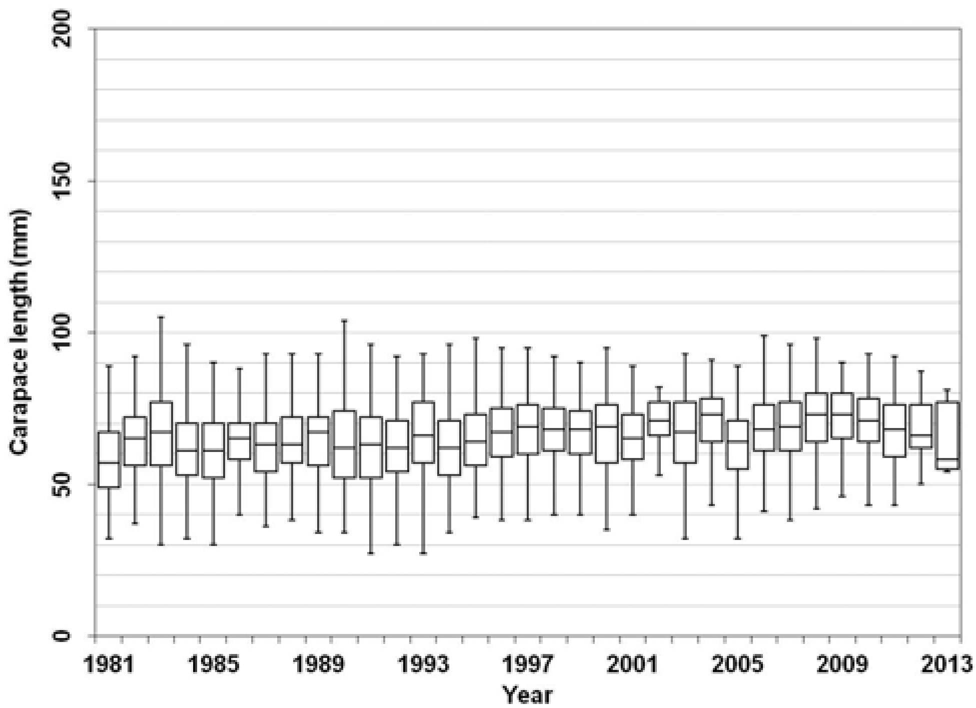


Figure 4.2.1.2.2.24. **Southern New England RI fall survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

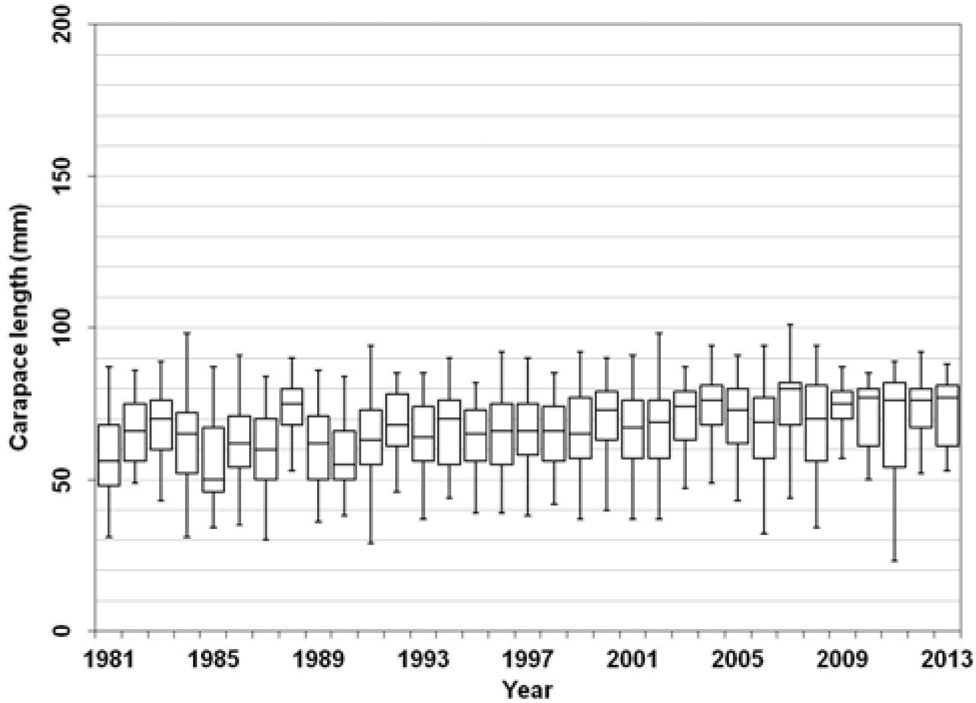


Figure 4.2.1.2.2.25. Southern New England RI spring survey annual female length frequencies. Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

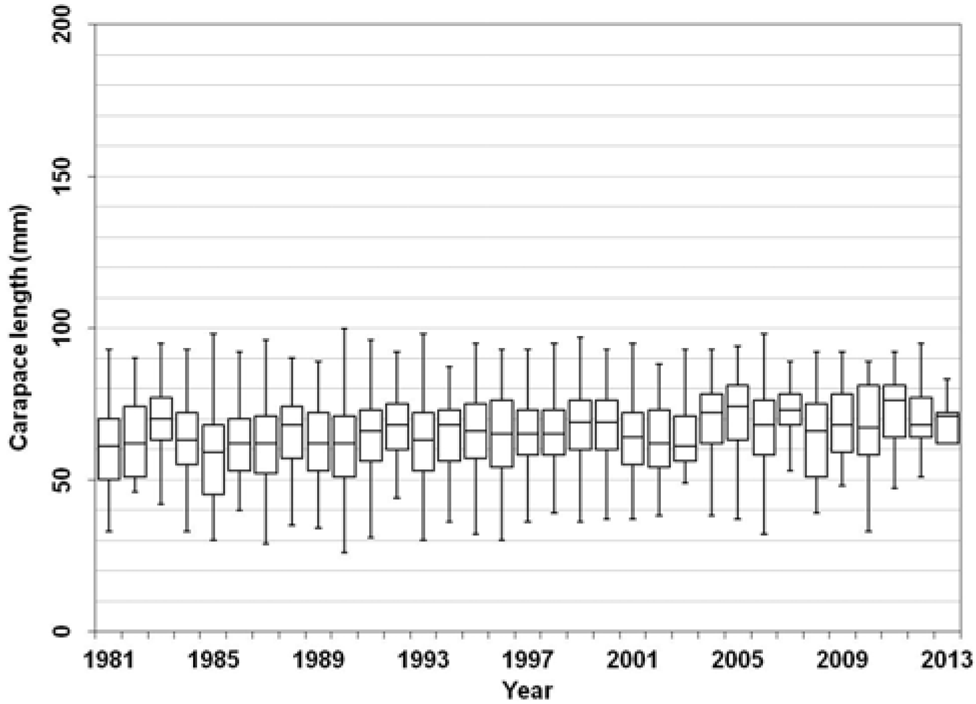


Figure 4.2.1.2.2.26. **Southern New England RI spring survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

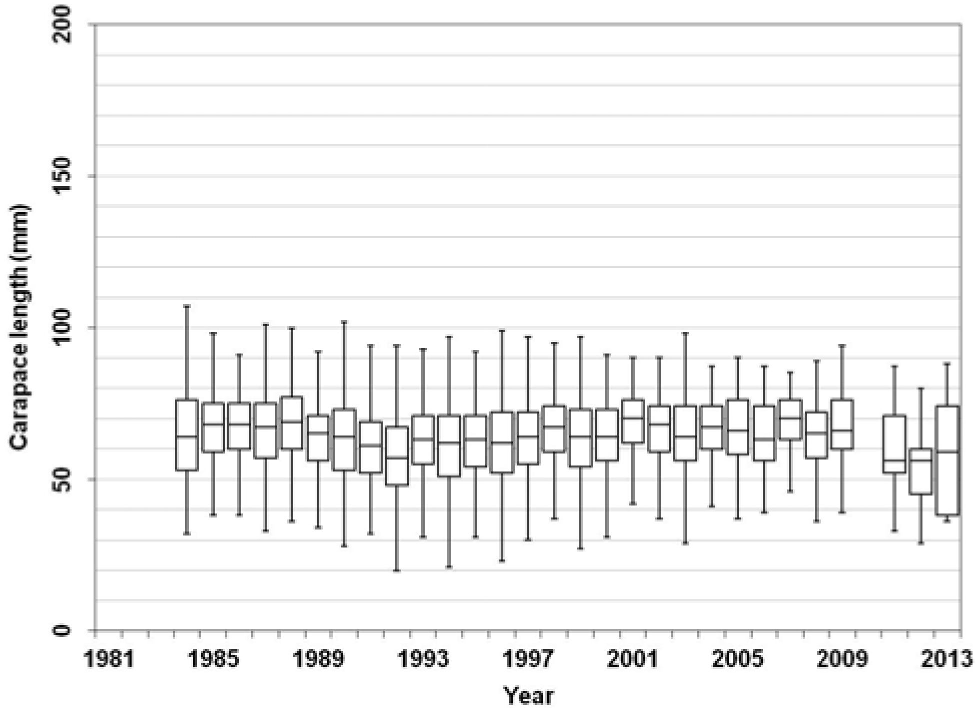


Figure 4.2.1.2.2.27. **Southern New England CT fall survey annual female length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown. There was no survey in 2010.

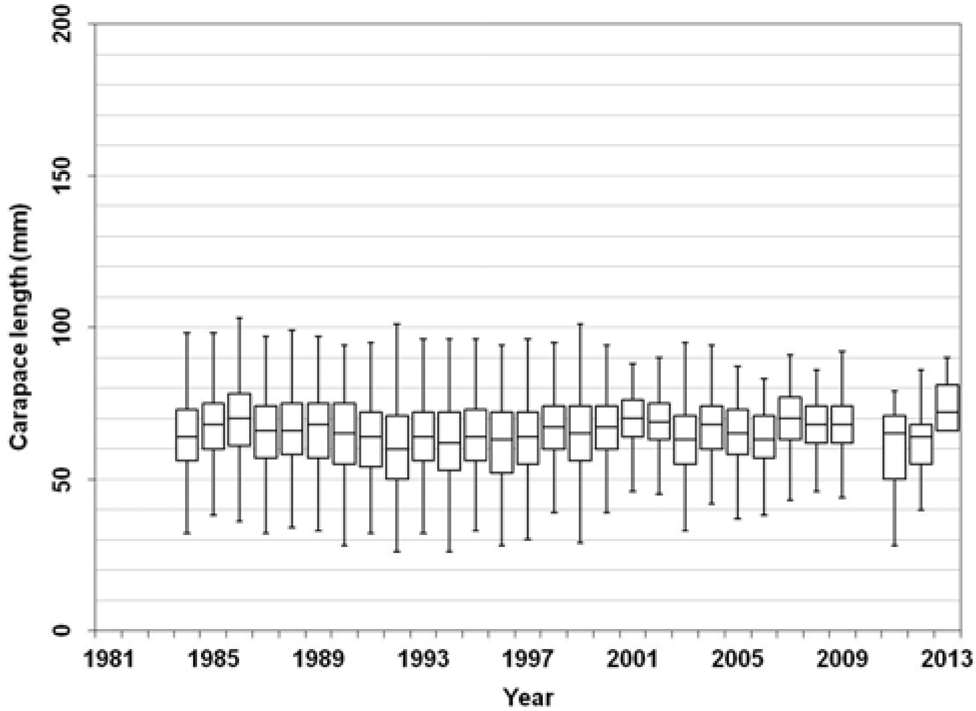


Figure 4.2.1.2.2.28. **Southern New England CT fall survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown. There was no survey in 2010.

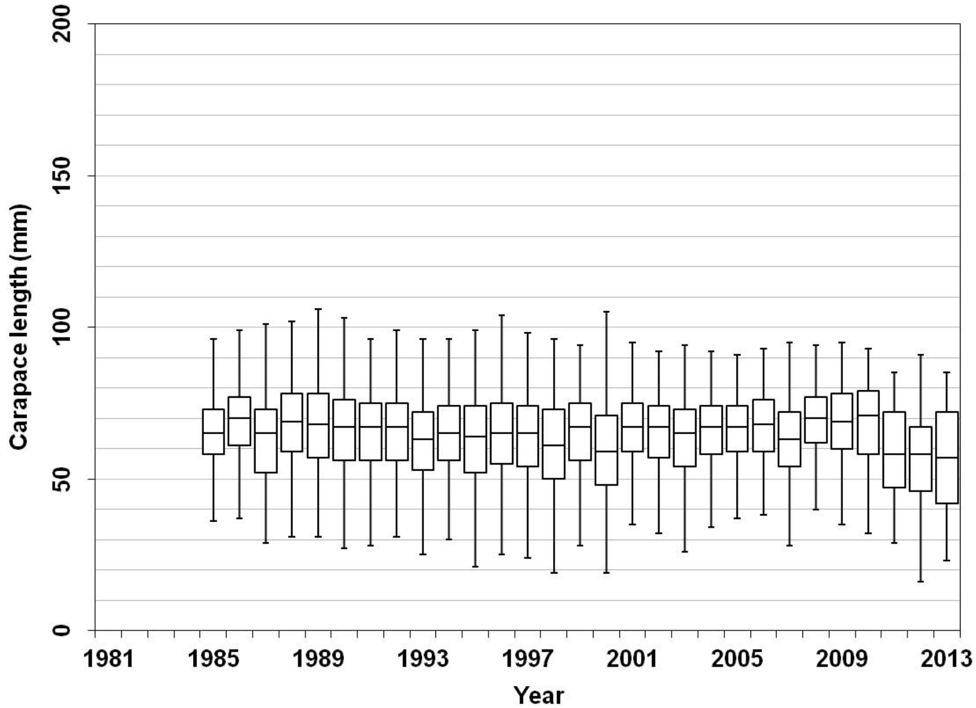


Figure 4.2.1.2.2.29. **Southern New England CT spring survey annual female length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

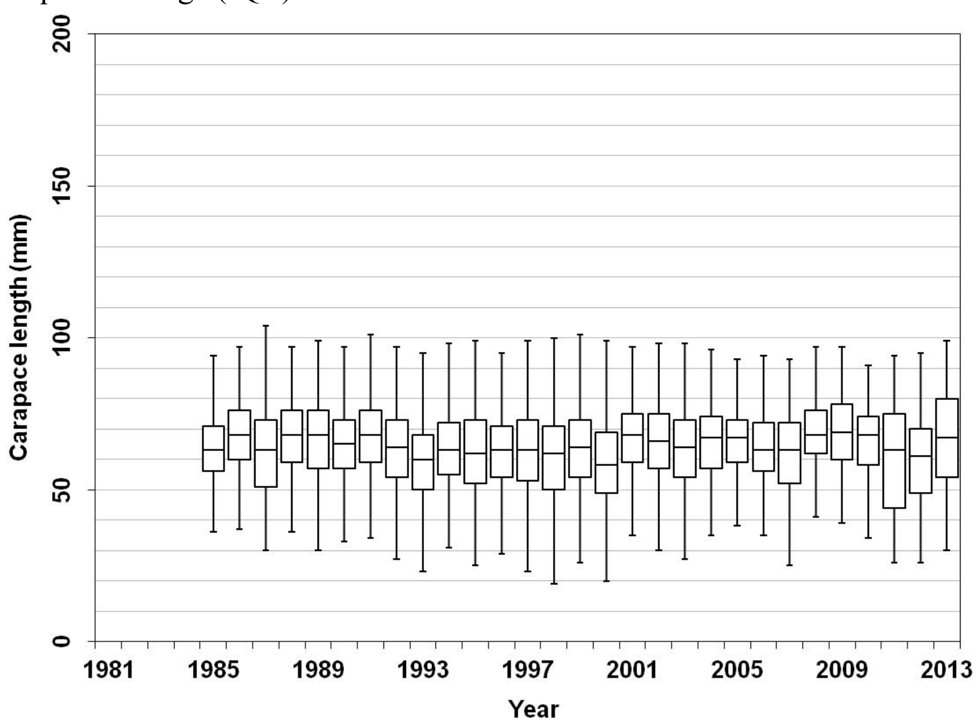


Figure 4.2.1.2.2.30. **Southern New England CT spring survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

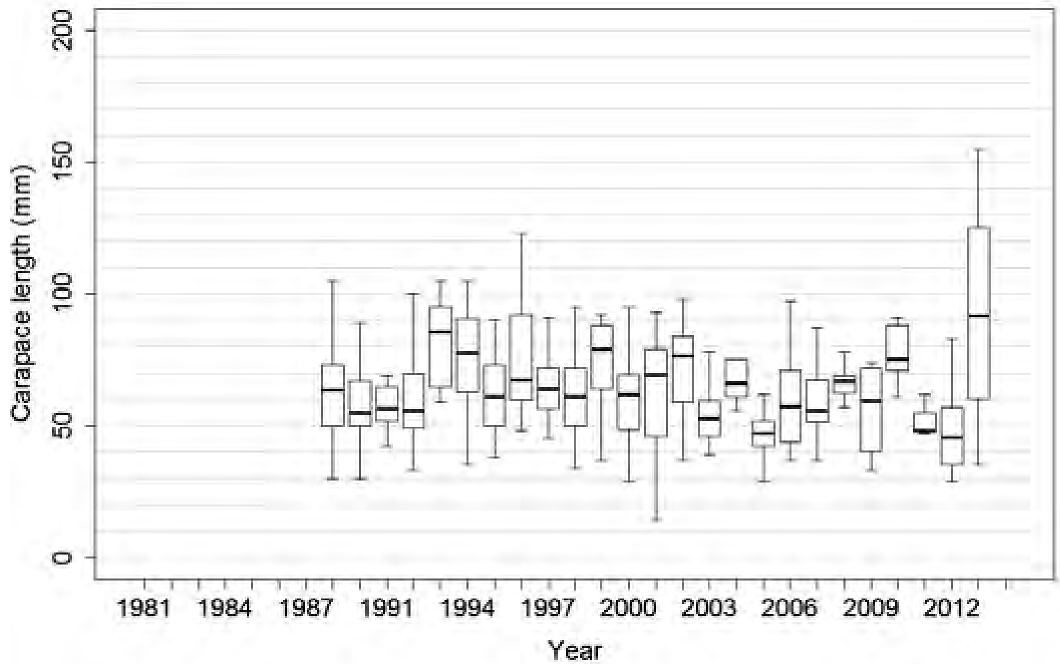


Figure 4.2.1.2.2.31. **Southern New England NJ spring survey annual female length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

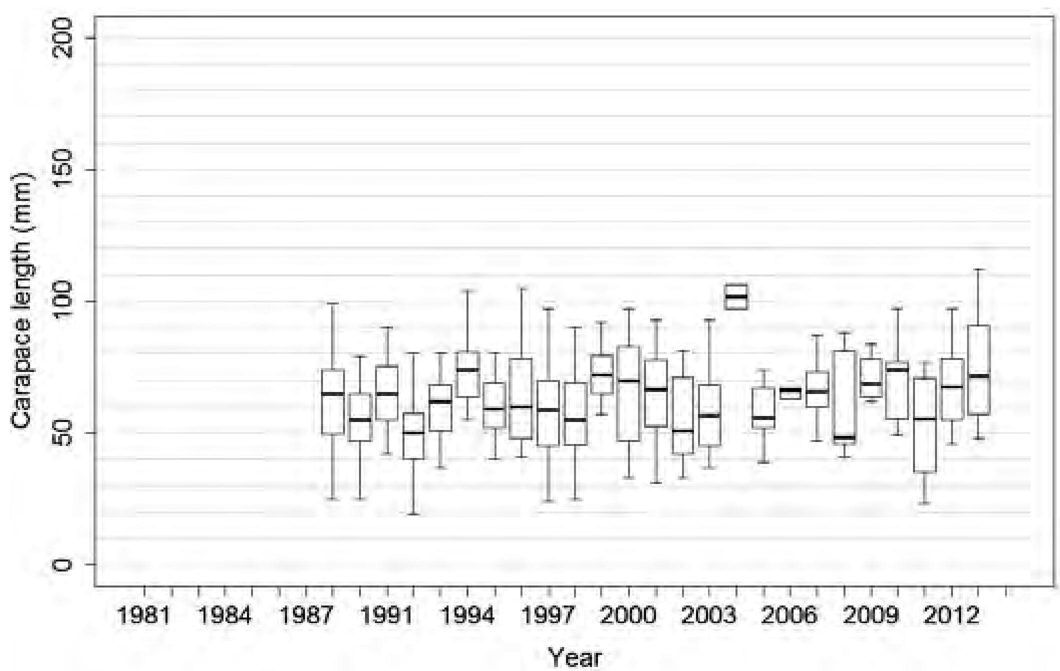


Figure 4.2.1.2.2.32. **Southern New England NJ spring survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

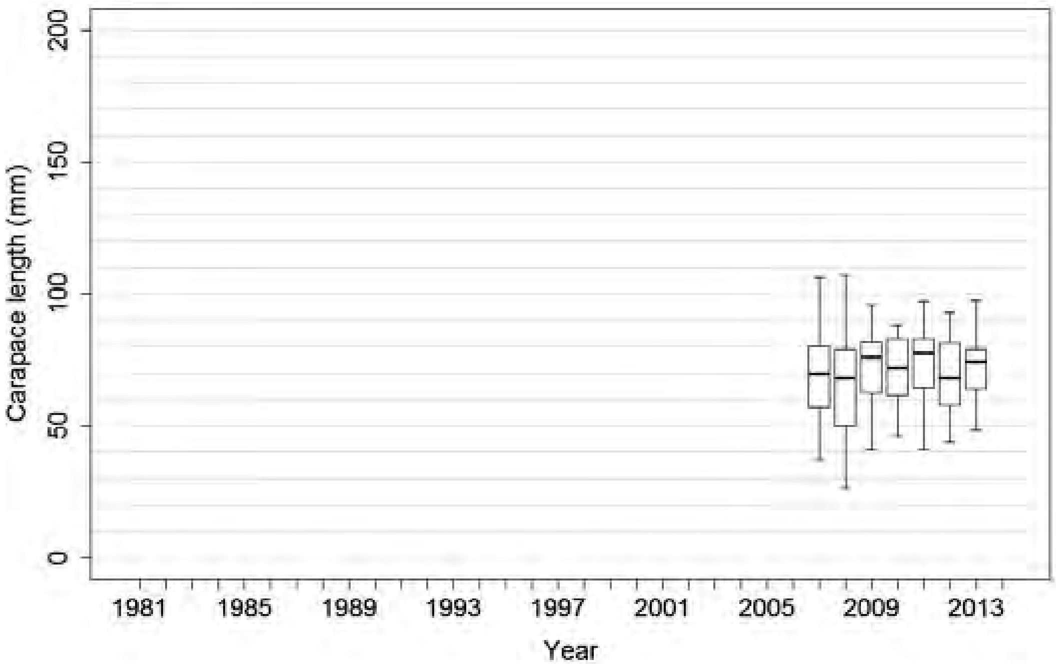


Figure 4.2.1.2.2.33. **Southern New England NEAMAP fall survey annual female length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

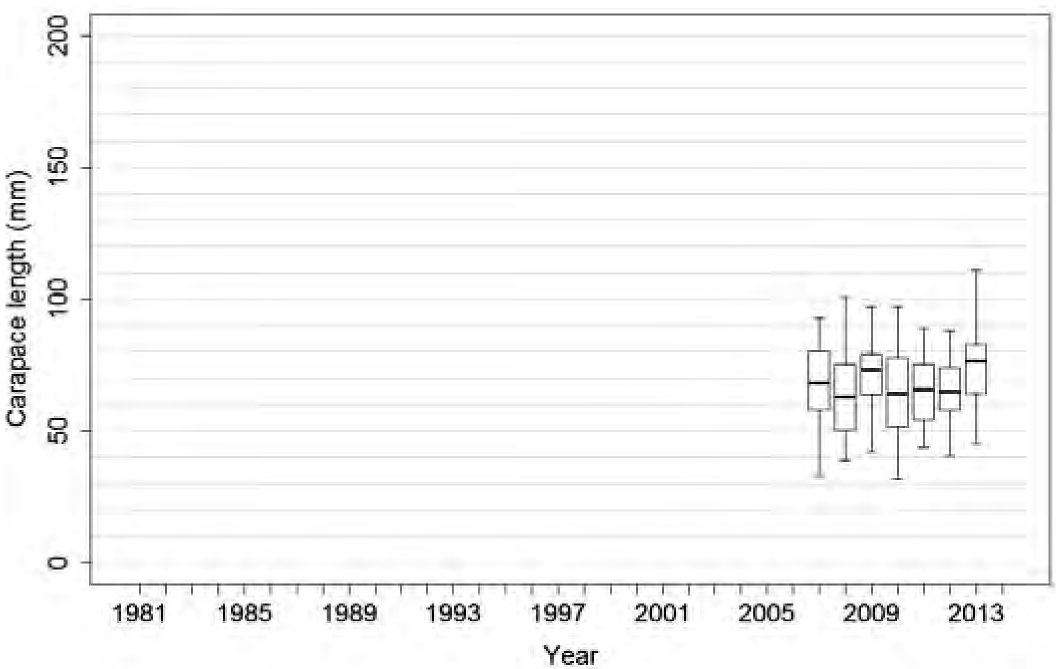


Figure 4.2.1.2.2.34. **Southern New England NEAMAP fall survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

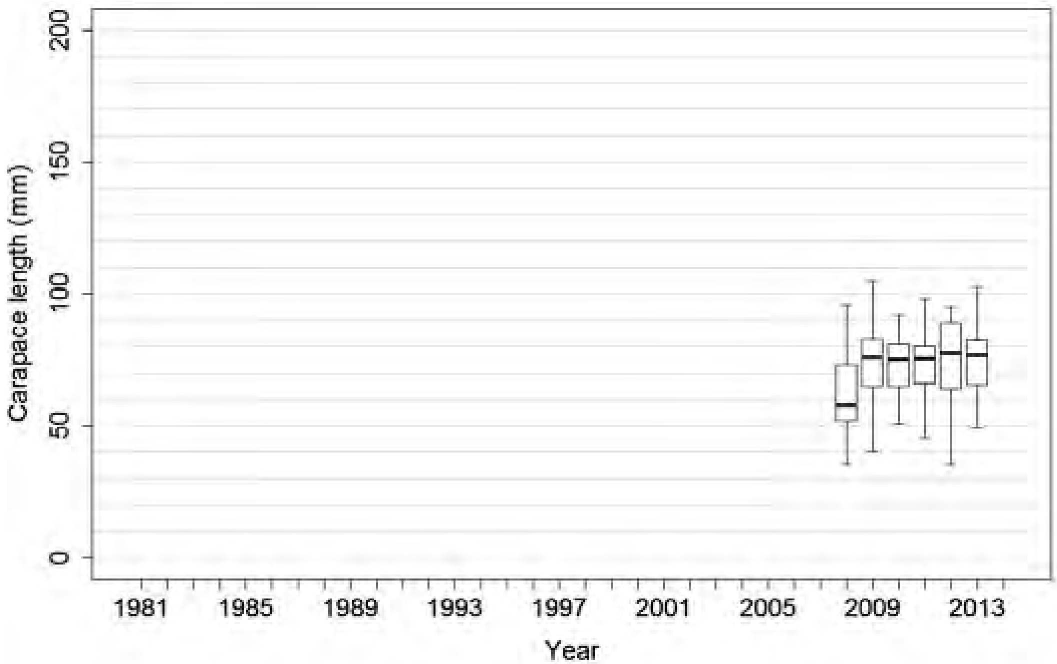


Figure 4.2.1.2.2.35. **Southern New England NEAMAP spring survey annual female length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

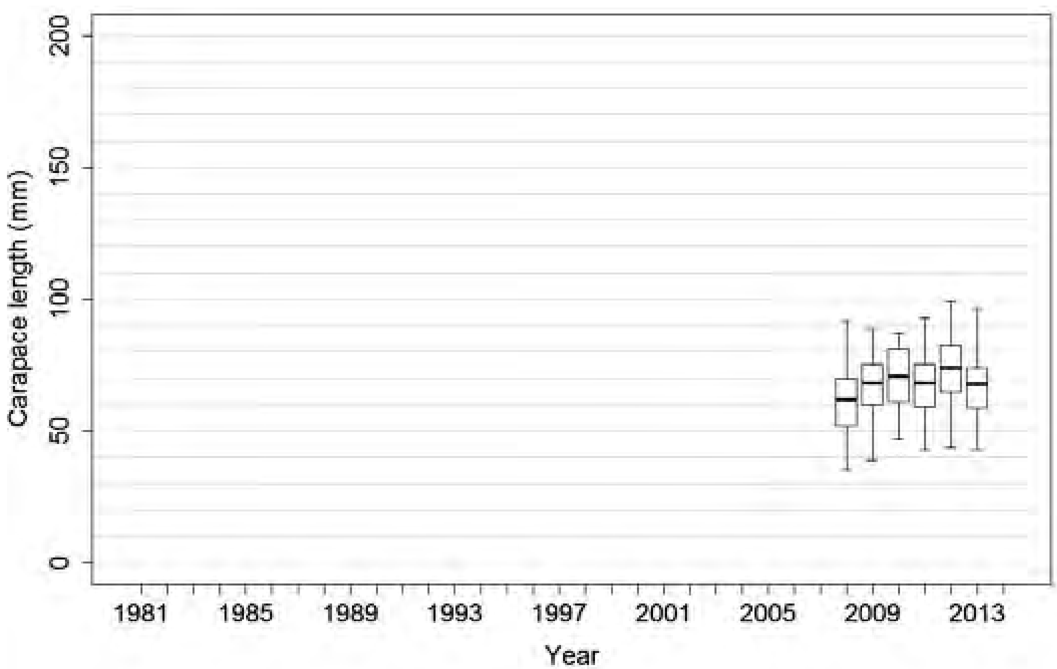


Figure 4.2.1.2.2.36. **Southern New England NEAMAP spring survey annual male length frequencies.** Box shows the median and quartiles, whiskers represent the data points at or within 1.5x the interquartile range (IQR). Outliers are not shown.

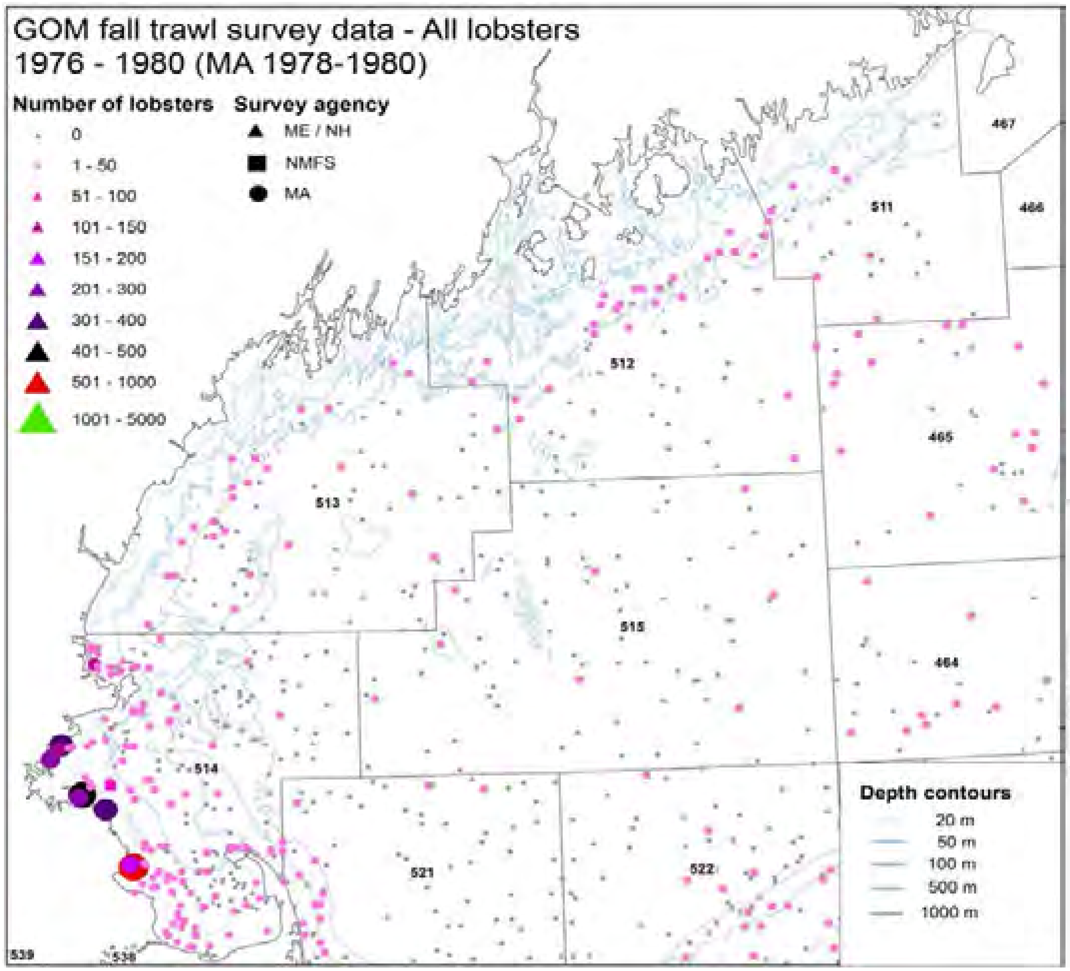


Figure 4.2.1.3.1.1 A

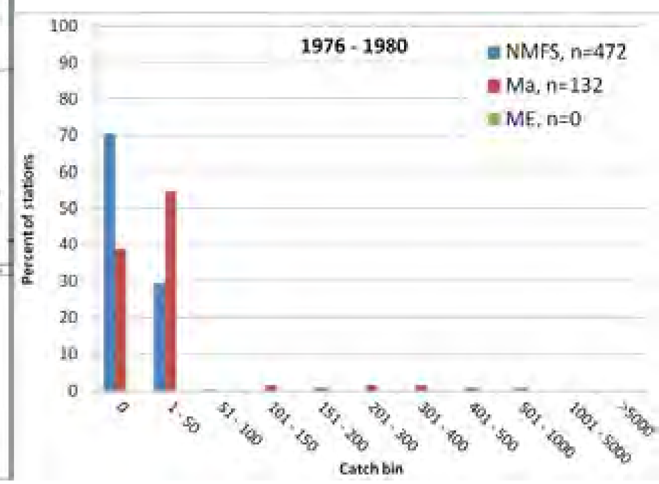
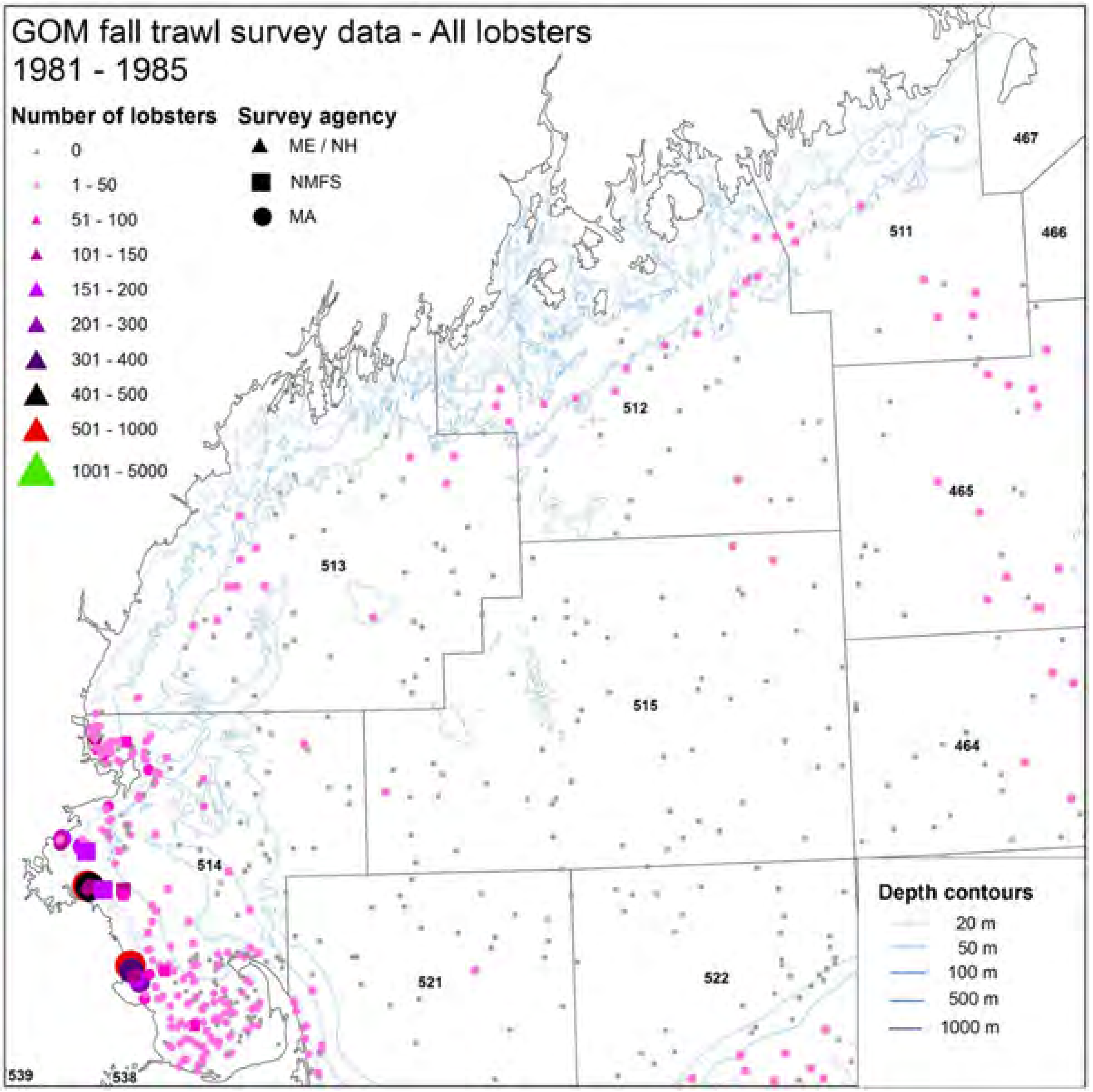


Figure 4.2.1.3.1.1 A – H. Mean catch per tow of lobster (all sizes) at each fall sampling location from all GOM bottom trawl surveys (ME/NH, MA, and NMFS), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.



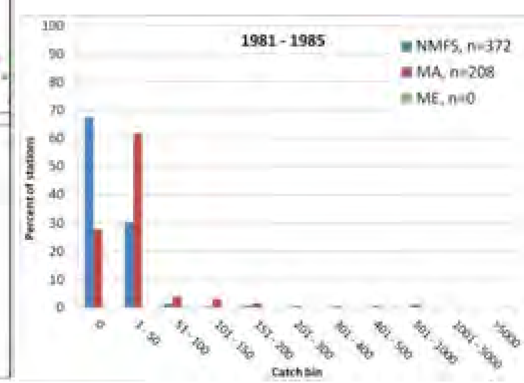


Figure 4.2.1.3.1.1 B

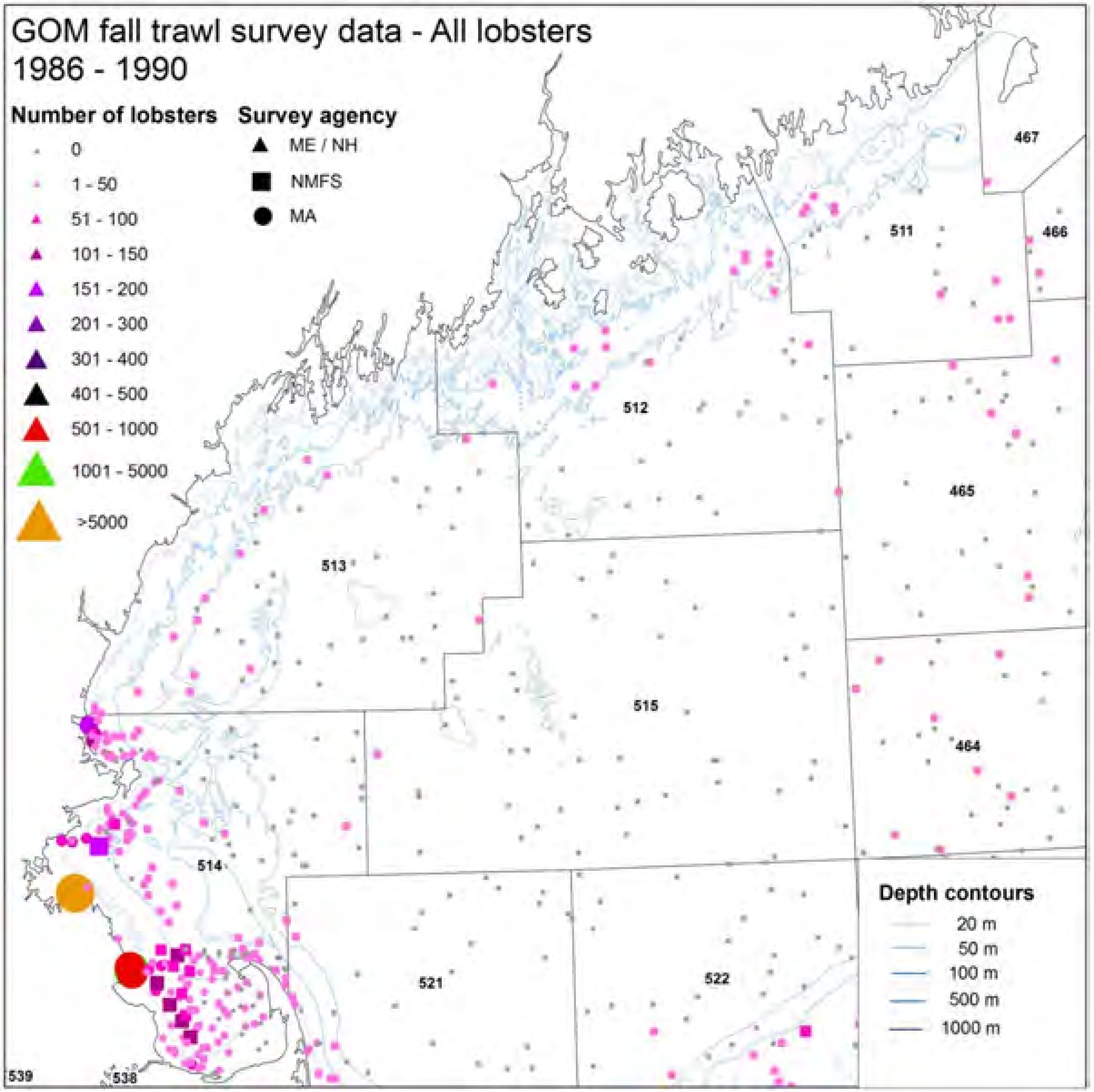
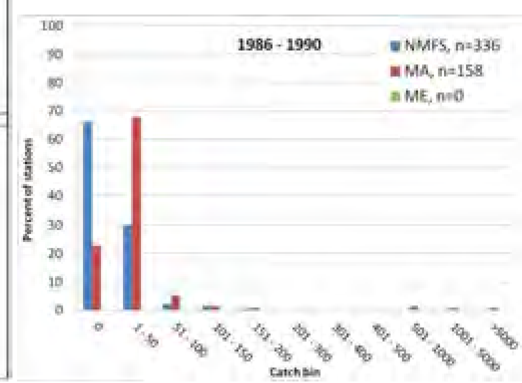


Figure 4.2.1.3.1.1 C



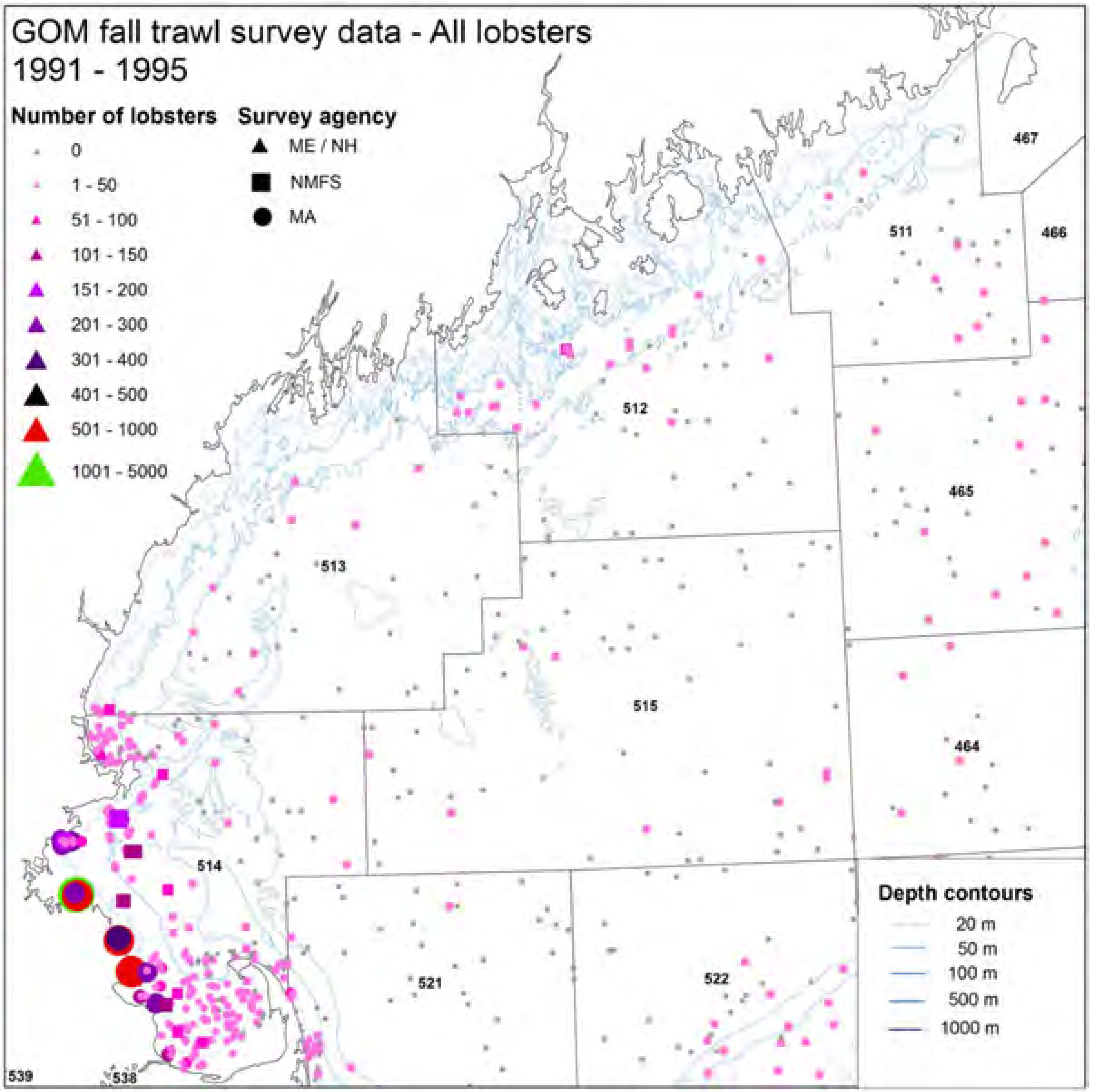
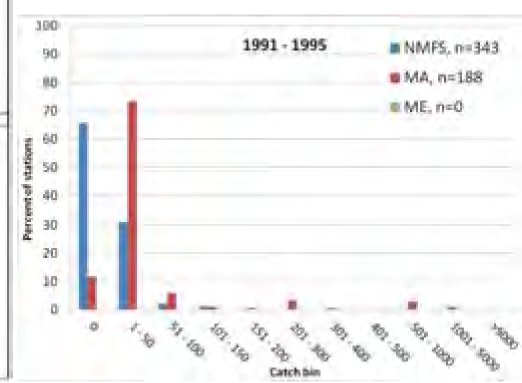


Figure 4.2.1.3.1.1 D



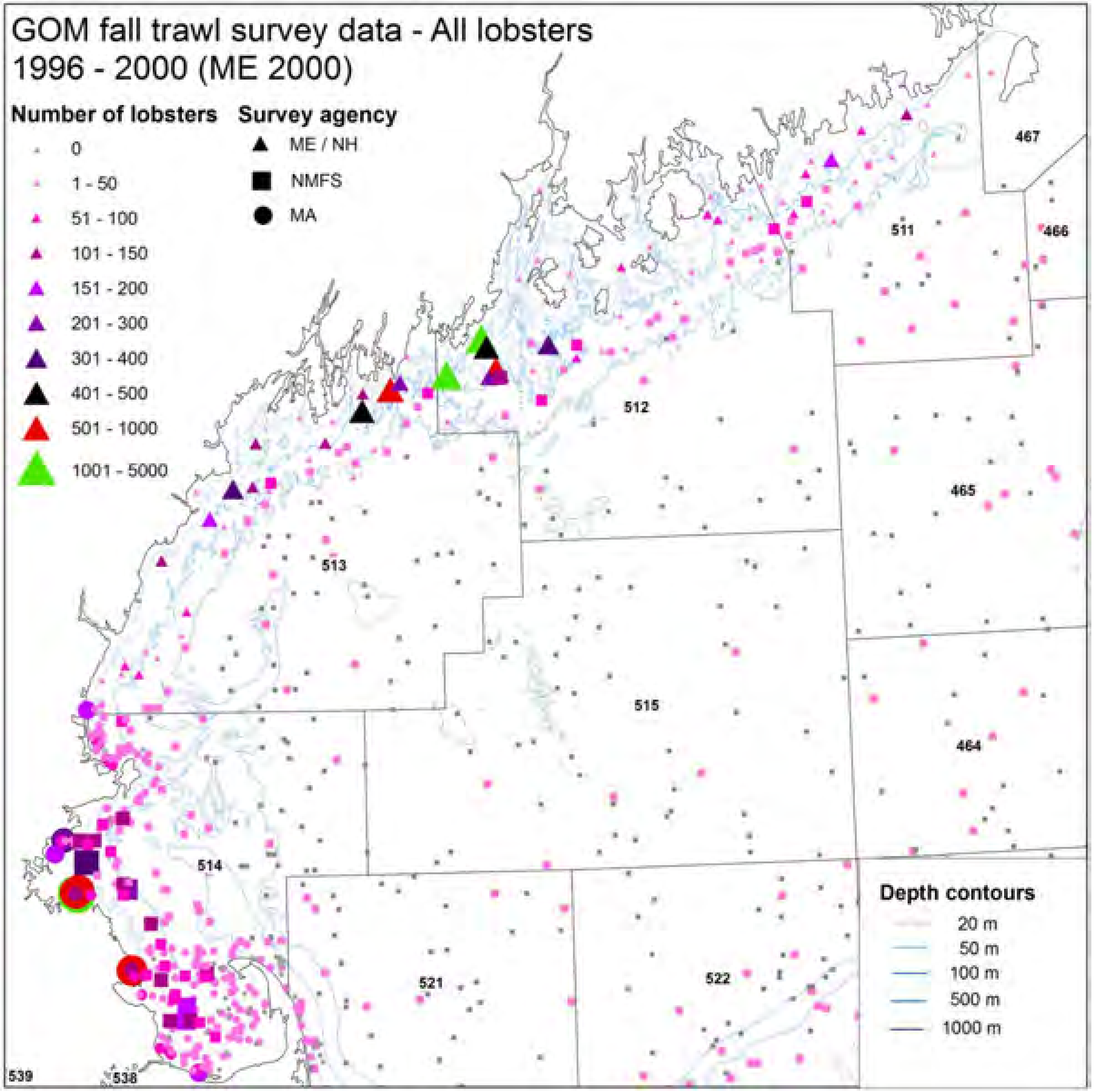
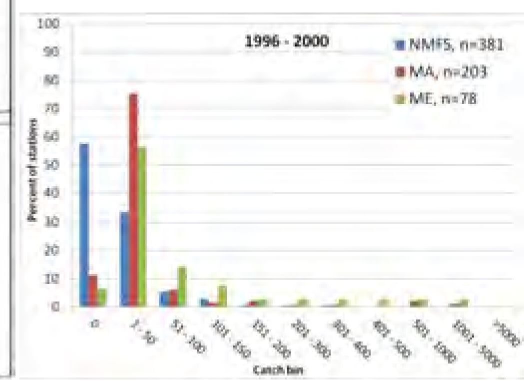


Figure 4.2.1.3.1.1 E



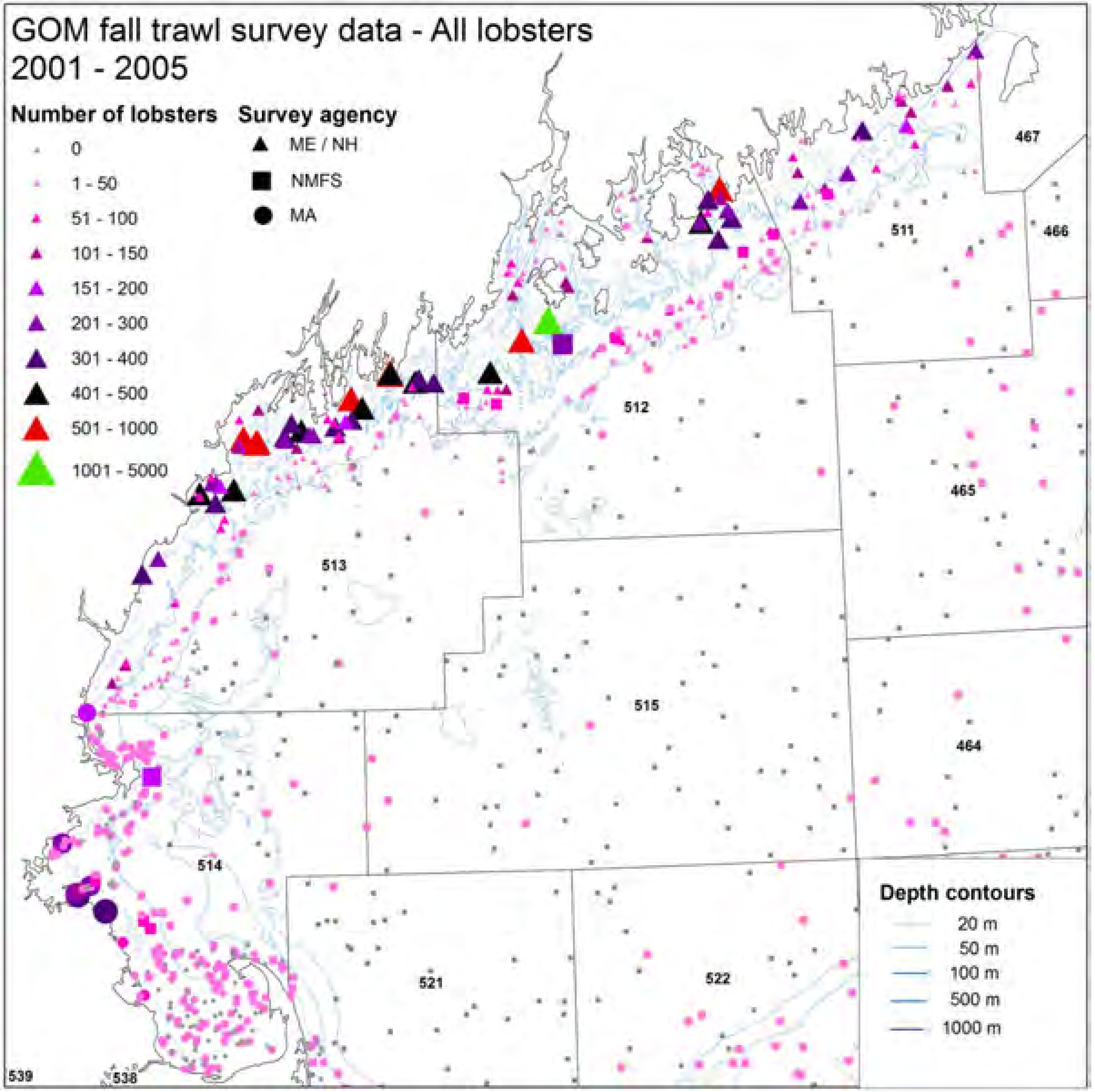
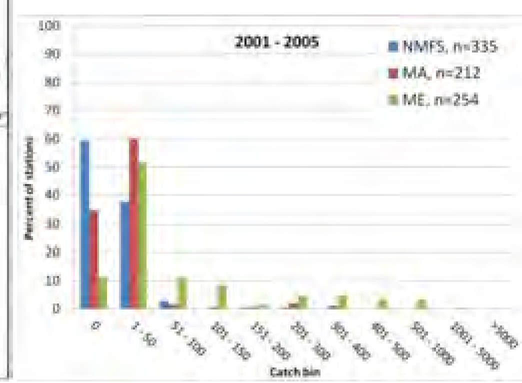


Figure 4.2.1.3.1.1 F



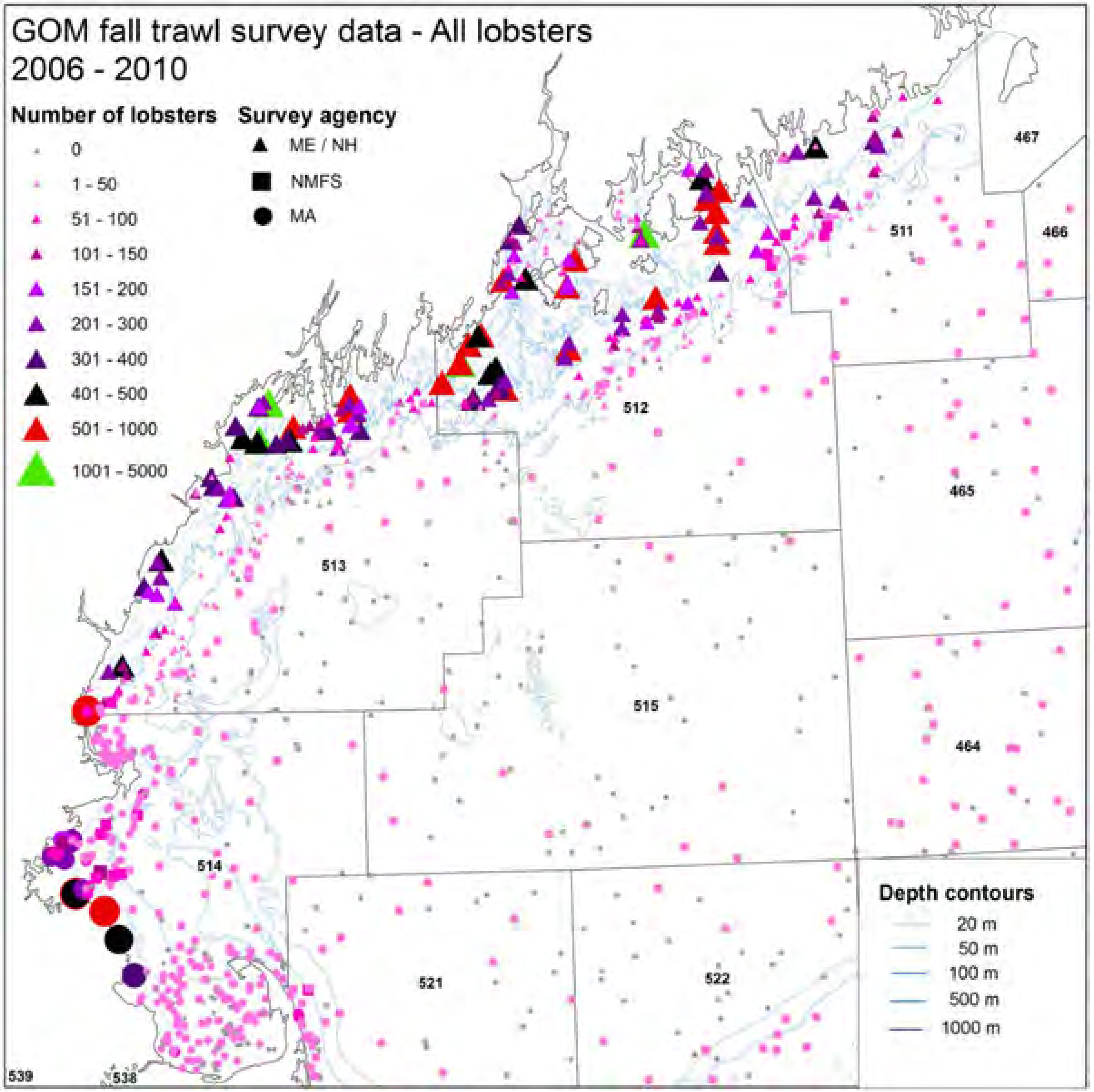
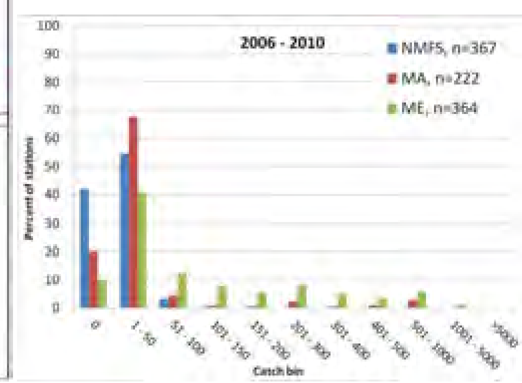


Figure 4.2.1.3.1.1 G



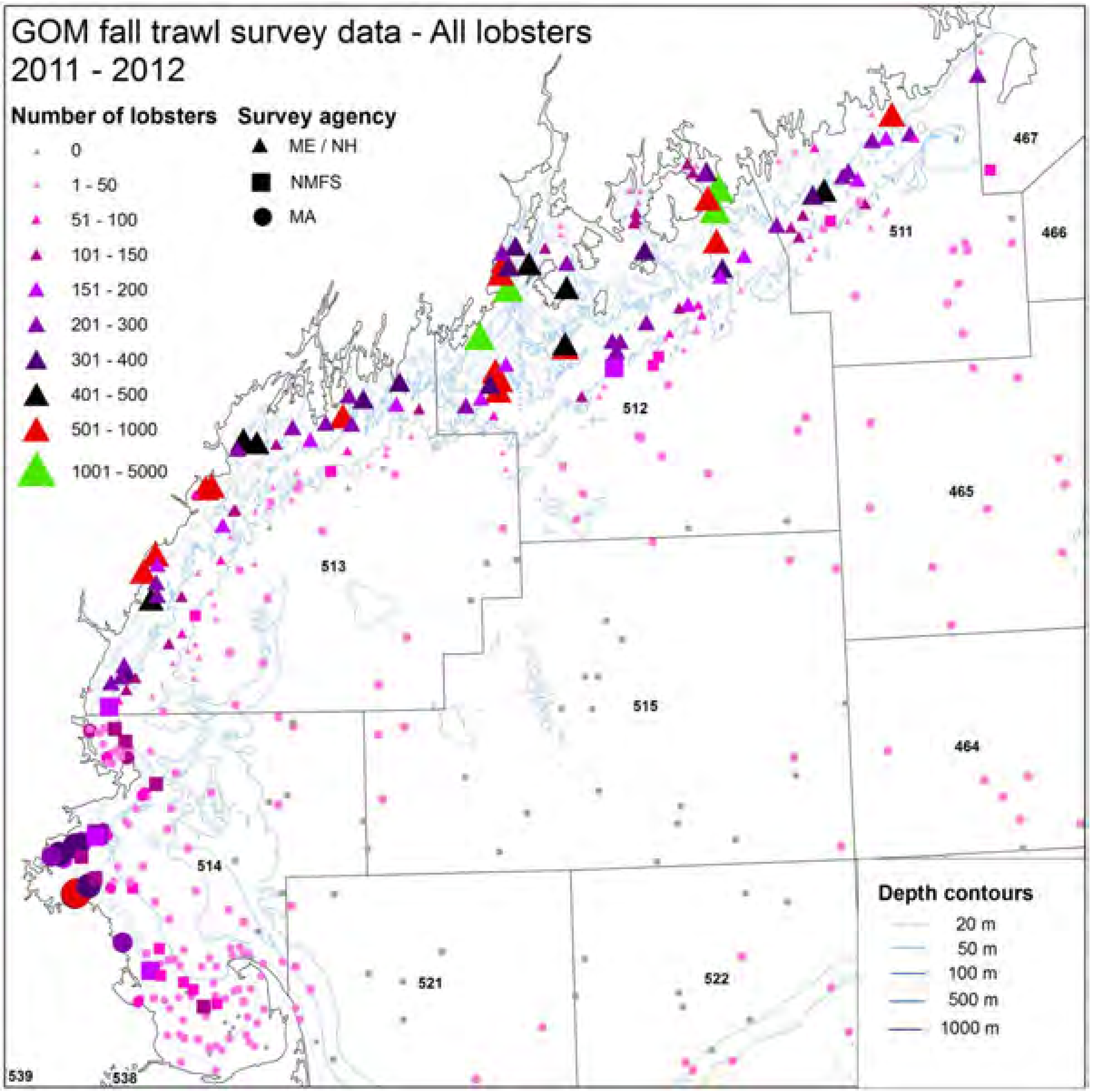
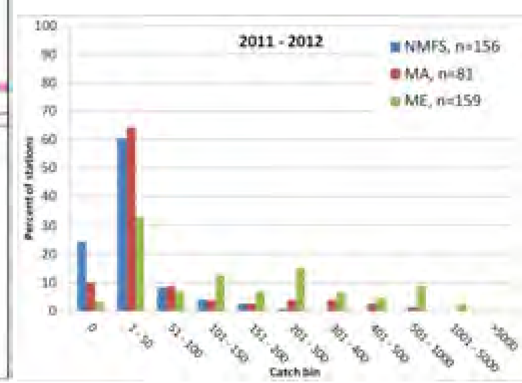


Figure 4.2.1.3.1.1 H



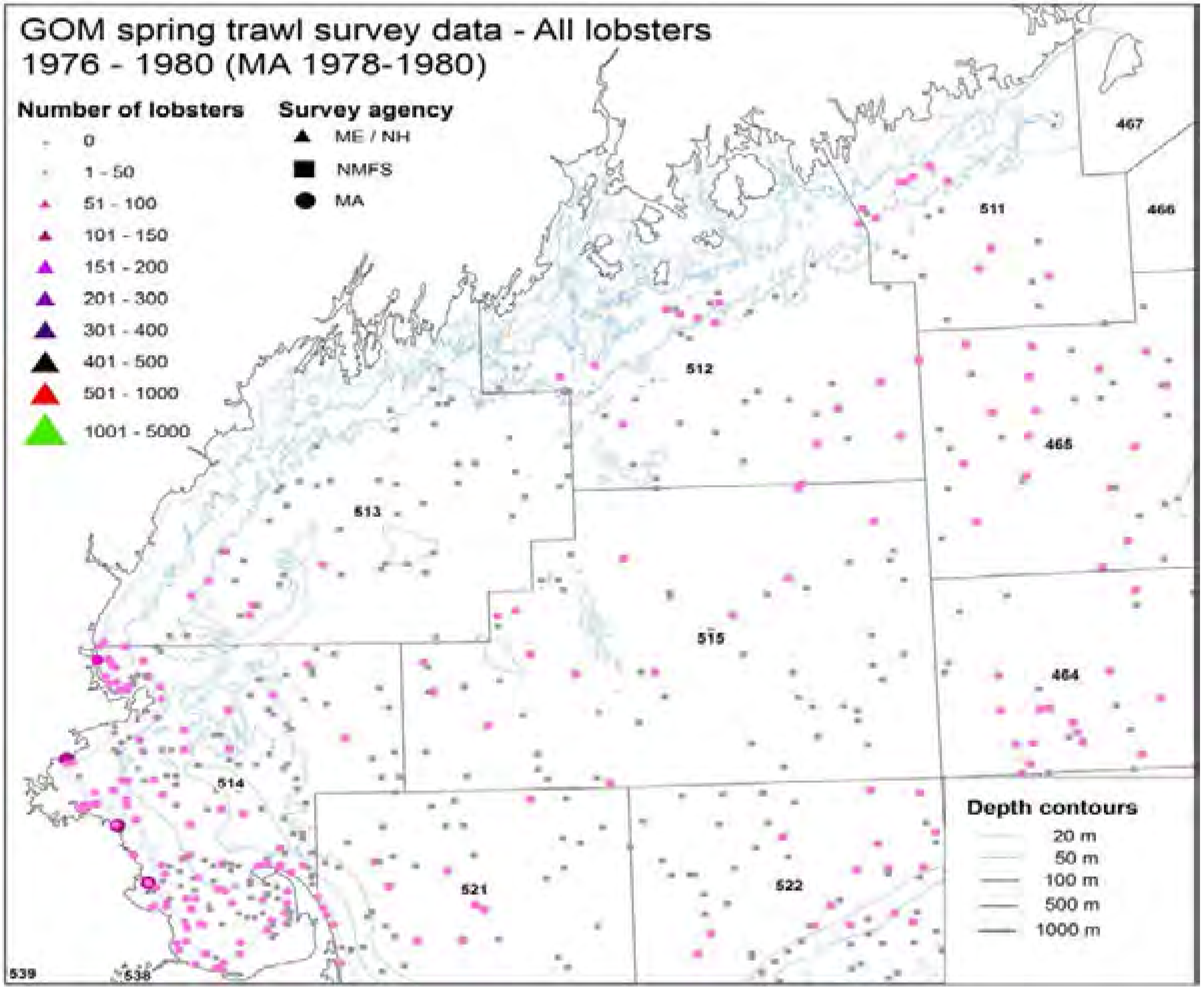


Figure 4.2.1.3.1.2 A

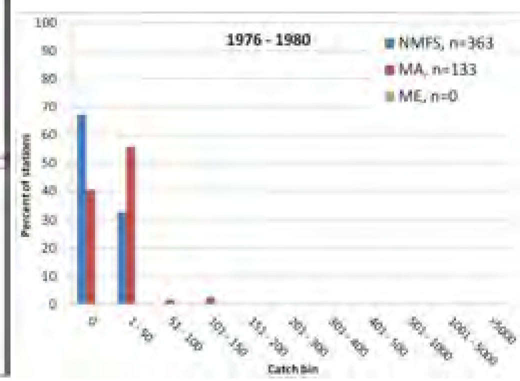


Figure 4.2.1.3.1.2 A – H. **Mean catch per tow of lobster (all sizes) at each spring sampling location from all GOM bottom trawl surveys (ME/NH, MA, and NMFS), shown in 5 year time periods.** Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period

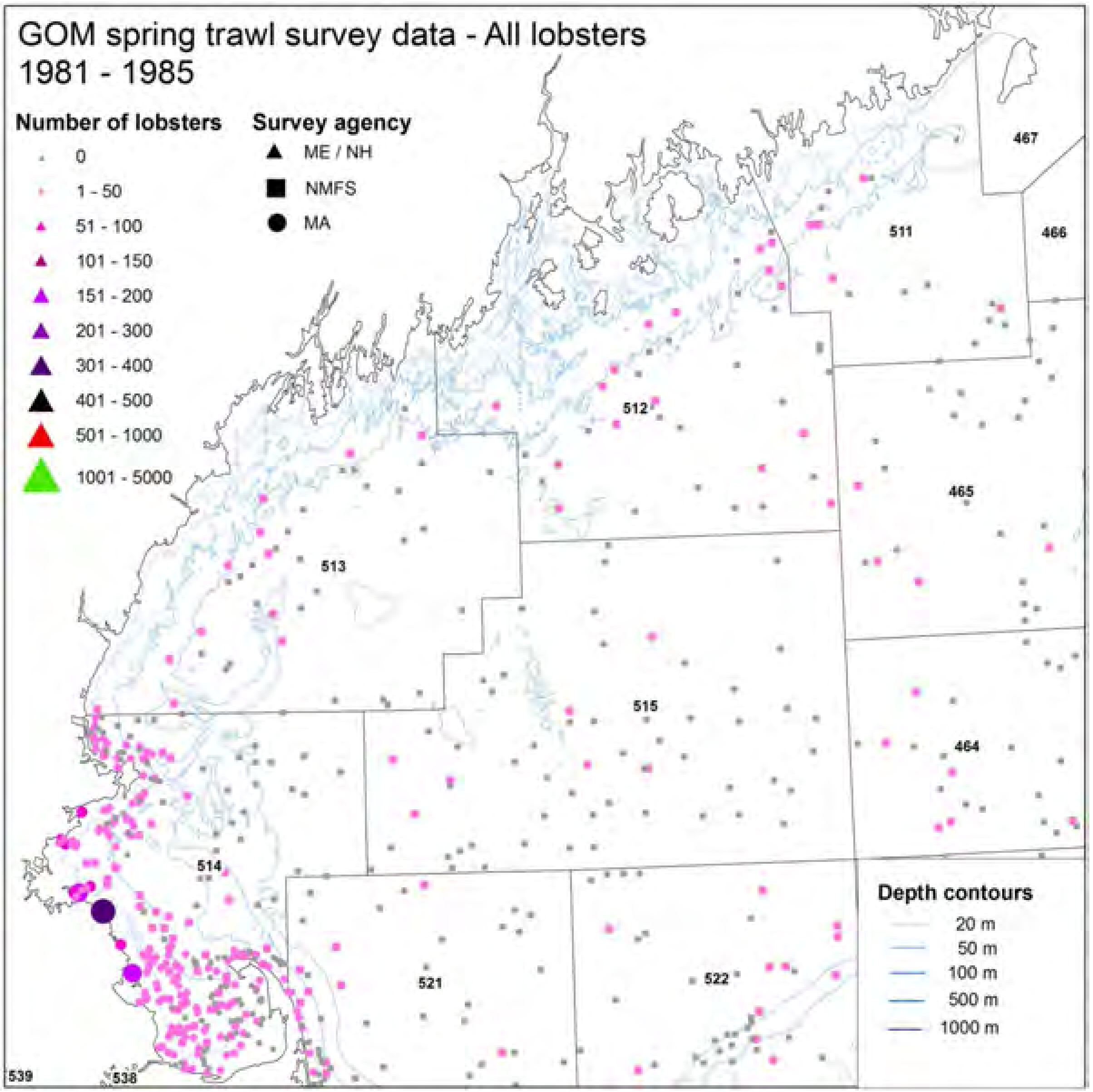
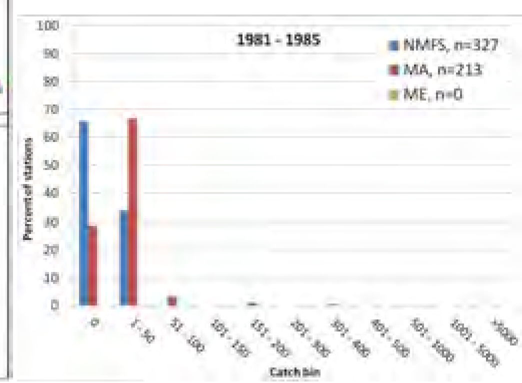


Figure 4.2.1.3.1.2 B



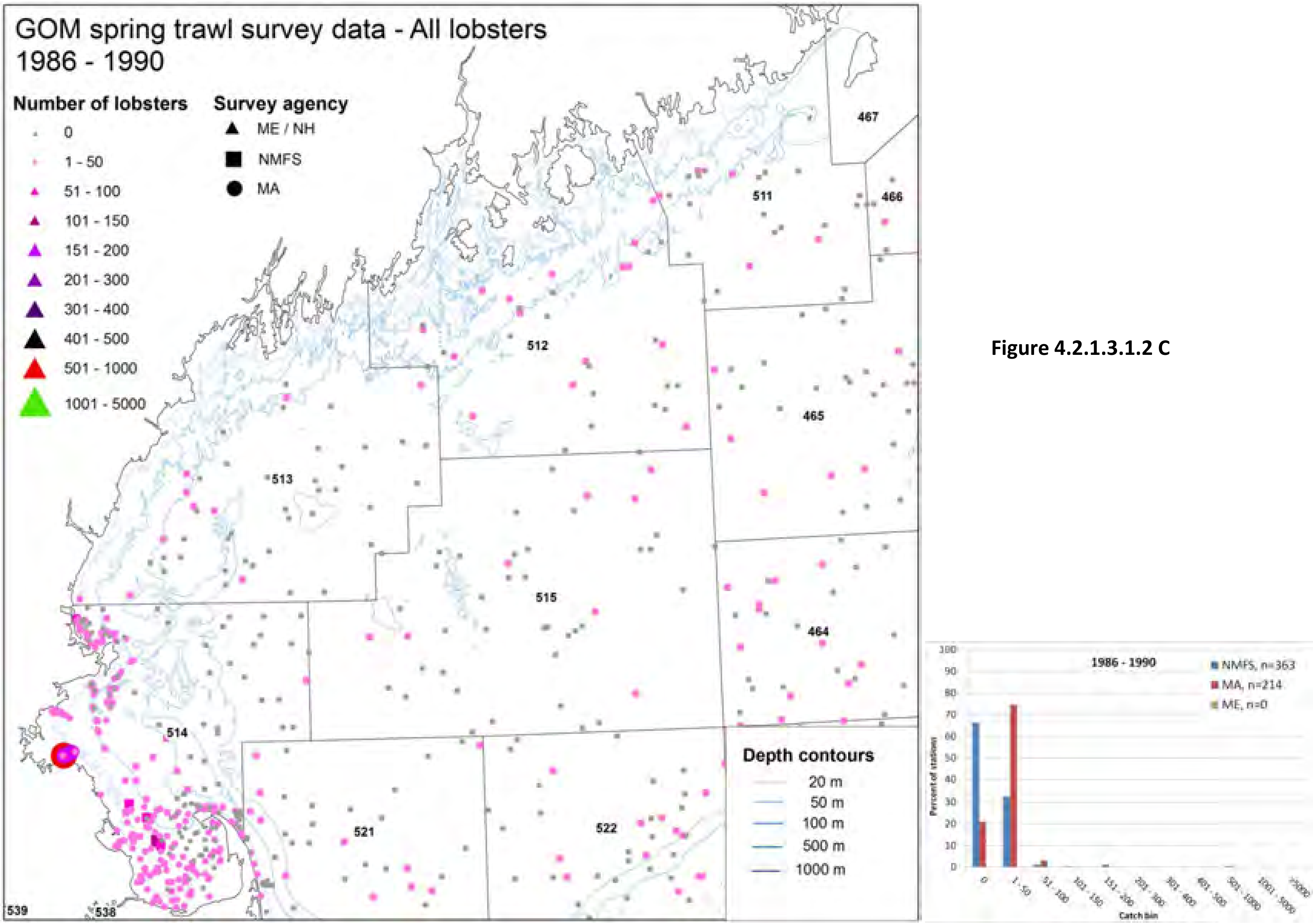
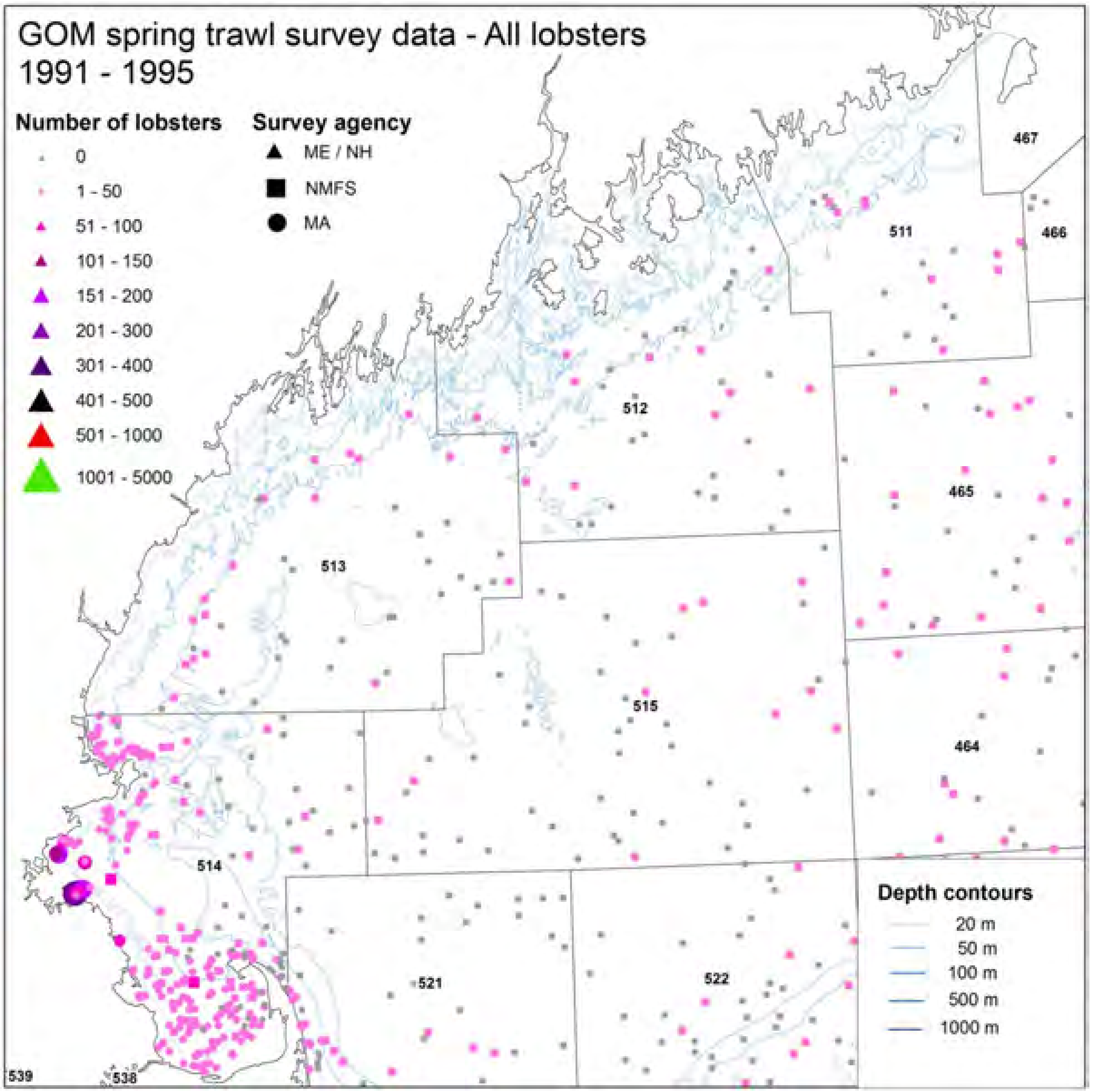


Figure 4.2.1.3.1.2 C



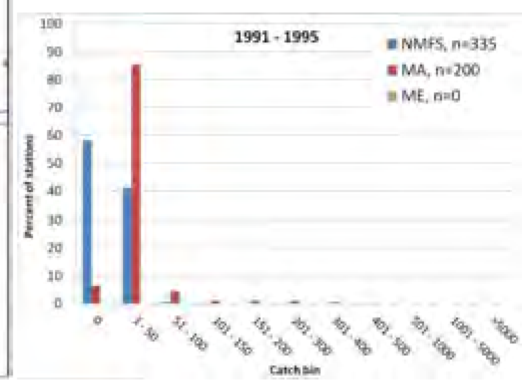


Figure 4.2.1.3.1.2 D

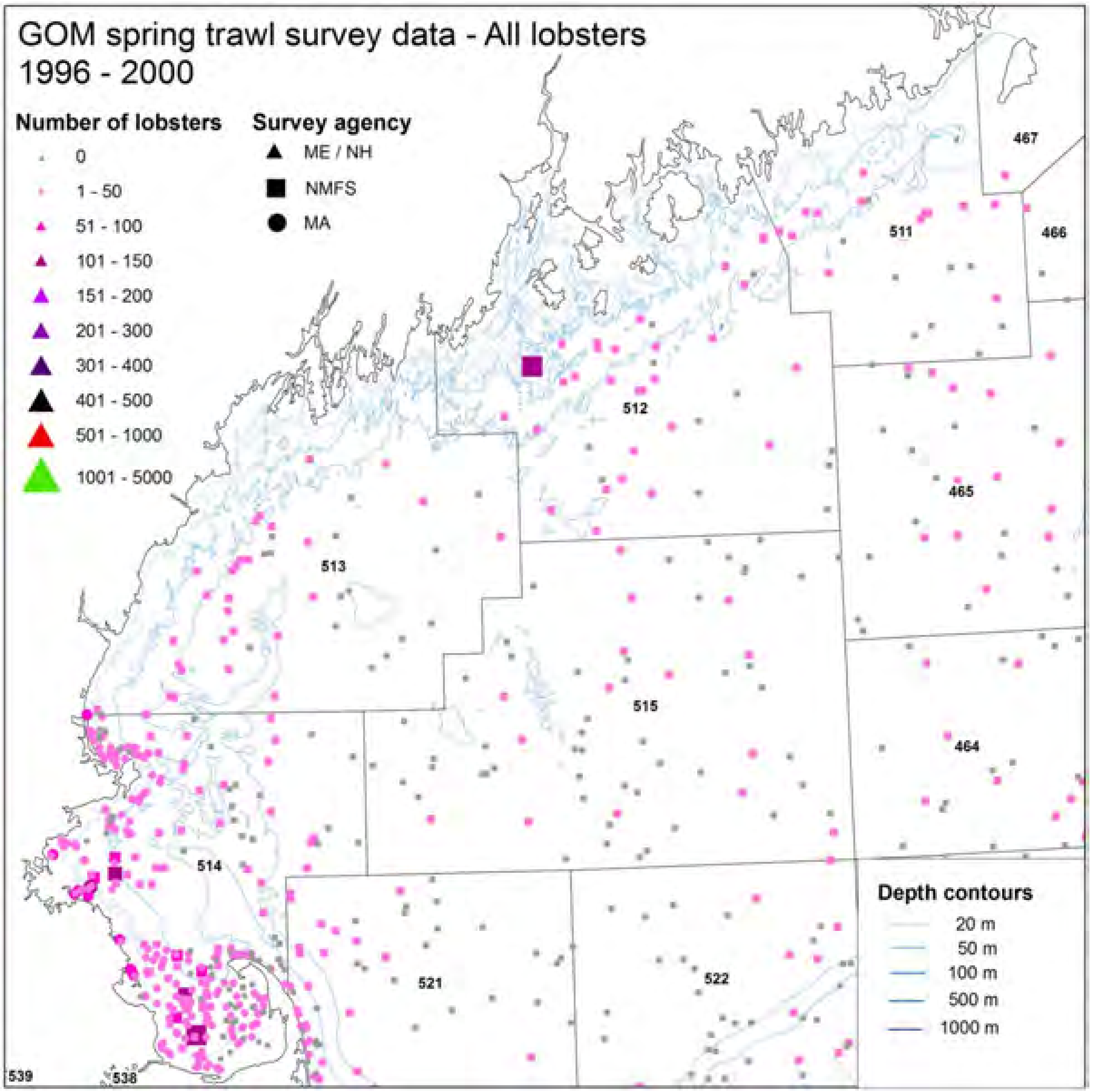
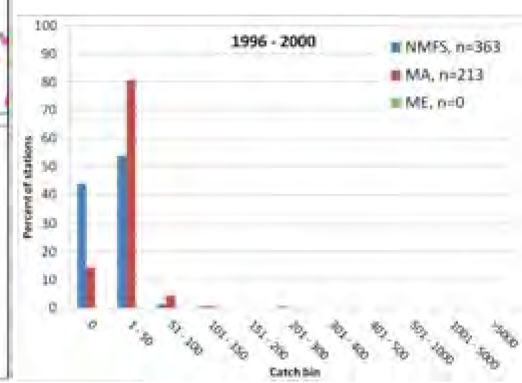


Figure 4.2.1.3.1.2 E



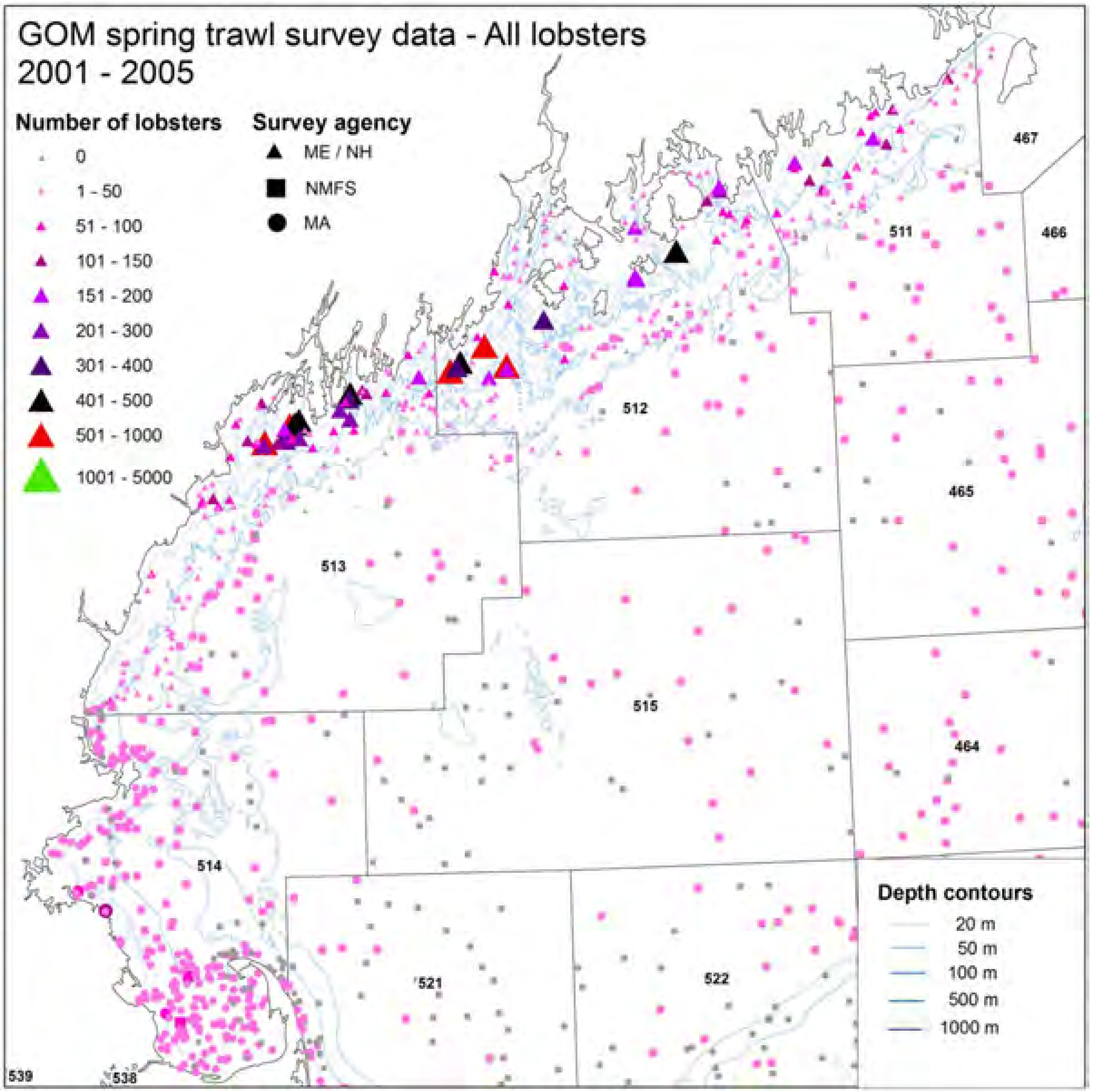
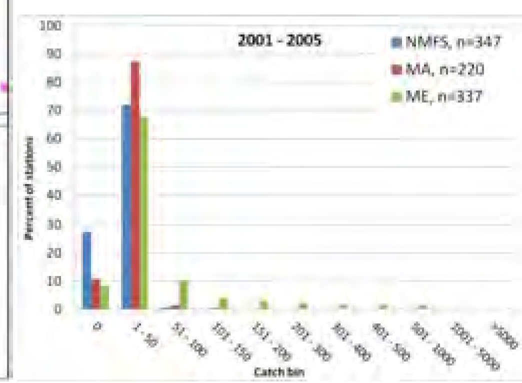


Figure 4.2.1.3.1.2 F



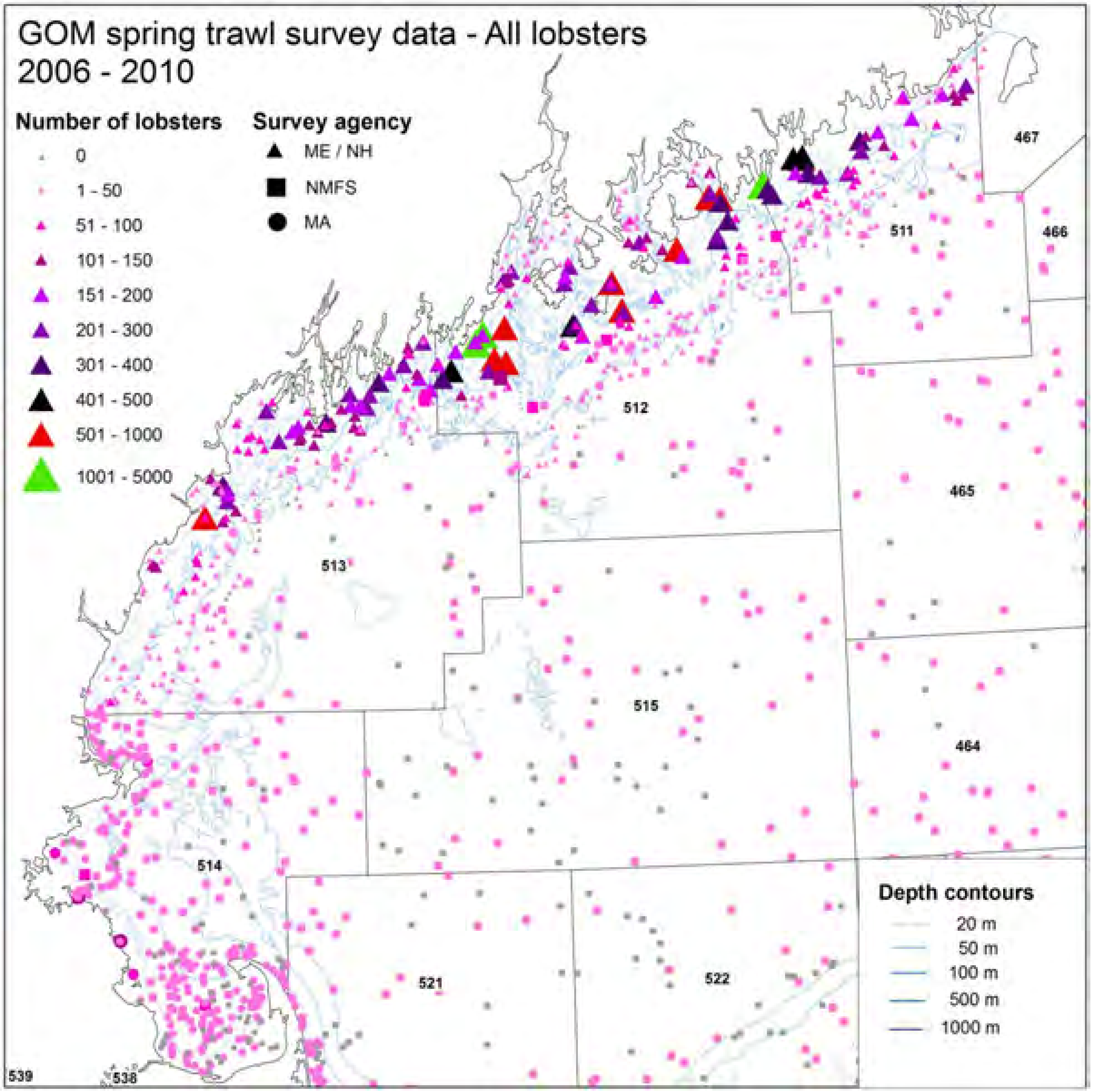
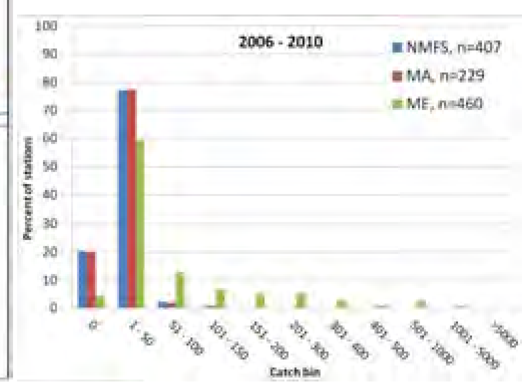


Figure 4.2.1.3.1.2 G



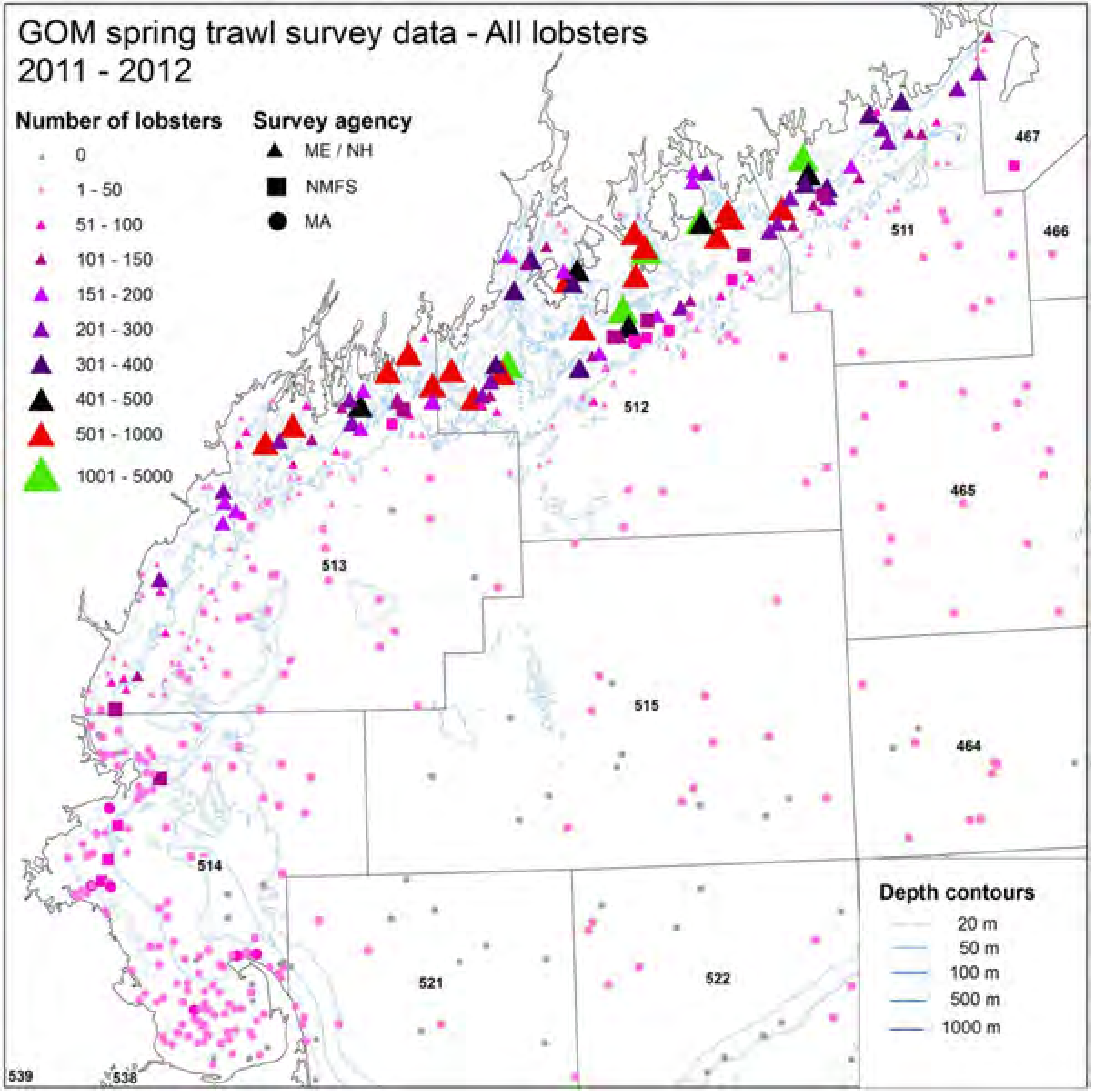
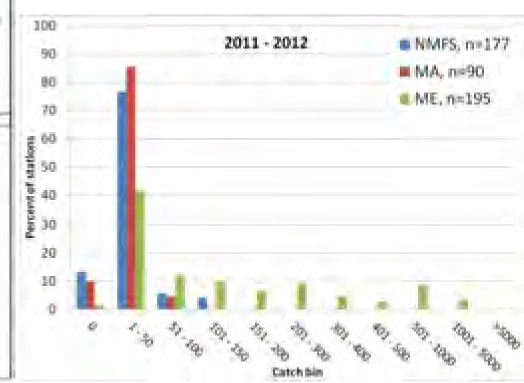


Figure 4.2.1.3.1.2 H



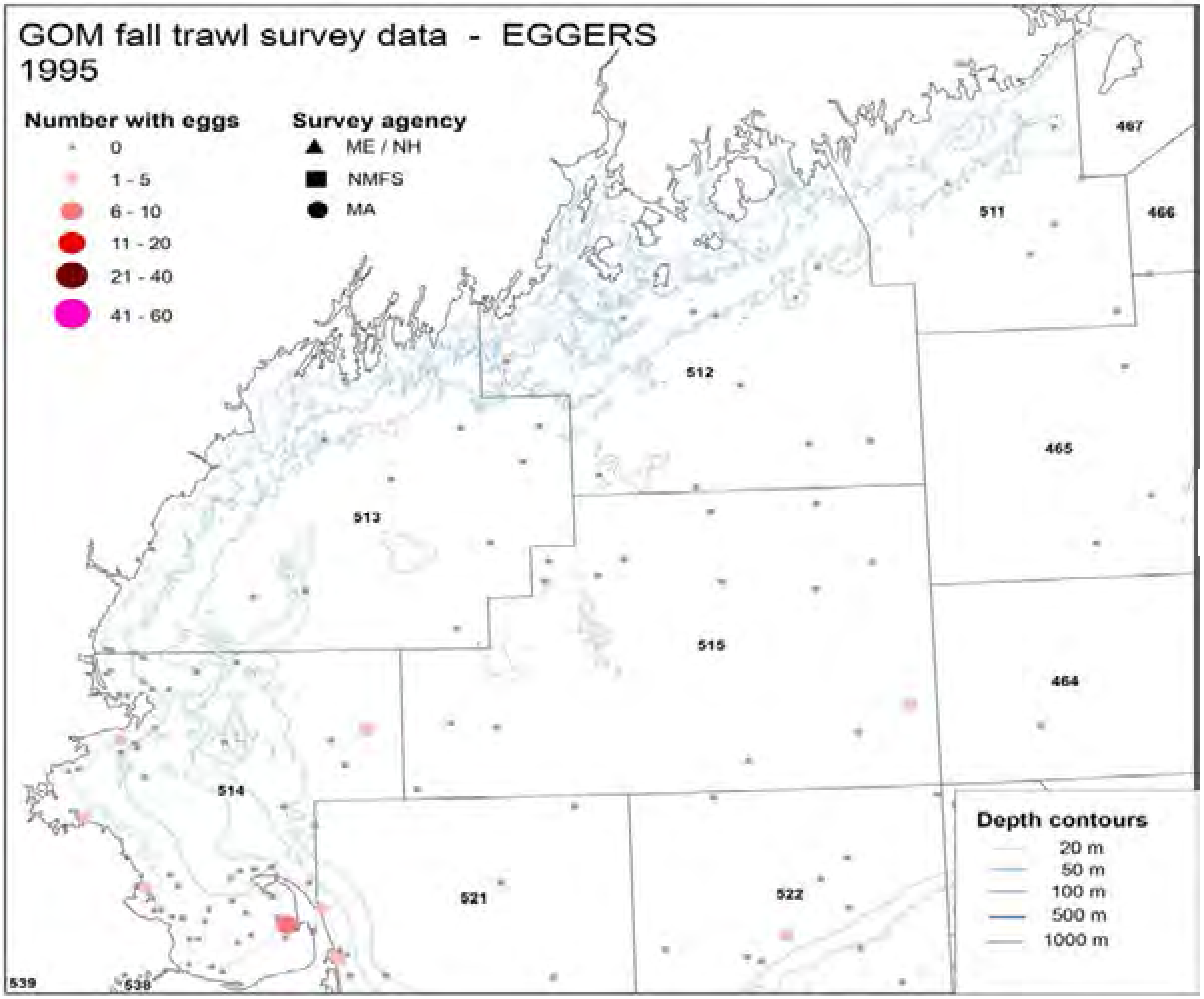


Figure 4.2.1.3.1.3 A

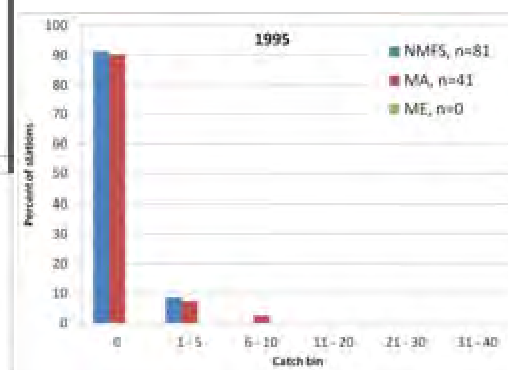


Figure 4.2.1.3.1.3 A – E. Mean catch per tow of ovigerous females (all sizes) at each fall sampling location from all GOM bottom trawl surveys (ME/NH, MA, and NMFS), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

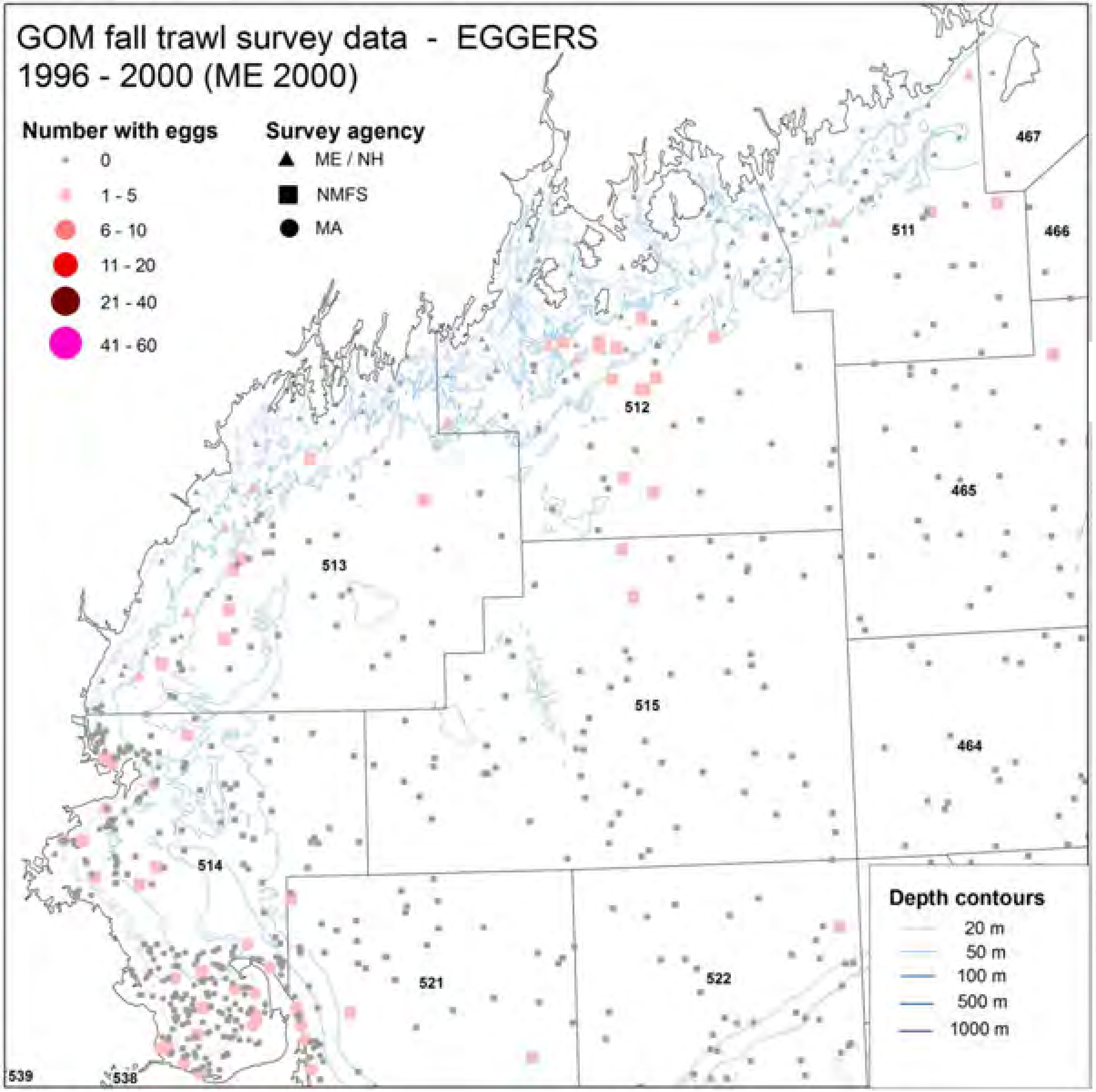
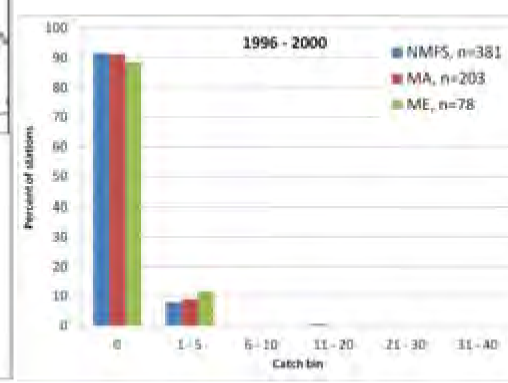


Figure 4.2.1.3.1.3 B



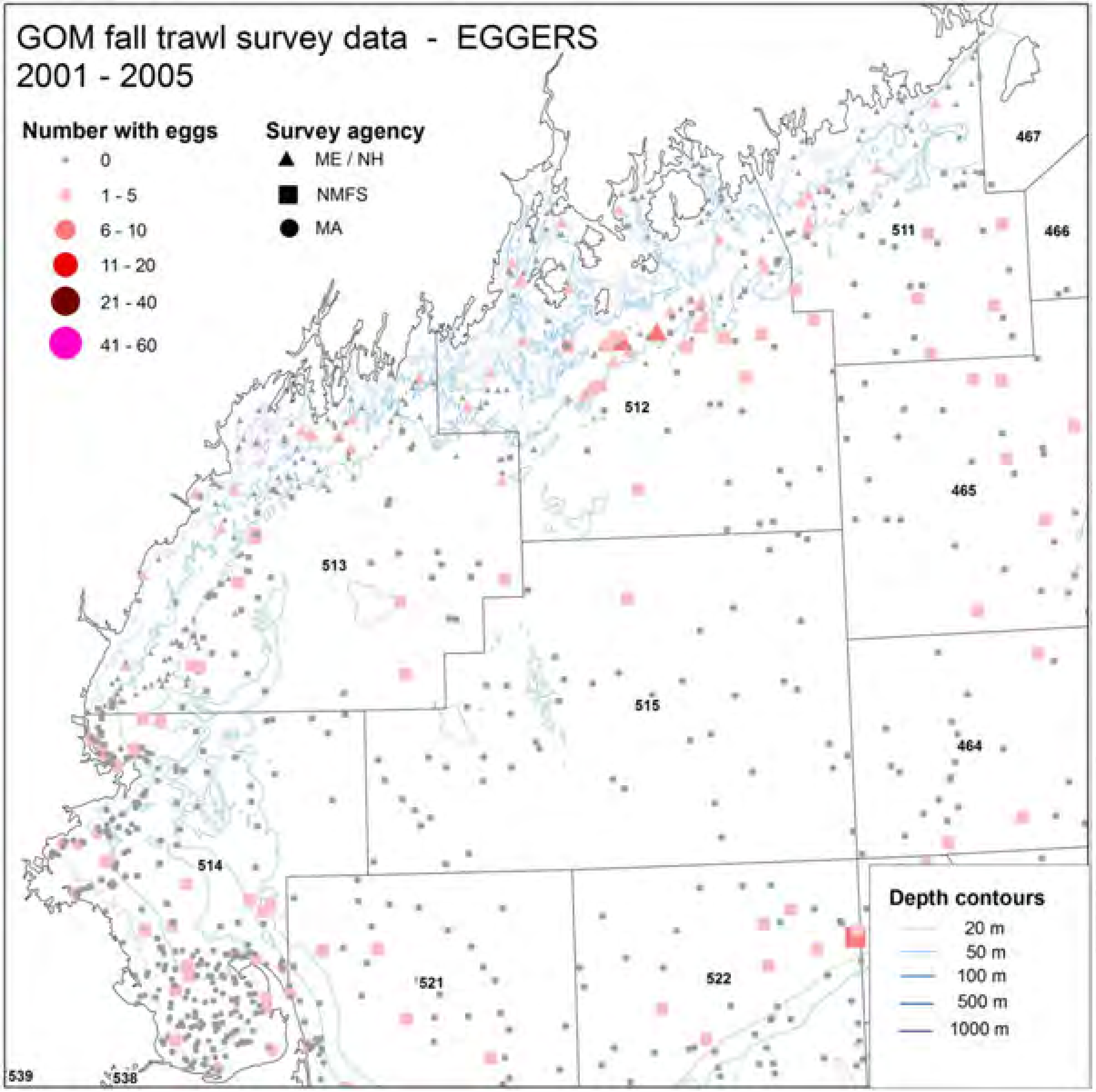
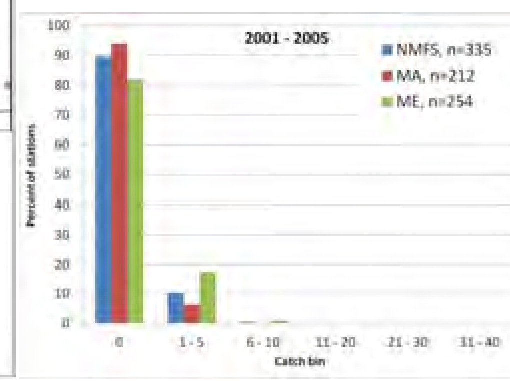


Figure 4.2.1.3.1.3 C



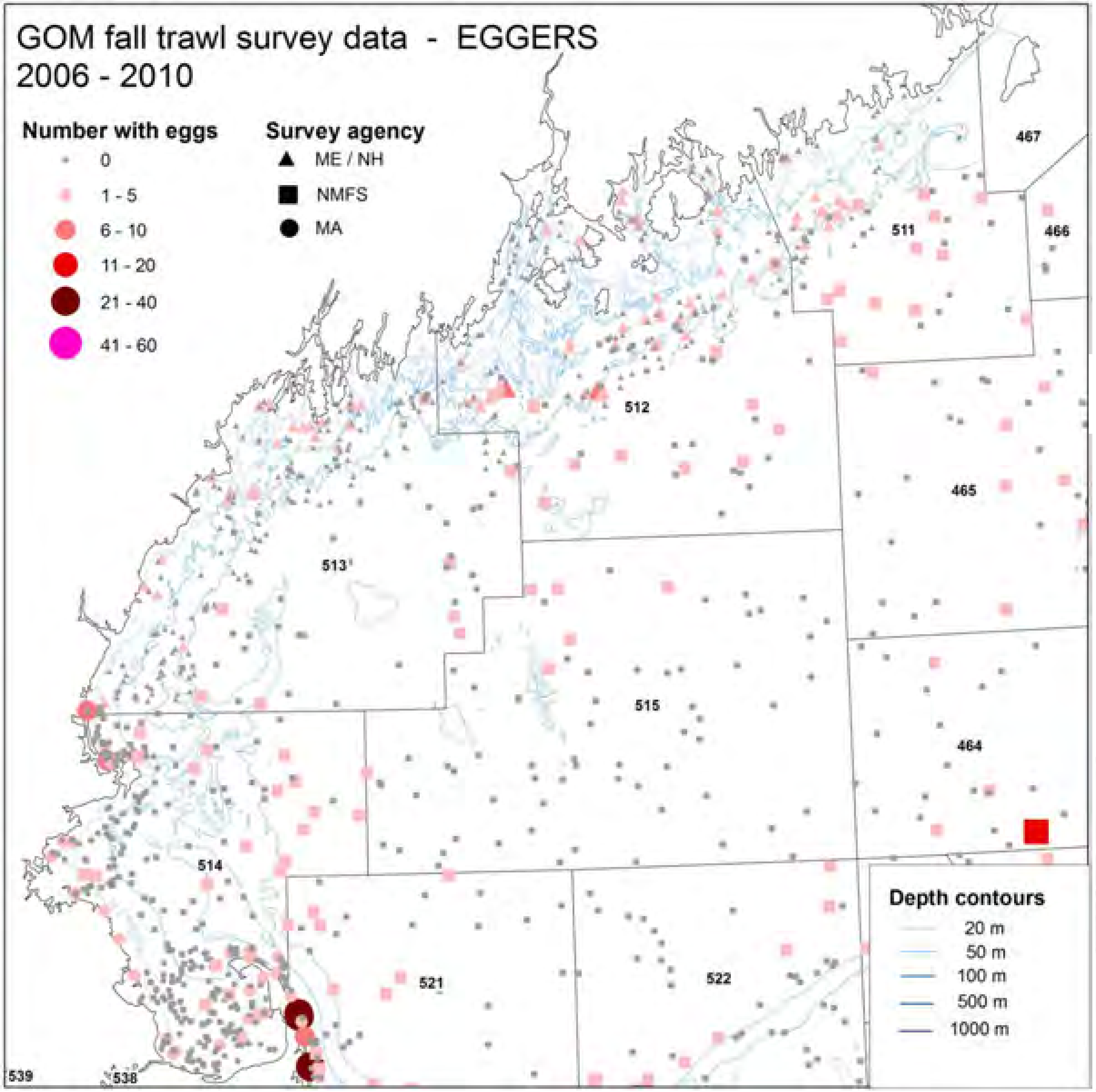
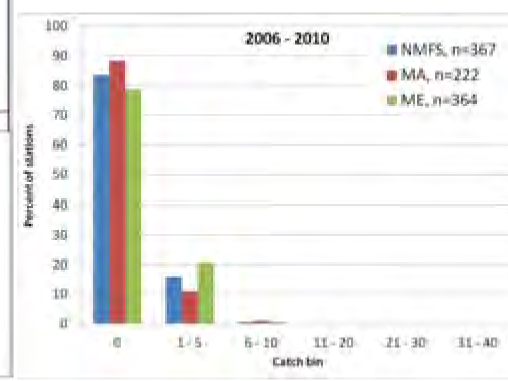


Figure 4.2.1.3.1.3 D



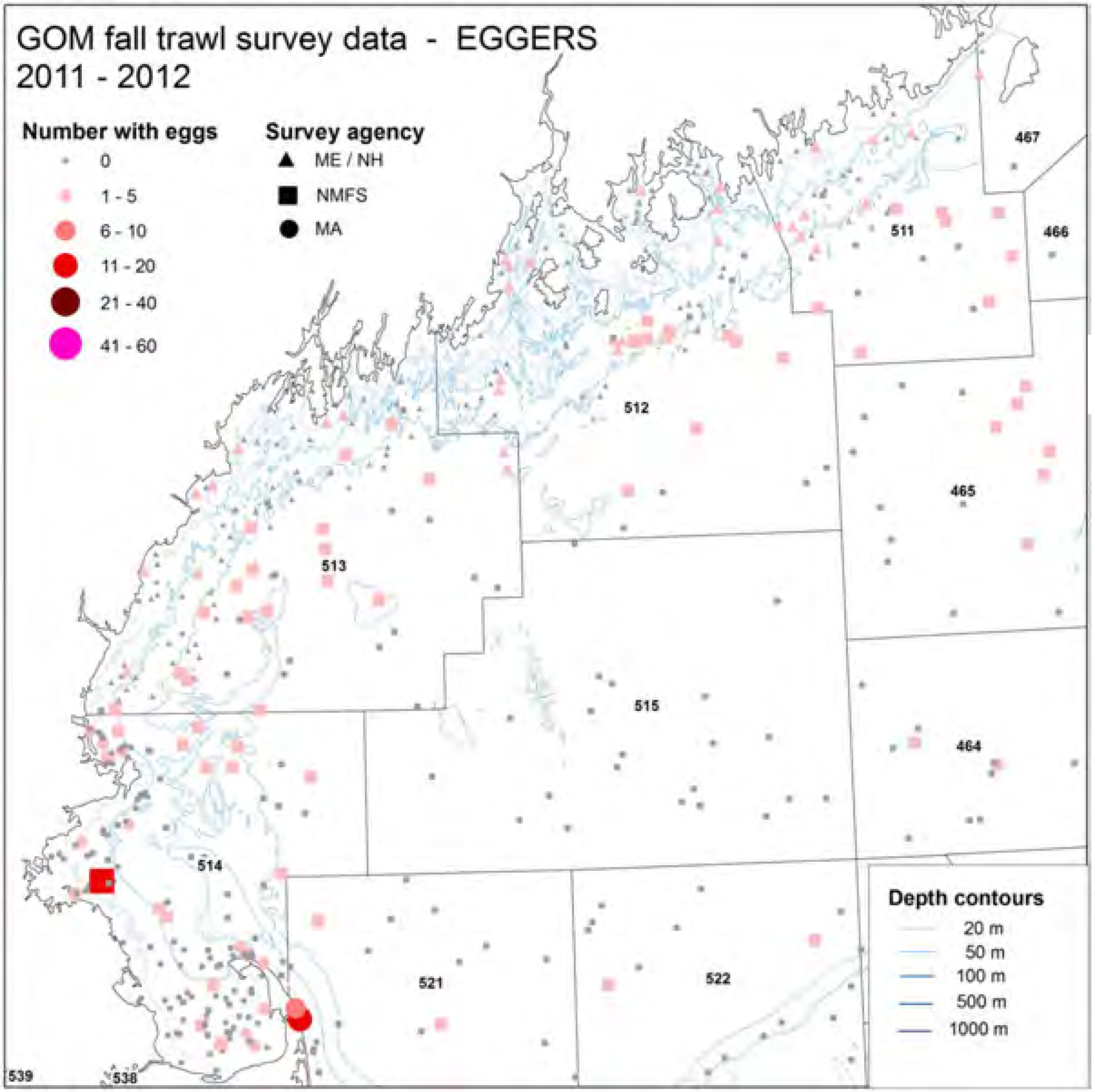
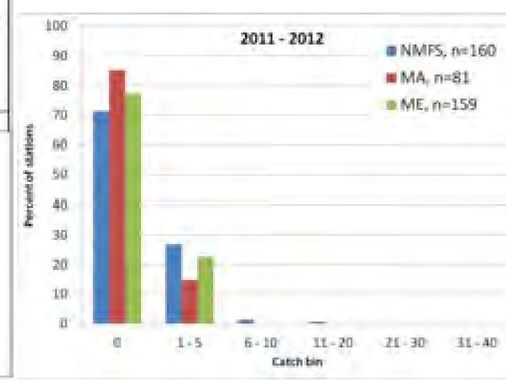


Figure 4.2.1.3.1.3 E



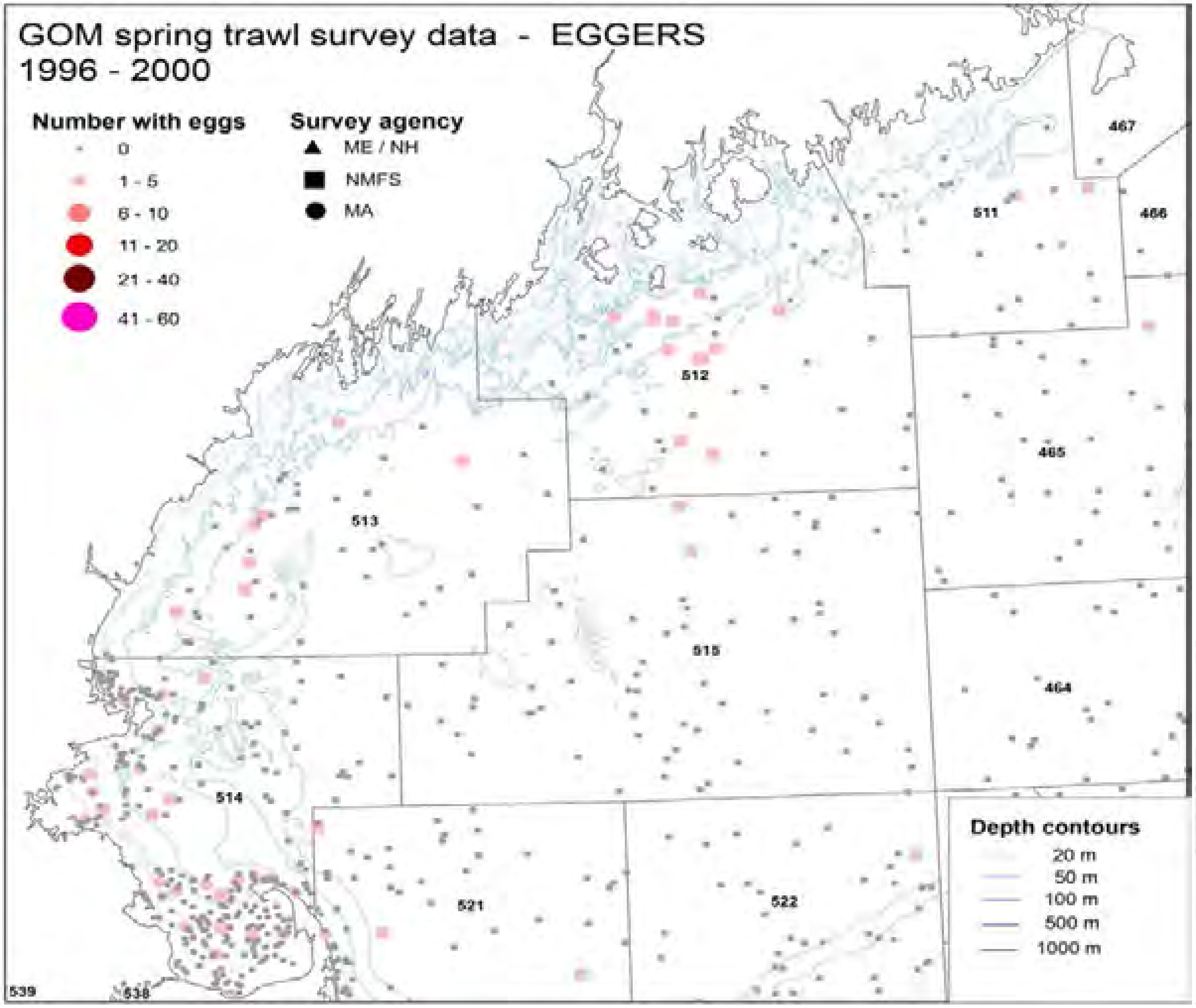


Figure 4.2.1.3.1.4 A

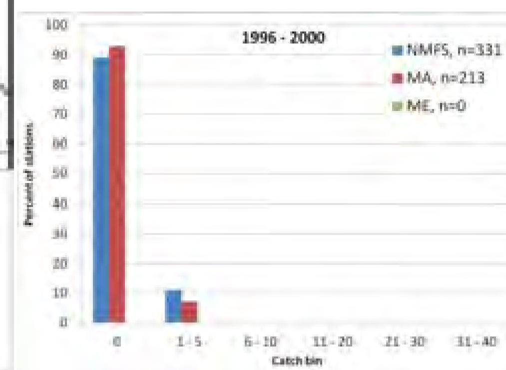


Figure 4.2.1.3.1.4 A – D. Mean catch per tow of ovigerous females (all sizes) at each spring sampling location from all GOM bottom trawl surveys (ME/NH, MA, and NMFS), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

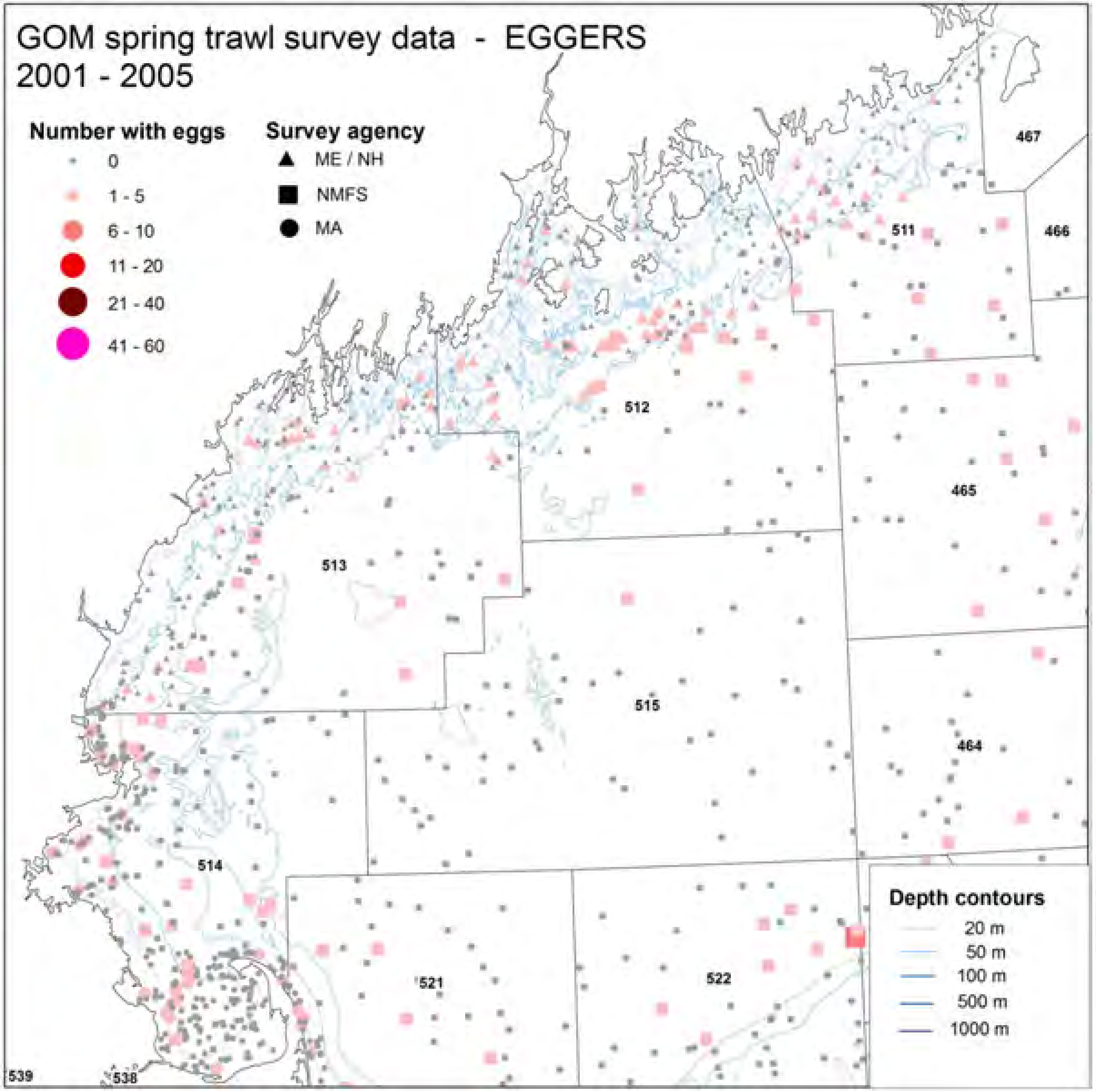
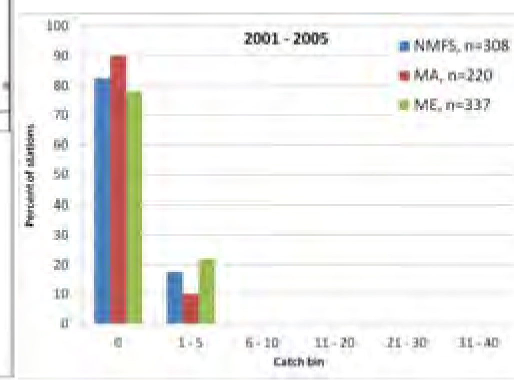


Figure 4.2.1.3.1.4 B



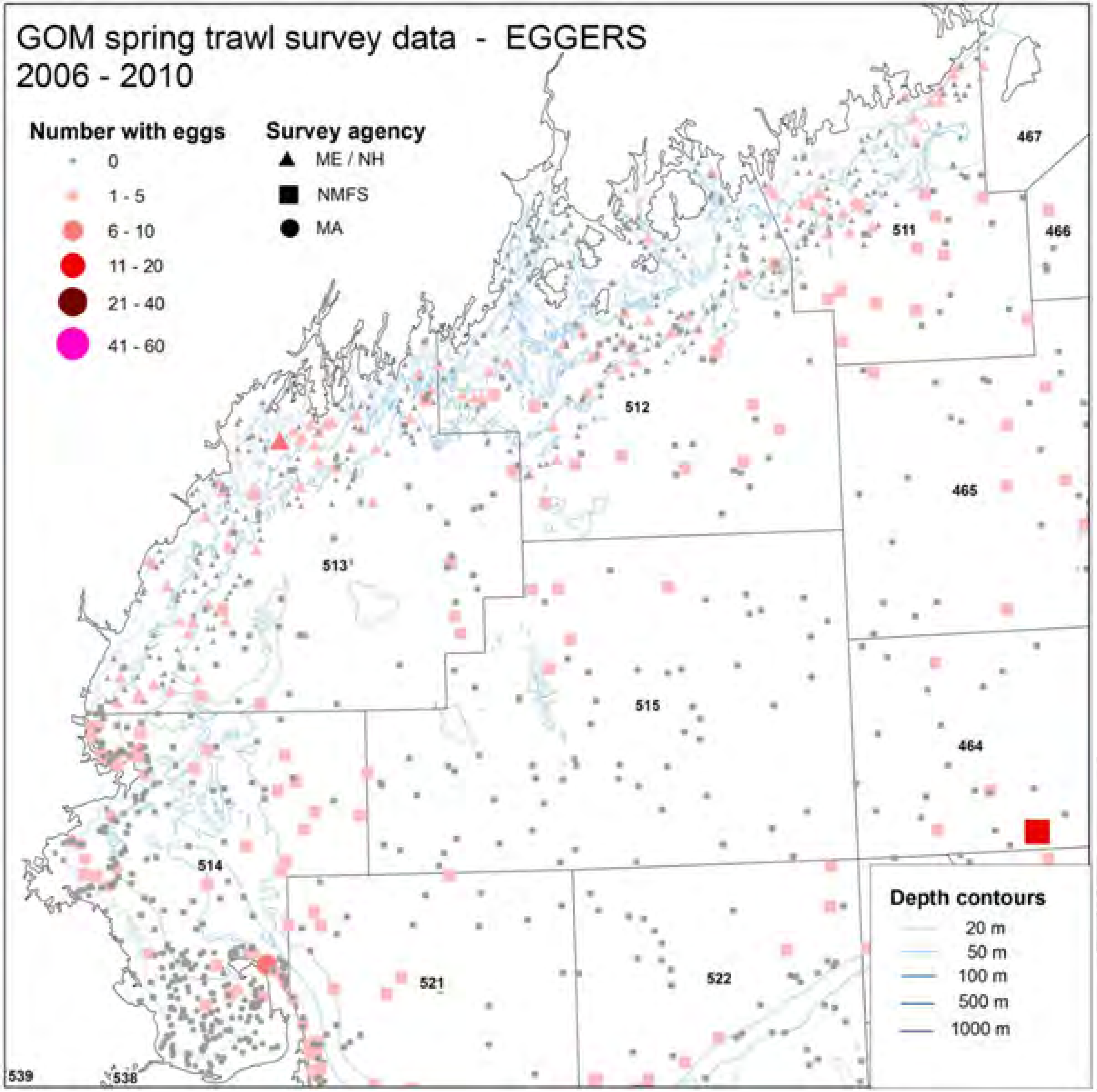
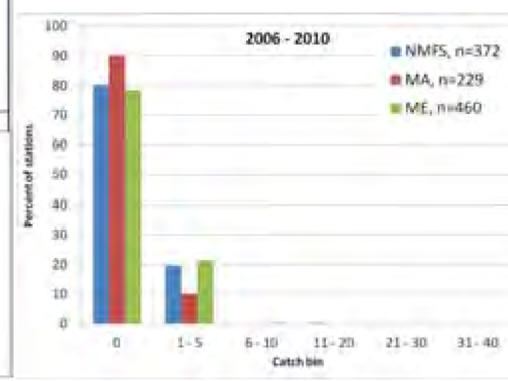


Figure 4.2.1.3.1.4 C



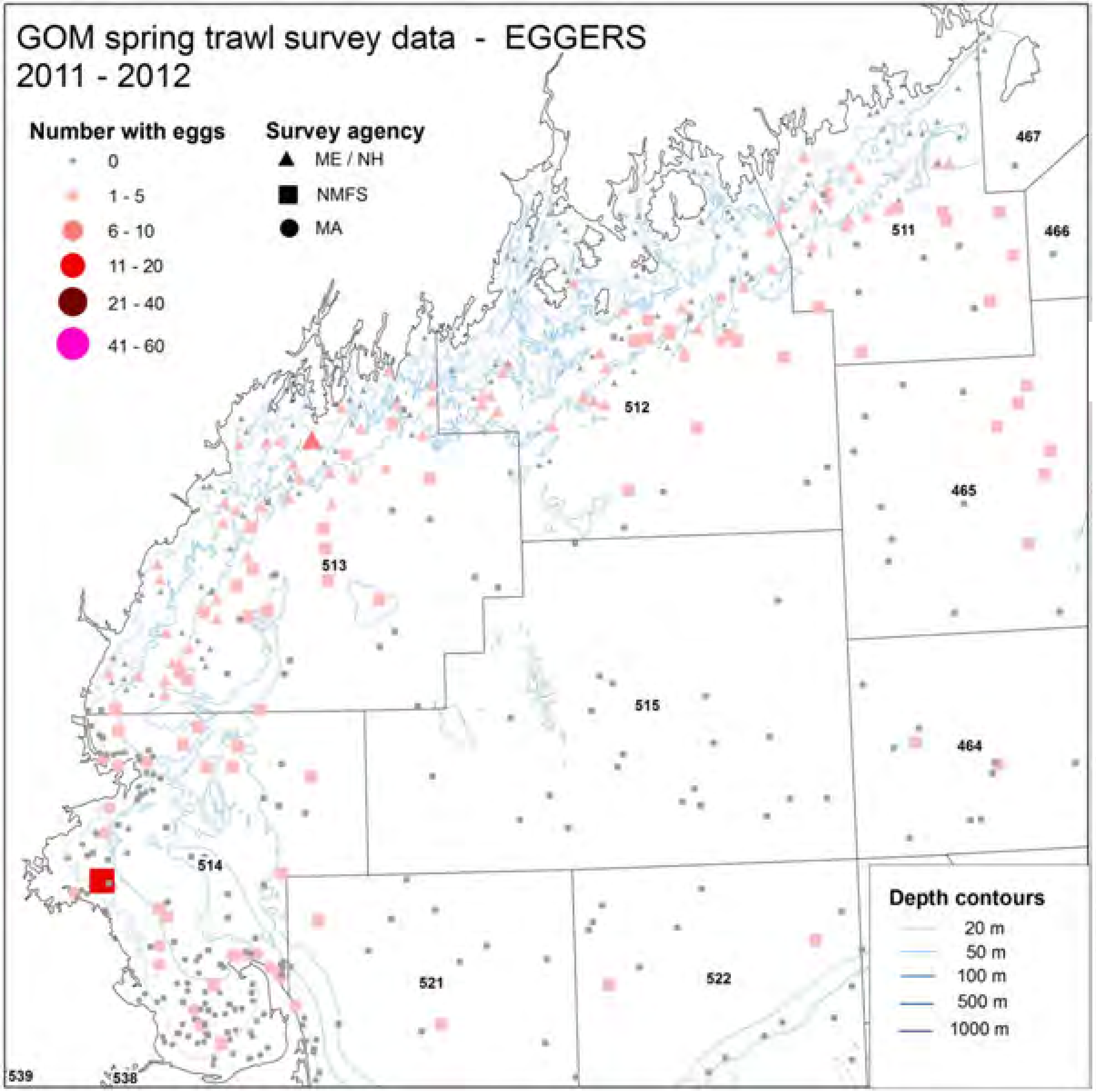
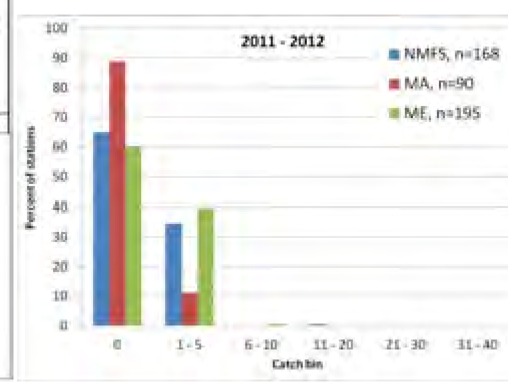


Figure 4.2.1.3.1.4 D



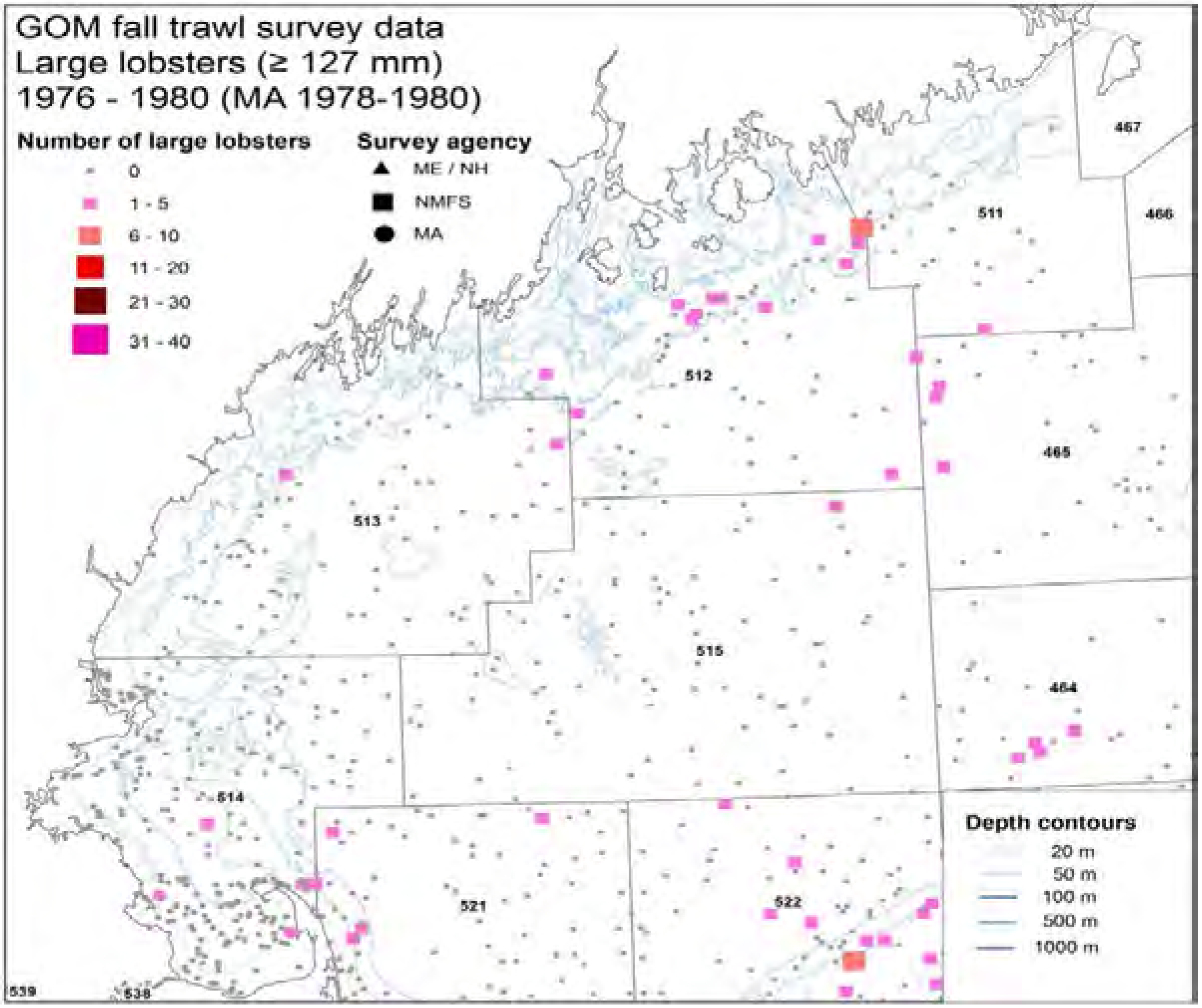


Figure 4.2.1.3.1.5 A

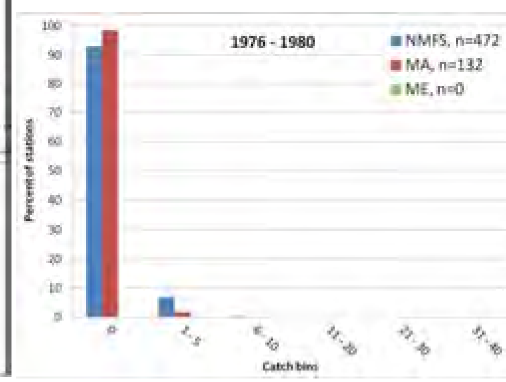
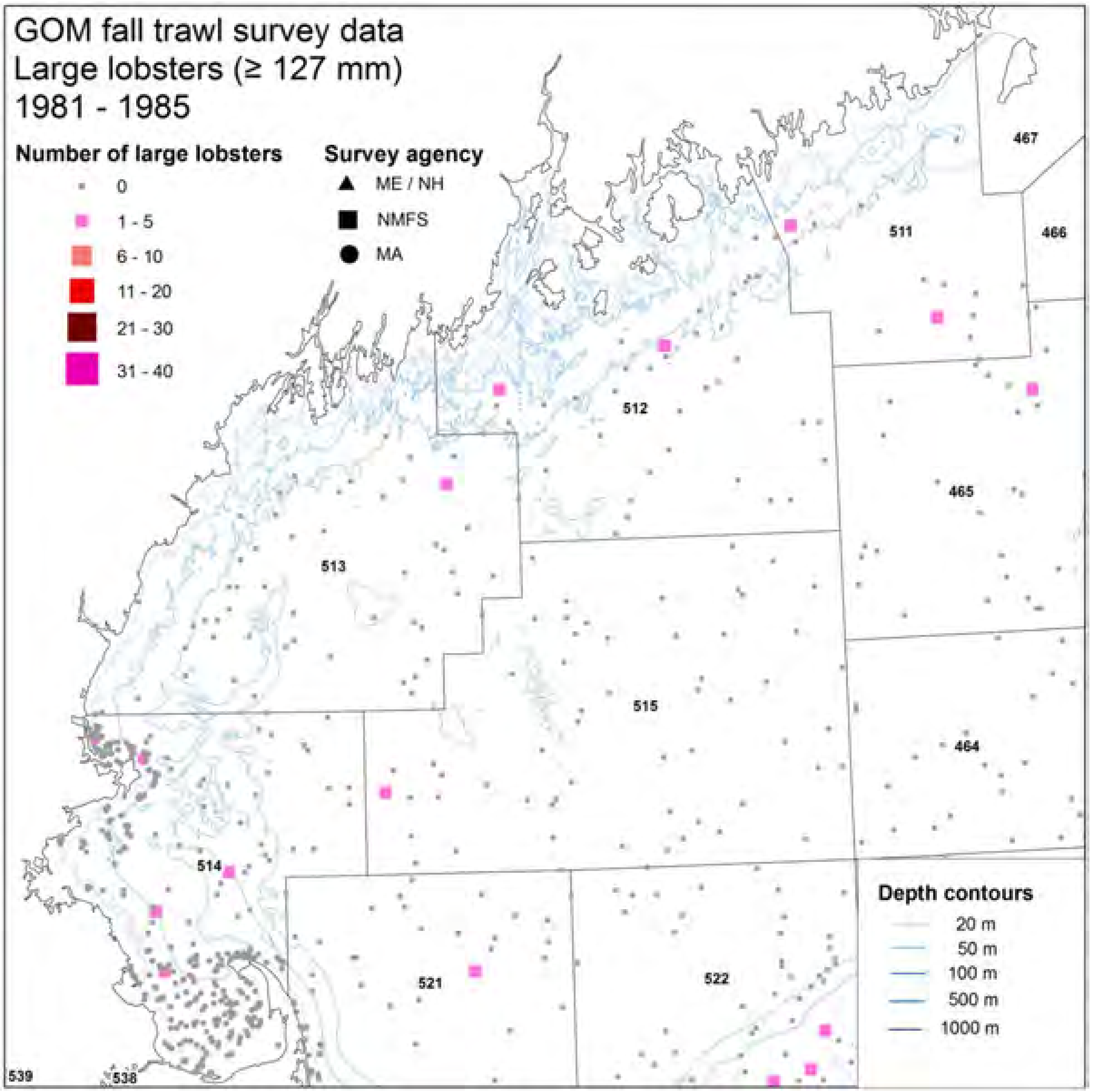


Figure 4.2.1.3.1.5 A – H. **Mean catch per tow of "large" lobster (≥ 127 mm CL) at each fall sampling location from all GOM bottom trawl surveys (ME/NH, MA, and NMFS), shown in 5 year time periods.** Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.



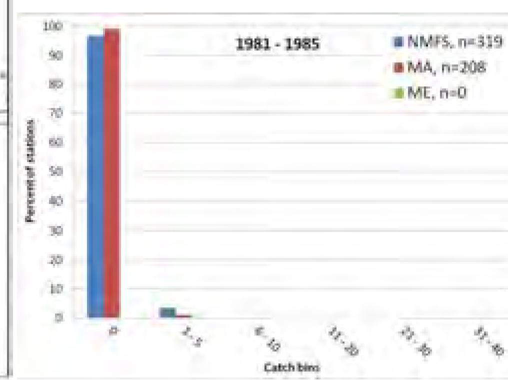


Figure 4.2.1.3.1.5 B

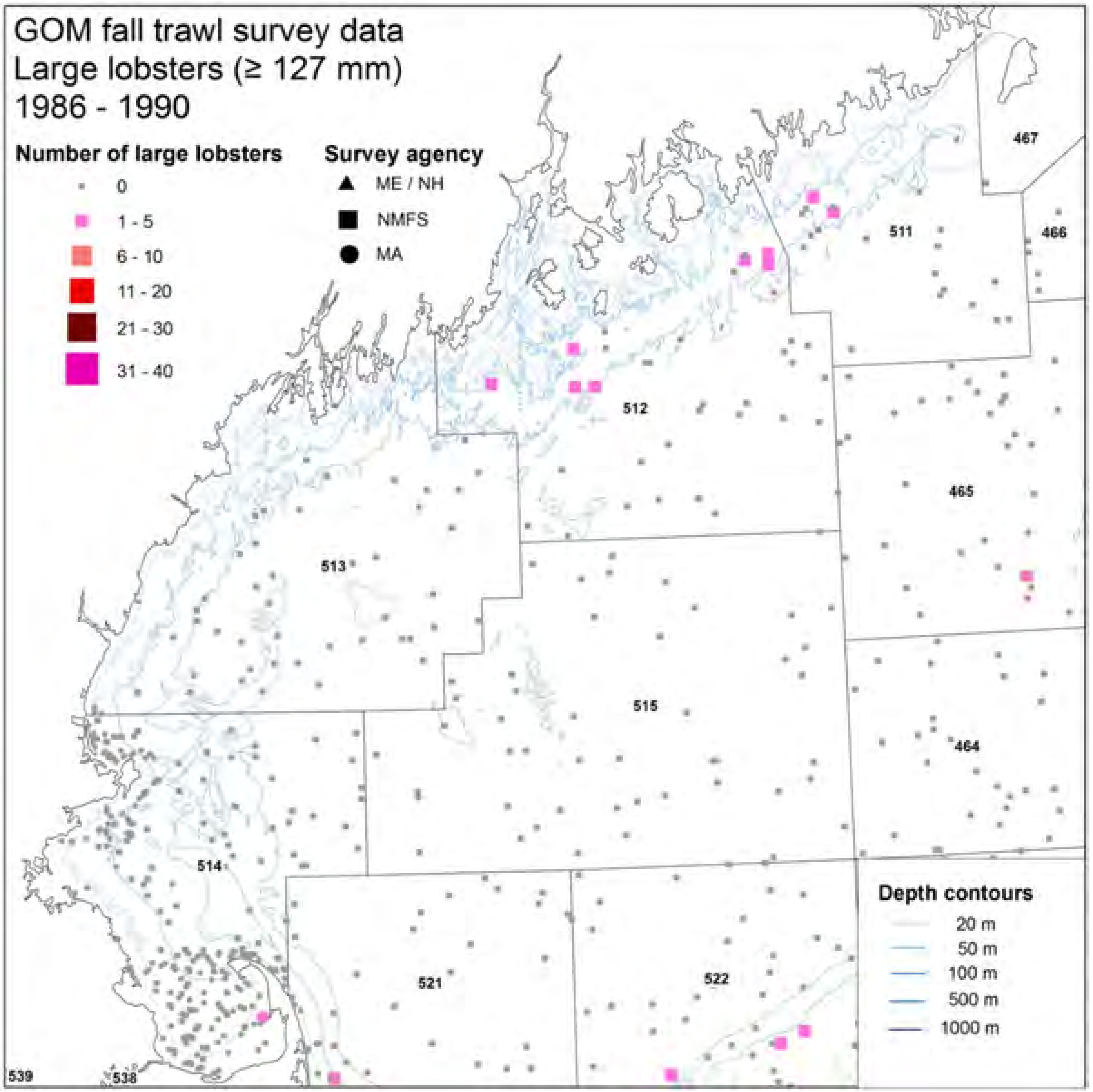
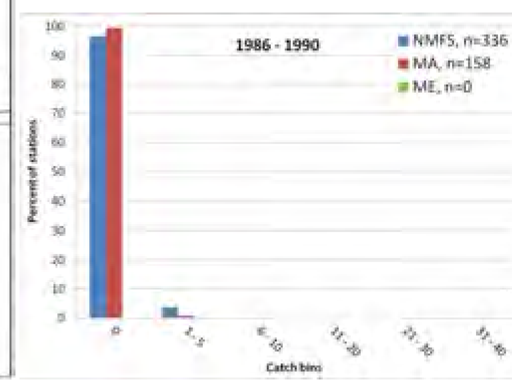


Figure 4.2.1.3.1.5 C



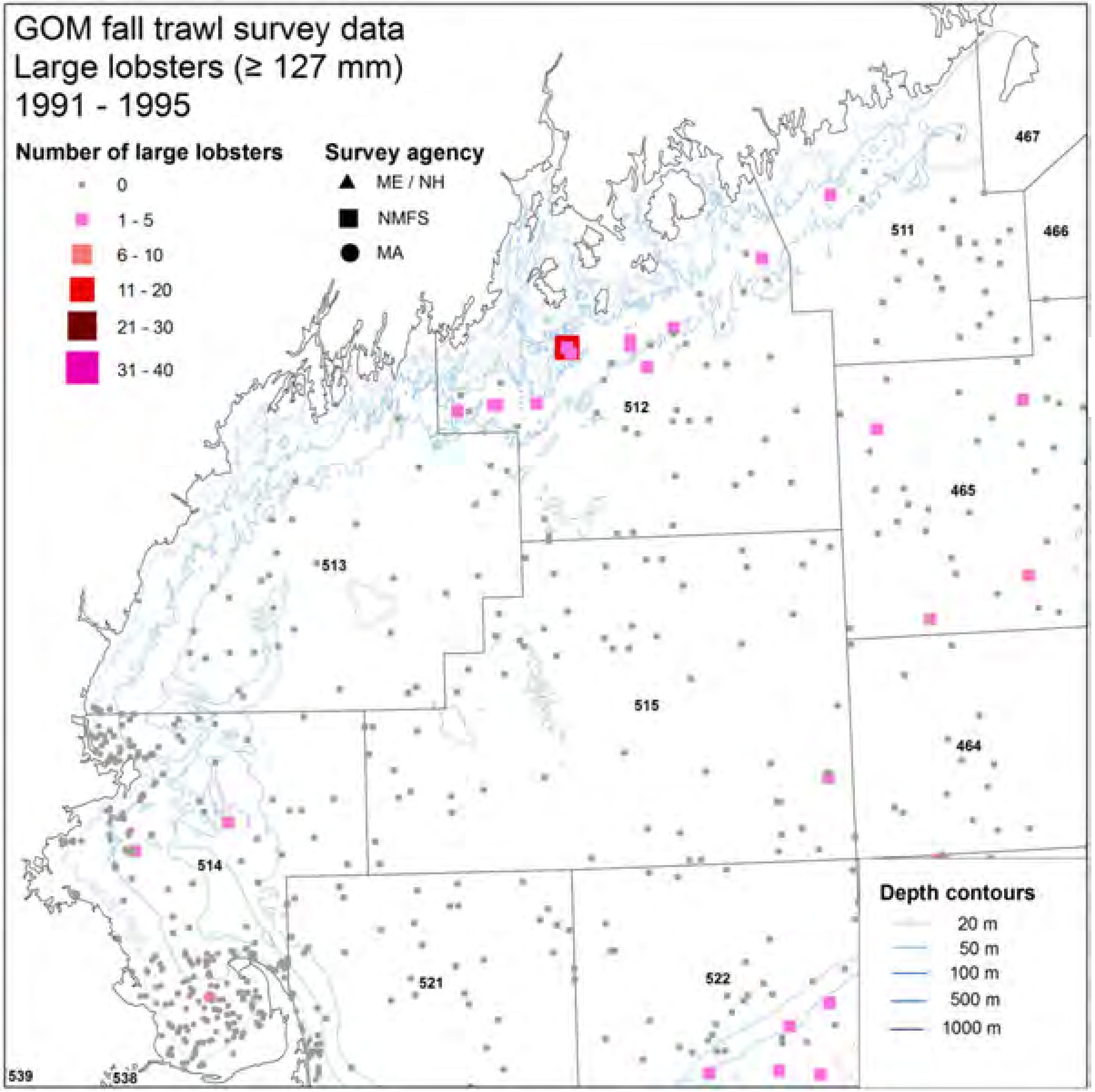
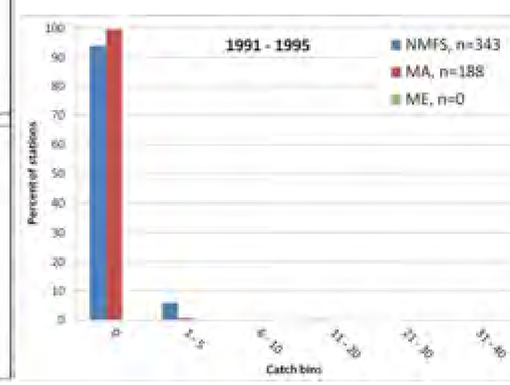


Figure 4.2.1.3.1.5 D



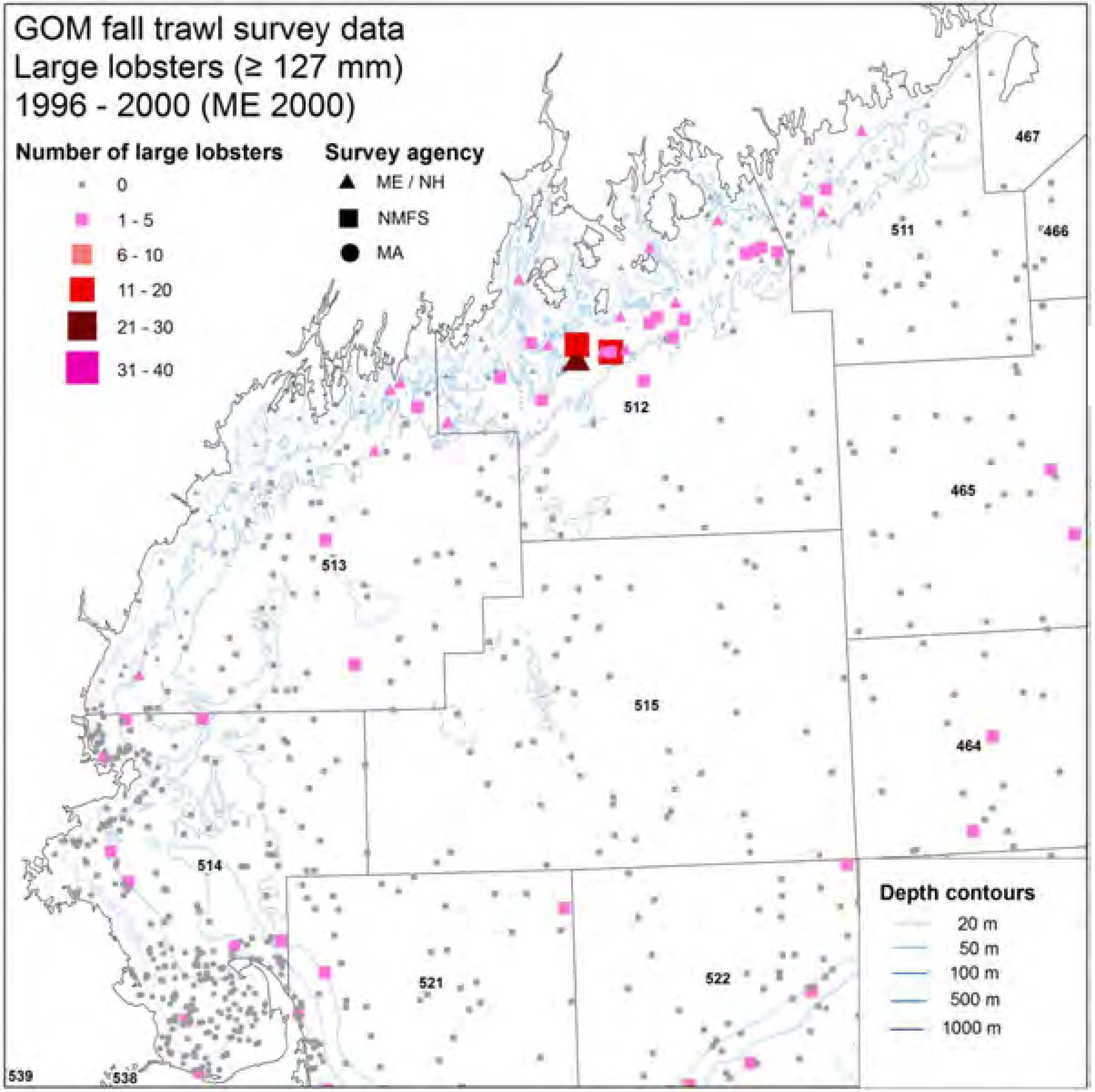
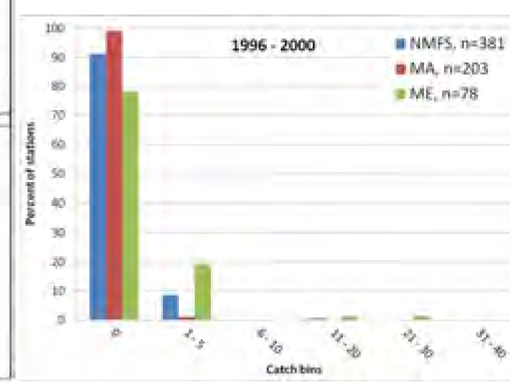


Figure 4.2.1.3.1.5 E



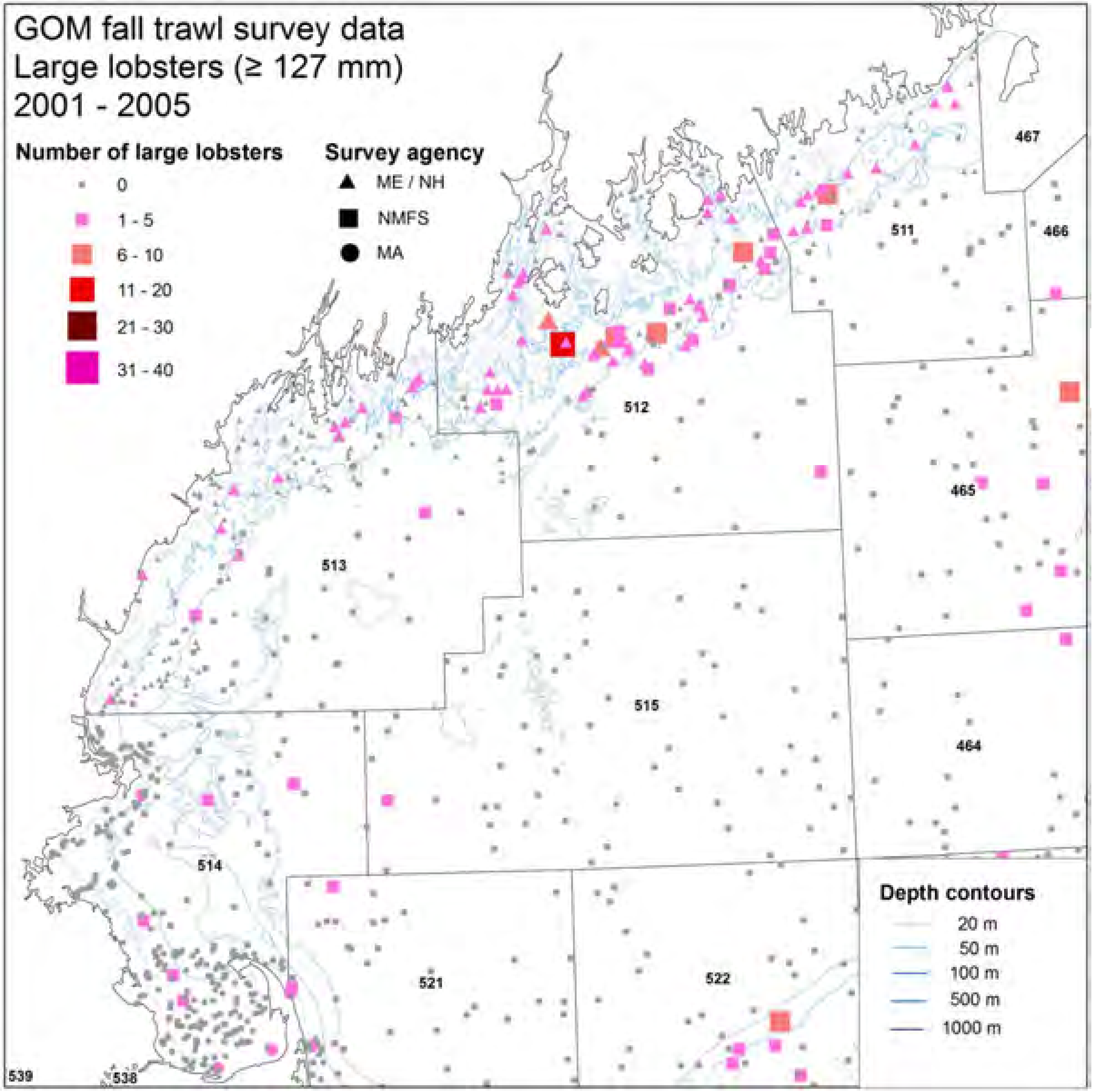
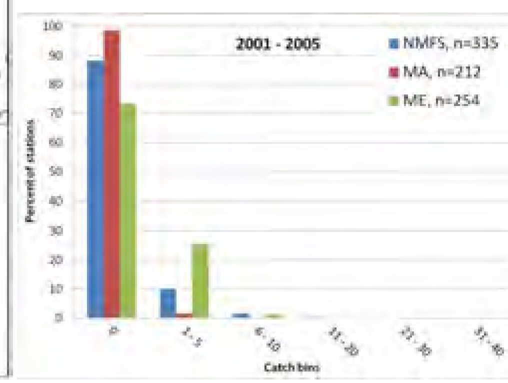


Figure 4.2.1.3.1.5 F



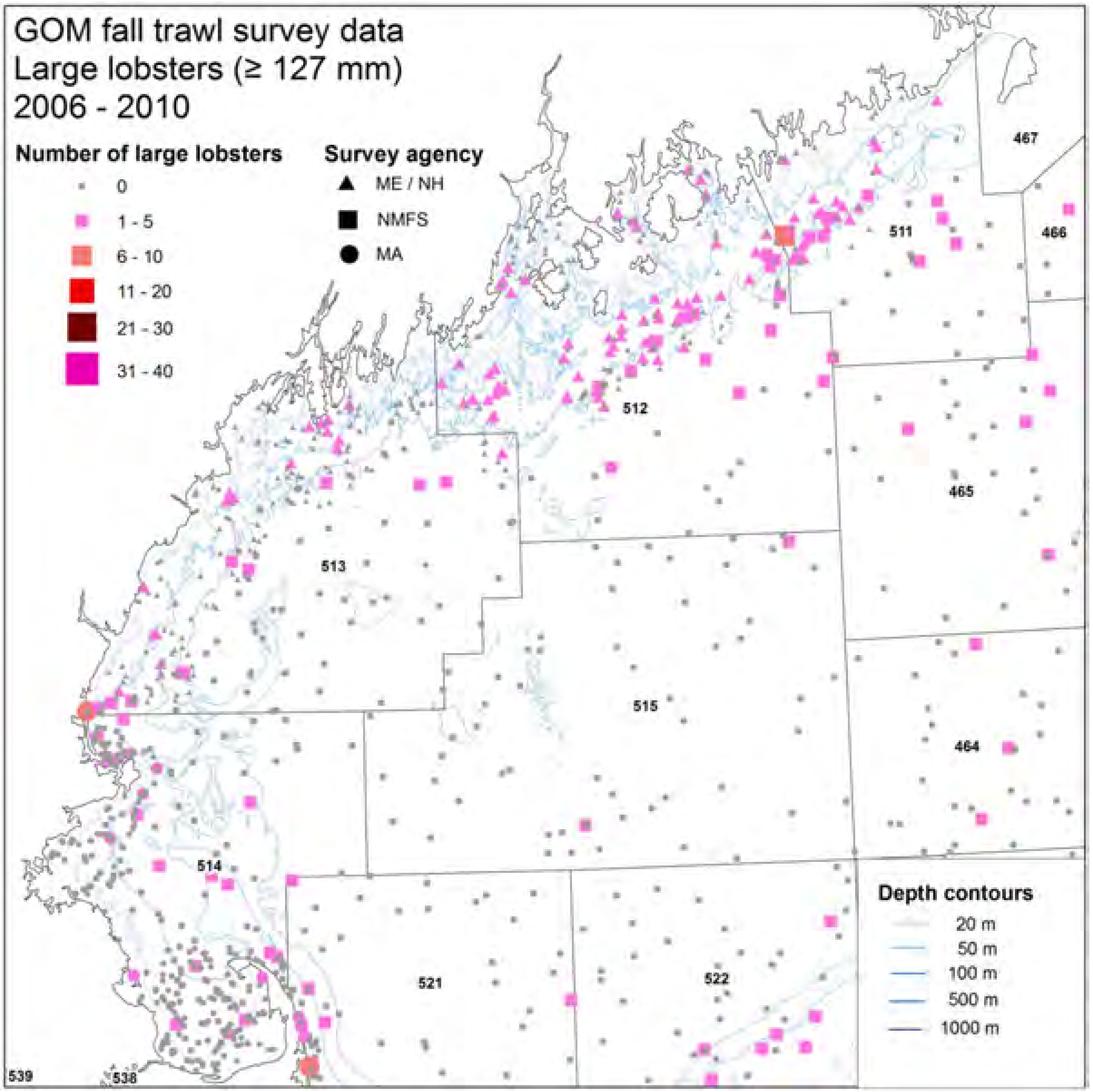
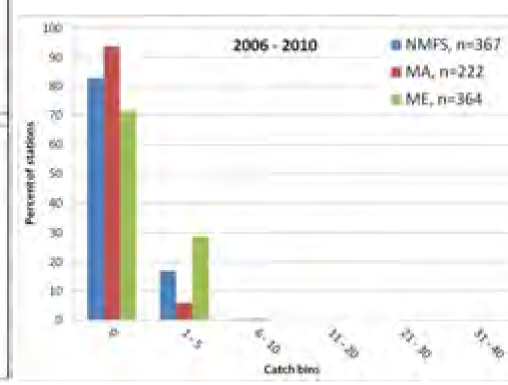
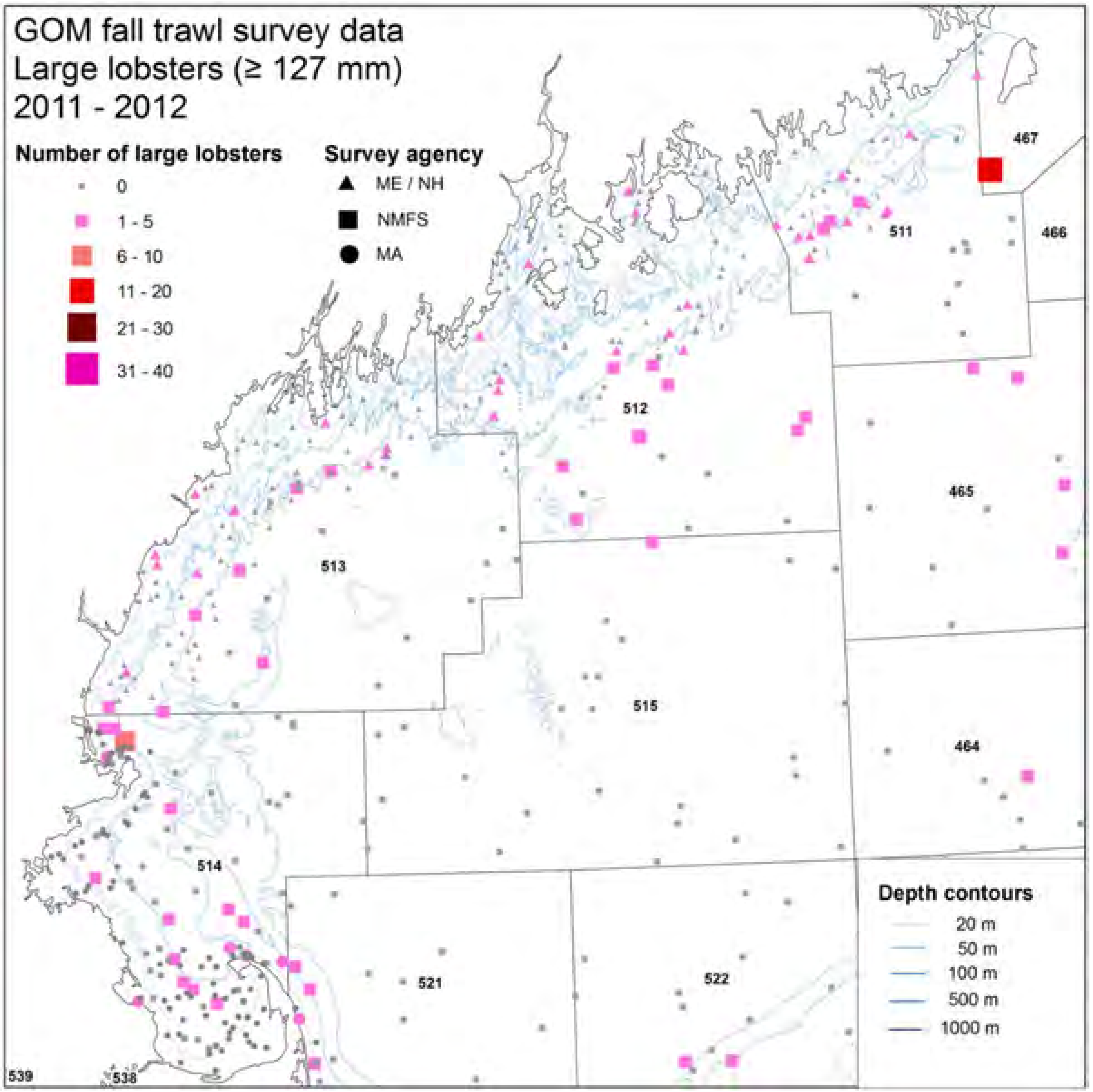


Figure 4.2.1.3.1.5 G





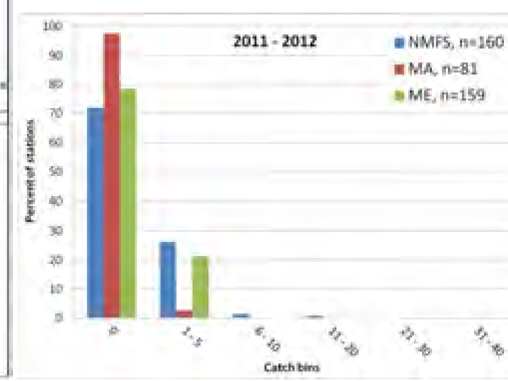


Figure 4.2.1.3.1.5 H

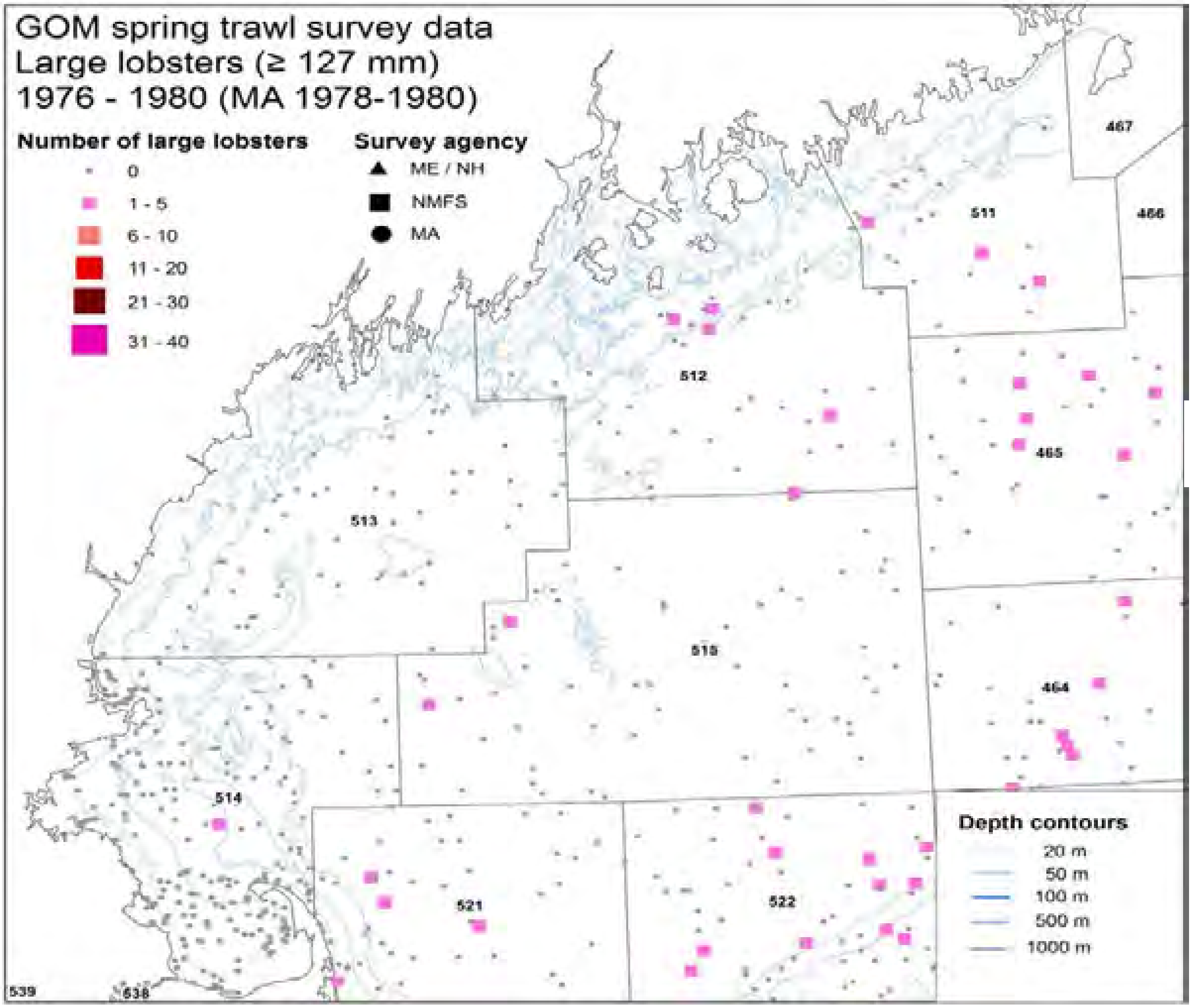


Figure 4.2.1.3.1.6 A

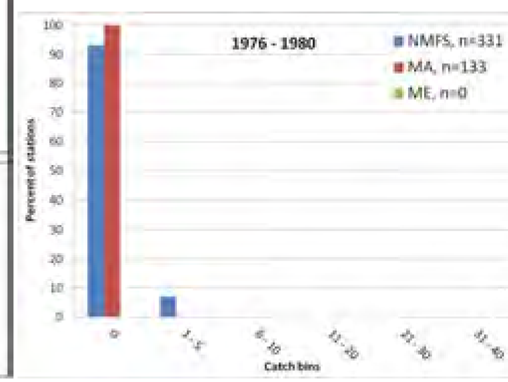


Figure 4.2.1.3.1.6 A – H. **Mean catch per tow of "large" lobster (≥ 127 mm CL) at each spring sampling location from all GOM bottom trawl surveys (ME/NH, MA, and NMFS), shown in 5 year time periods.** Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

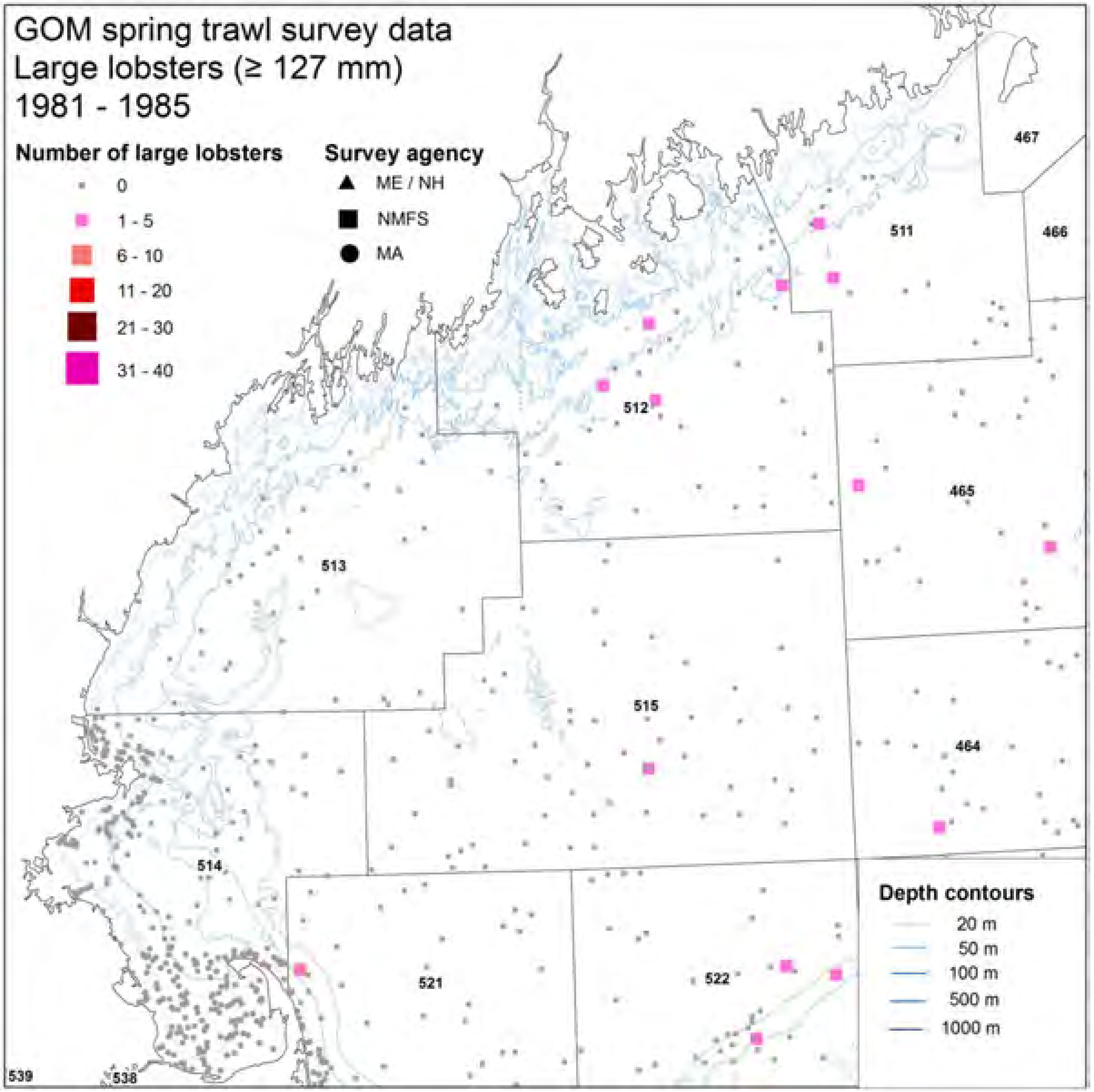
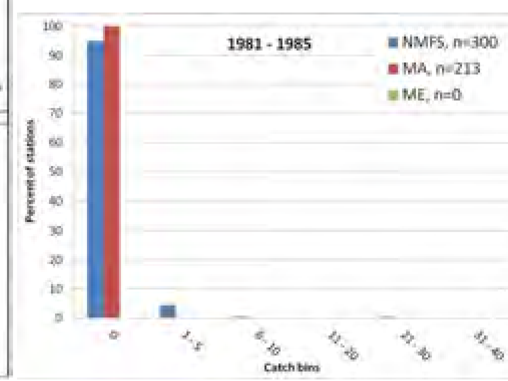
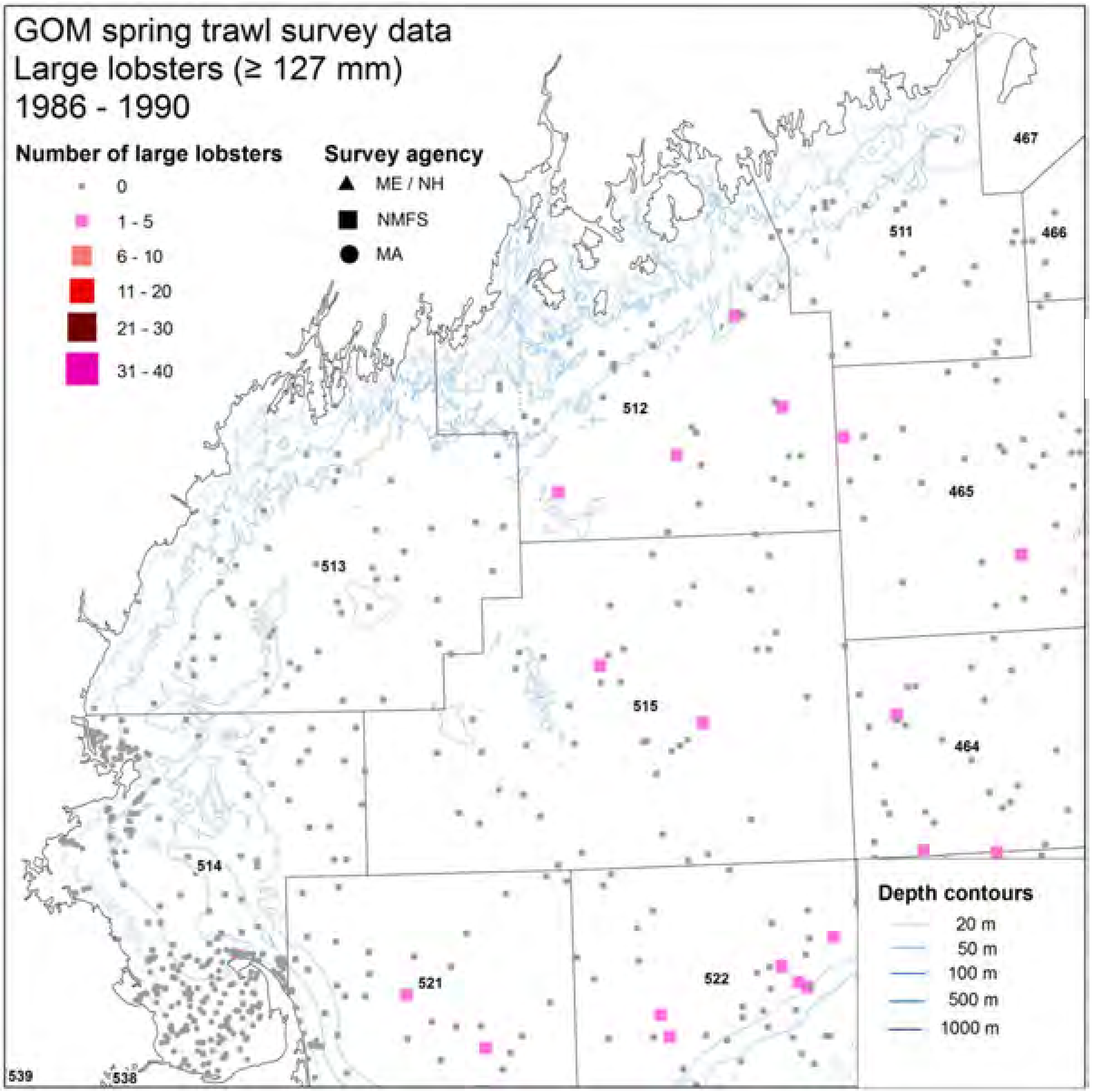


Figure 4.2.1.3.1.6 B





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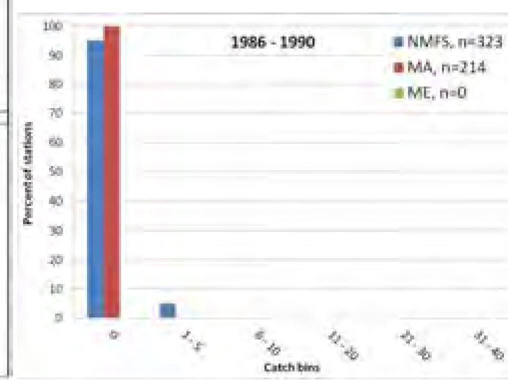


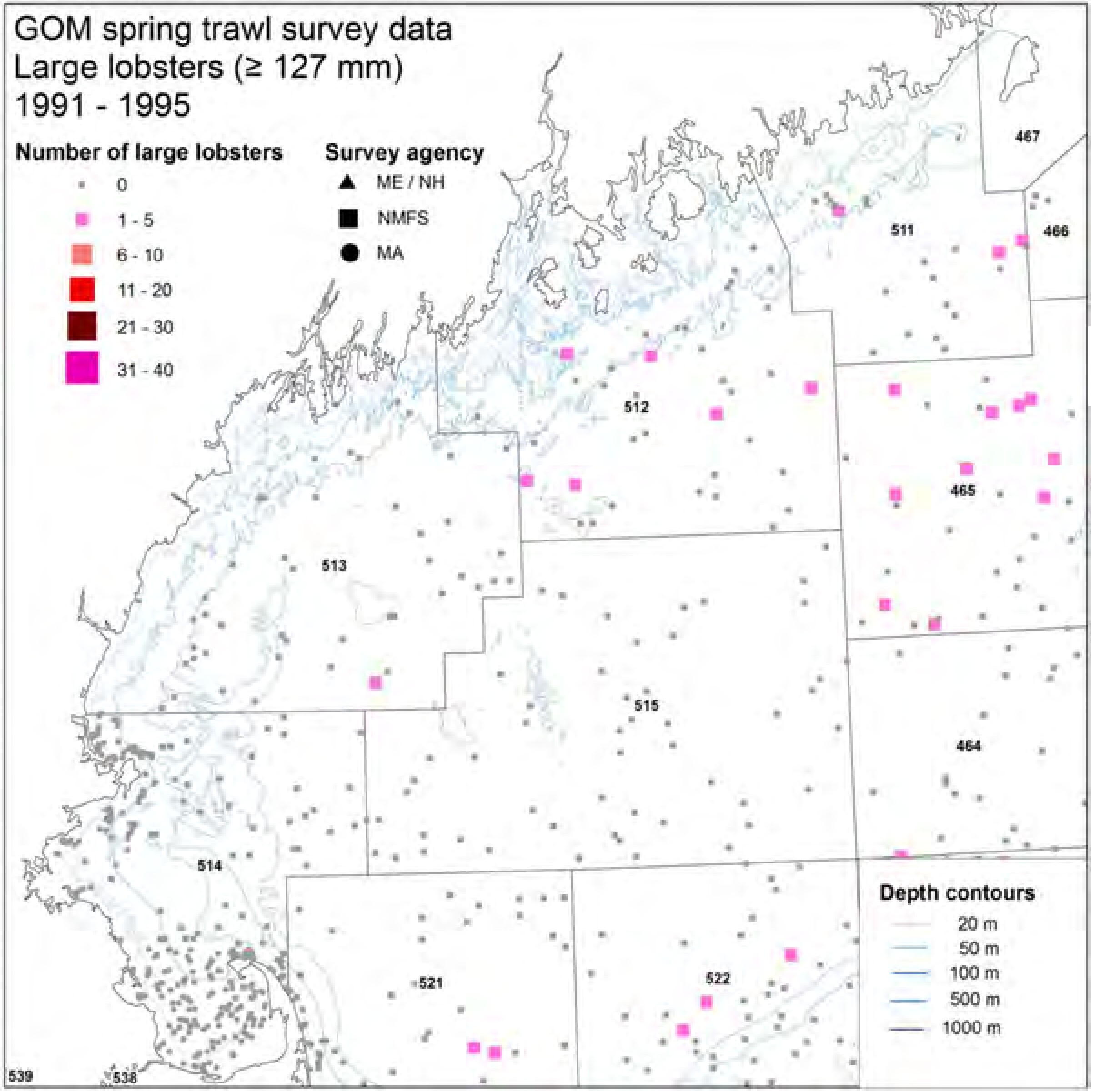
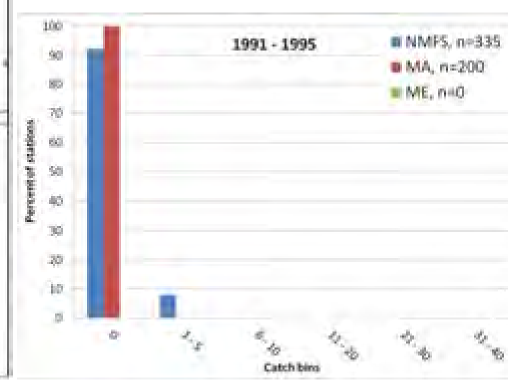


Figure 4.2.1.3.1.6 D



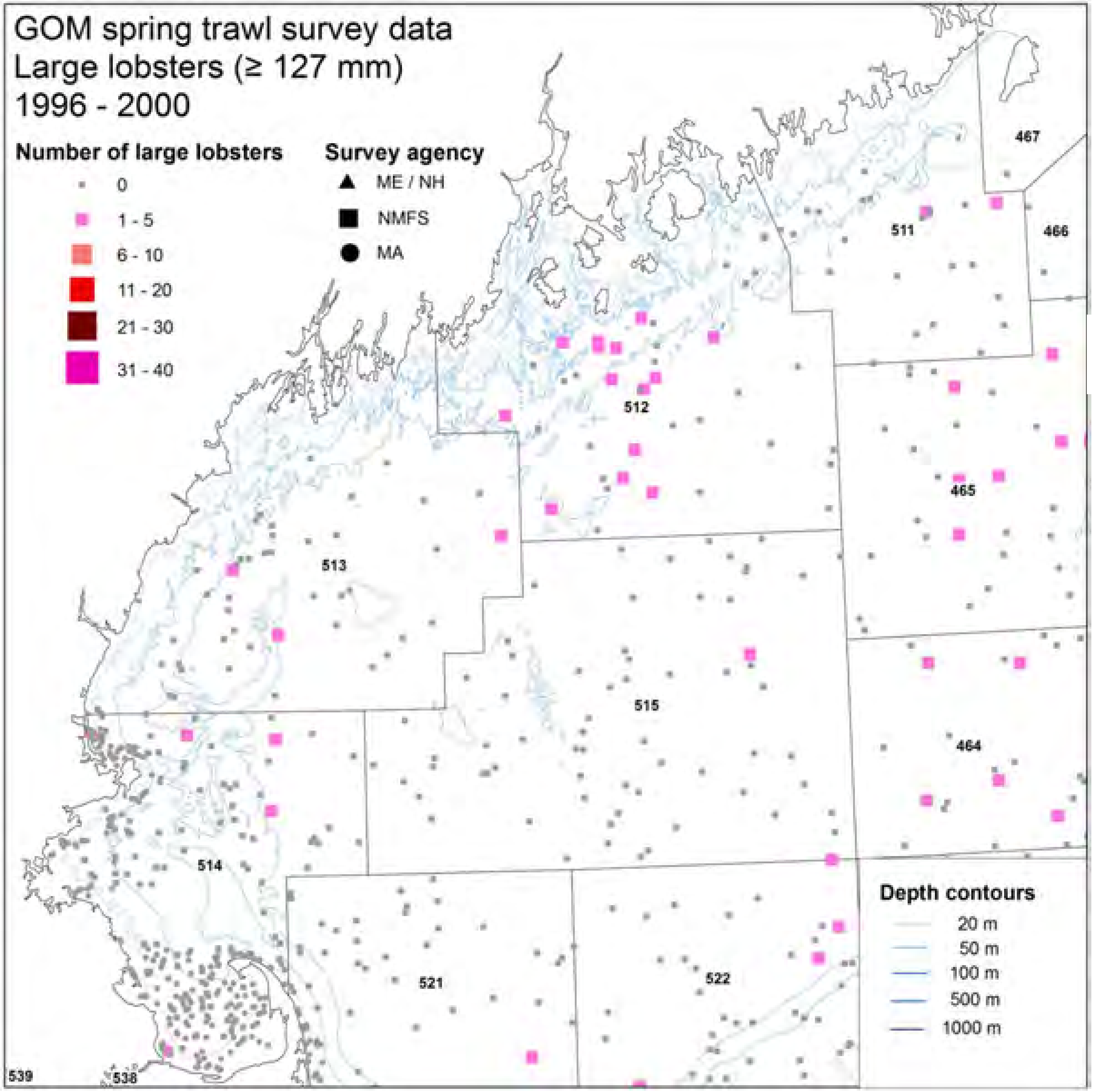
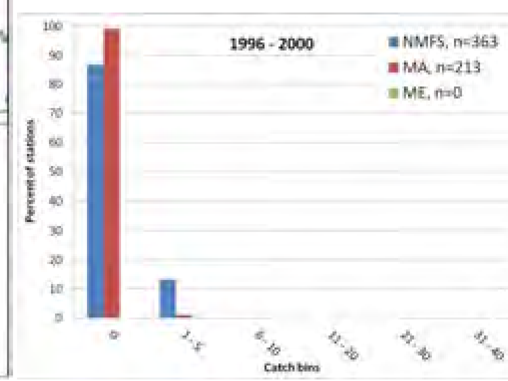


Figure 4.2.1.3.1.6 E



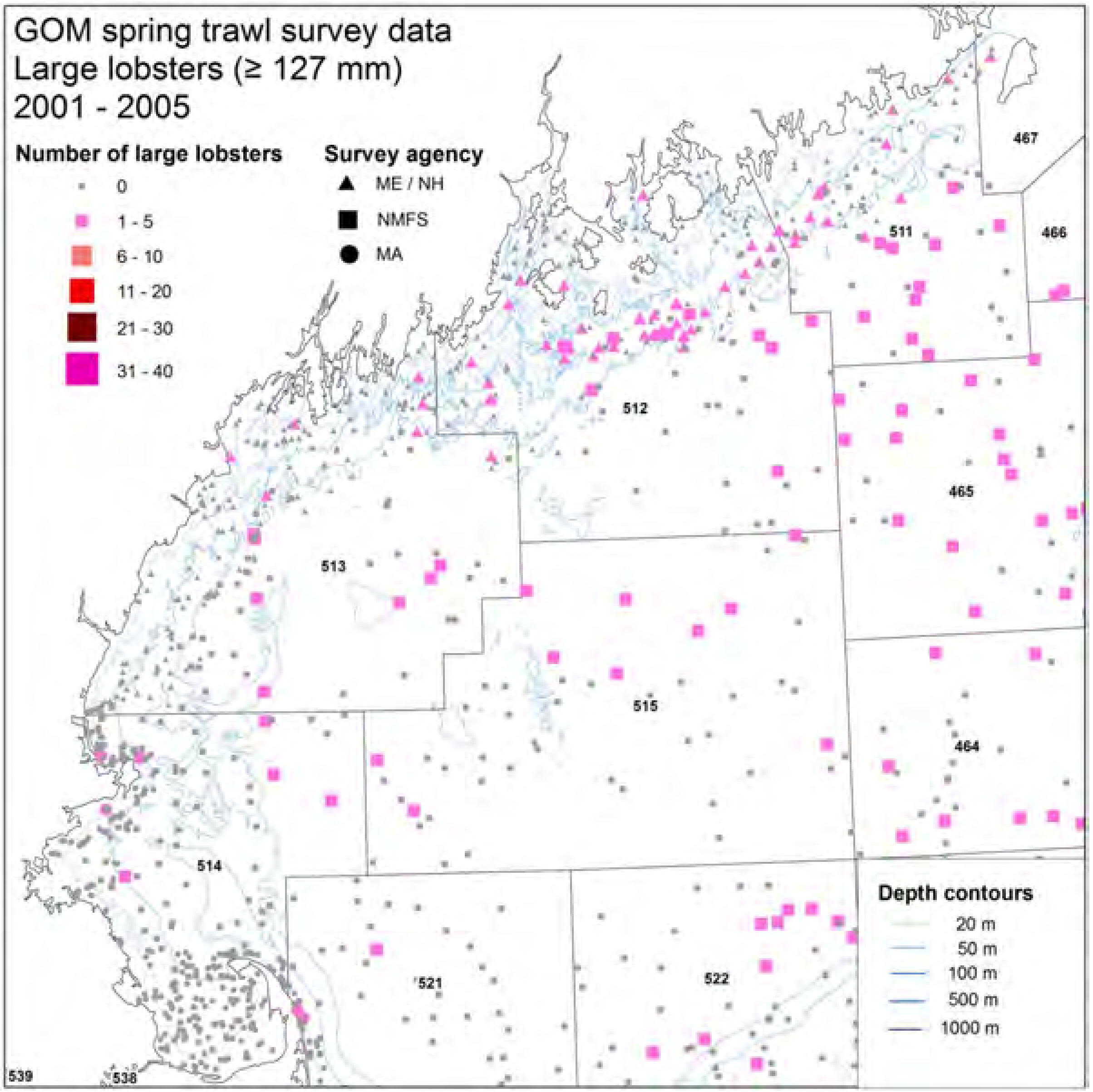
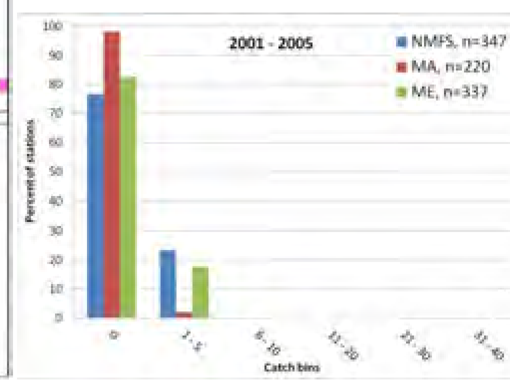


Figure 4.2.1.3.1.6 F



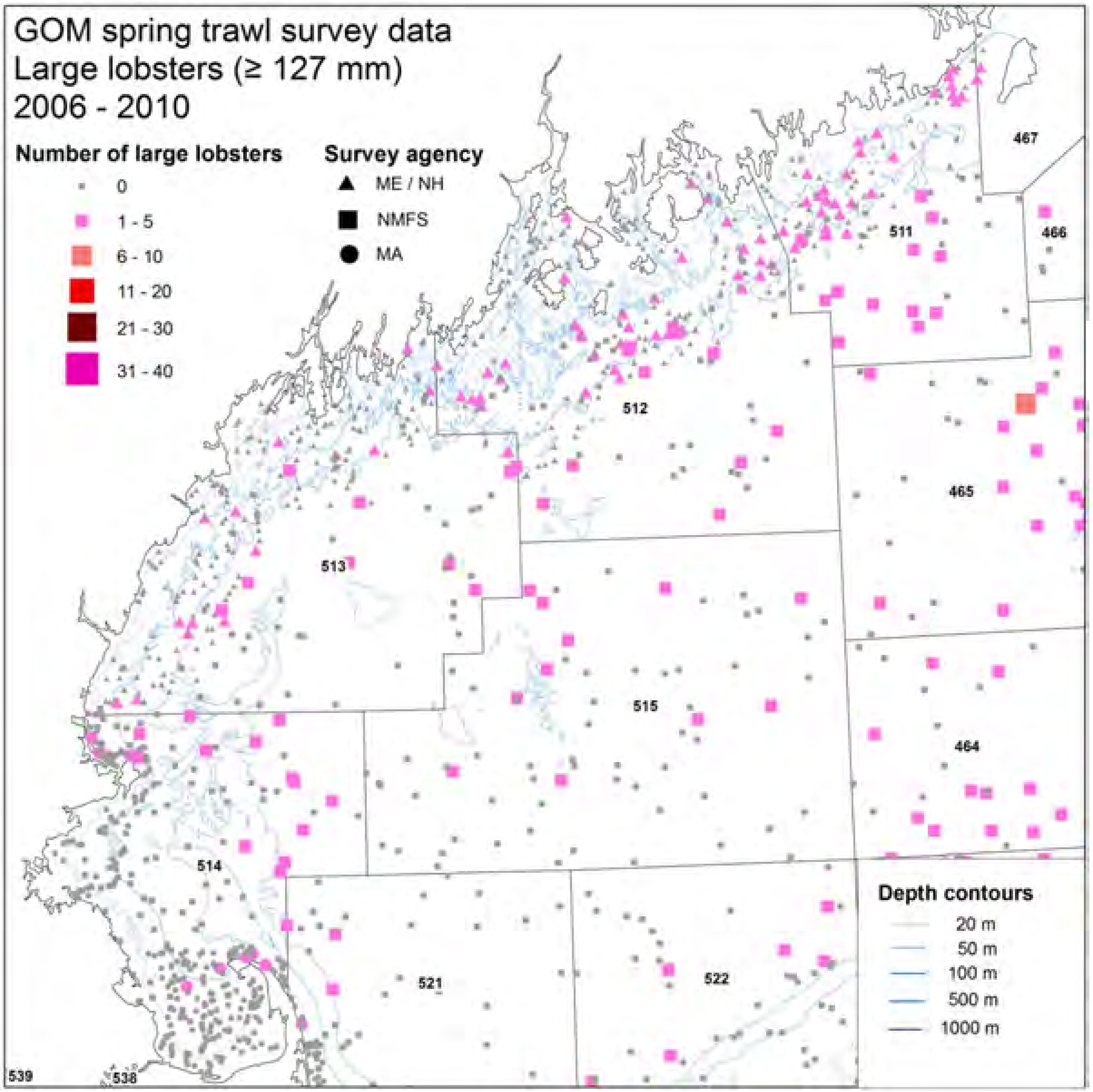
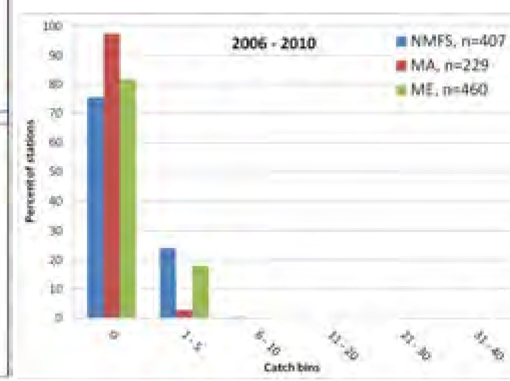
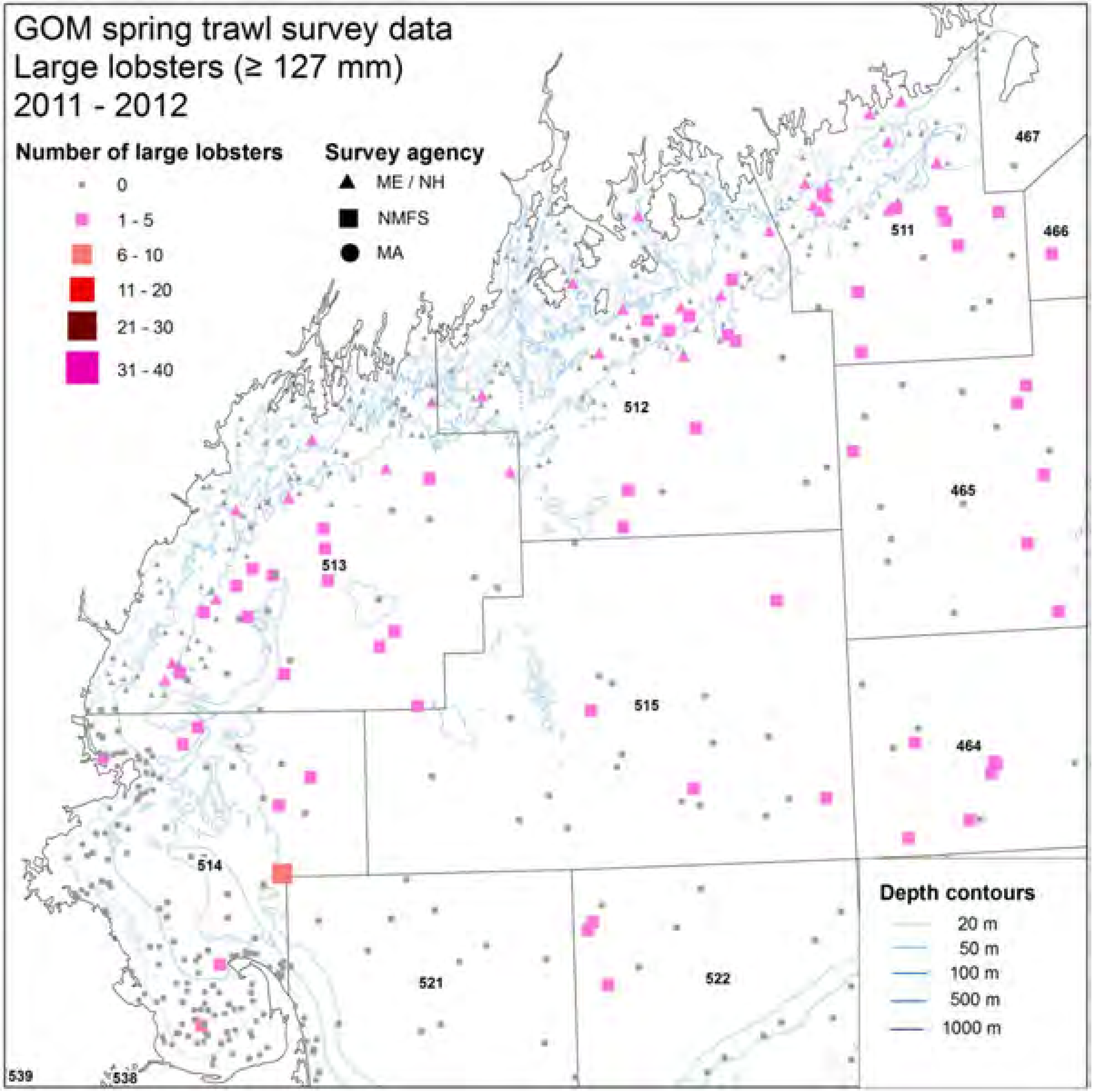


Figure 4.2.1.3.1.6 G





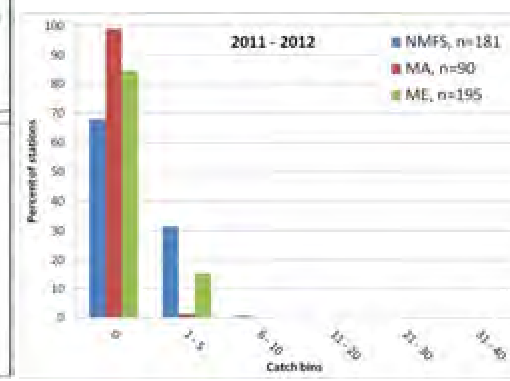


Figure 4.2.1.3.1.6 H

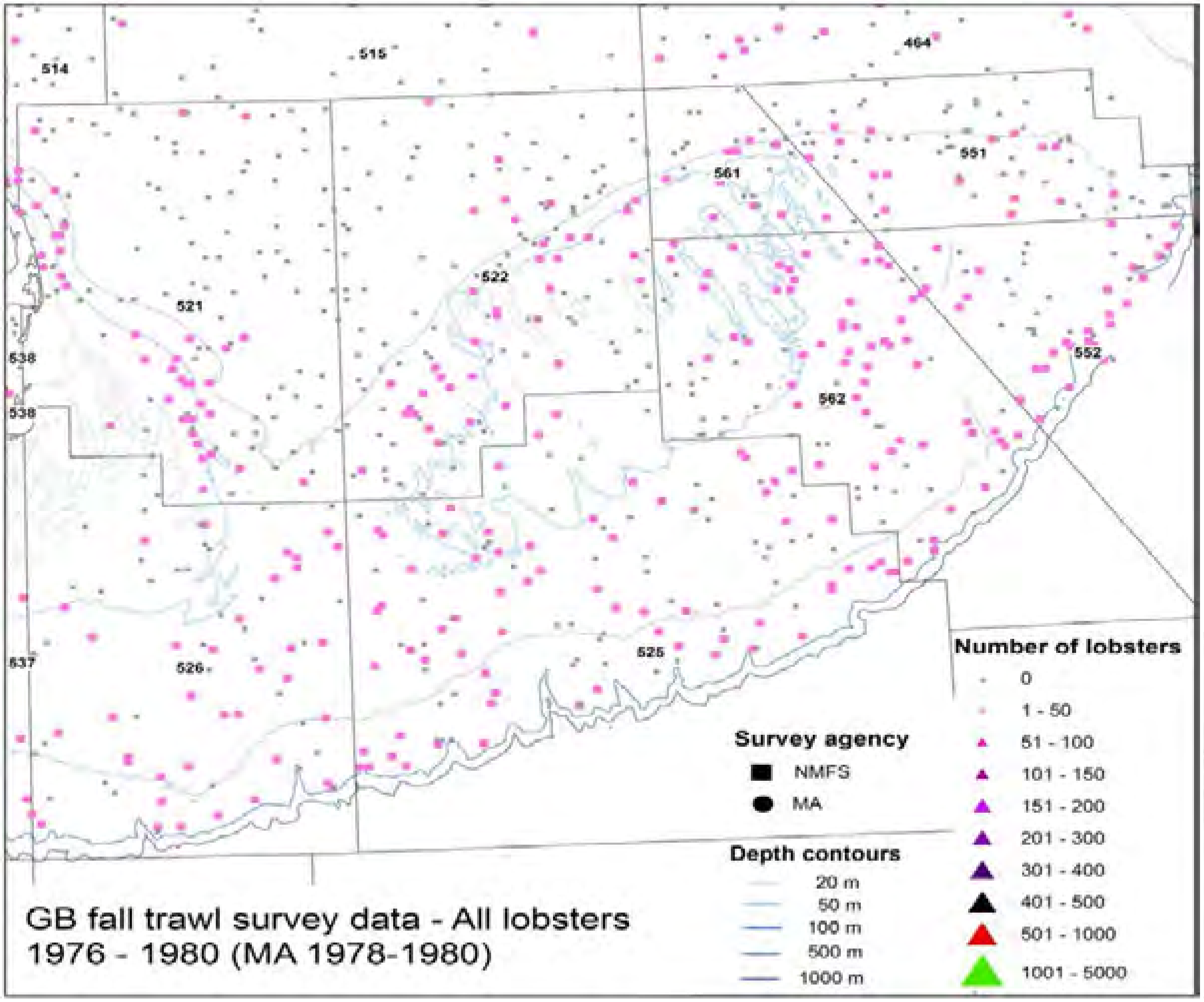


Figure 4.2.1.3.2.1 A

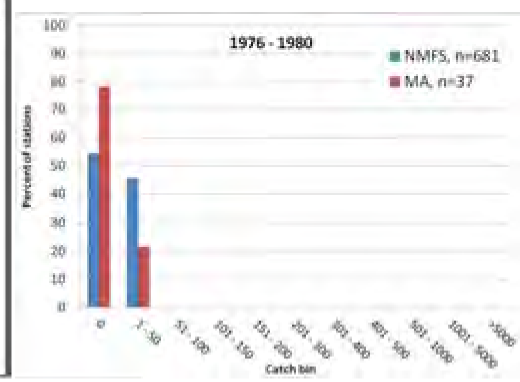


Figure 4.2.1.3.2.1 A – H. **Mean catch per tow of lobster (all sizes) at each fall sampling location from all GBK bottom trawl surveys (NMFS and MA), shown in 5 year time periods.** Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

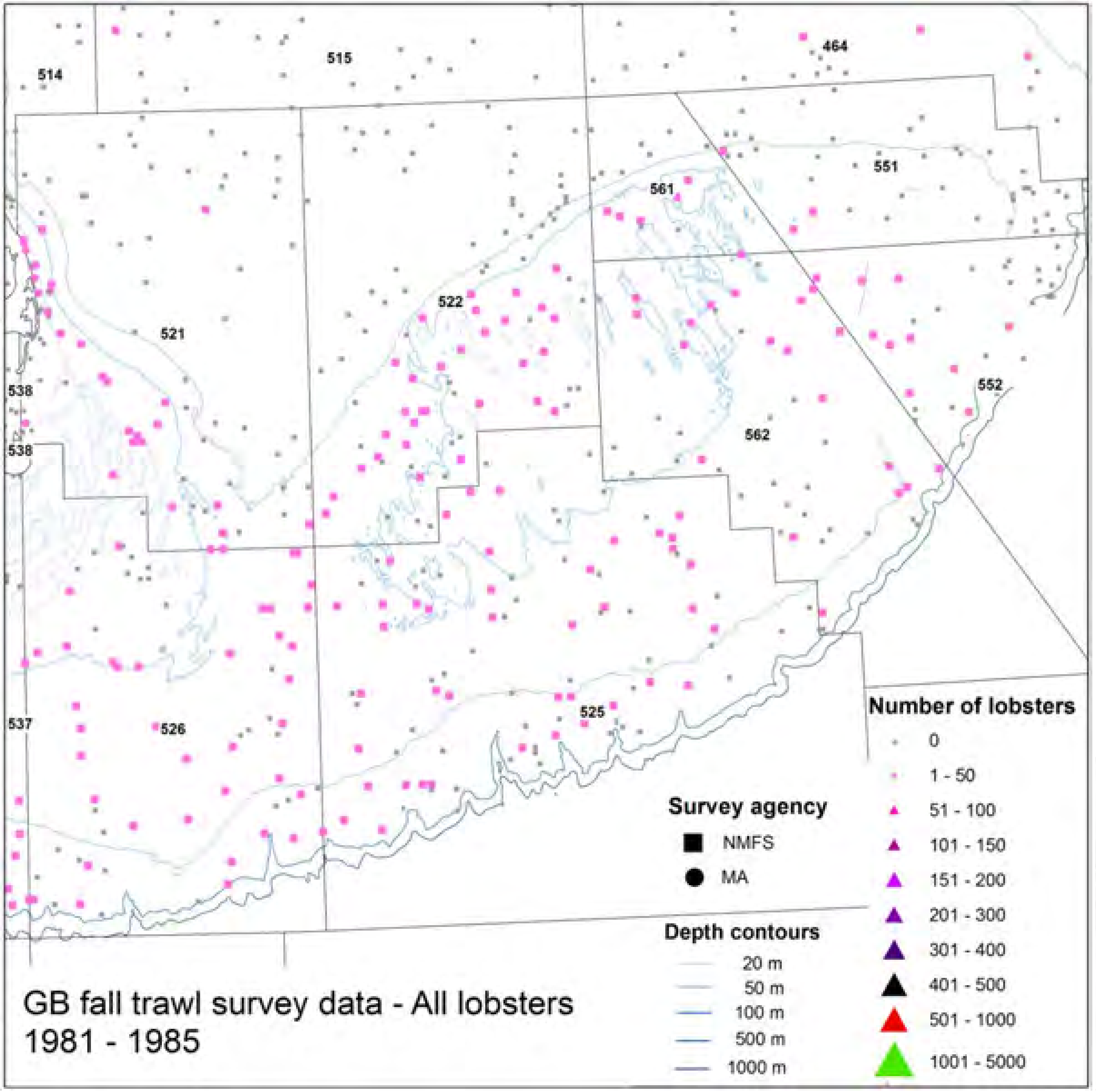
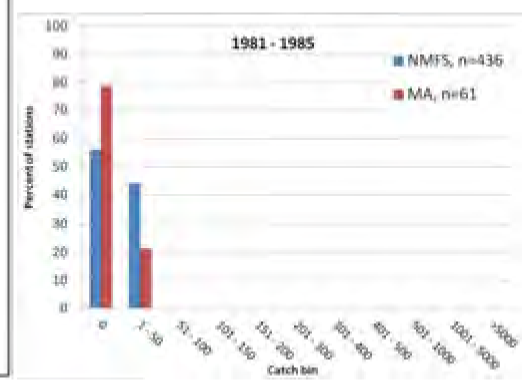


Figure 4.2.1.3.2.1 B



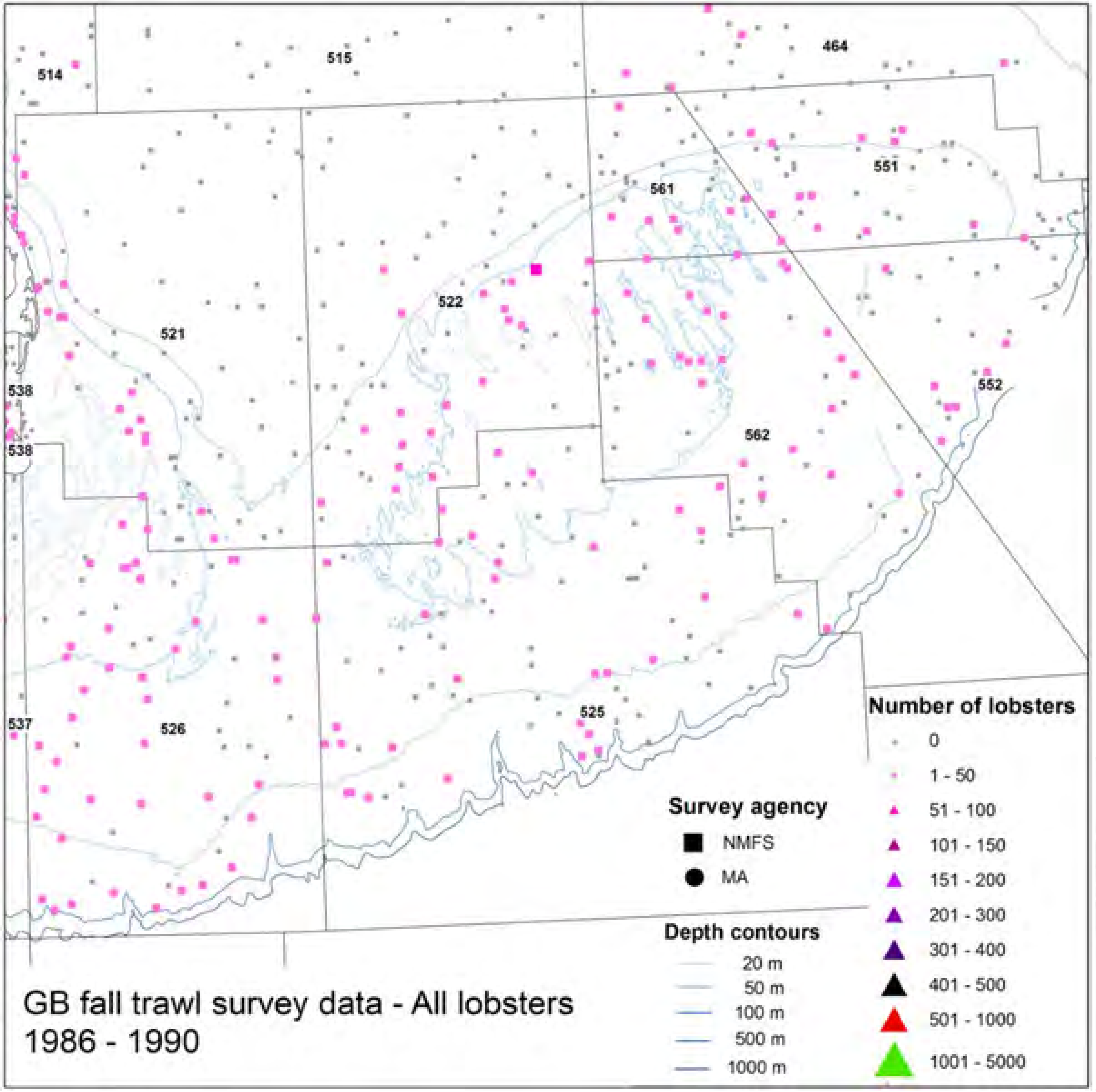
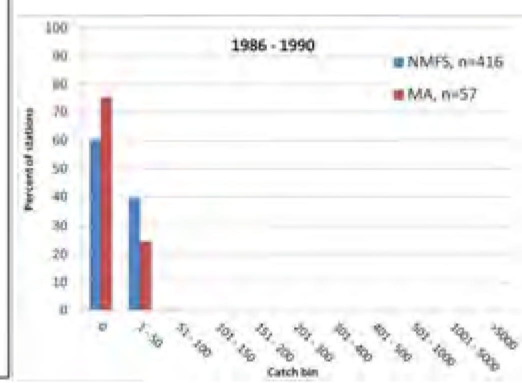


Figure 4.2.1.3.2.1 C



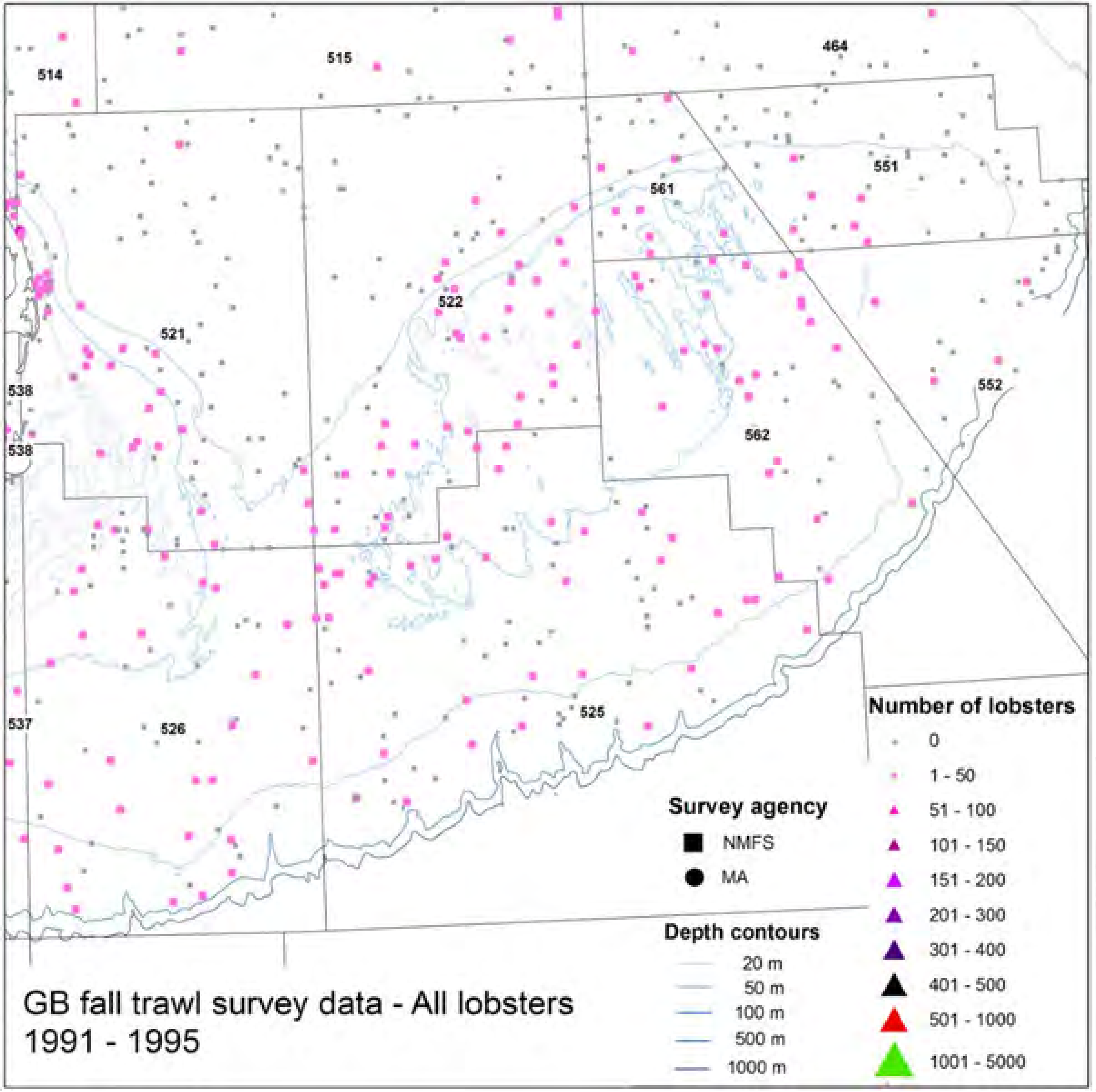
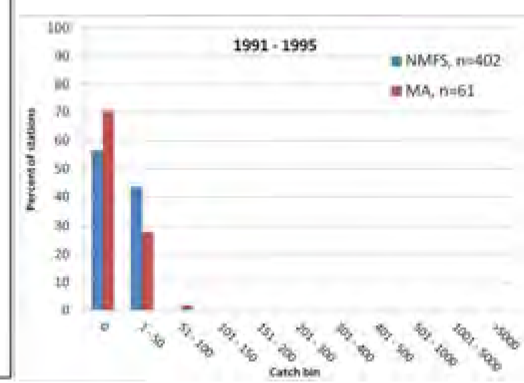


Figure 4.2.1.3.2.1 D



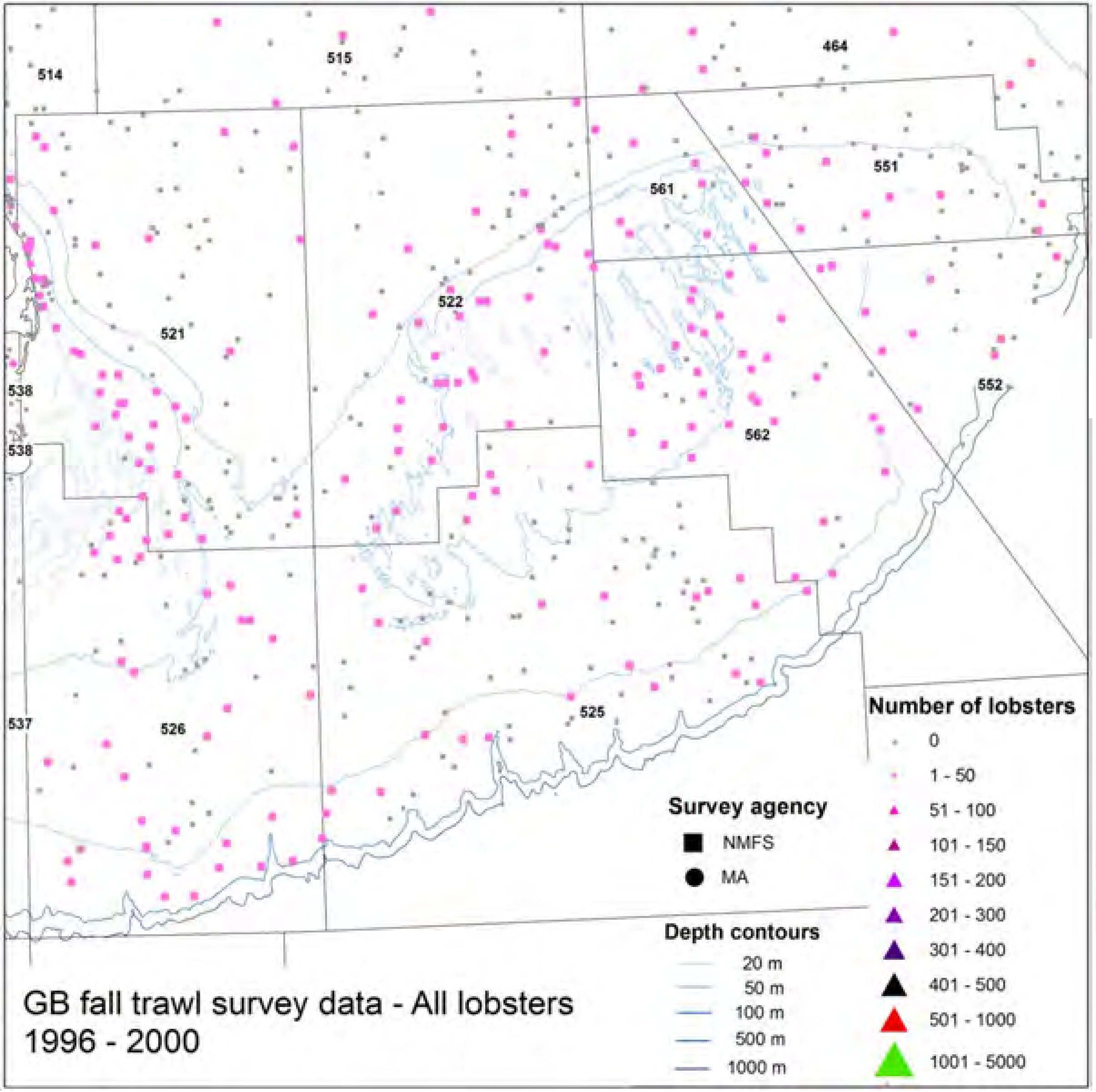
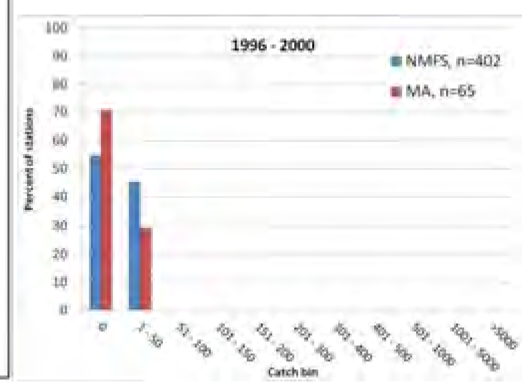


Figure 4.2.1.3.2.1 E



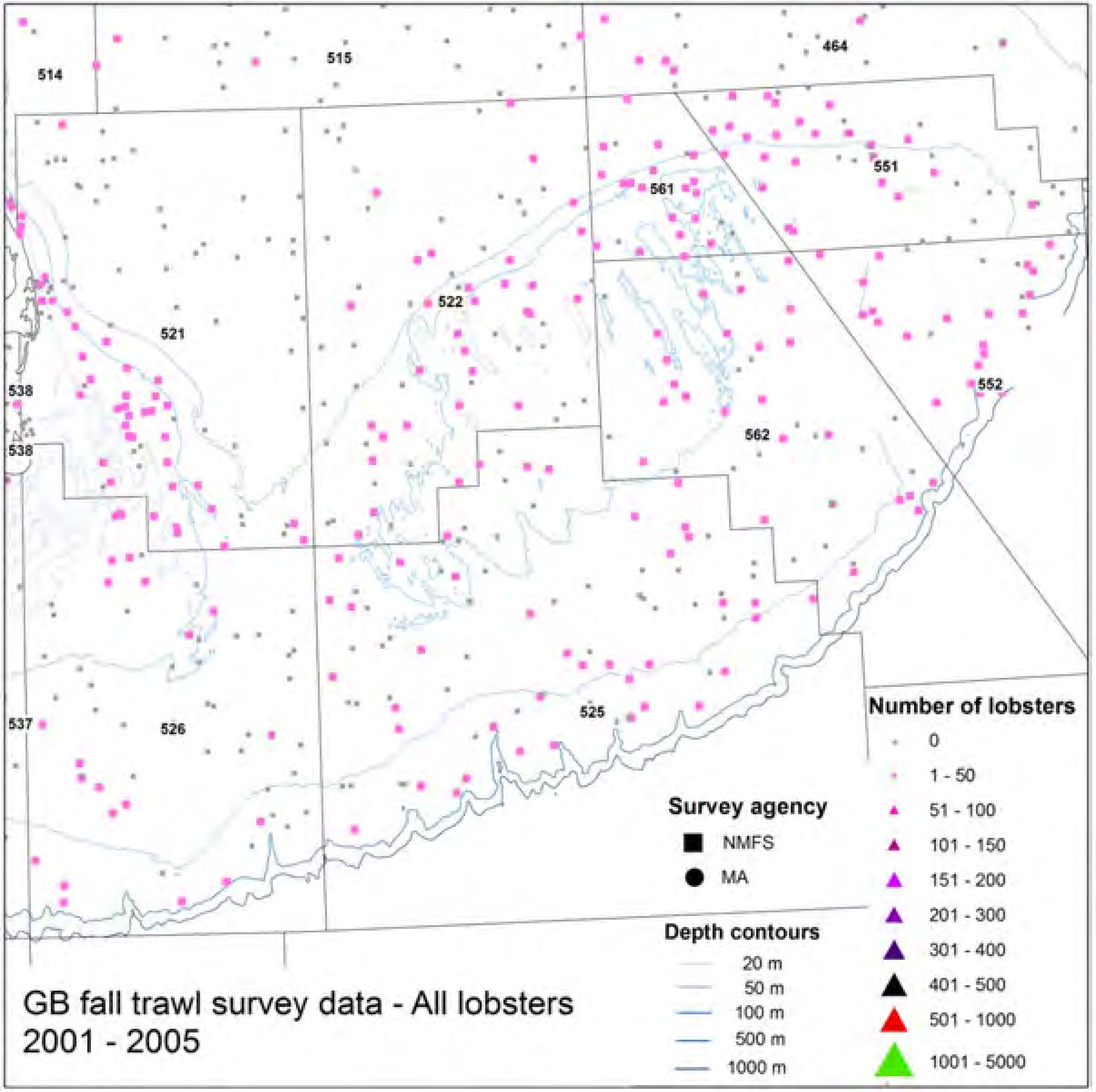
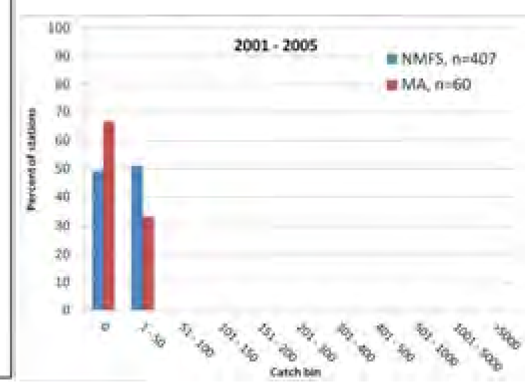


Figure 4.2.1.3.2.1 F



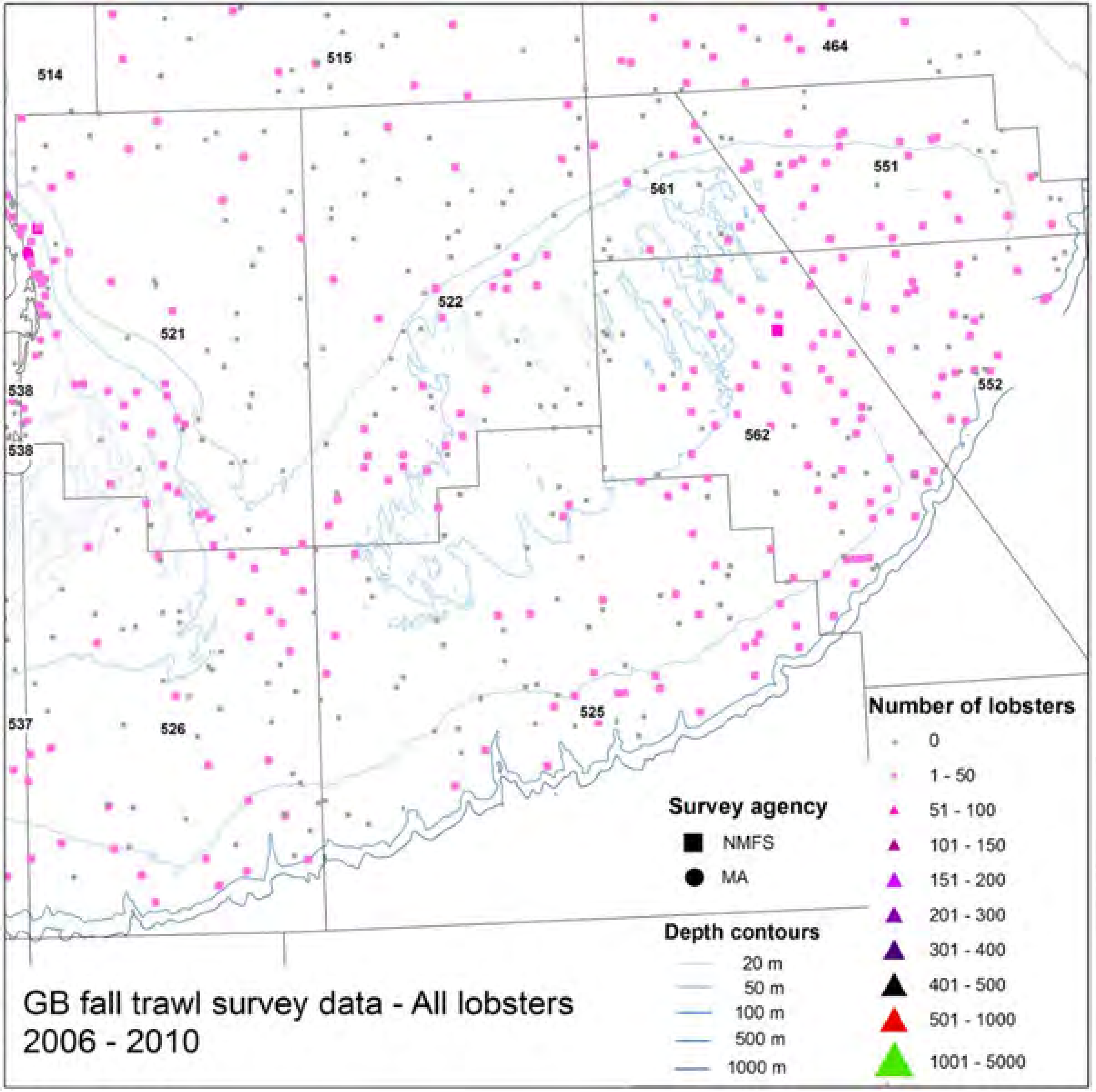
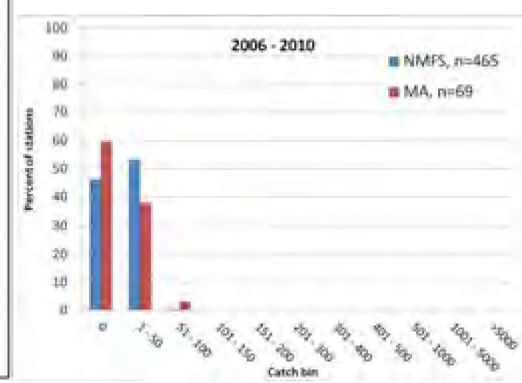


Figure 4.2.1.3.2.1 G



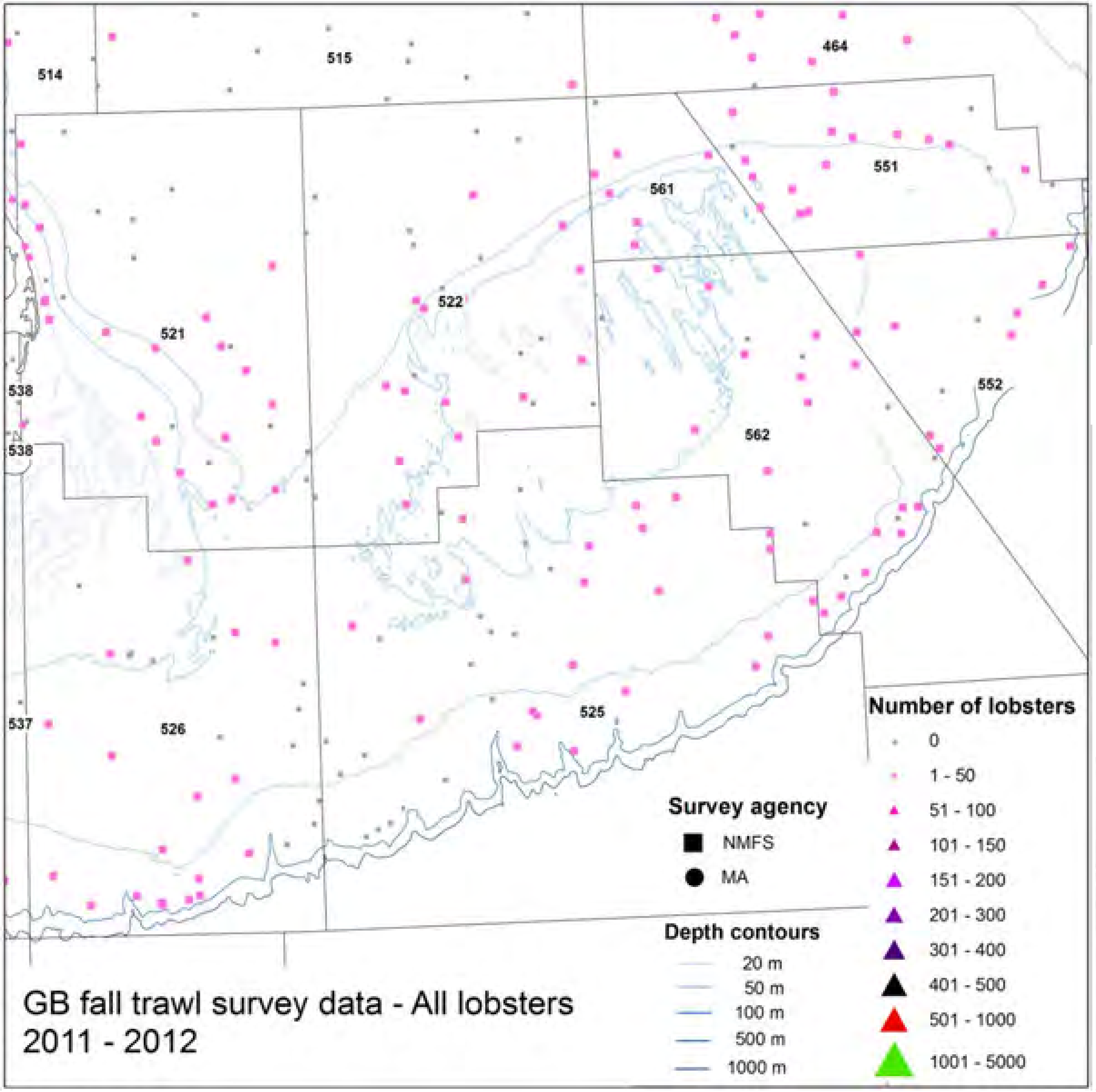
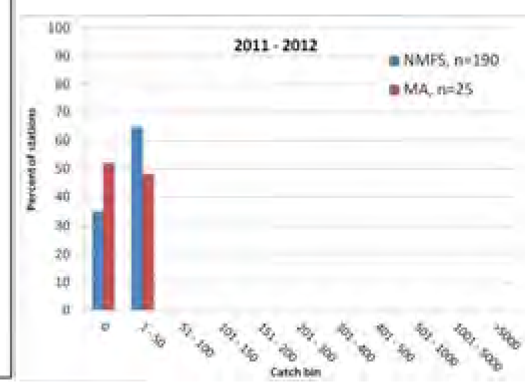


Figure 4.2.1.3.2.1 H



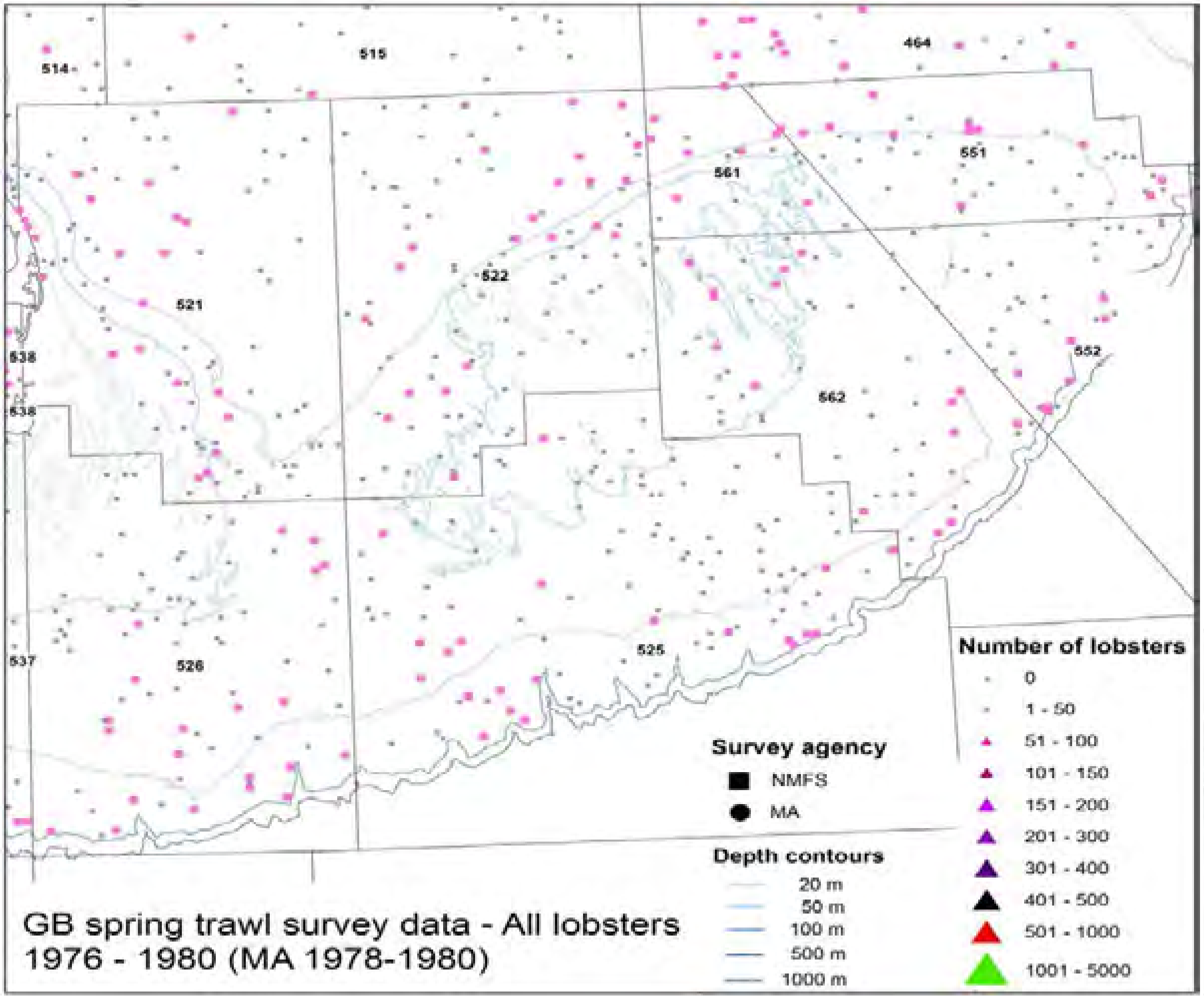


Figure 4.2.1.3.2.2 A

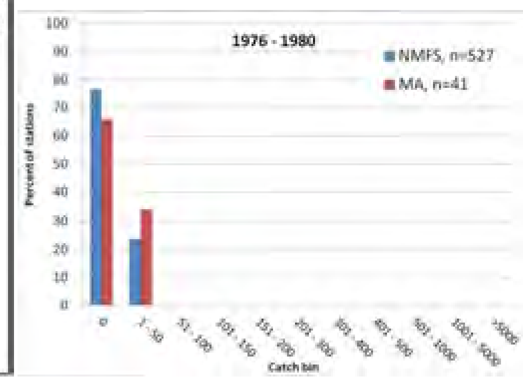


Figure 4.2.1.3.2.2 A – H. Mean catch per tow of lobster (all sizes) at each spring sampling location from all GBK bottom trawl surveys (NMFS and MA), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

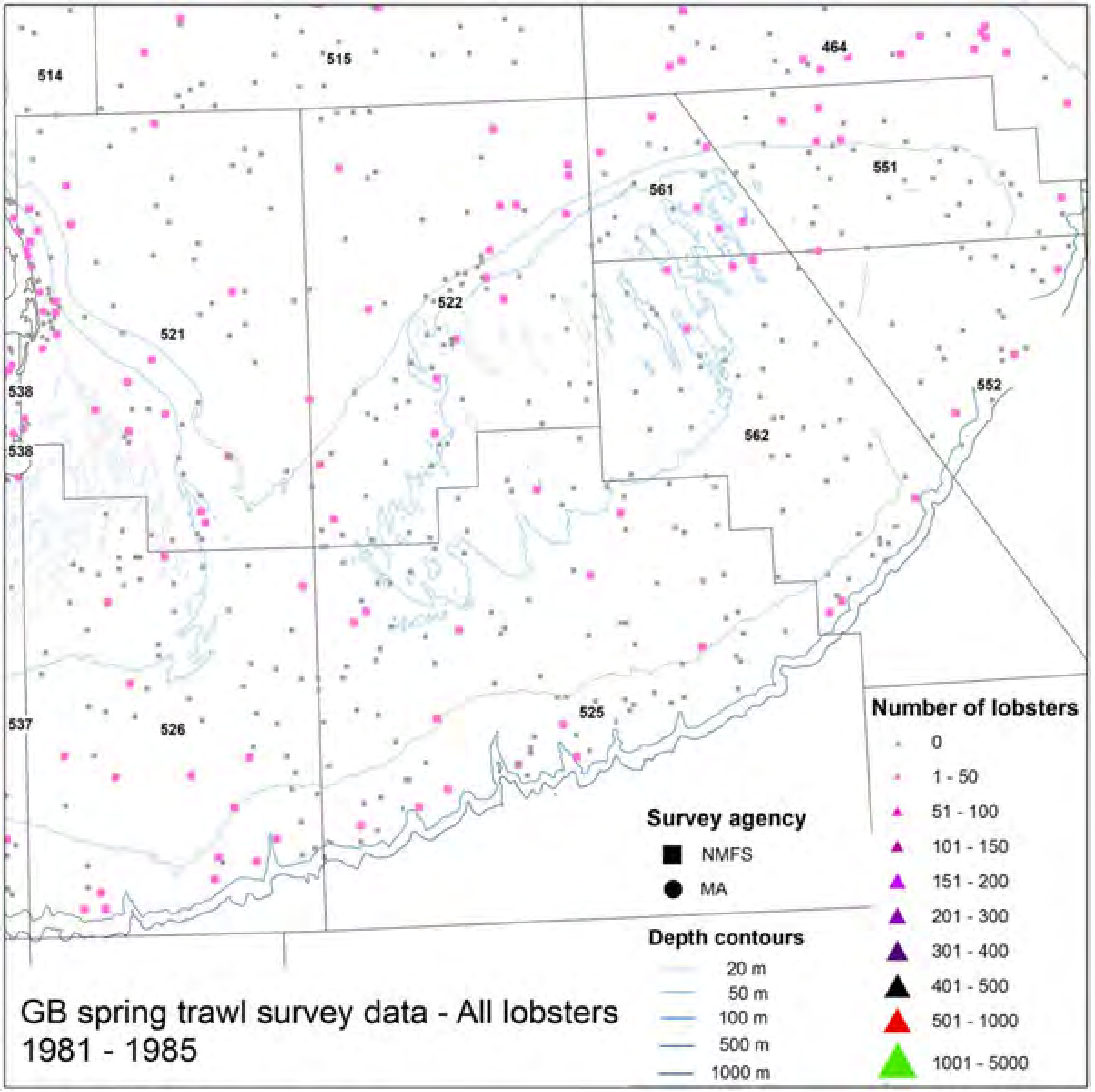
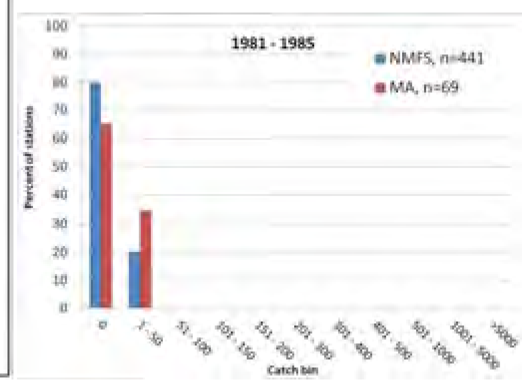


Figure 4.2.1.3.2.2 B



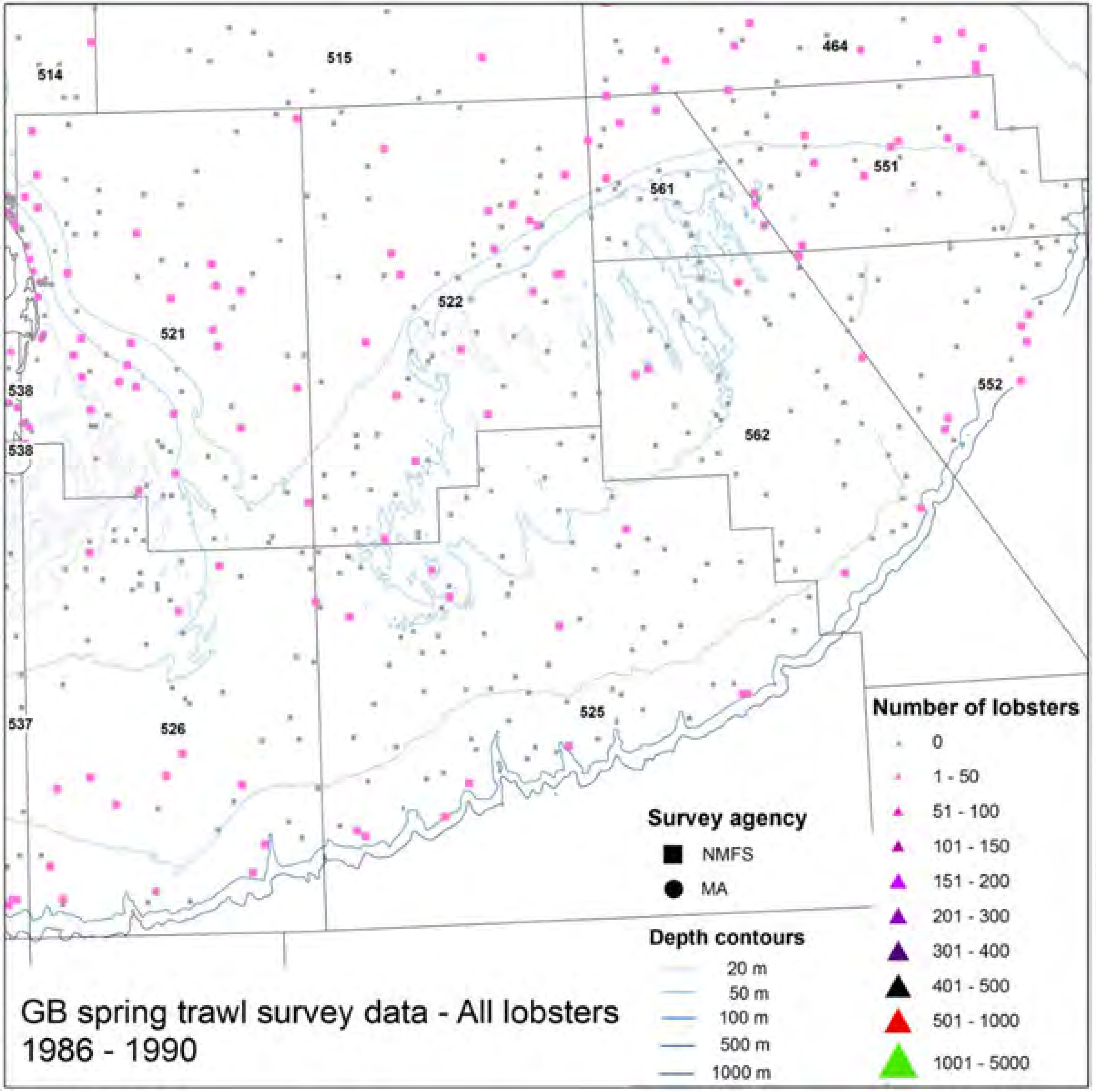
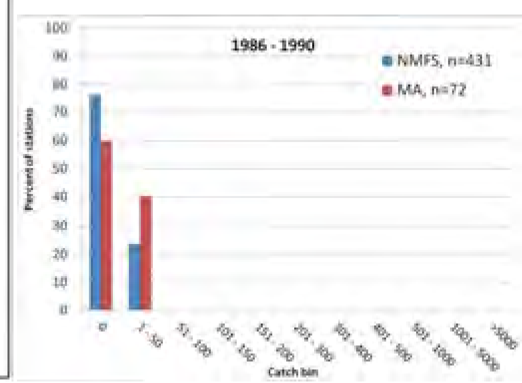


Figure 4.2.1.3.2.2 C



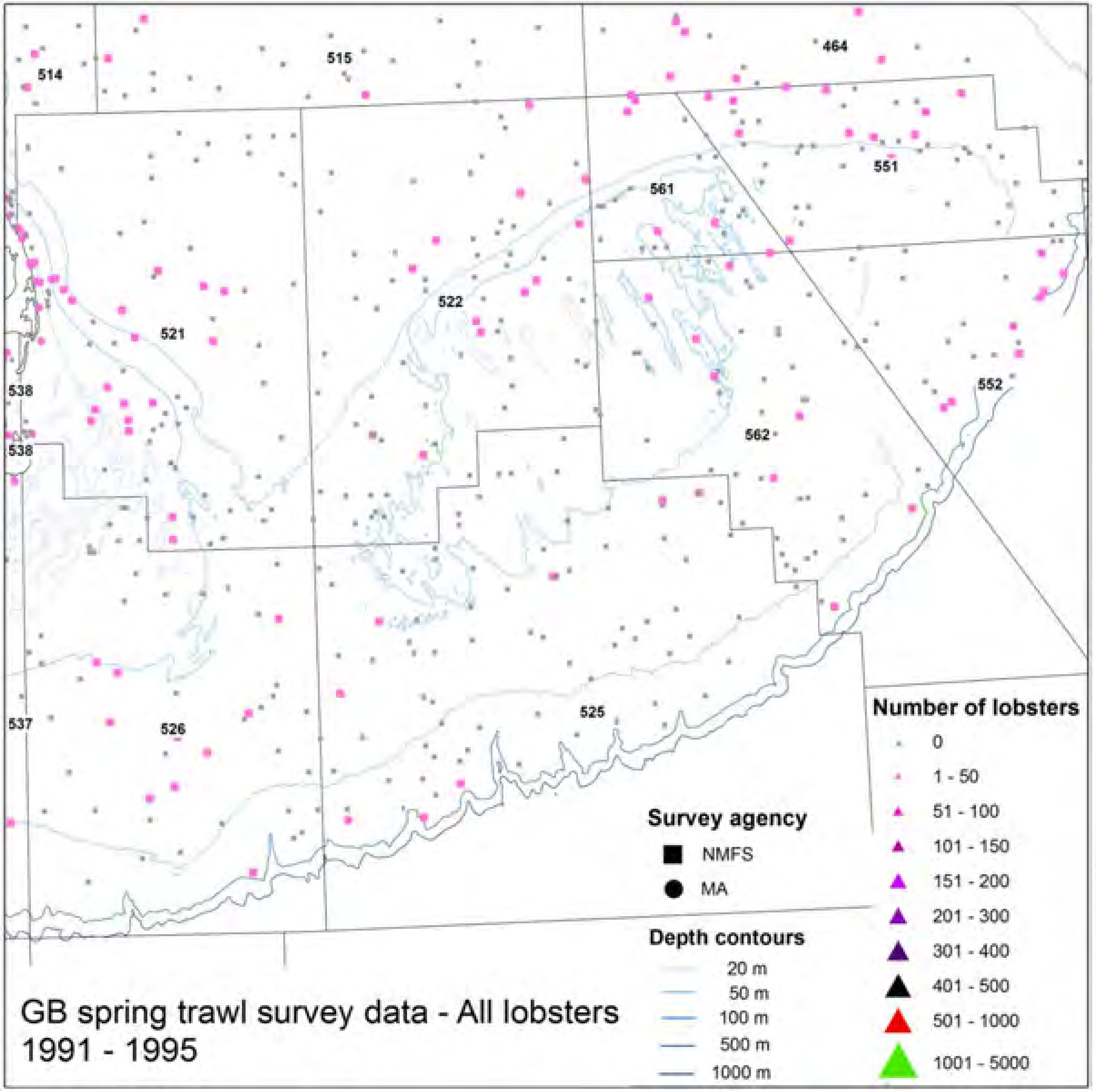
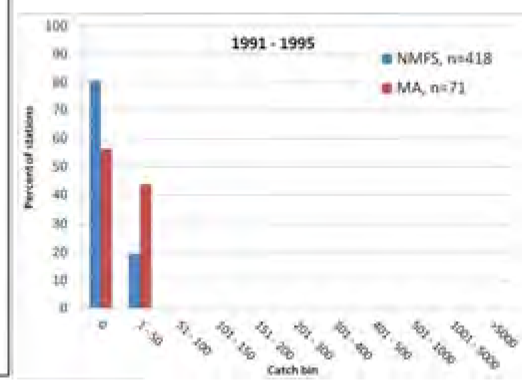
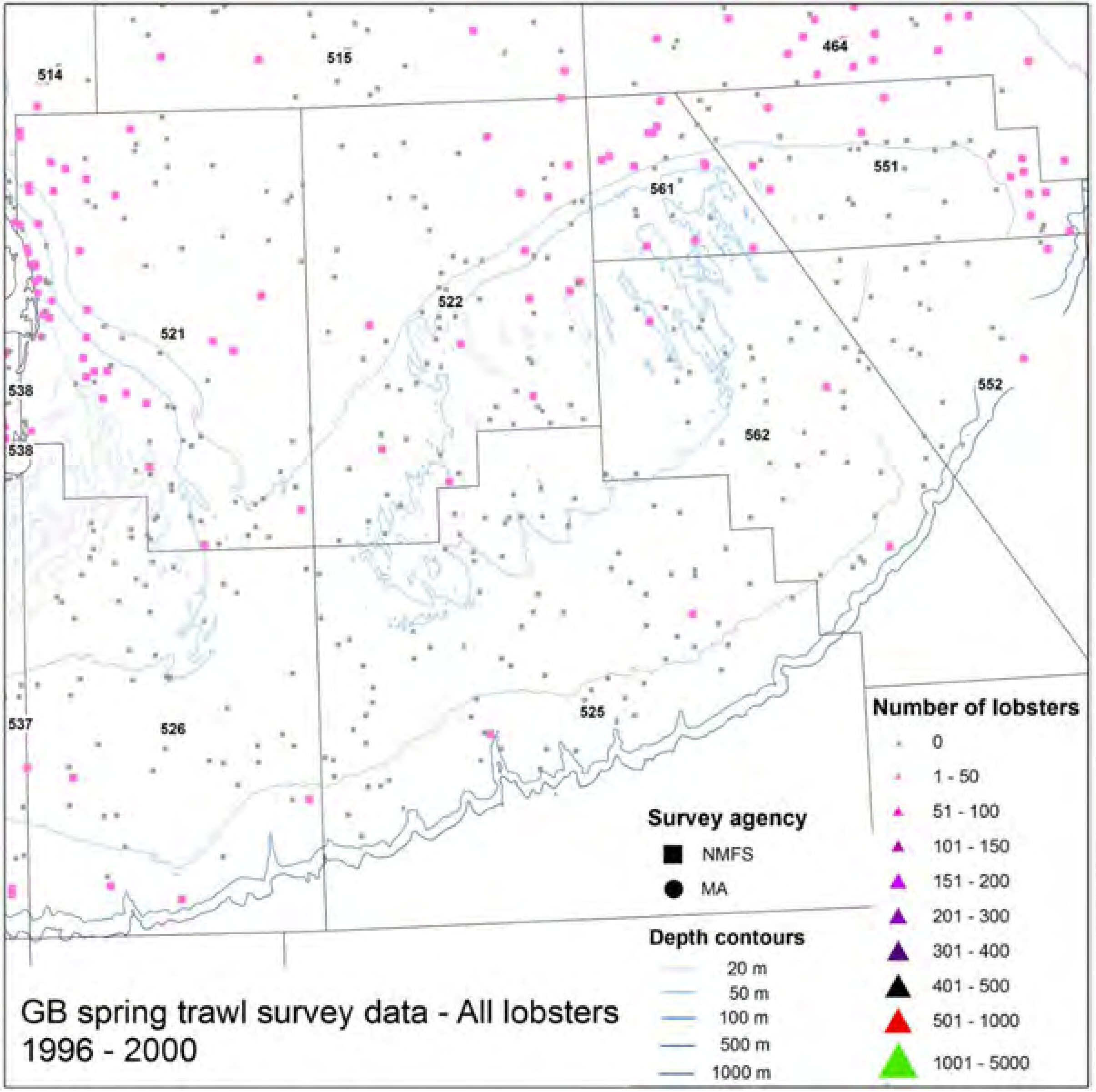


Figure 4.2.1.3.2.2 D





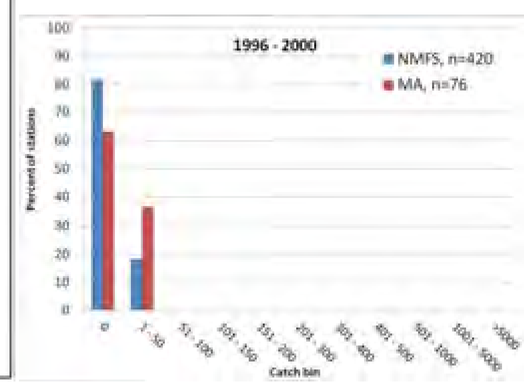


Figure 4.2.1.3.2.2 E

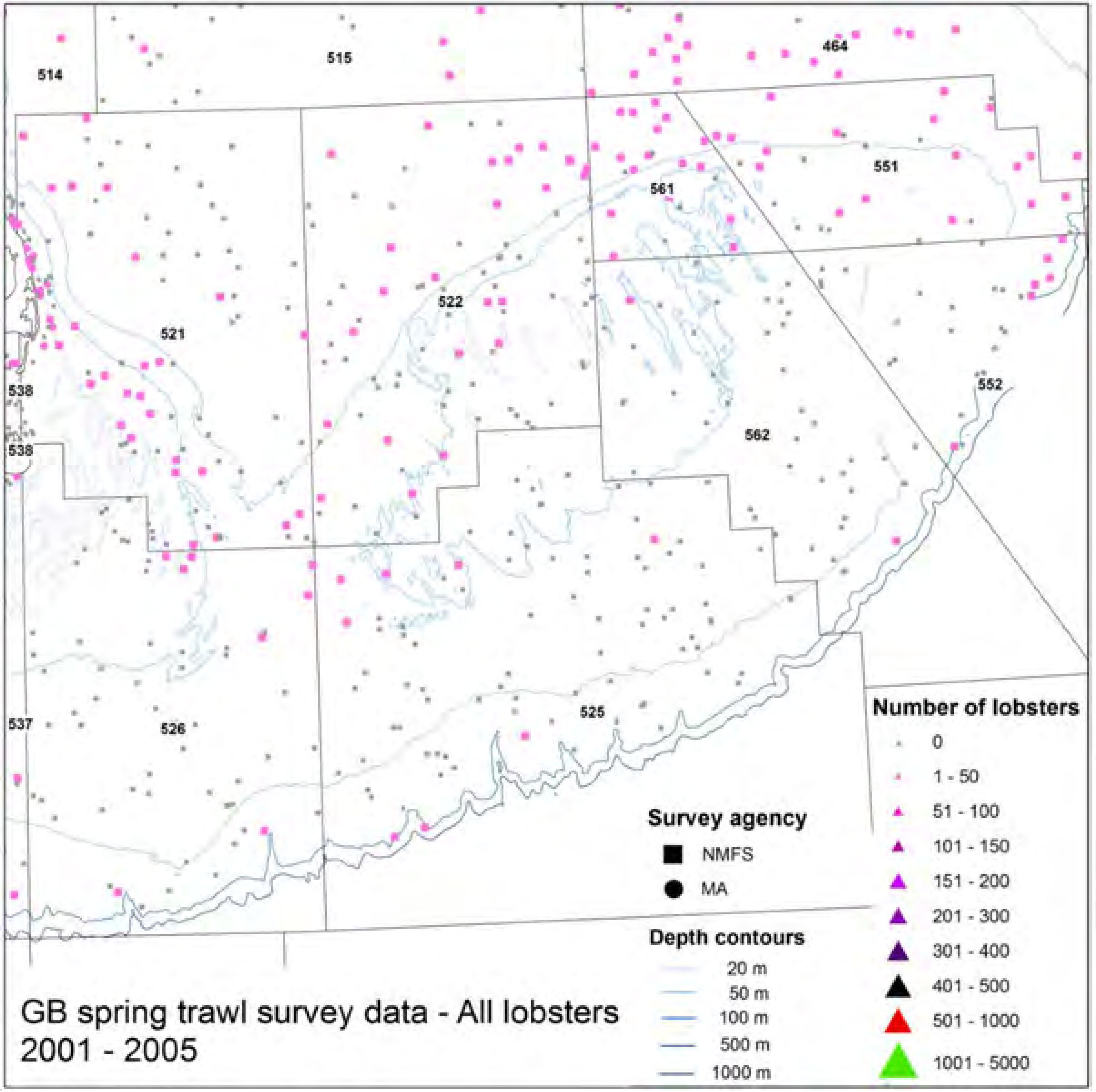
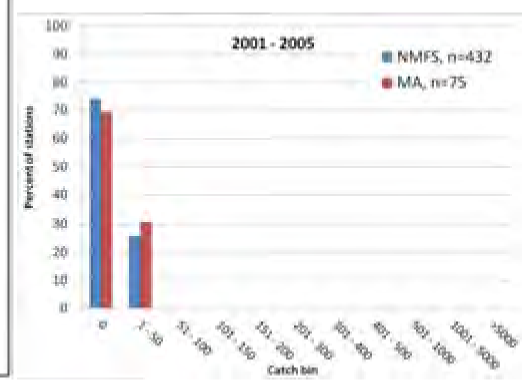


Figure 4.2.1.3.2.2 F



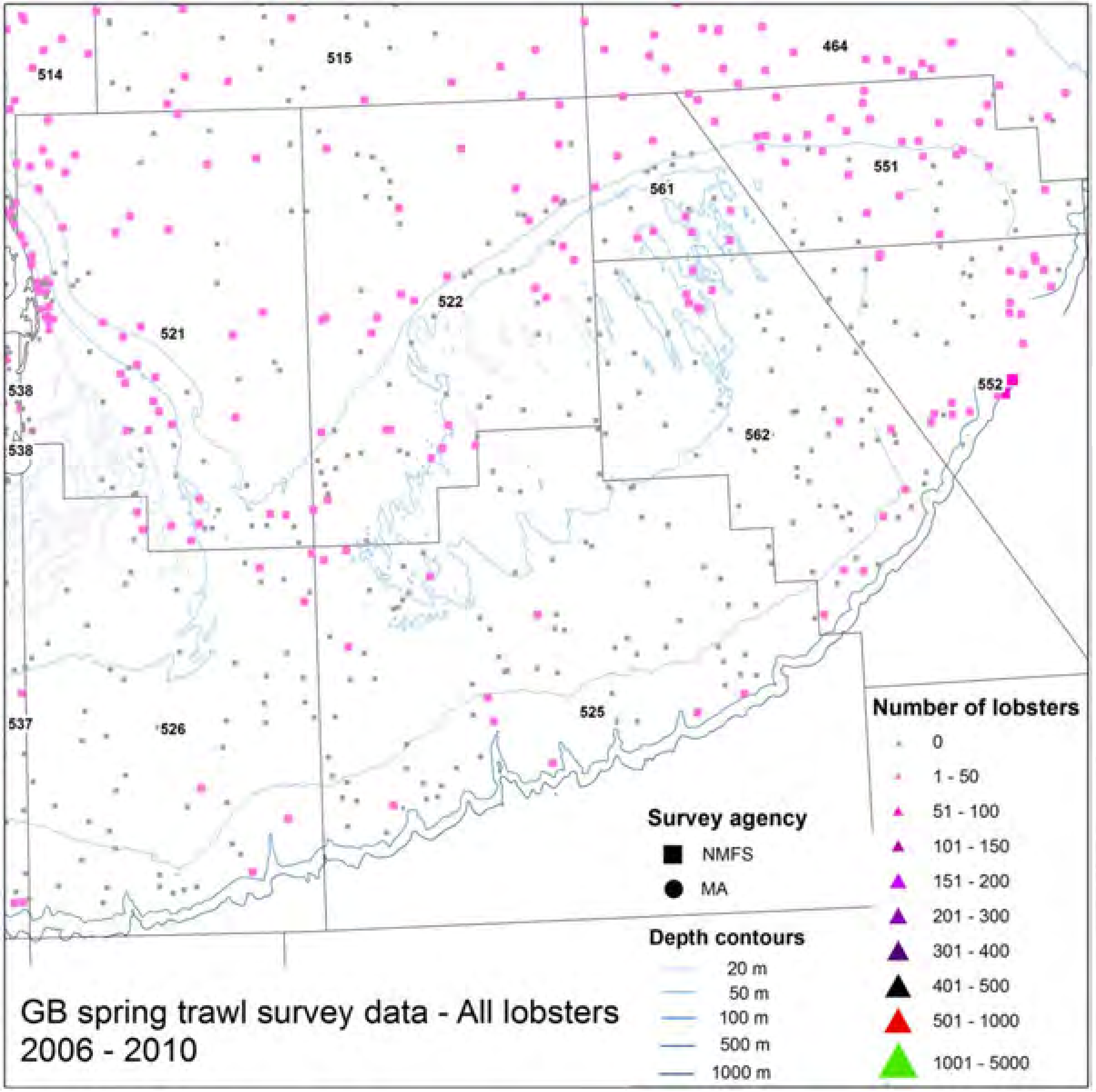
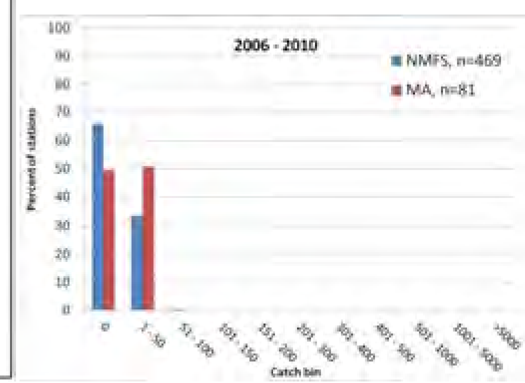


Figure 4.2.1.3.2.2 G



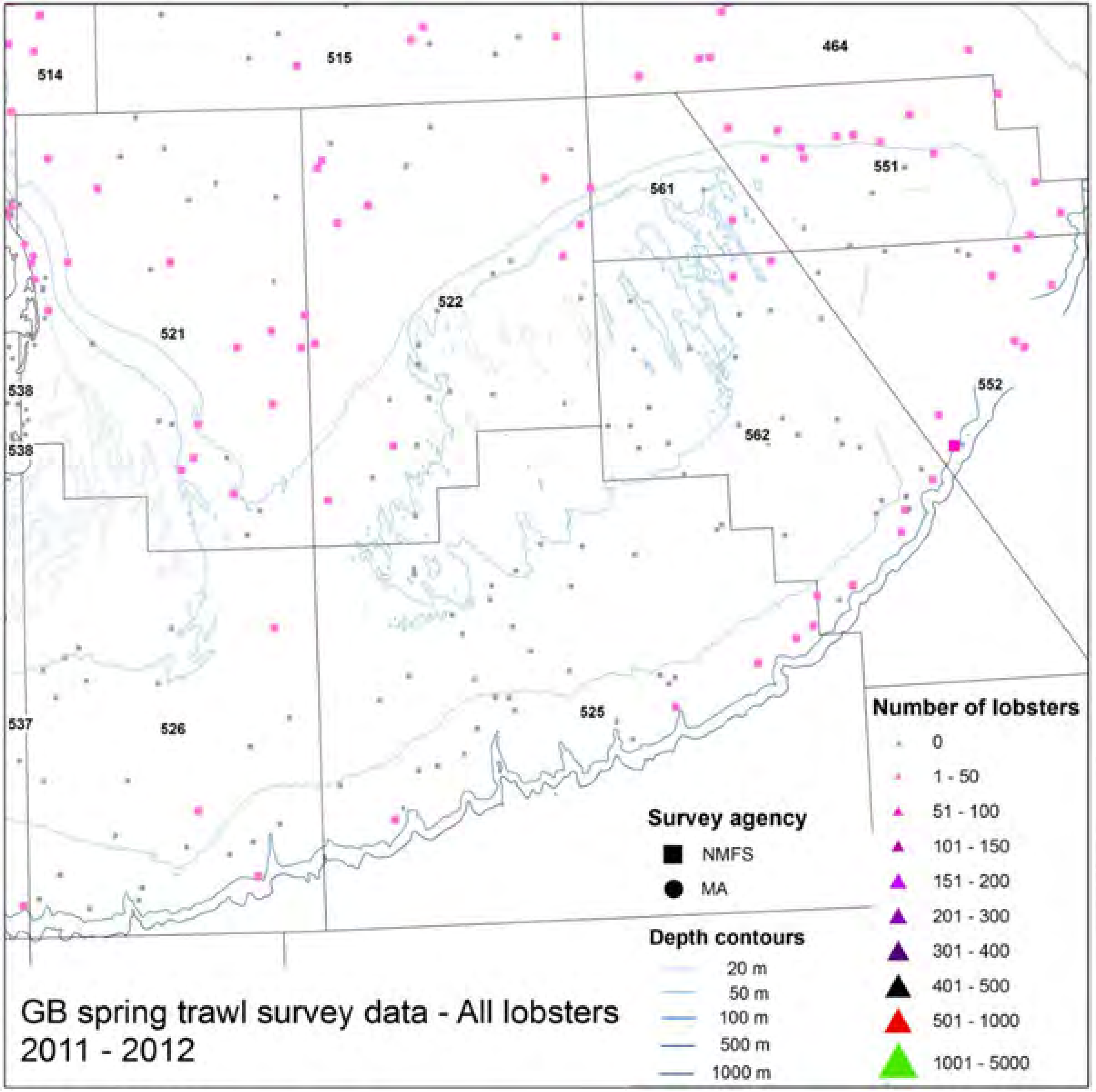
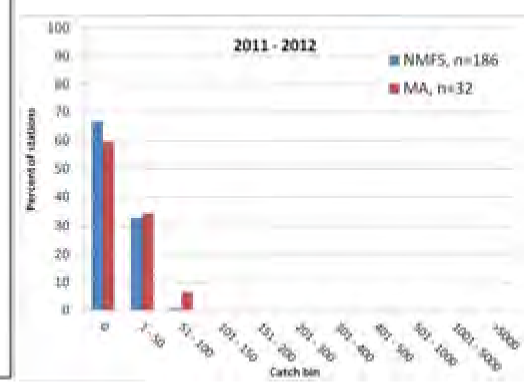


Figure 4.2.1.3.2.2 H



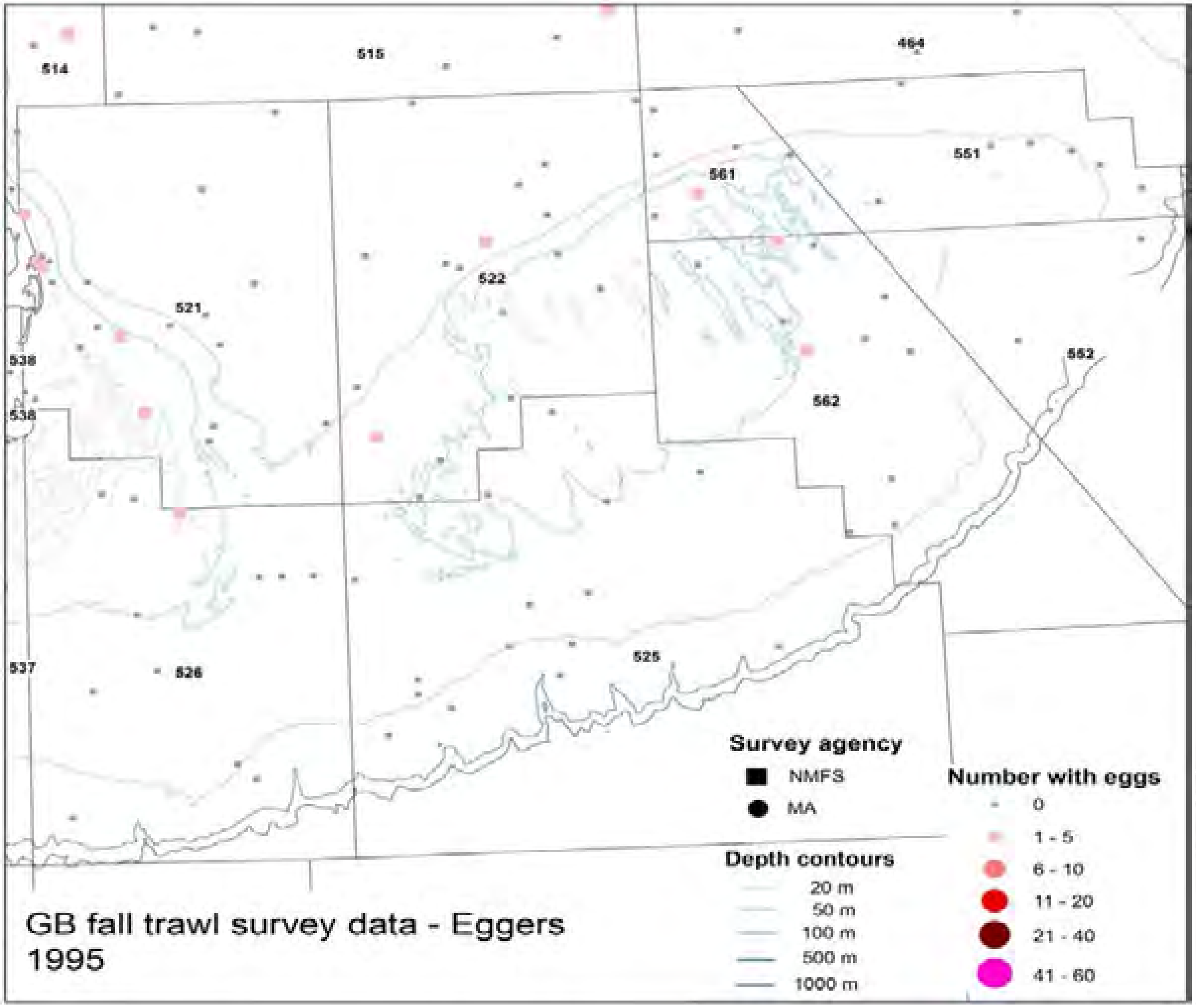


Figure 4.2.1.3.2.3 A

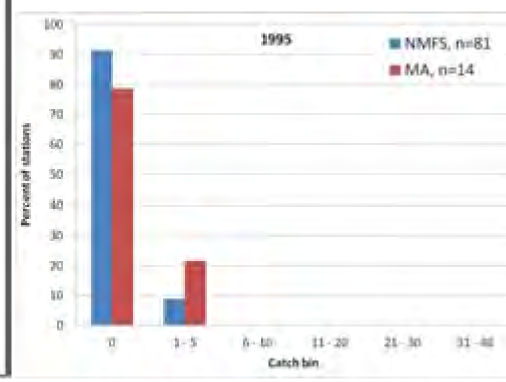


Figure 4.2.1.3.2.3 A – E. Mean catch per tow of ovigerous females (all sizes) at each fall sampling location from all GBK bottom trawl surveys (NMFS and MA), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

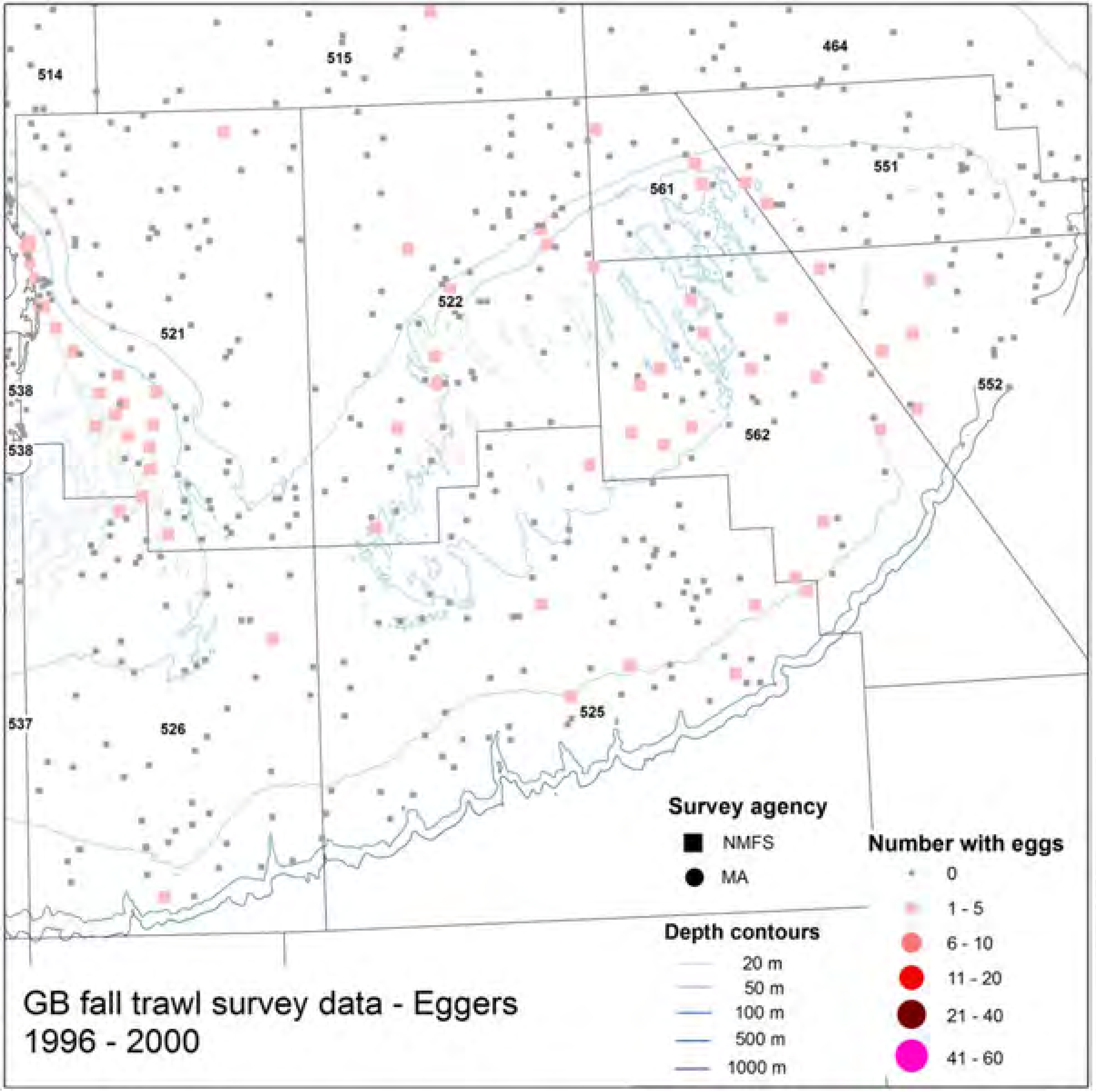
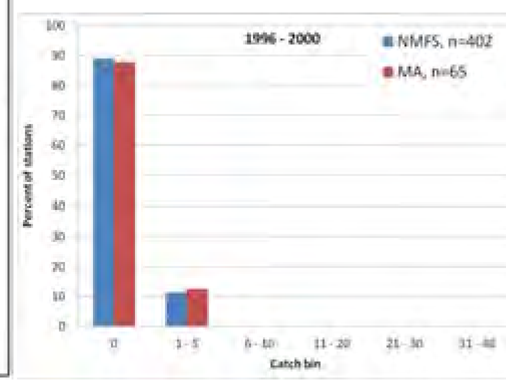


Figure 4.2.1.3.2.3 B



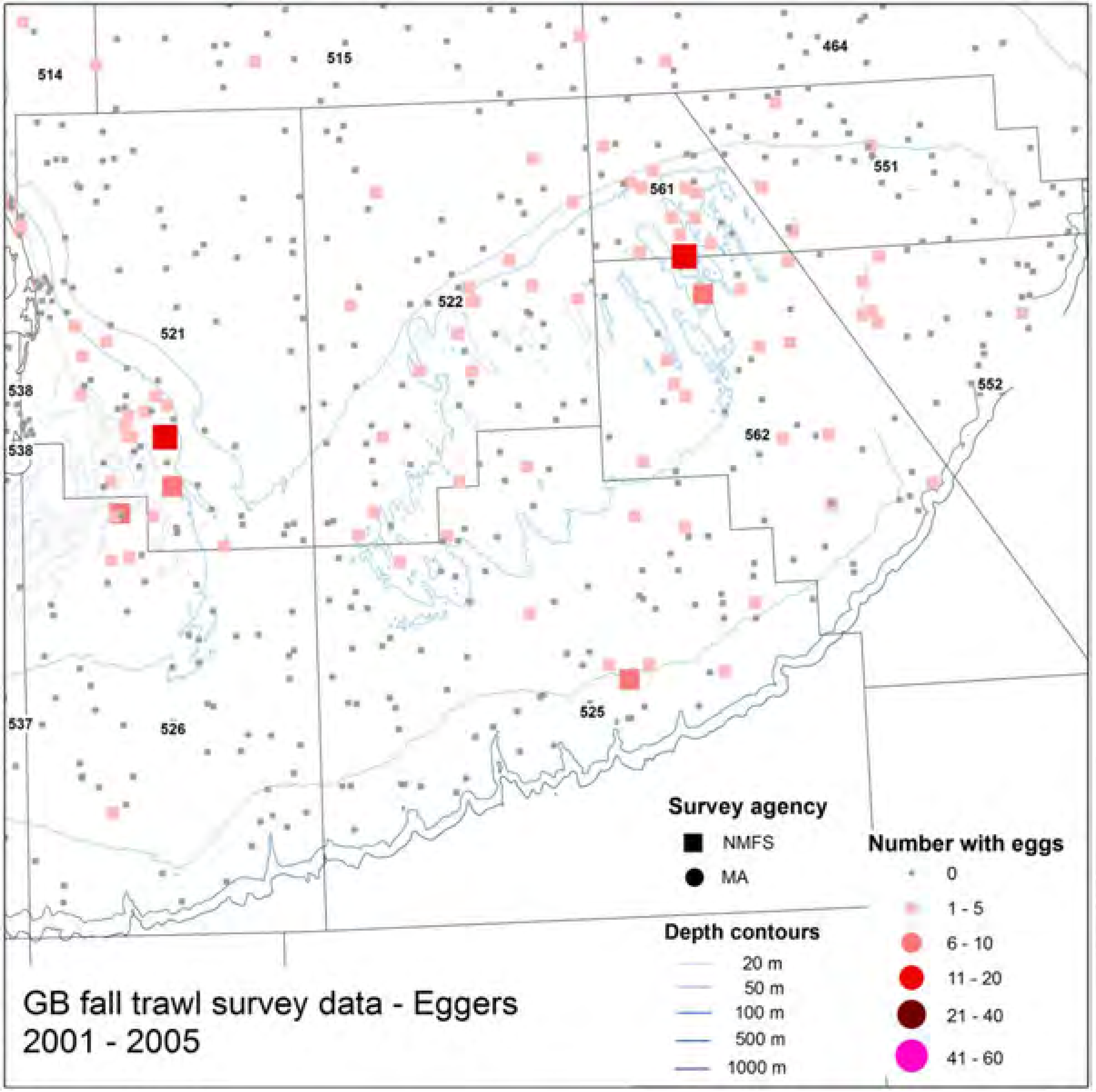
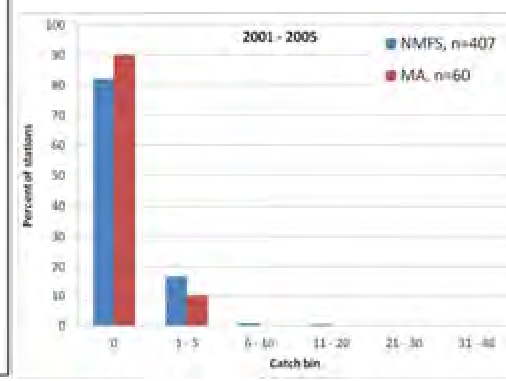


Figure 4.2.1.3.2.3 C



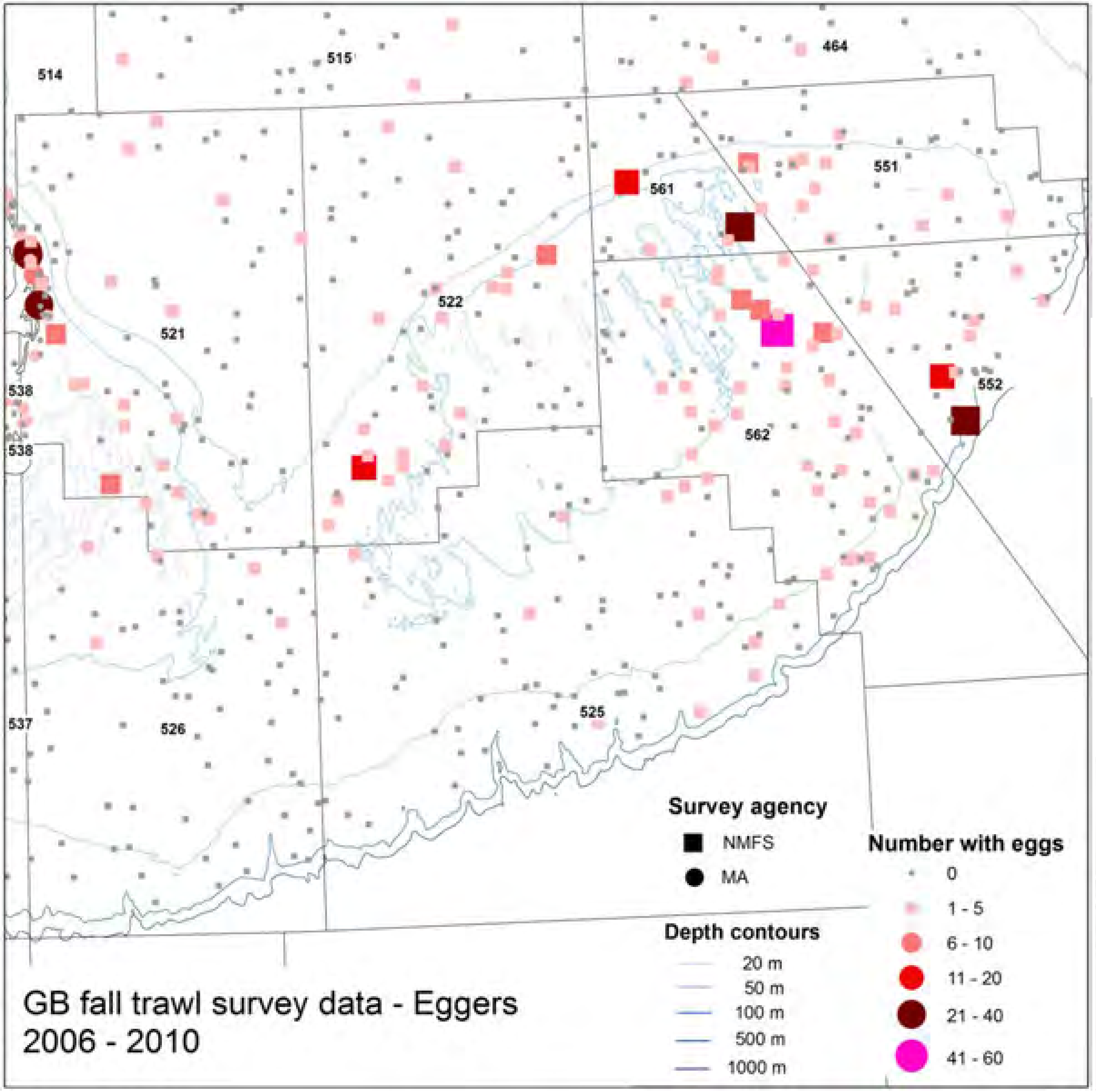
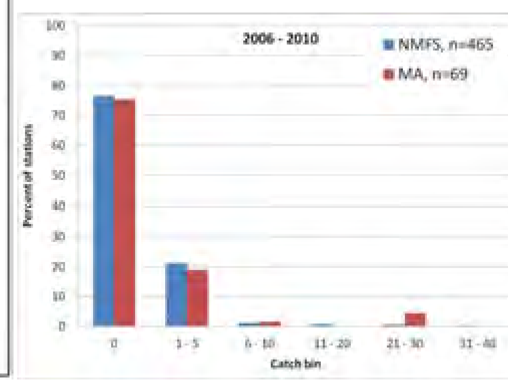


Figure 4.2.1.3.2.3 D



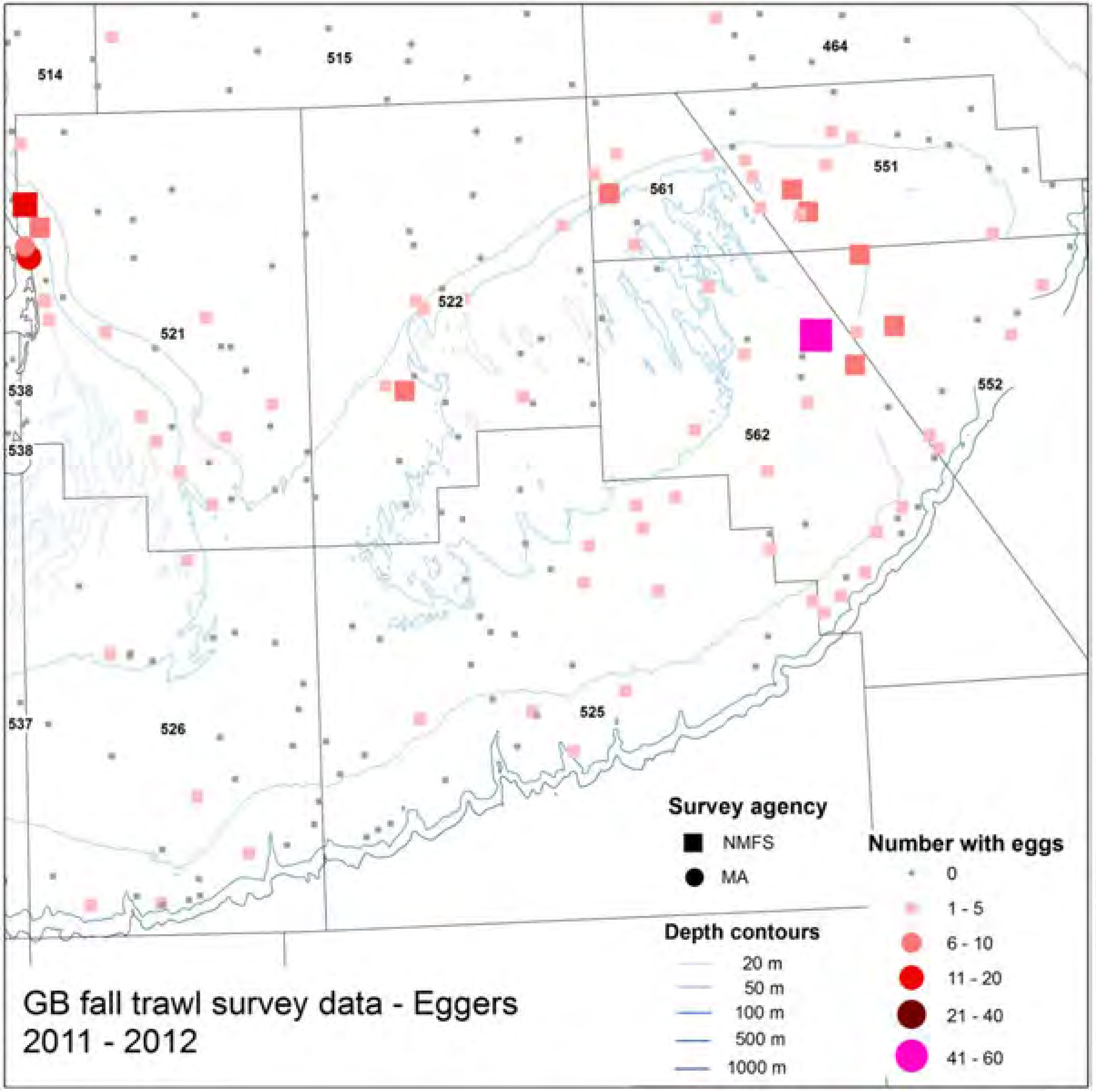
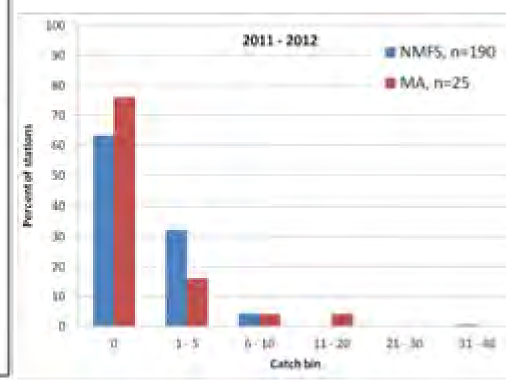


Figure 4.2.1.3.2.3 E



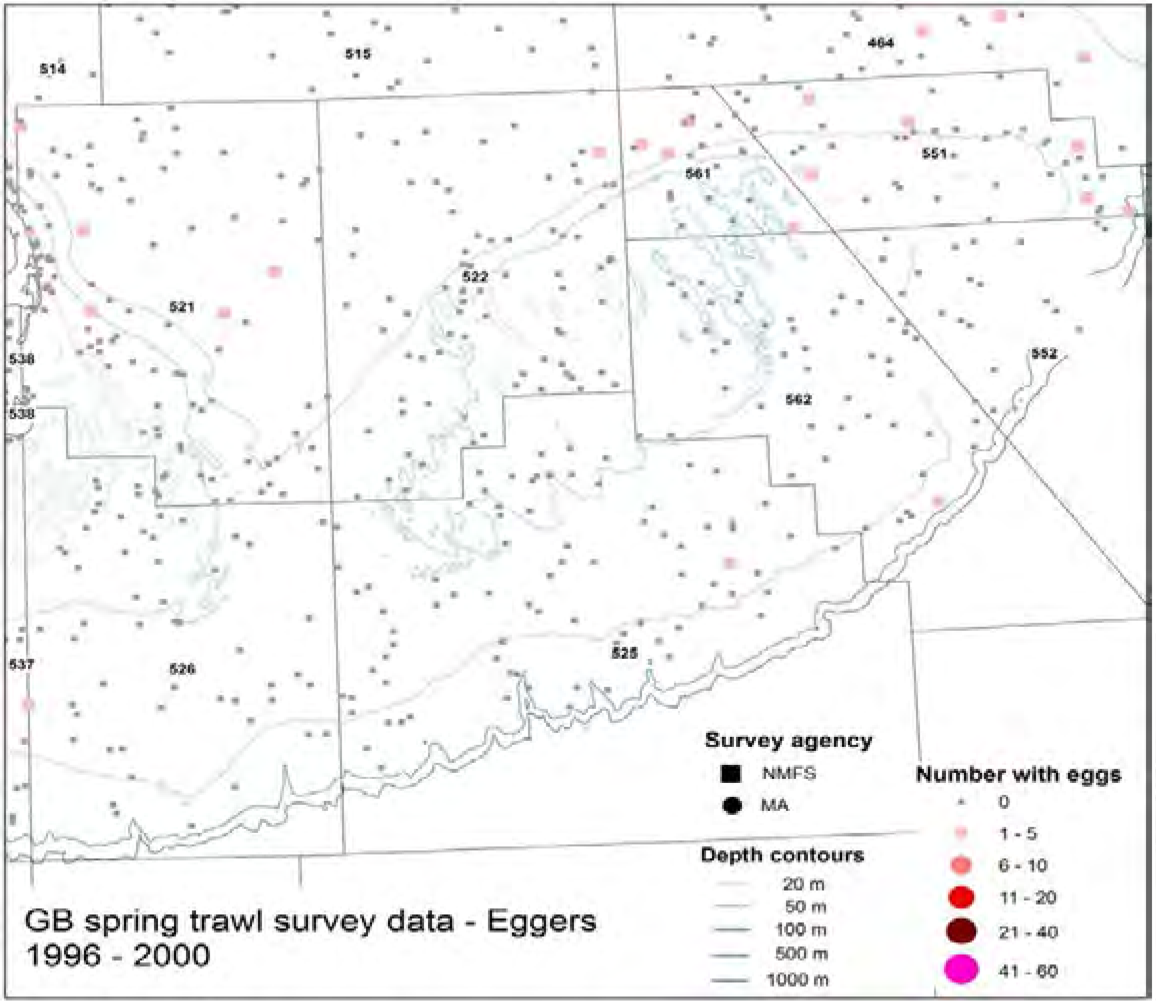


Figure 4.2.1.3.2.4 A

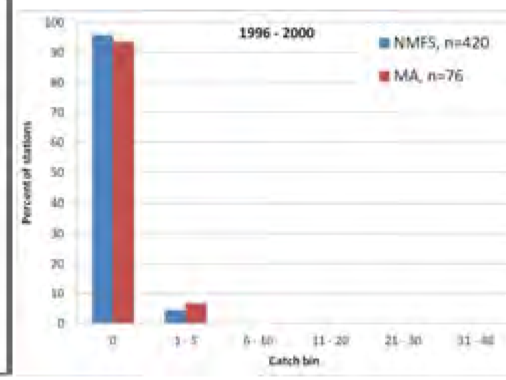


Figure 4.2.1.3.2.4 A – D. **Mean catch per tow of ovigerous females (all sizes) at each spring sampling location from all GBK bottom trawl surveys (NMFS and MA), shown in 5 year time periods.** Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

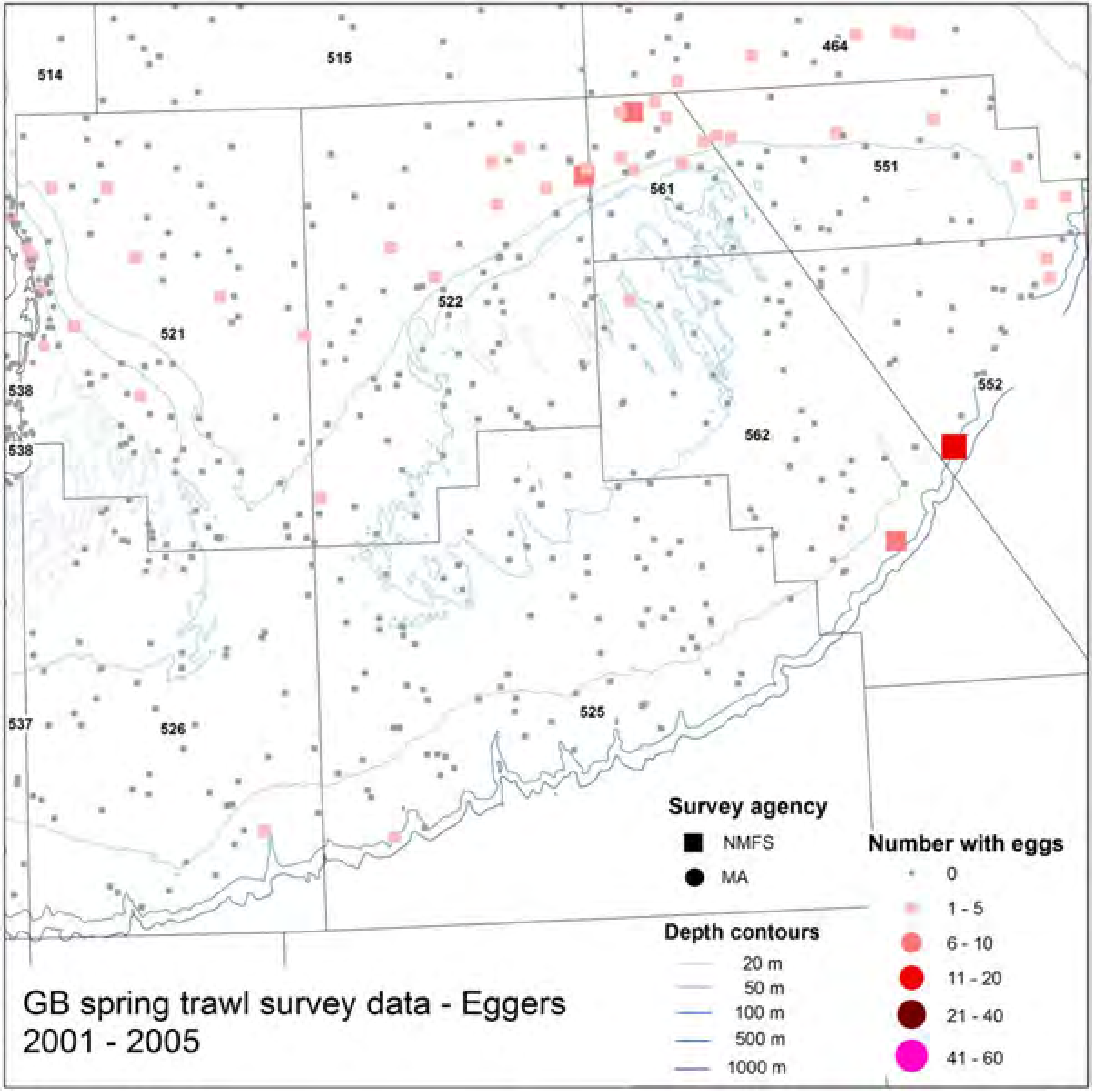
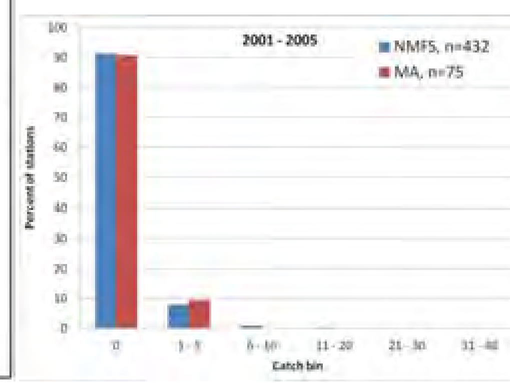


Figure 4.2.1.3.2.4 B



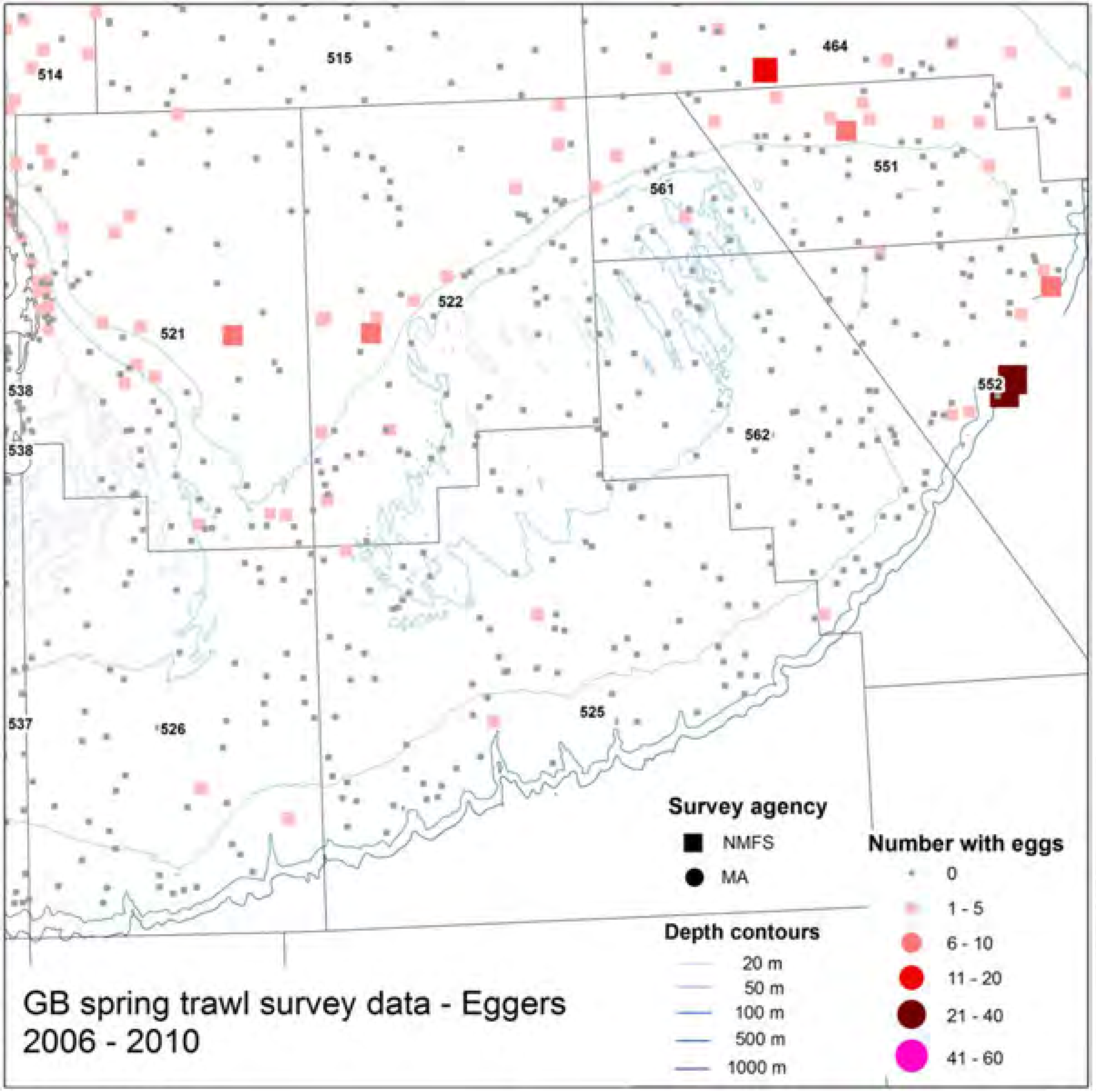
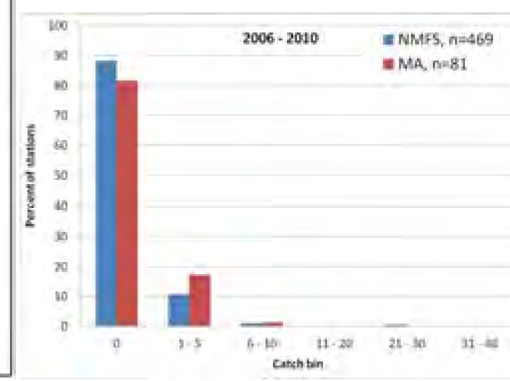


Figure 4.2.1.3.2.4 C



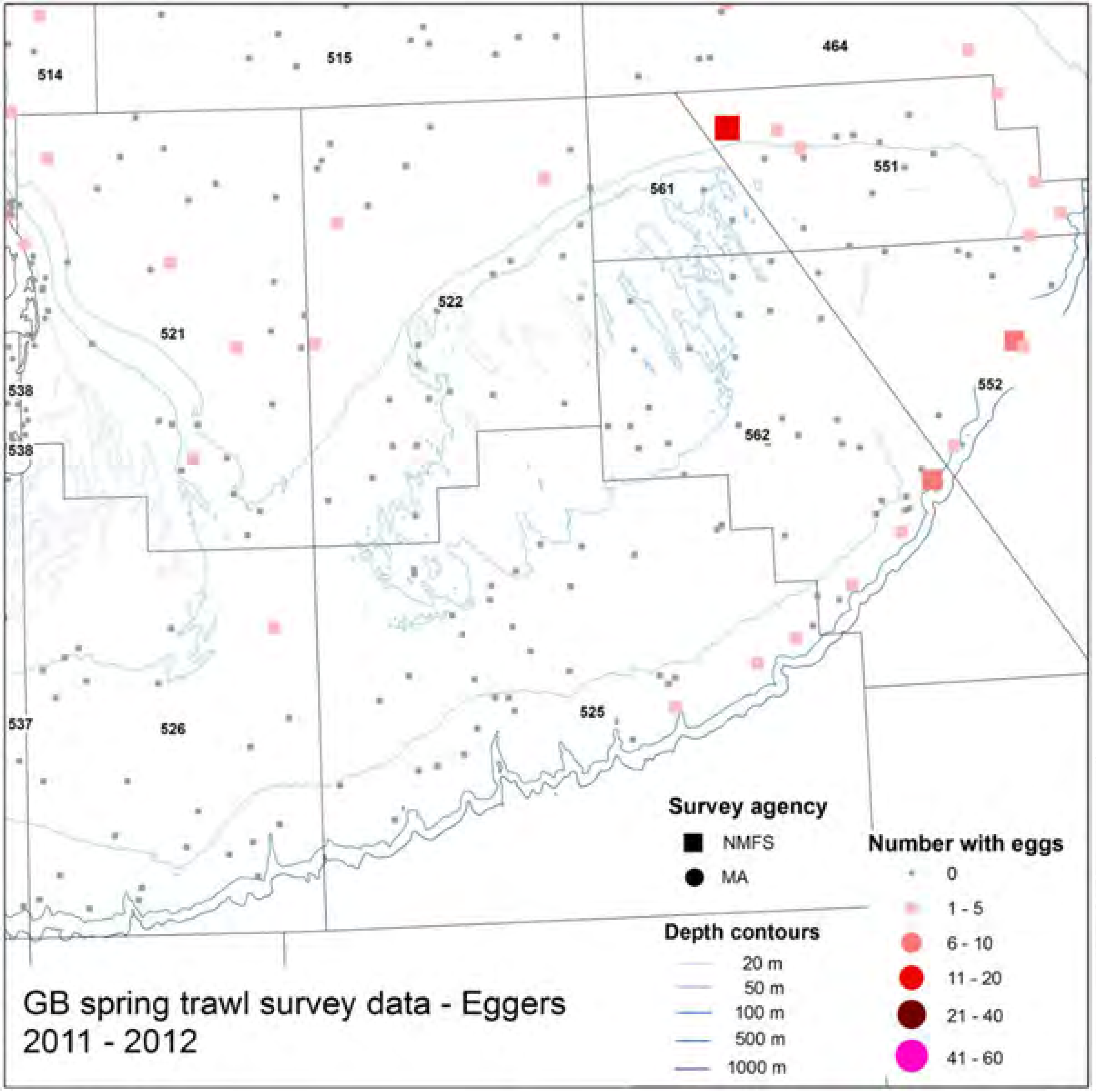
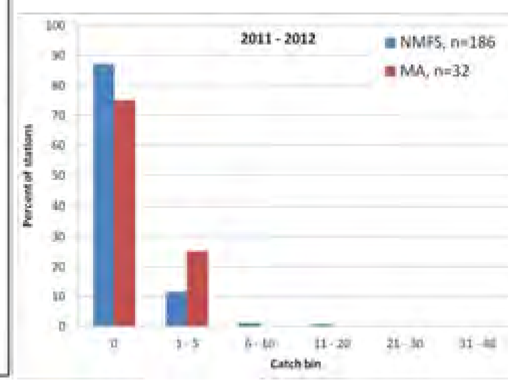


Figure 4.2.1.3.2.4 D



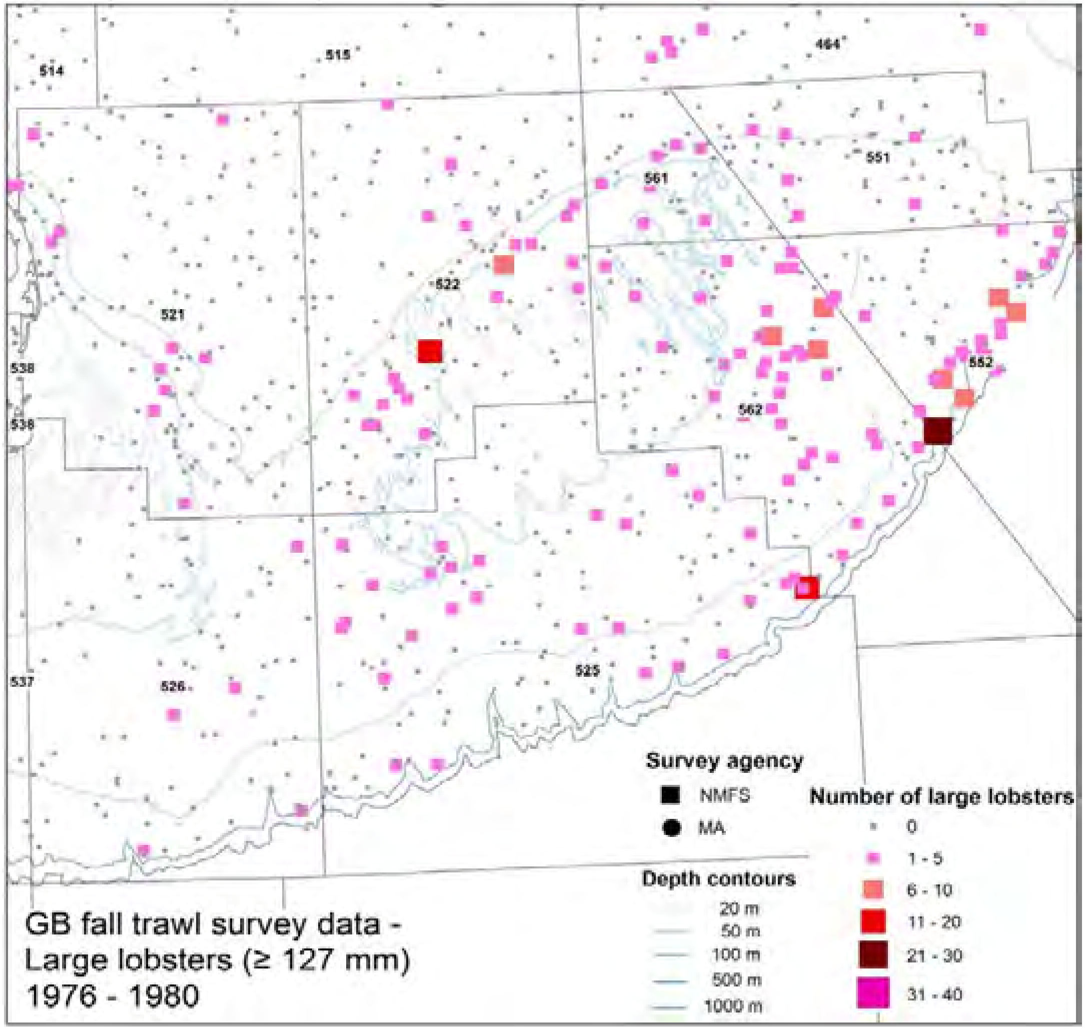


Figure 4.2.1.3.2.5 A

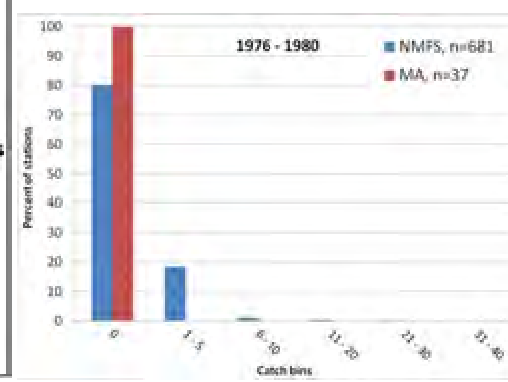


Figure 4.2.1.3.2.5 A – H. **Mean catch per tow of "large" lobster (≥ 127 mm CL) at each fall sampling location from all GBK bottom trawl surveys (NMFS and MA), shown in 5 year time periods.** Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

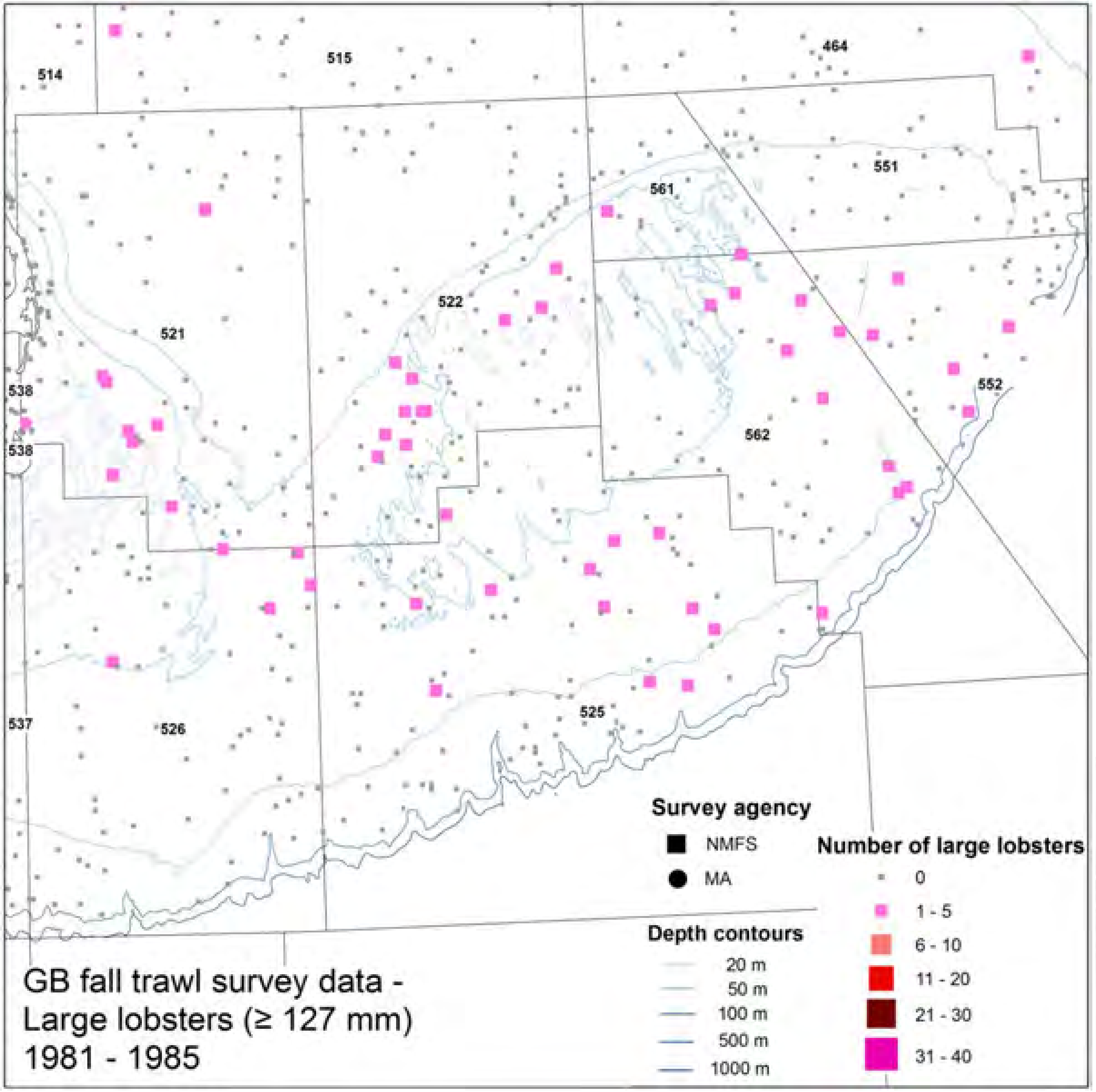
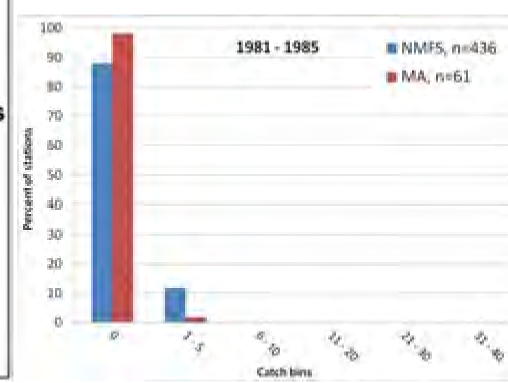
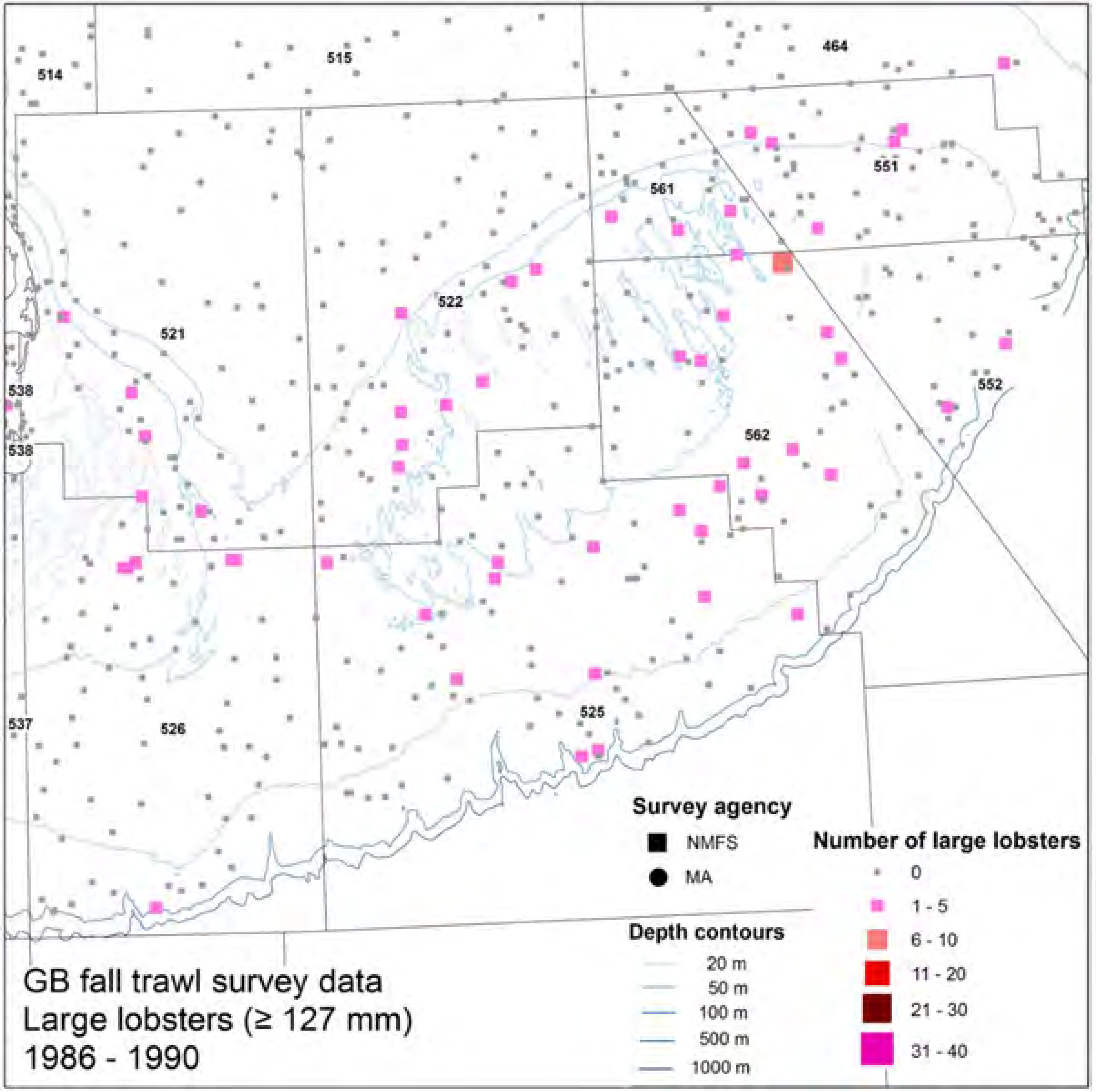


Figure 4.2.1.3.2.5 B





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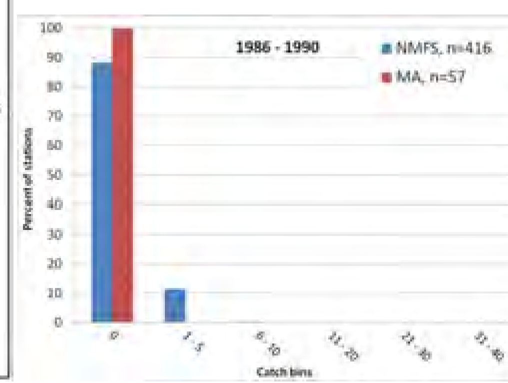

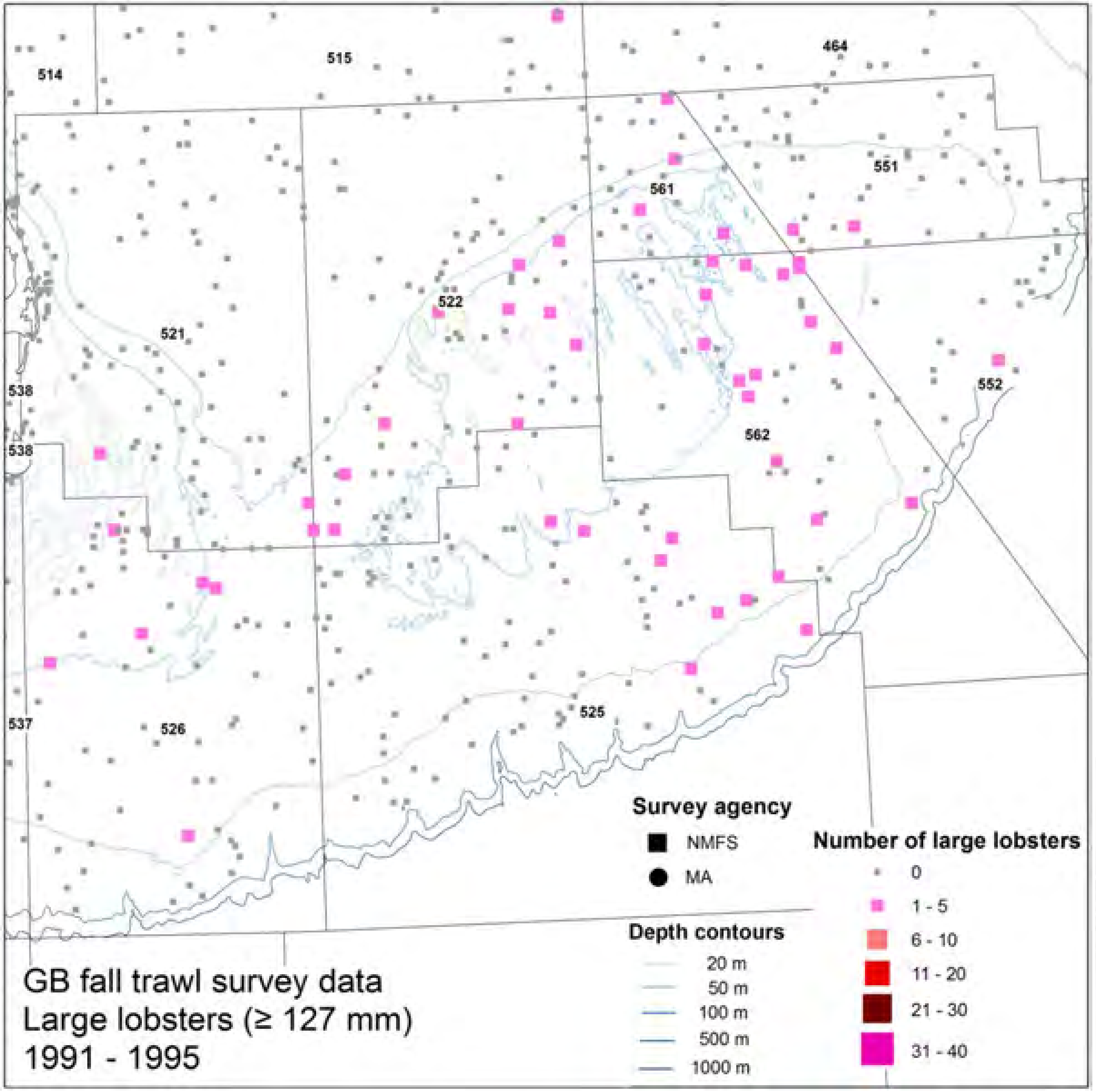

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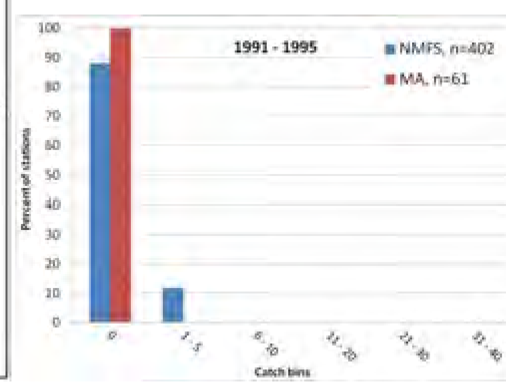

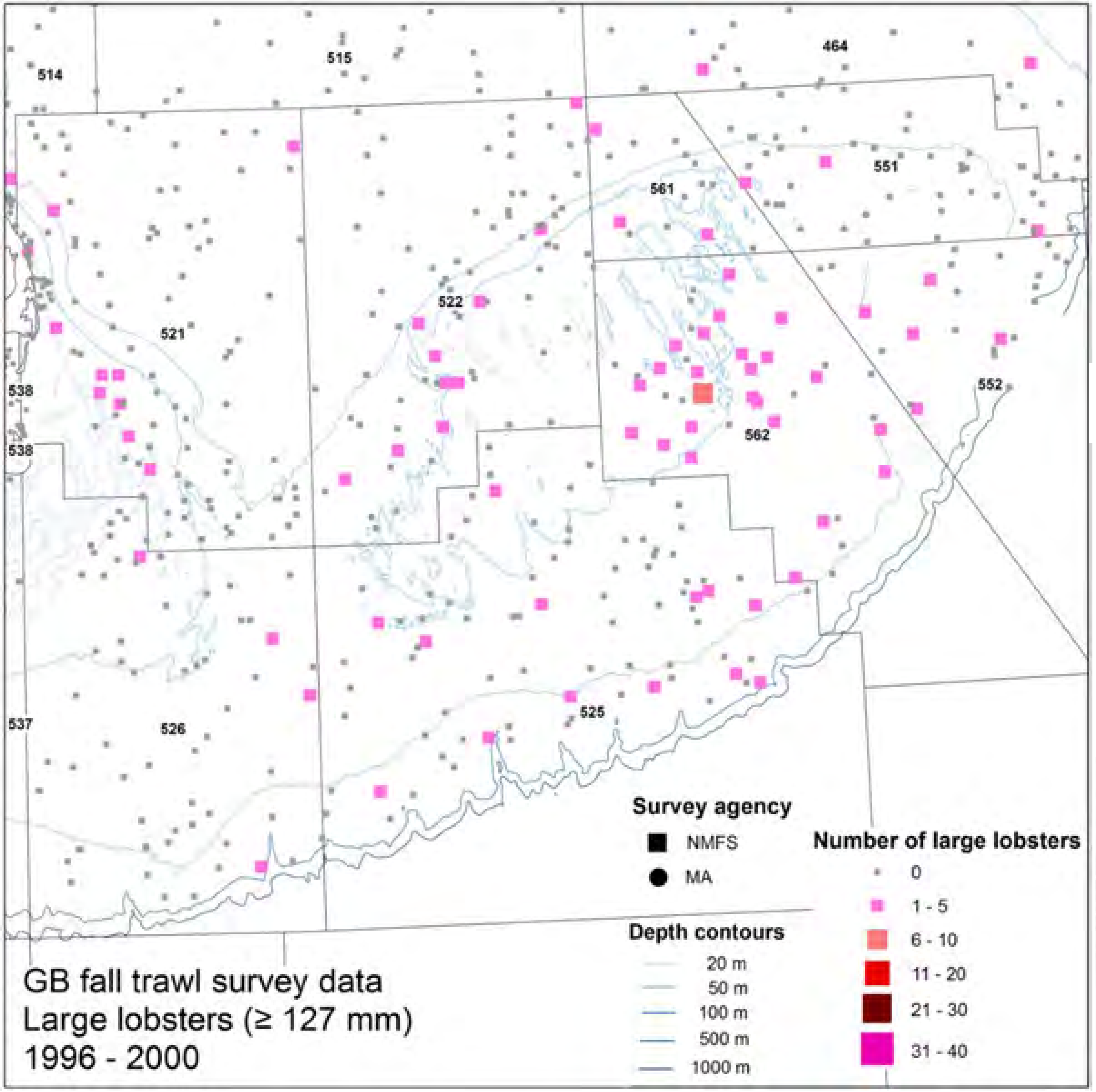

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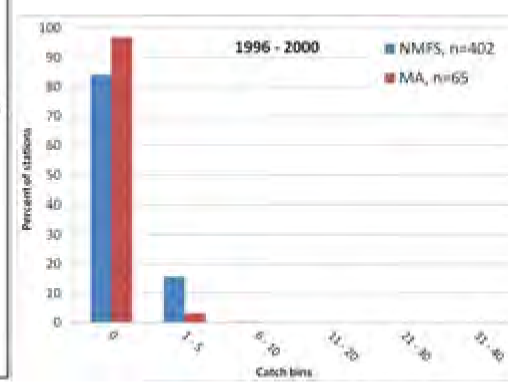


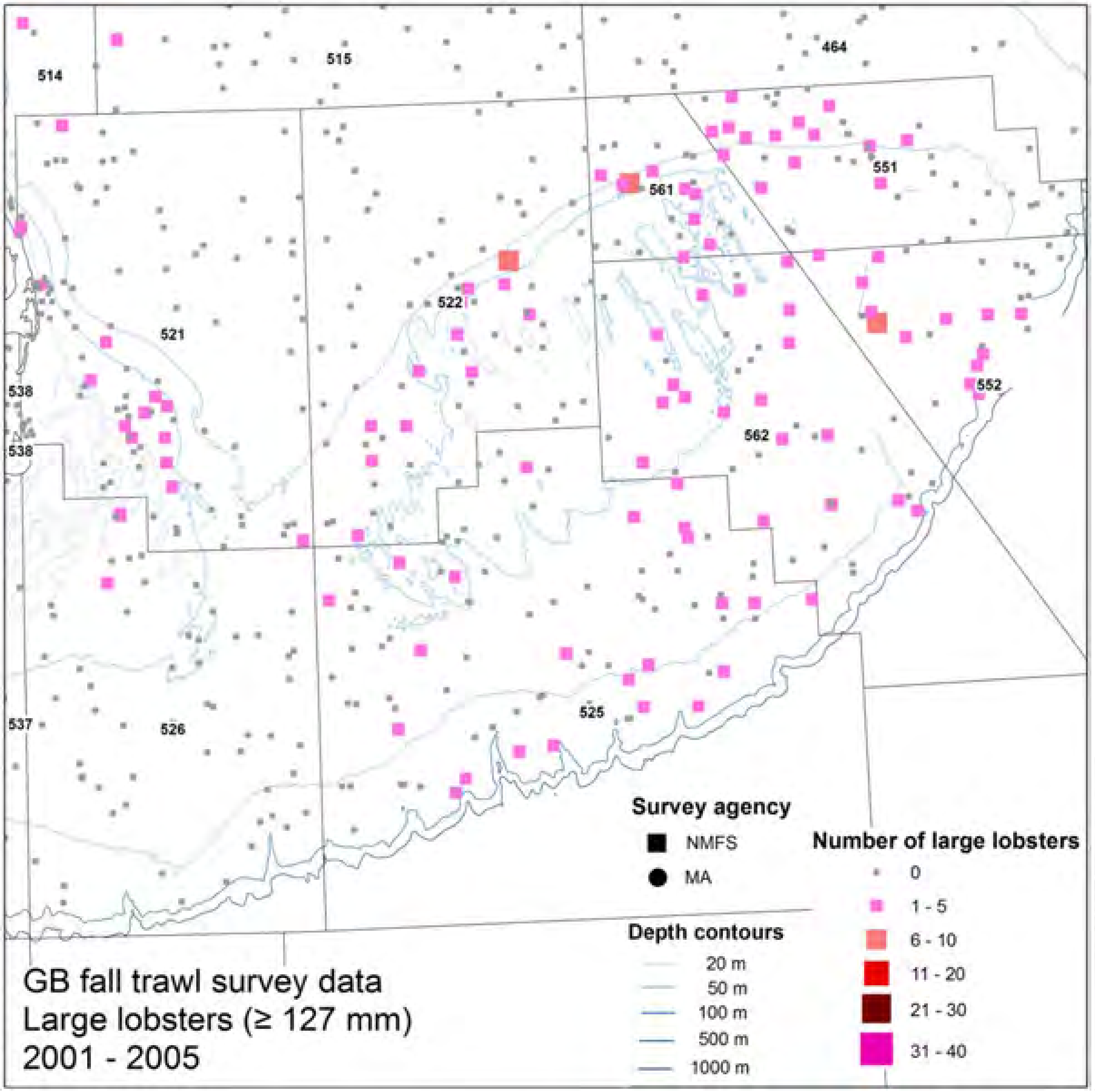
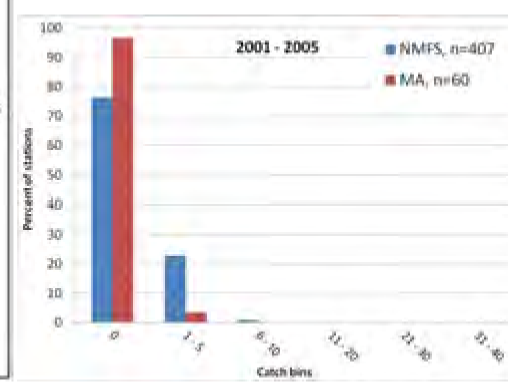


Figure 4.2.1.3.2.5 F



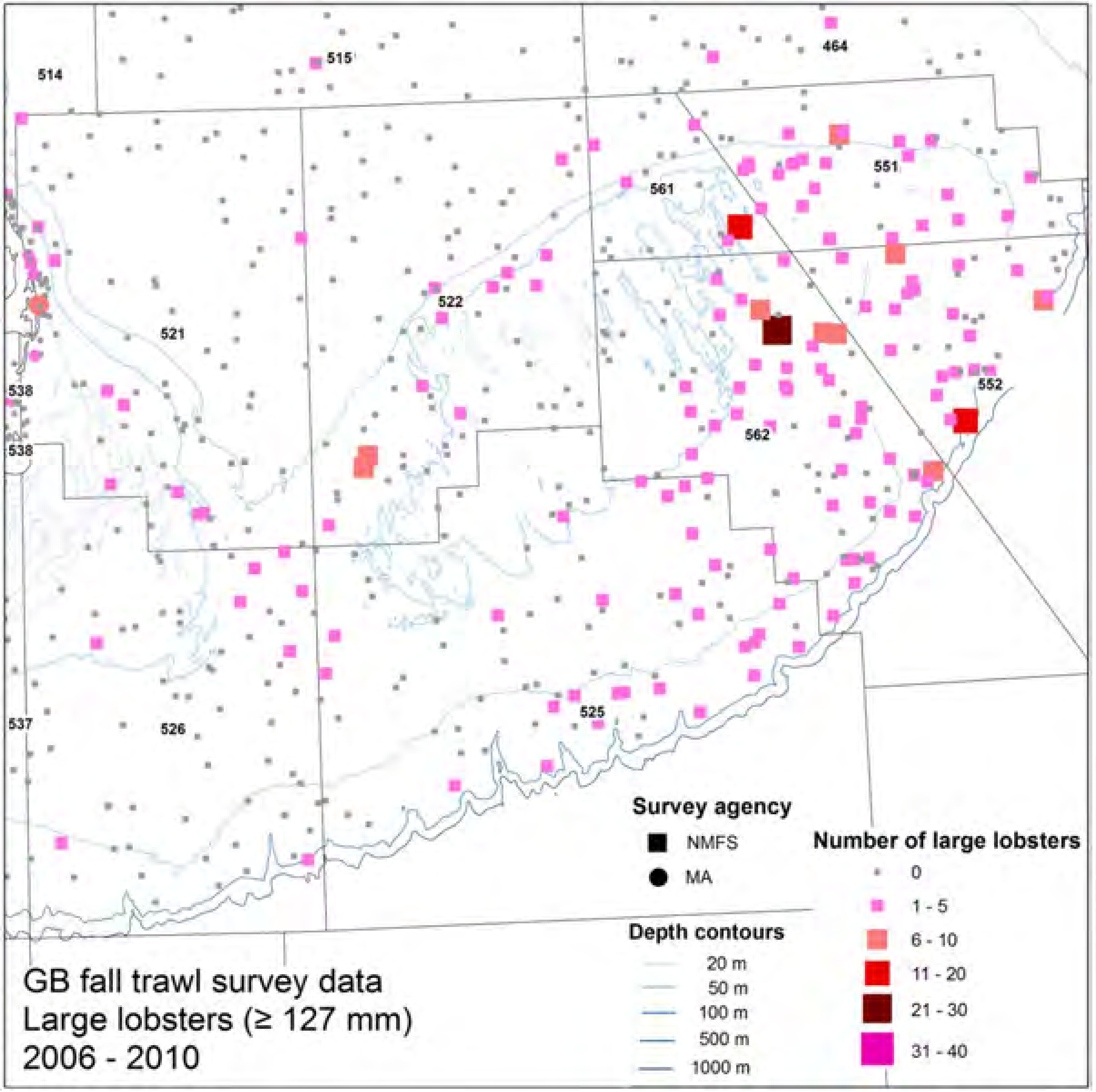
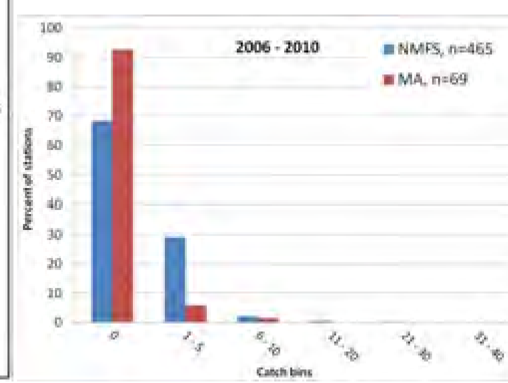


Figure 4.2.1.3.2.5 G



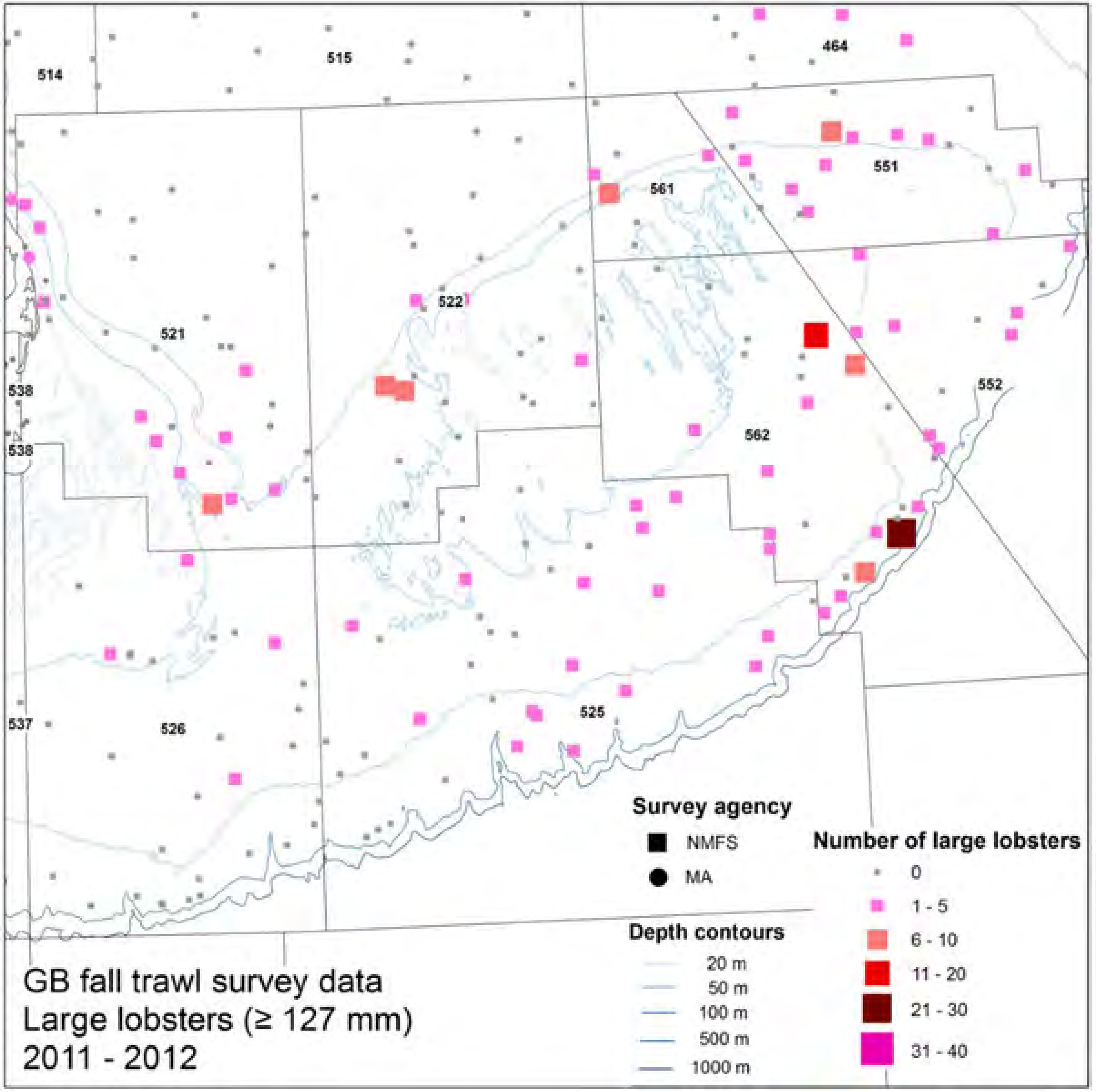
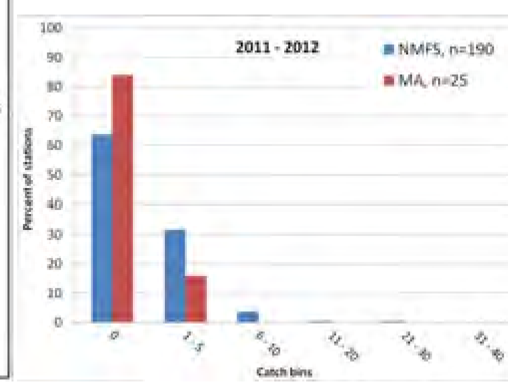


Figure 4.2.1.3.2.5 H



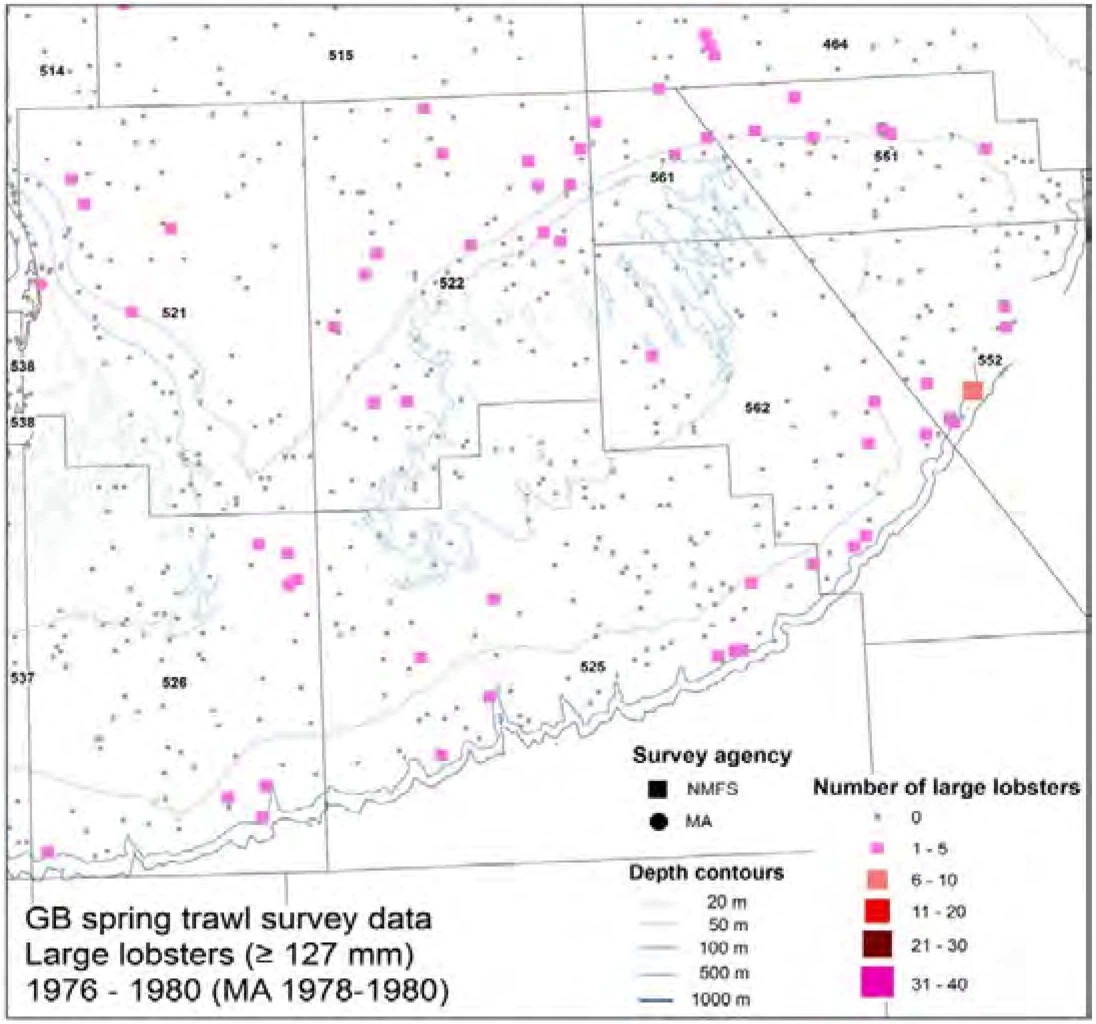


Figure 4.2.1.3.2.6 A

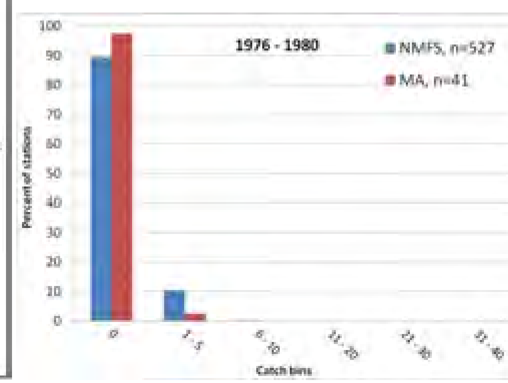


Figure 4.2.1.3.2.6 A – H. Mean catch per tow of "large" lobster (≥ 127 mm CL) at each spring sampling location from all GBK bottom trawl surveys (NMFS and MA), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

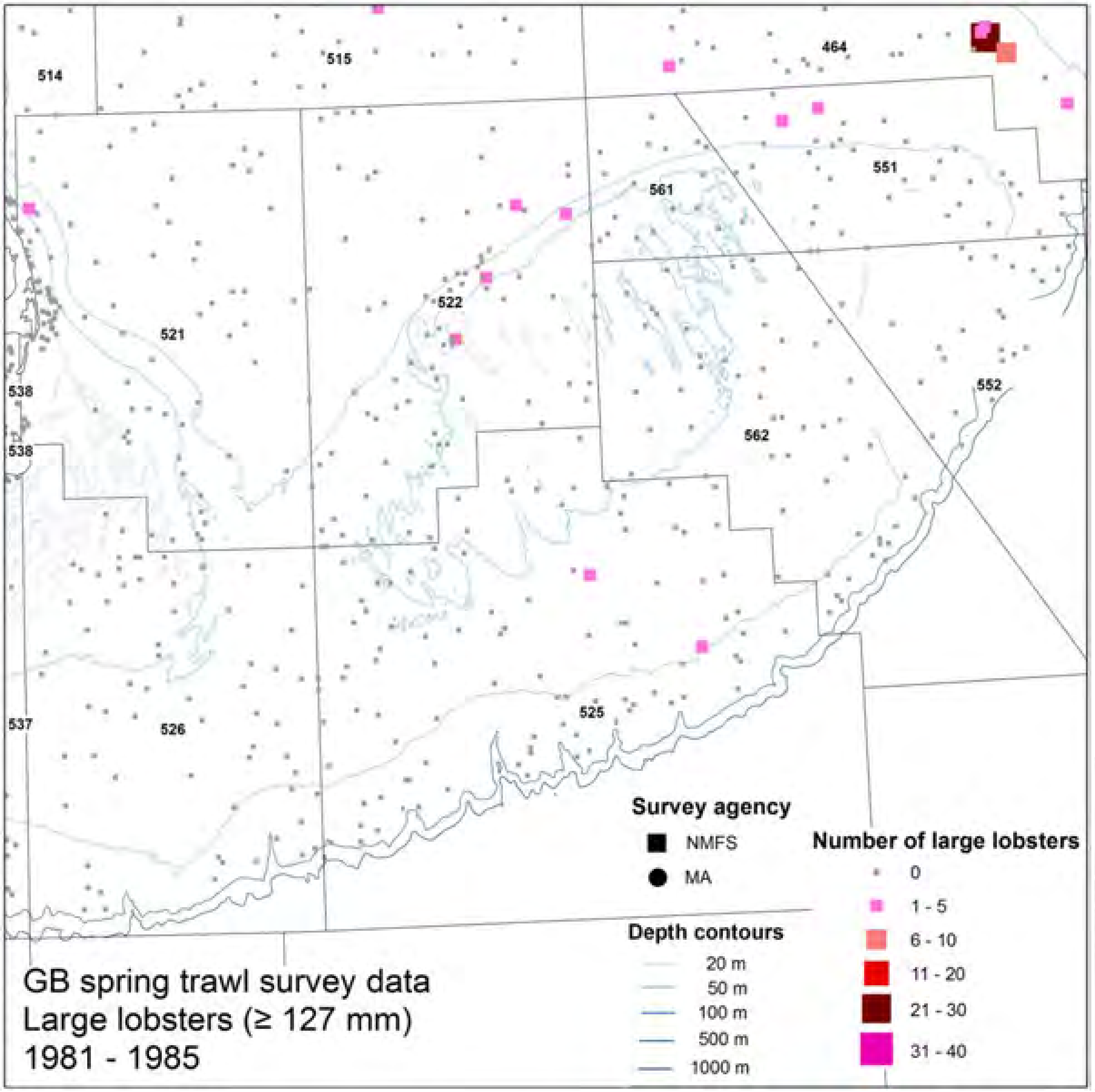
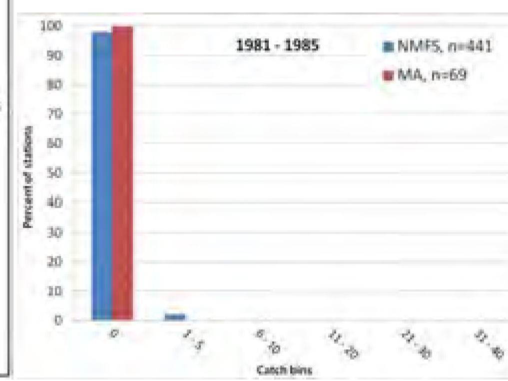
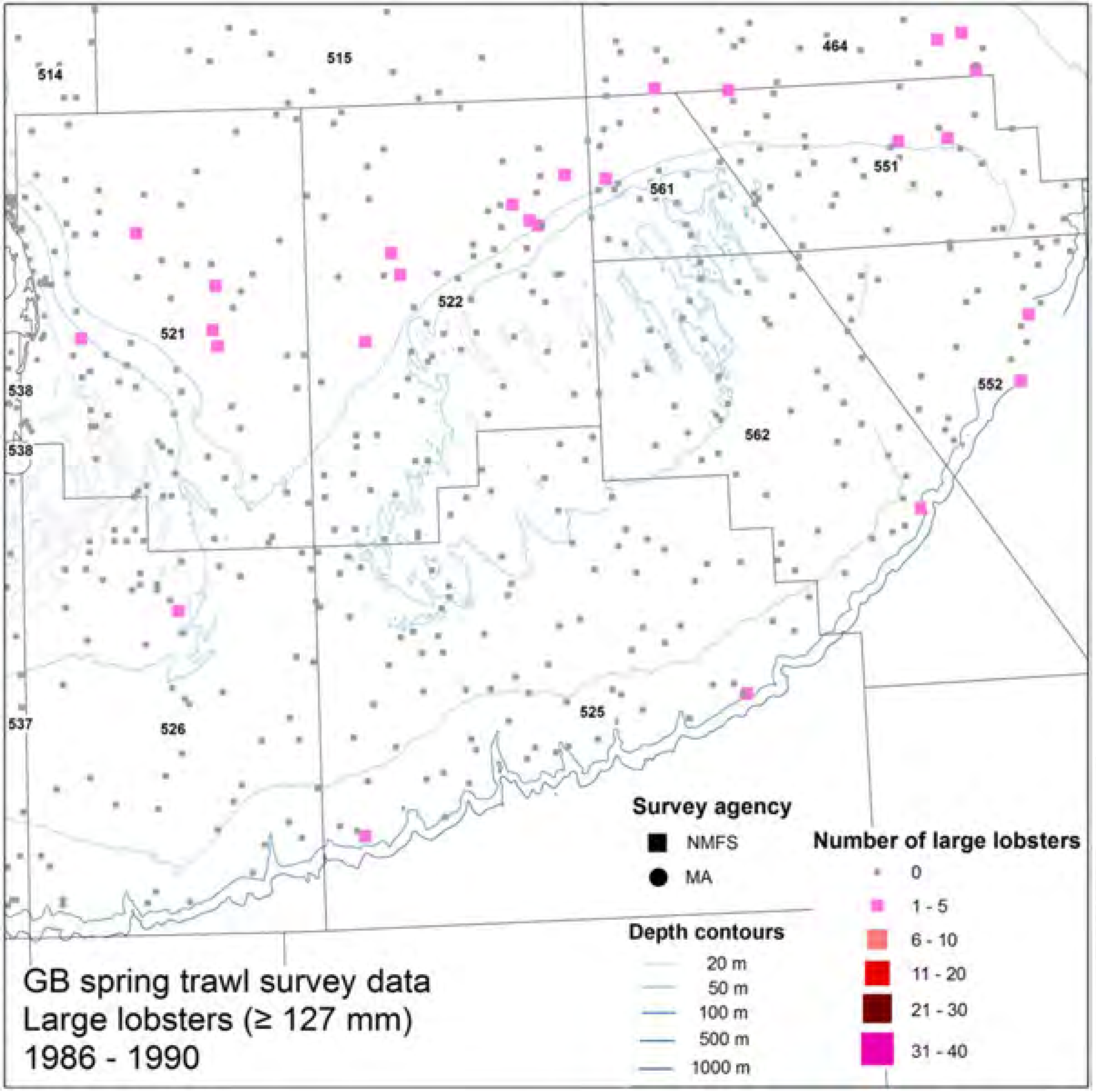
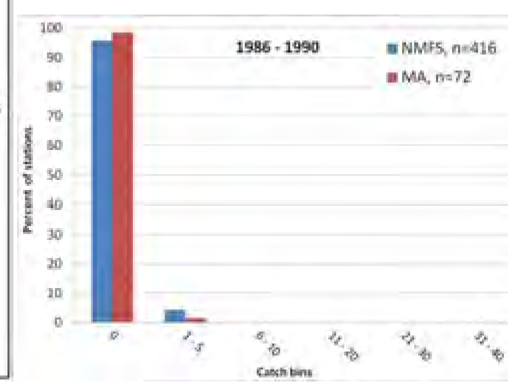


Figure 4.2.1.3.2.6 B







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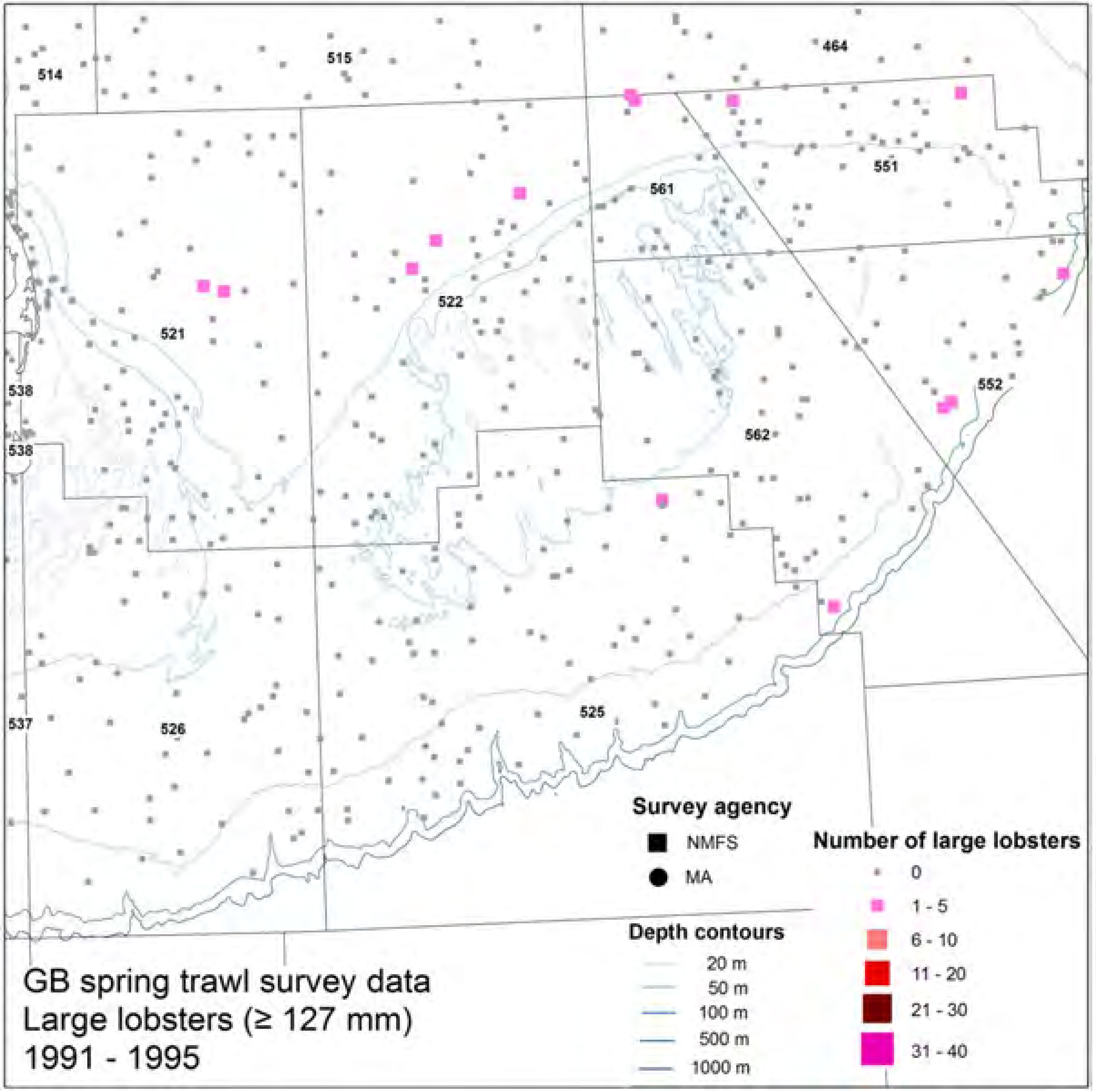
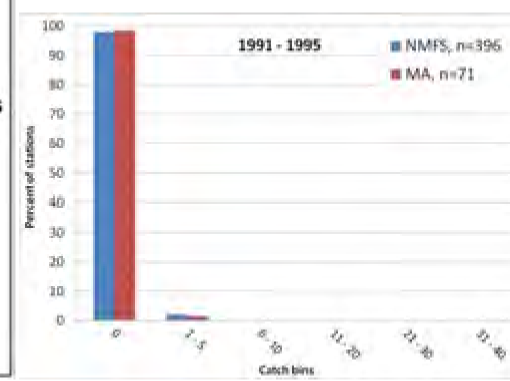


Figure 4.2.1.3.2.6 D



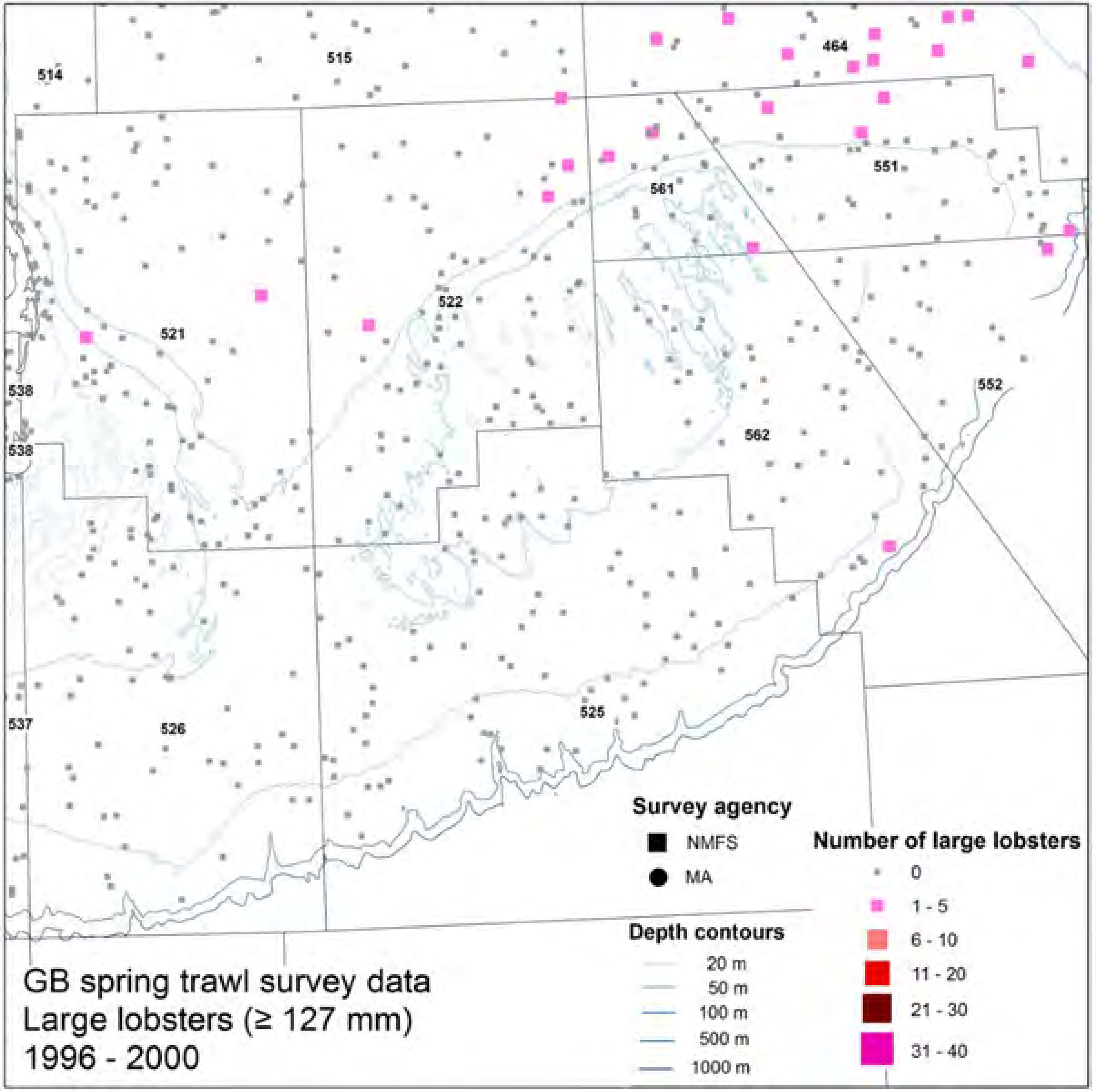
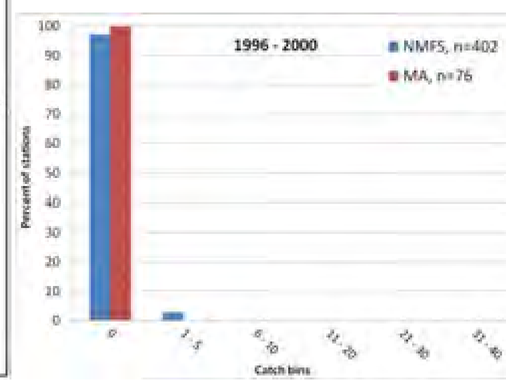
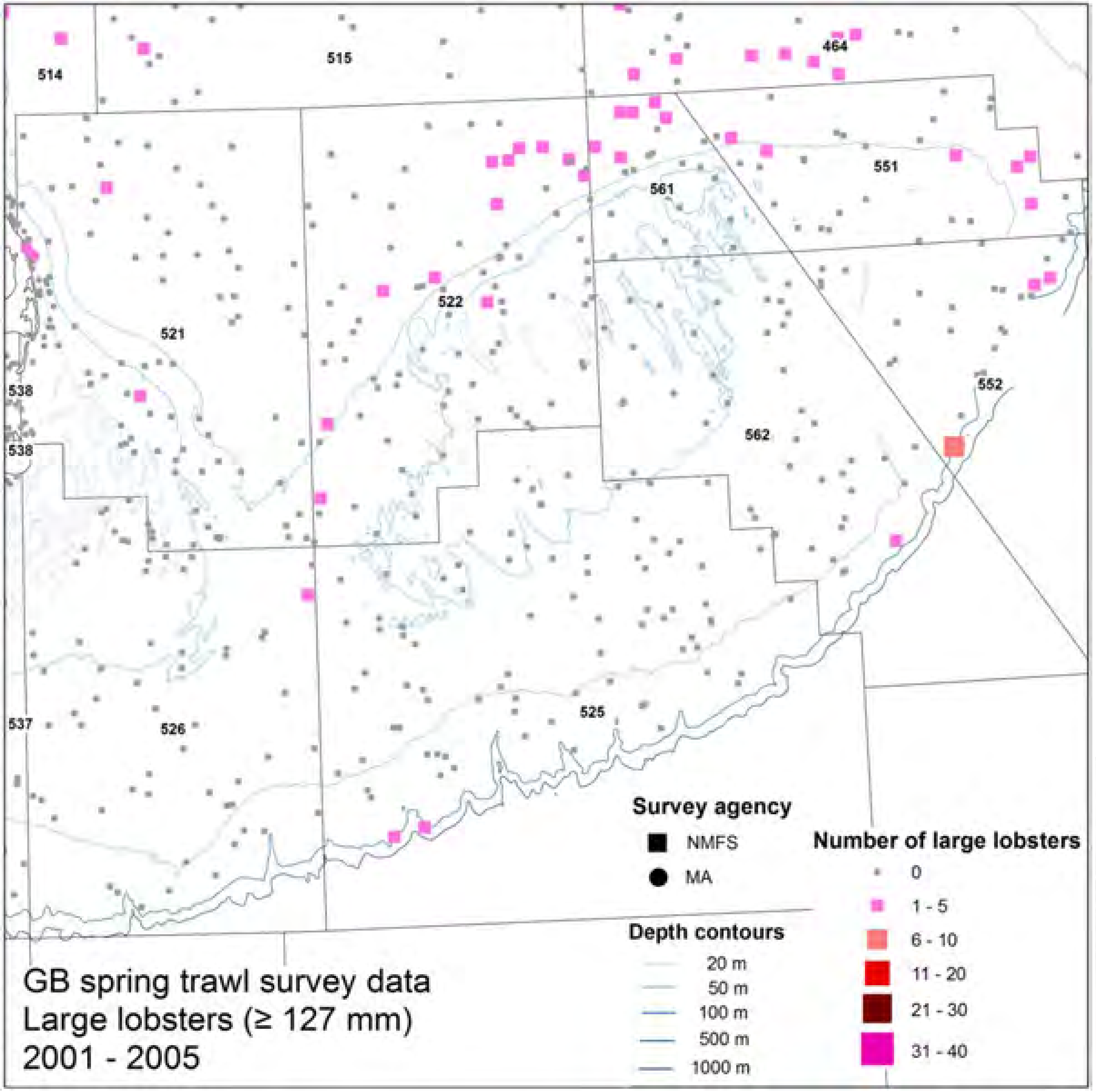


Figure 4.2.1.3.2.6 E





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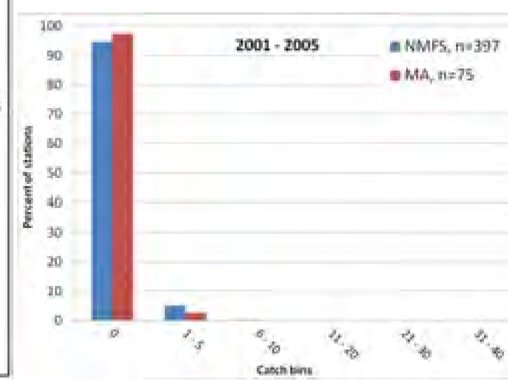


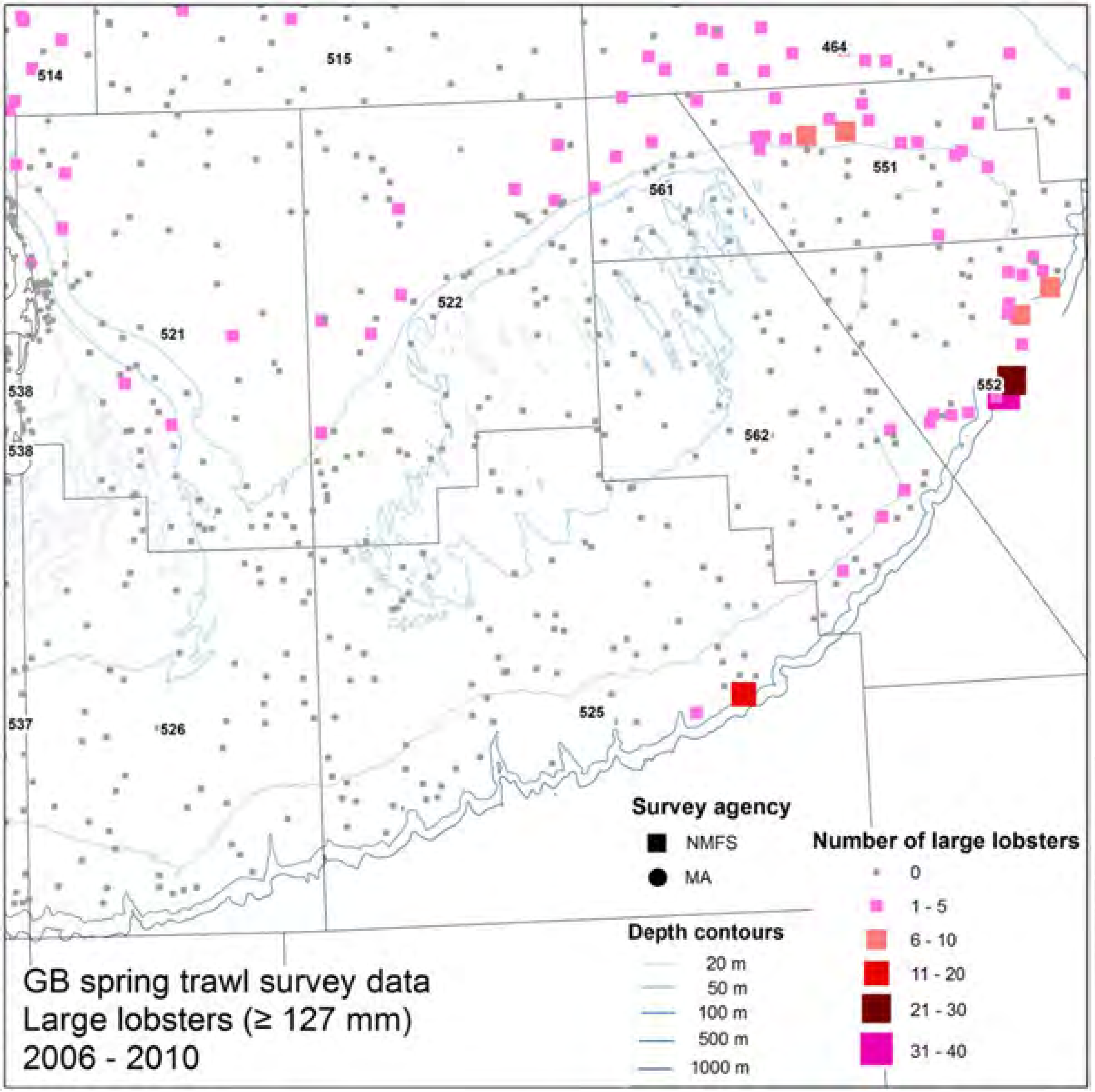
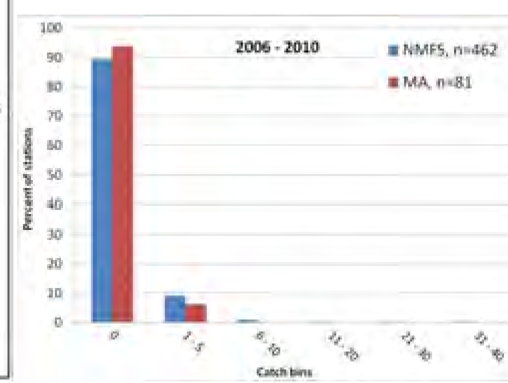


Figure 4.2.1.3.2.6 G



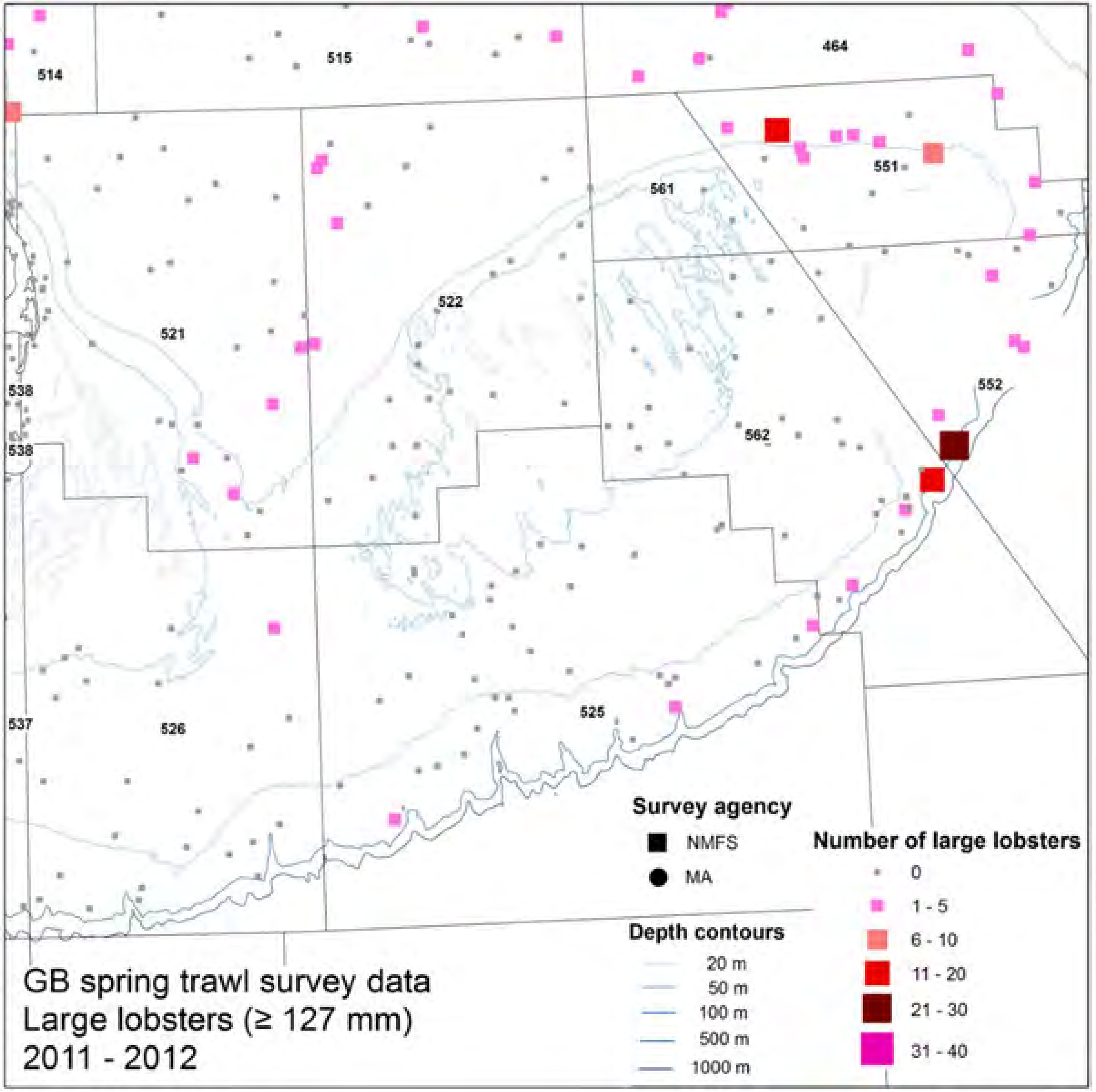
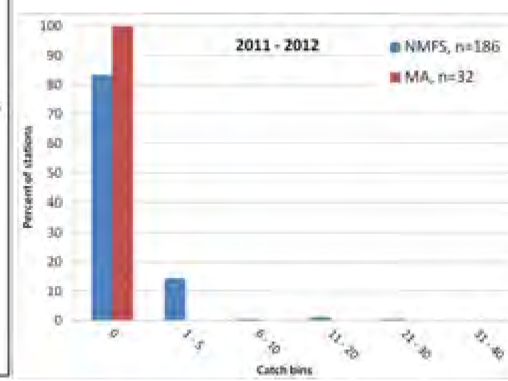


Figure 4.2.1.3.2.6 H



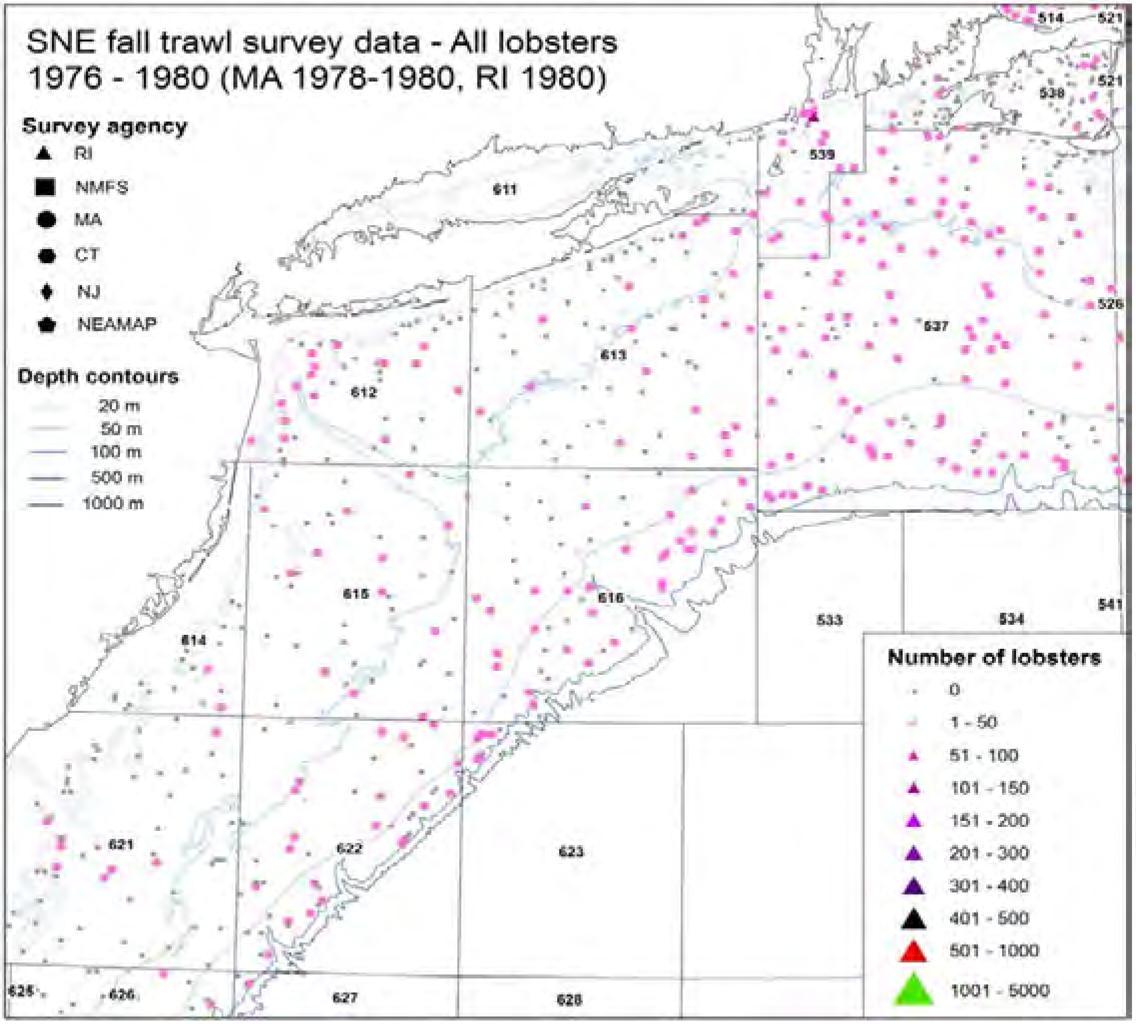


Figure 4.2.1.3.3.1 A

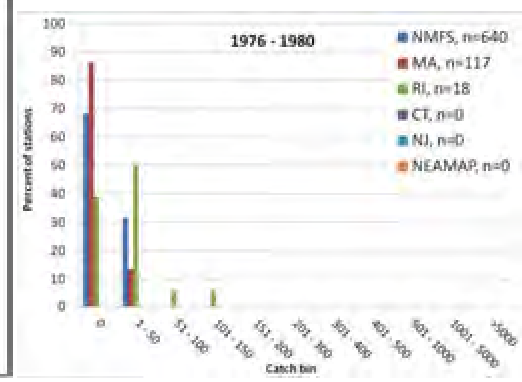


Figure 4.2.1.3.3.1 A – H. **Mean catch per tow of lobster (all sizes) at each fall sampling location from all SNE bottom trawl surveys (MA, RI, CT, NJ, NMFS, NEAMAP), shown in 5 year time periods.** Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

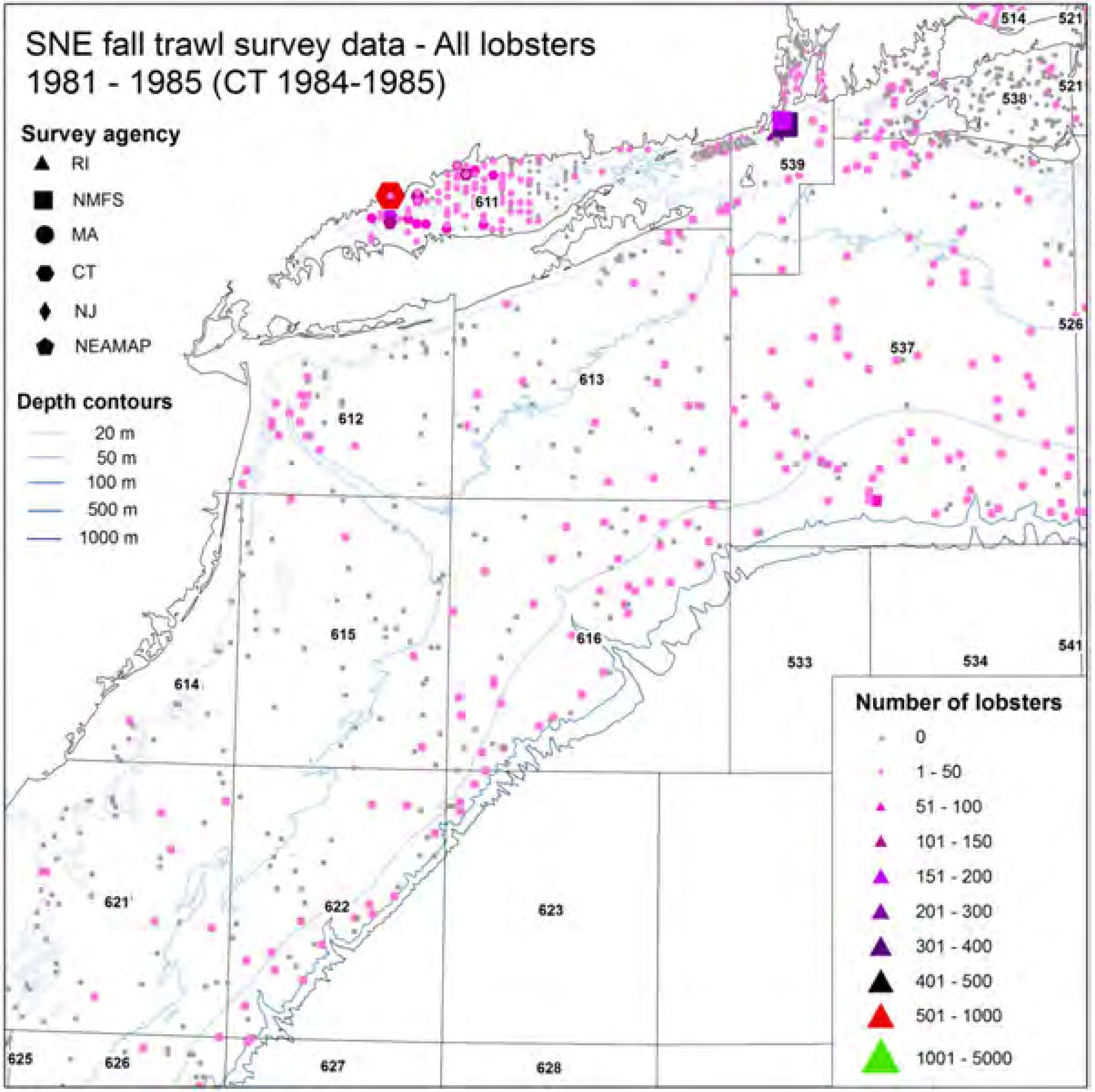
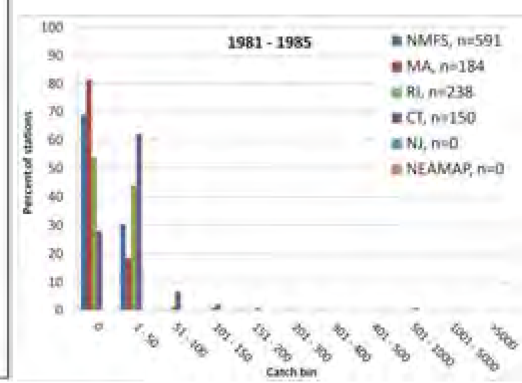


Figure 4.2.1.3.3.1 B



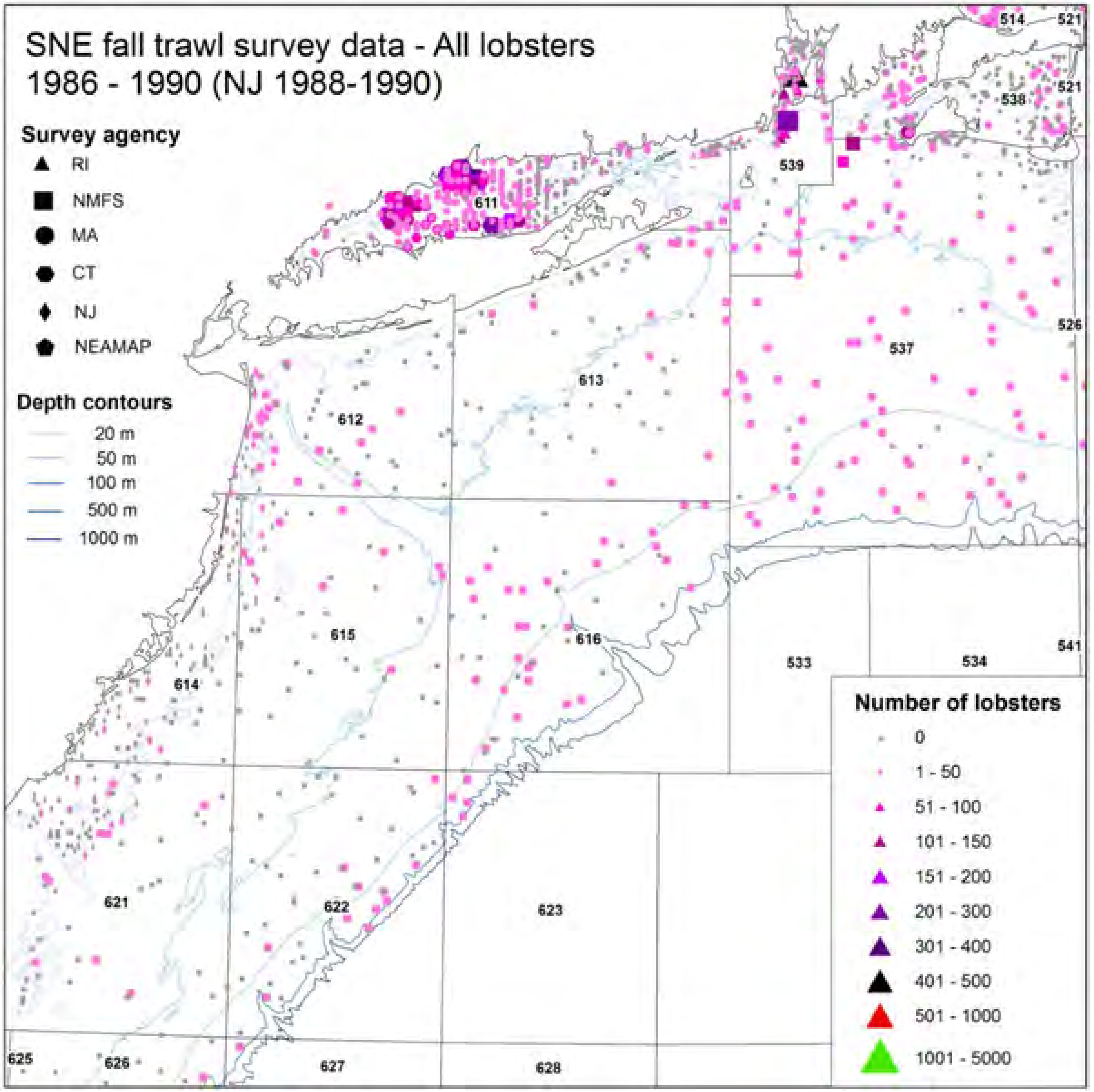
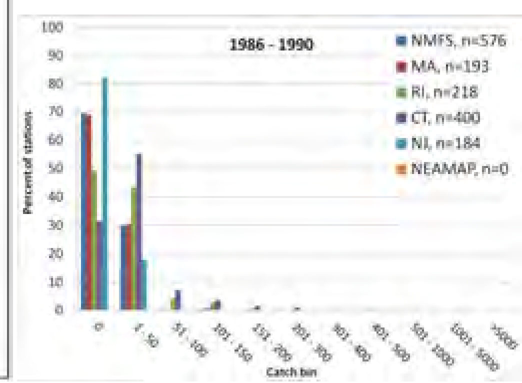


Figure 4.2.1.3.3.1 C



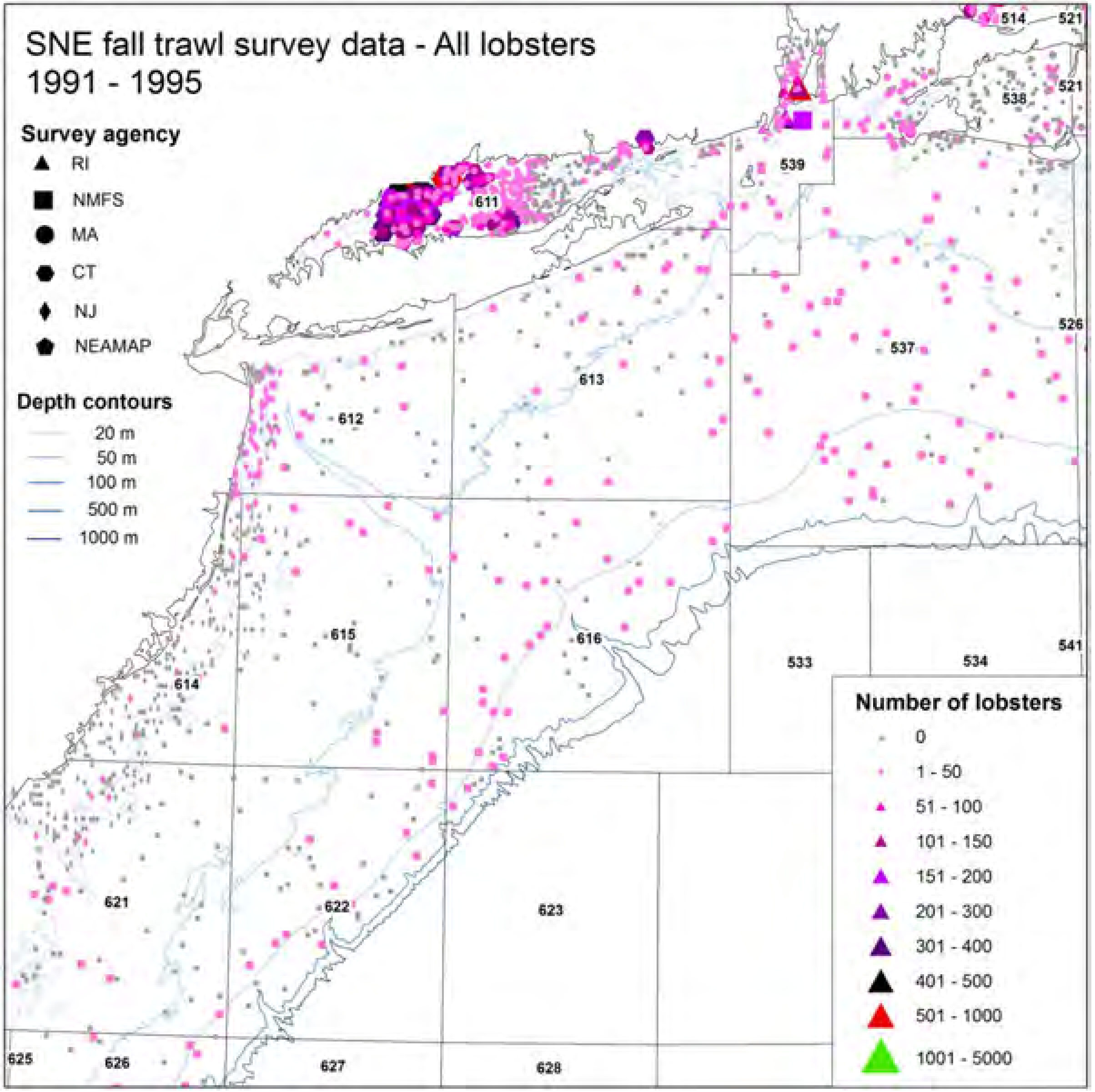
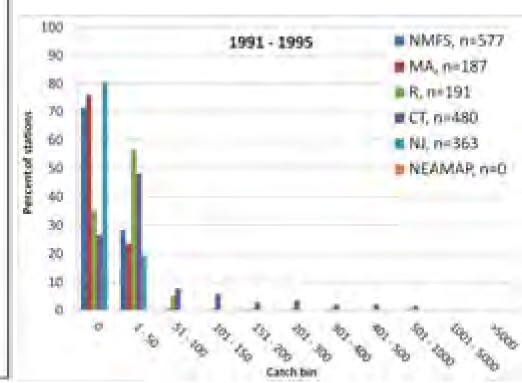
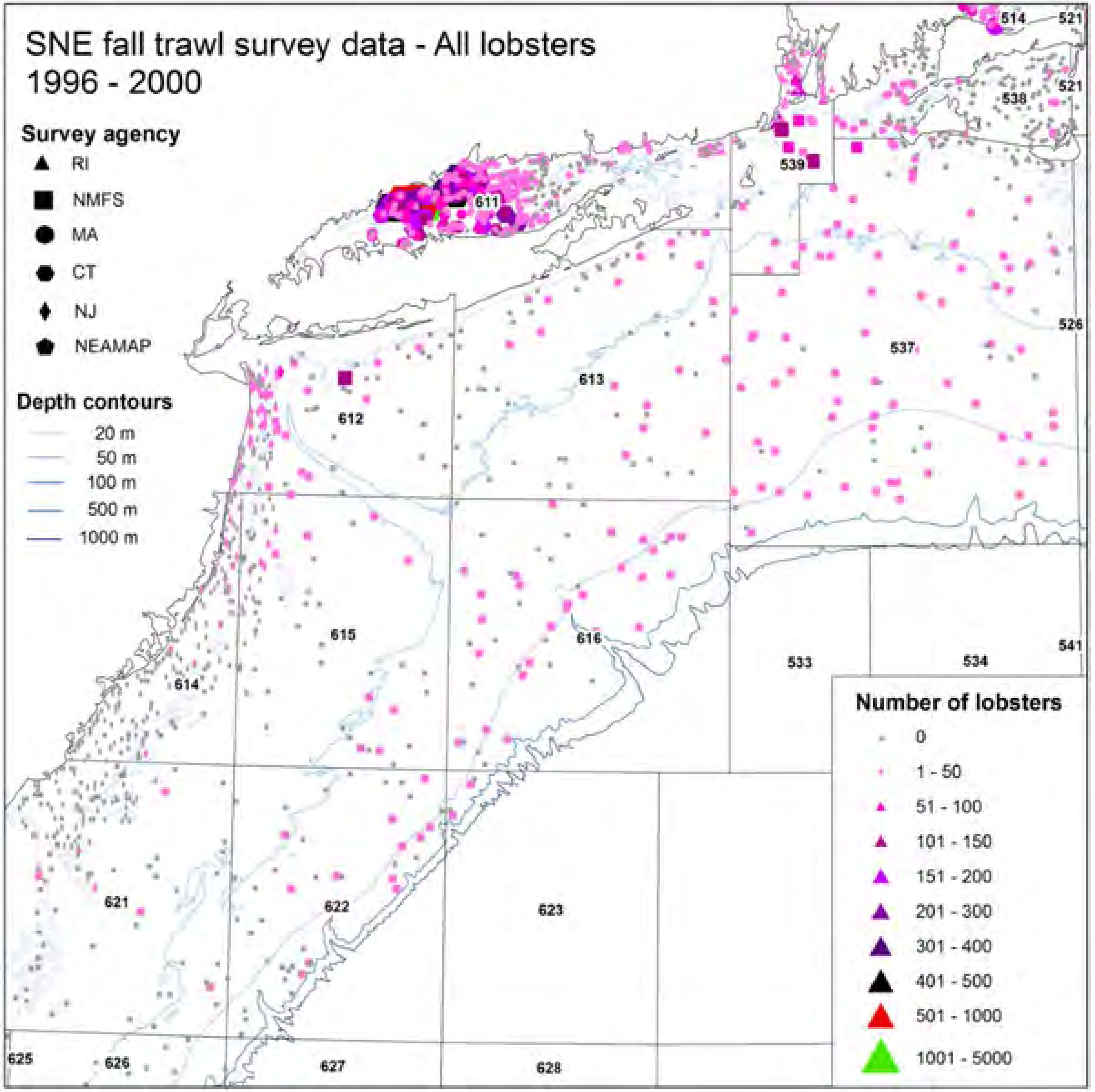


Figure 4.2.1.3.3.1 D





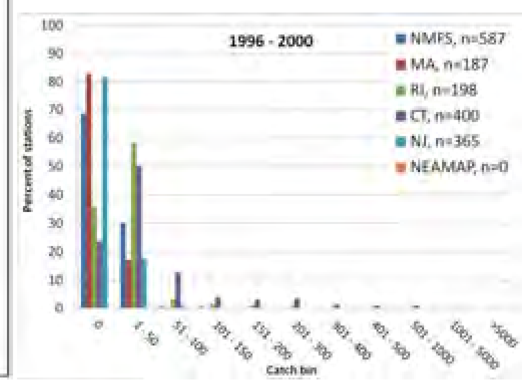


Figure 4.2.1.3.3.1 E

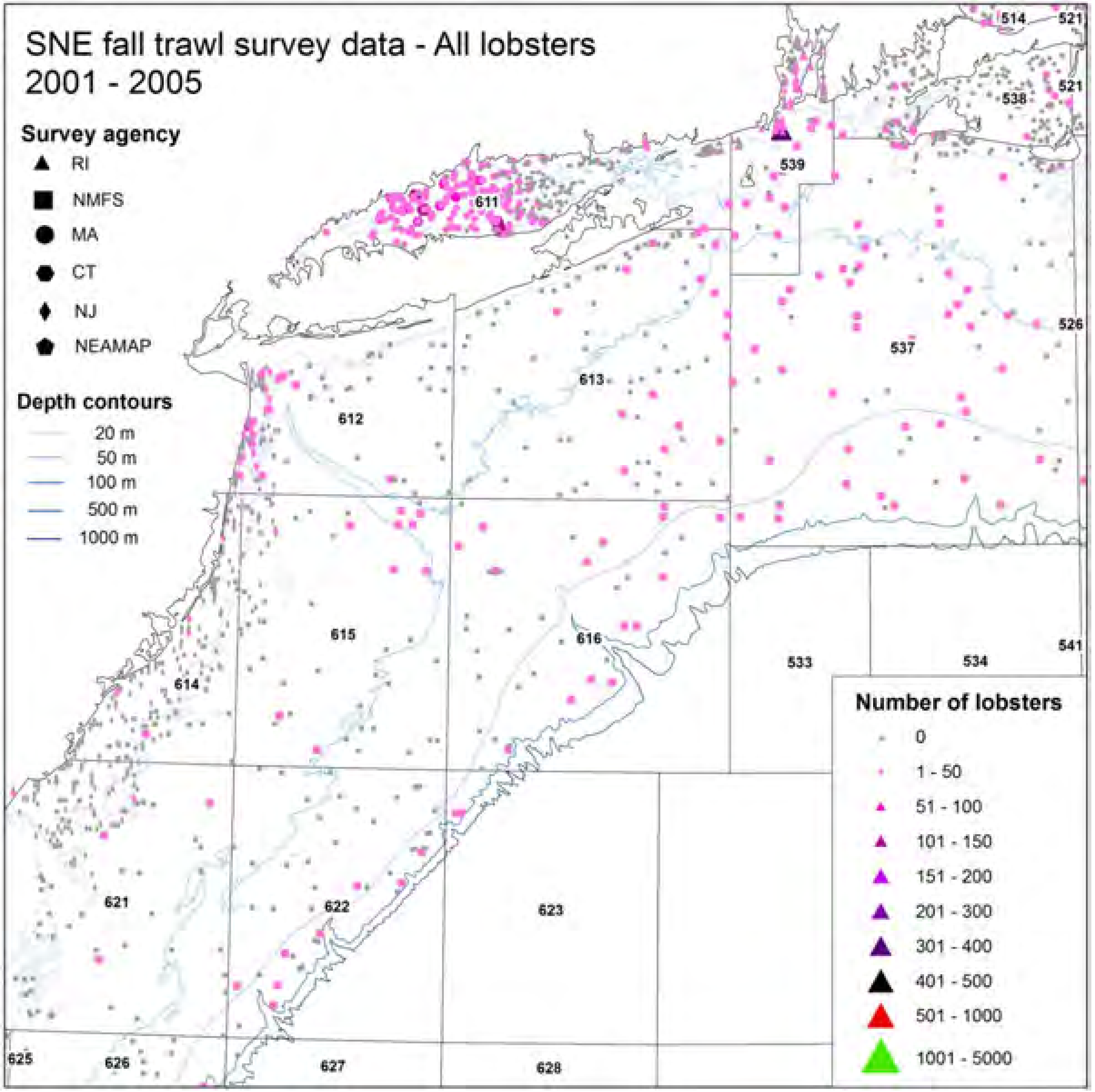
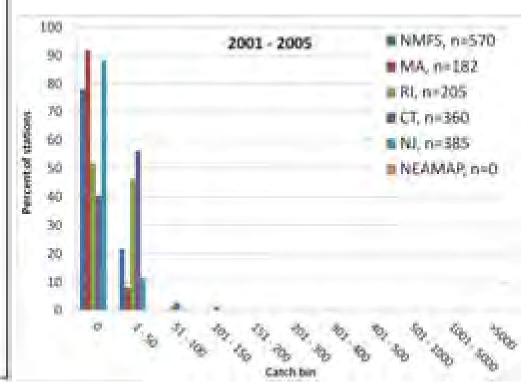


Figure 4.2.1.3.3.1 F



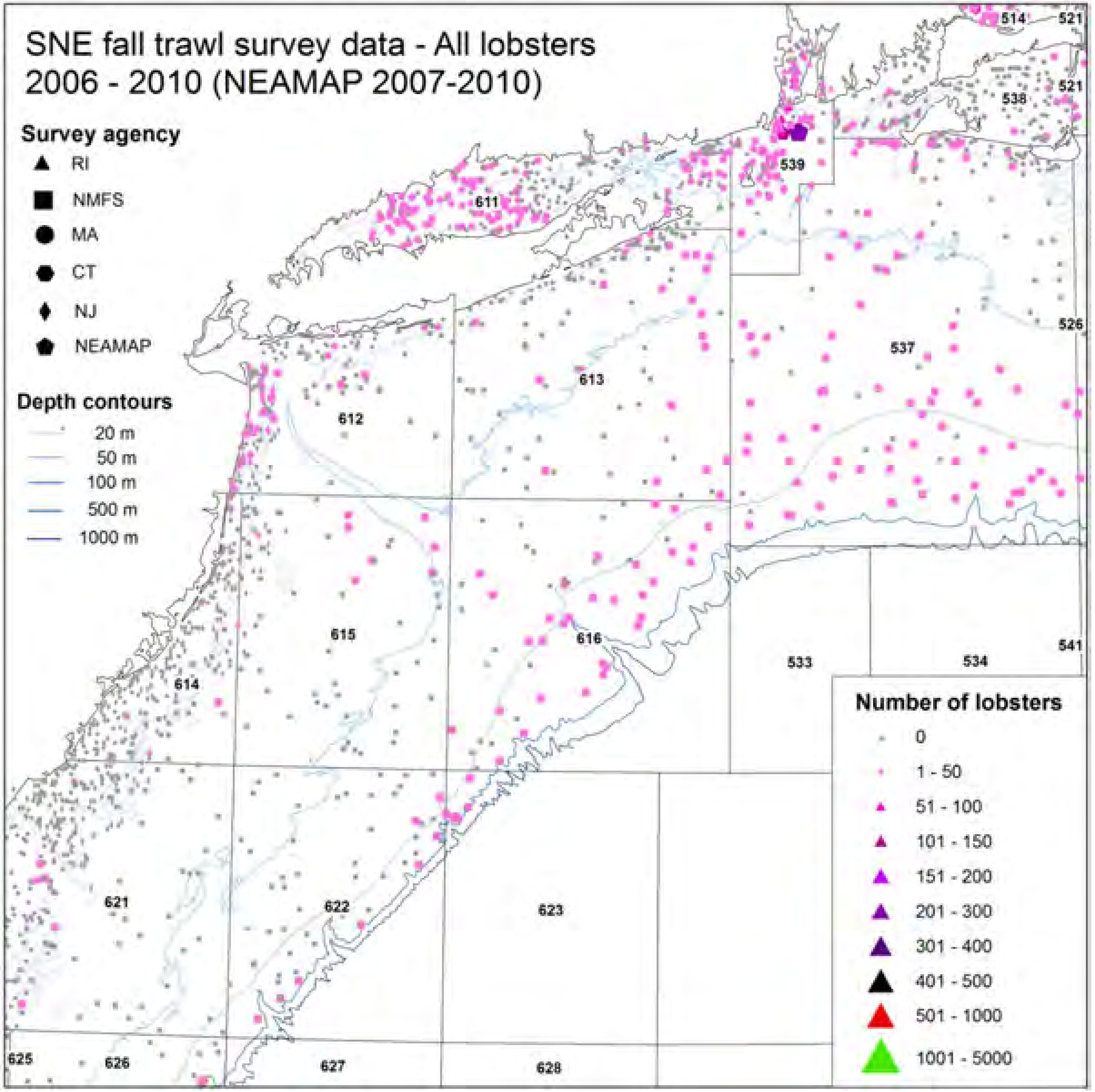
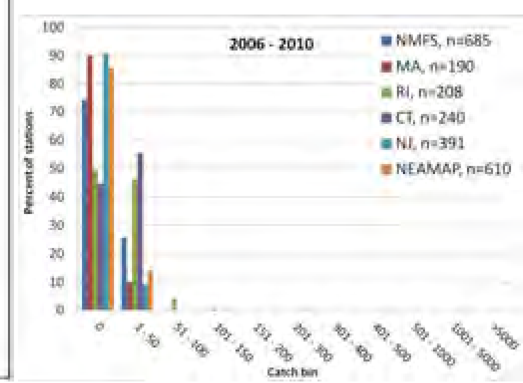


Figure 4.2.1.3.3.1 G



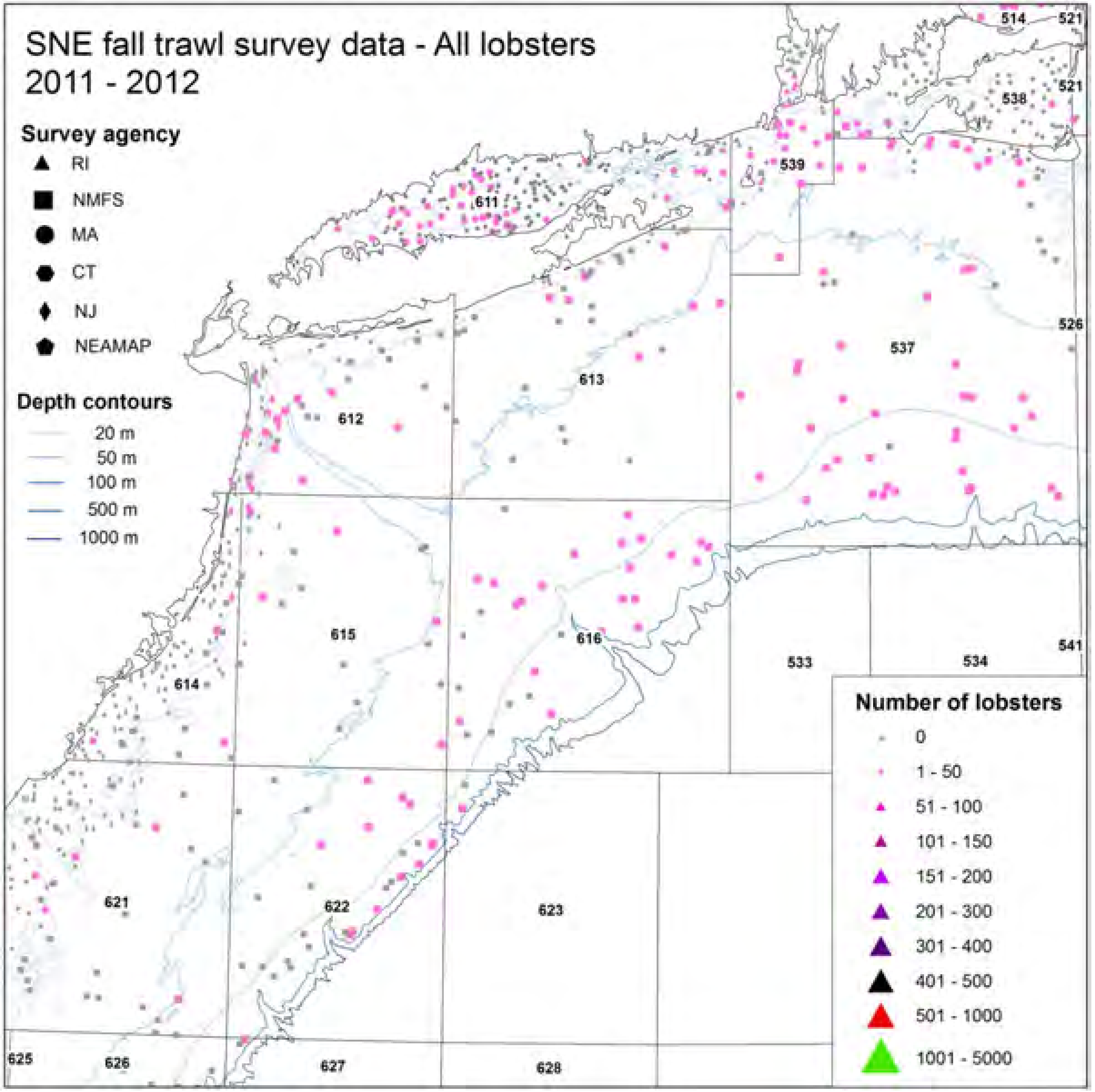
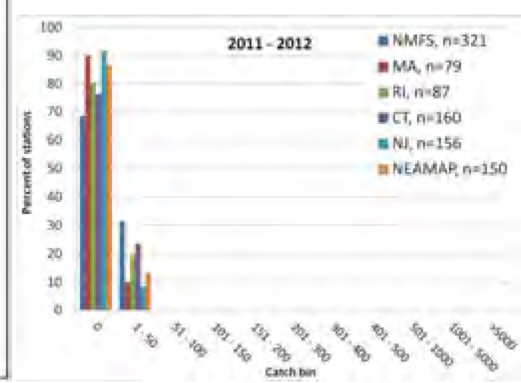


Figure 4.2.1.3.3.1 H



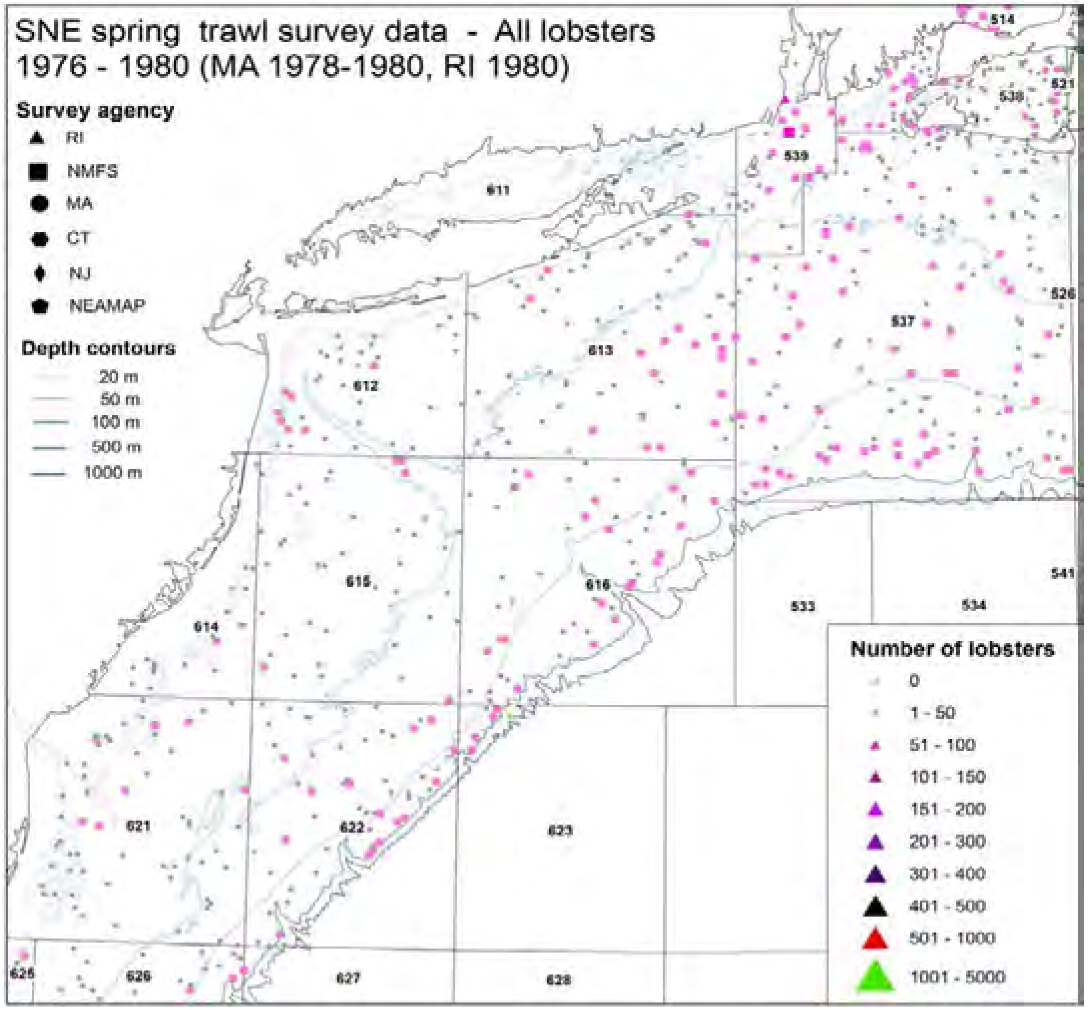


Figure 4.2.1.3.3.2 A

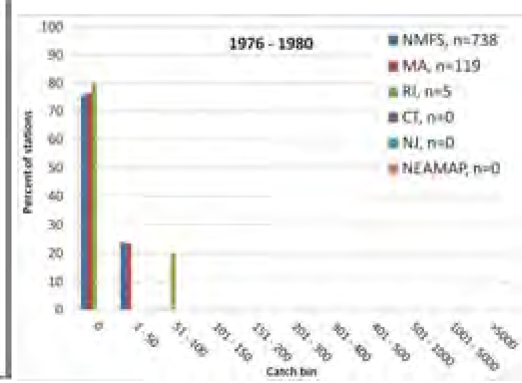


Figure 4.2.1.3.3.2 A – H. Mean catch per tow of lobster (all sizes) at each spring sampling location from all SNE bottom trawl surveys (MA, RI, CT, NJ, NMFS, NEAMAP), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

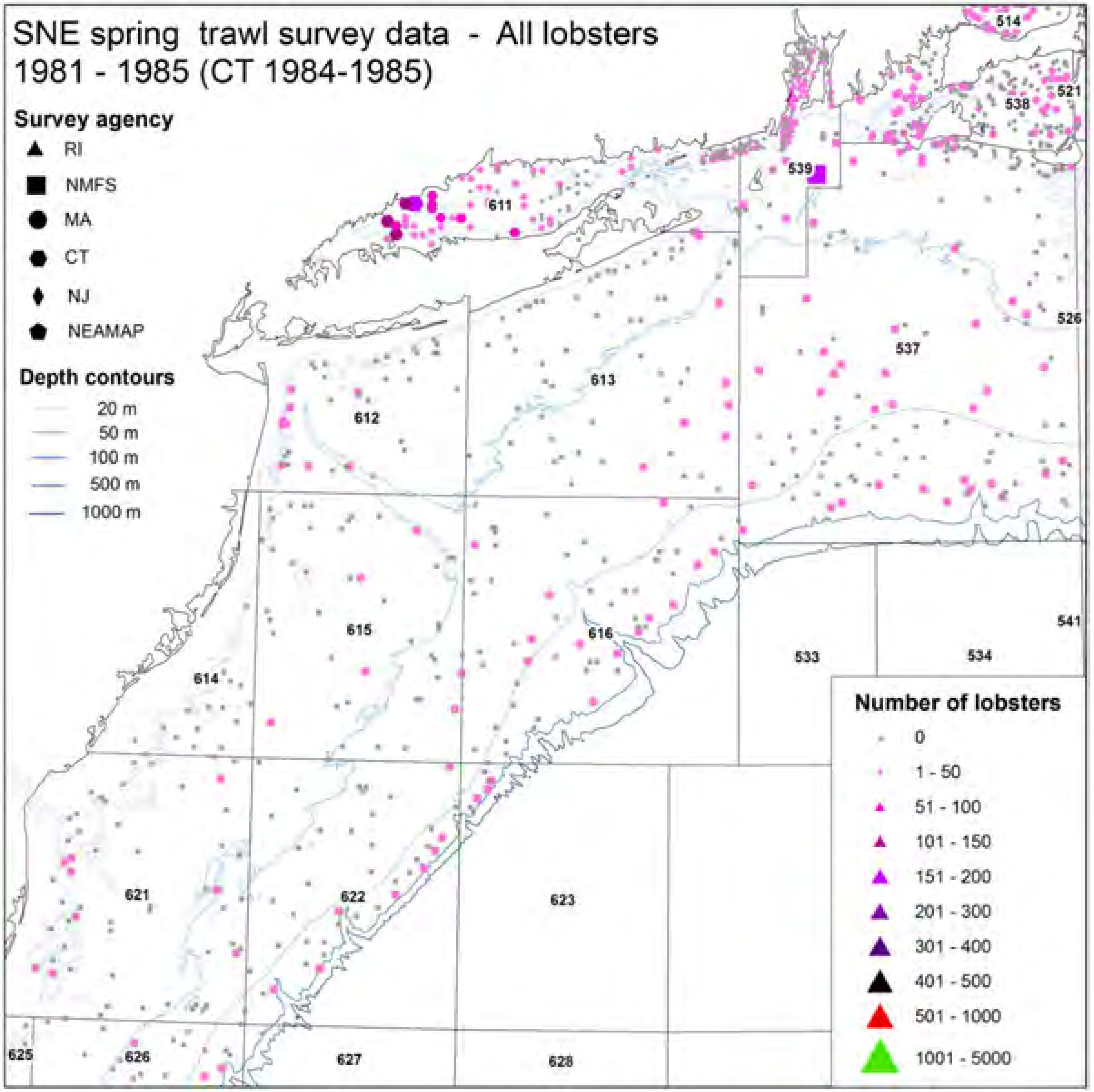
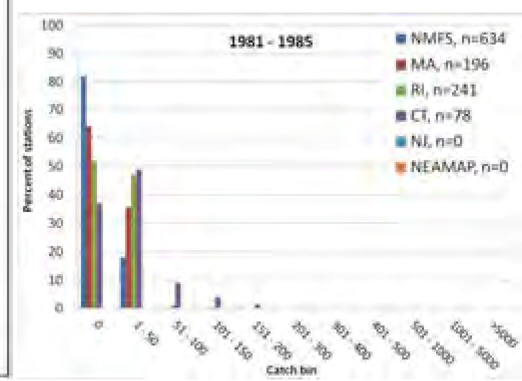
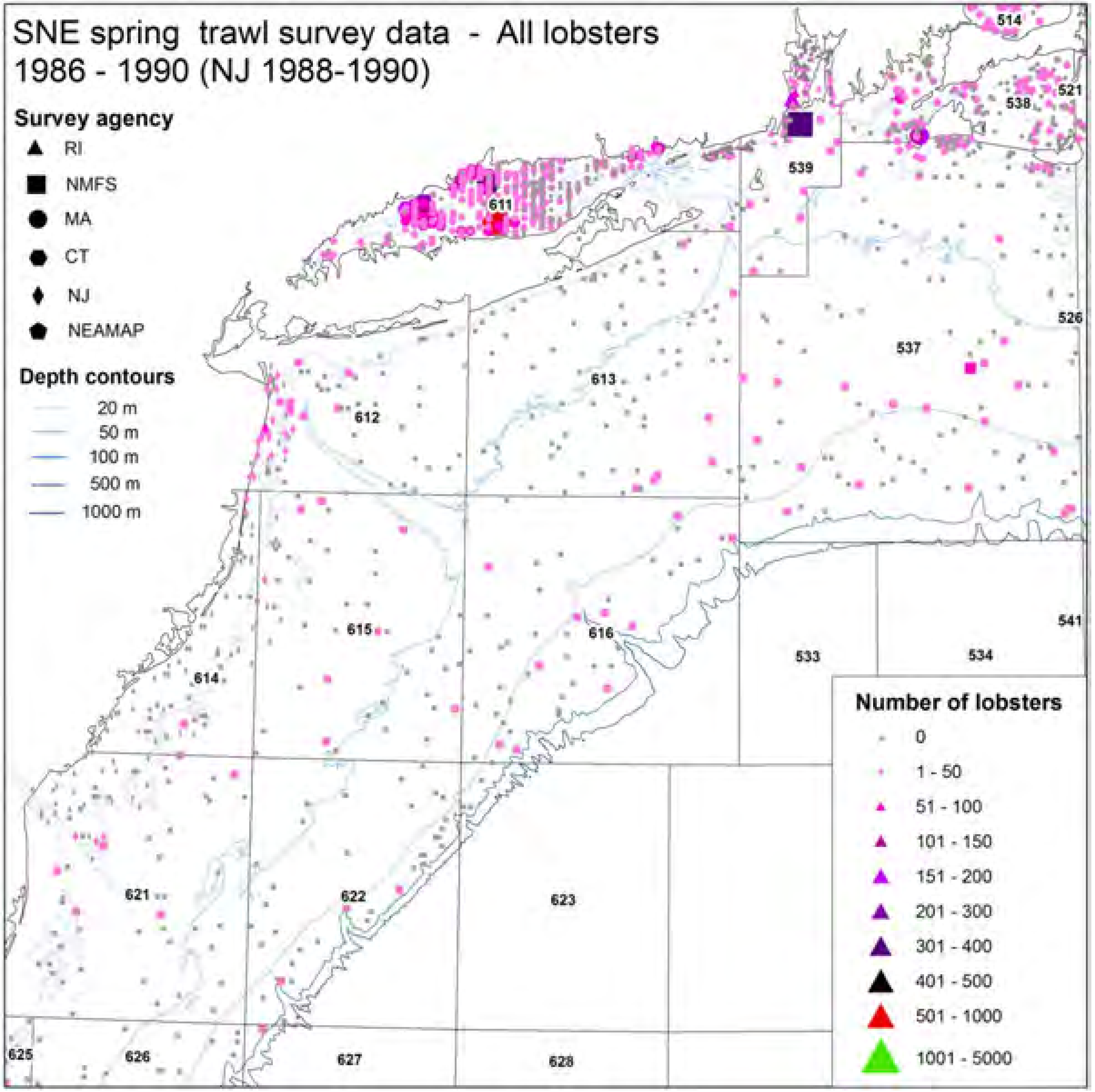


Figure 4.2.1.3.3.2 B





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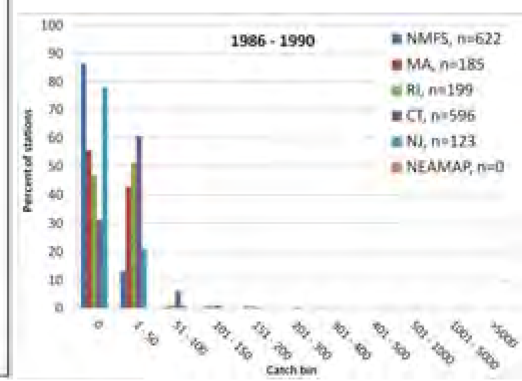


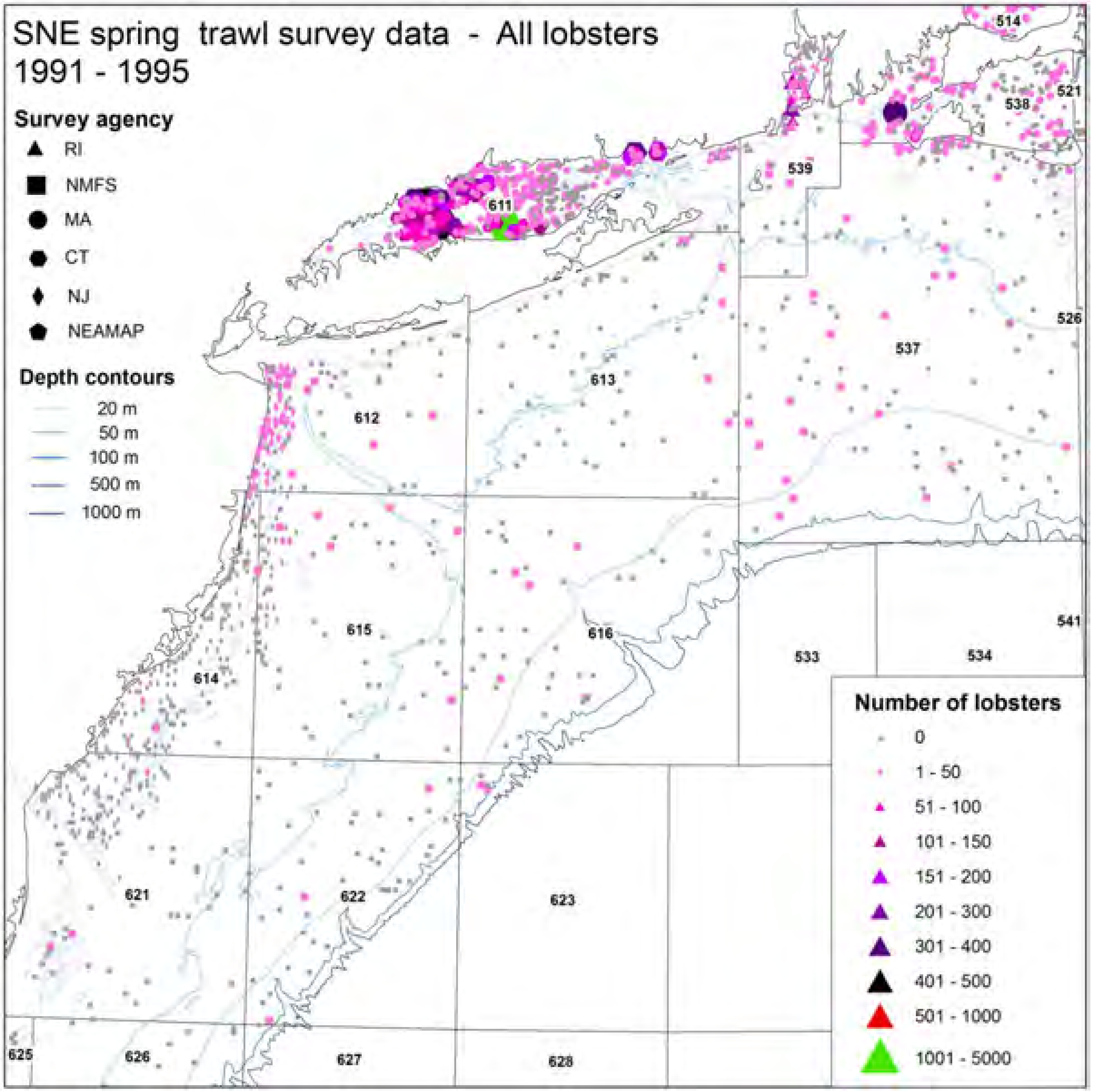
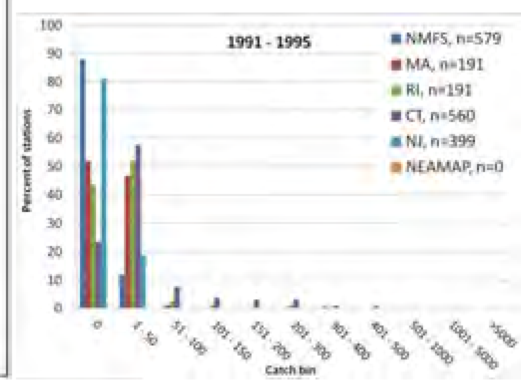


Figure 4.2.1.3.3.2 D



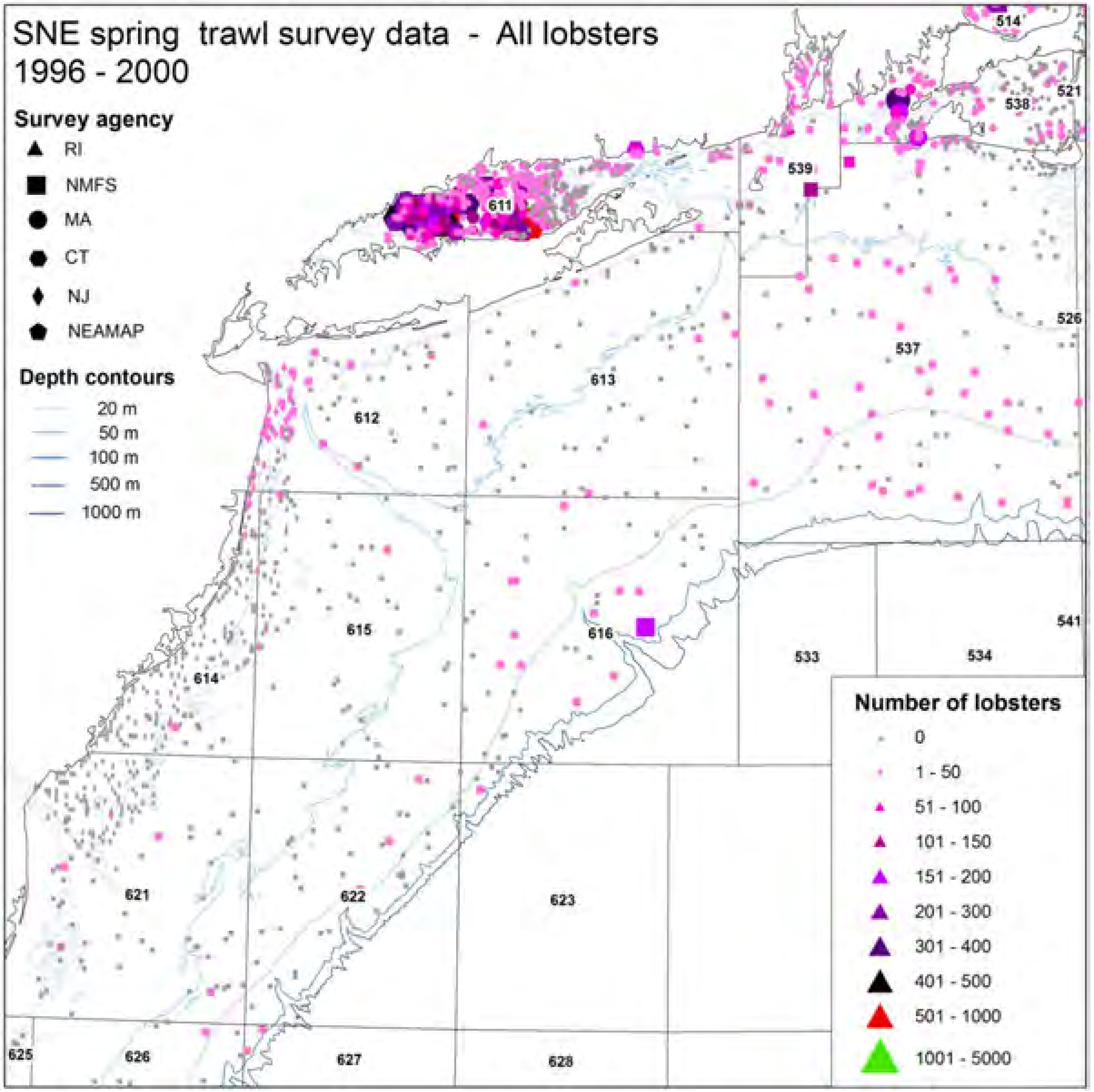
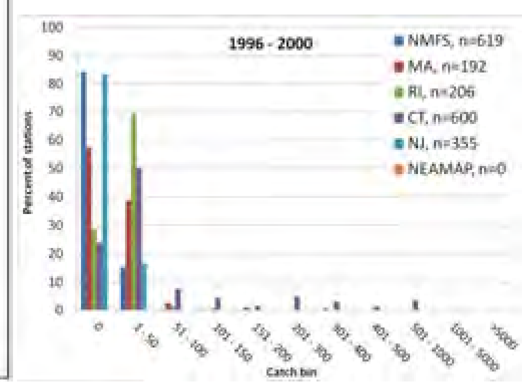


Figure 4.2.1.3.3.2 E



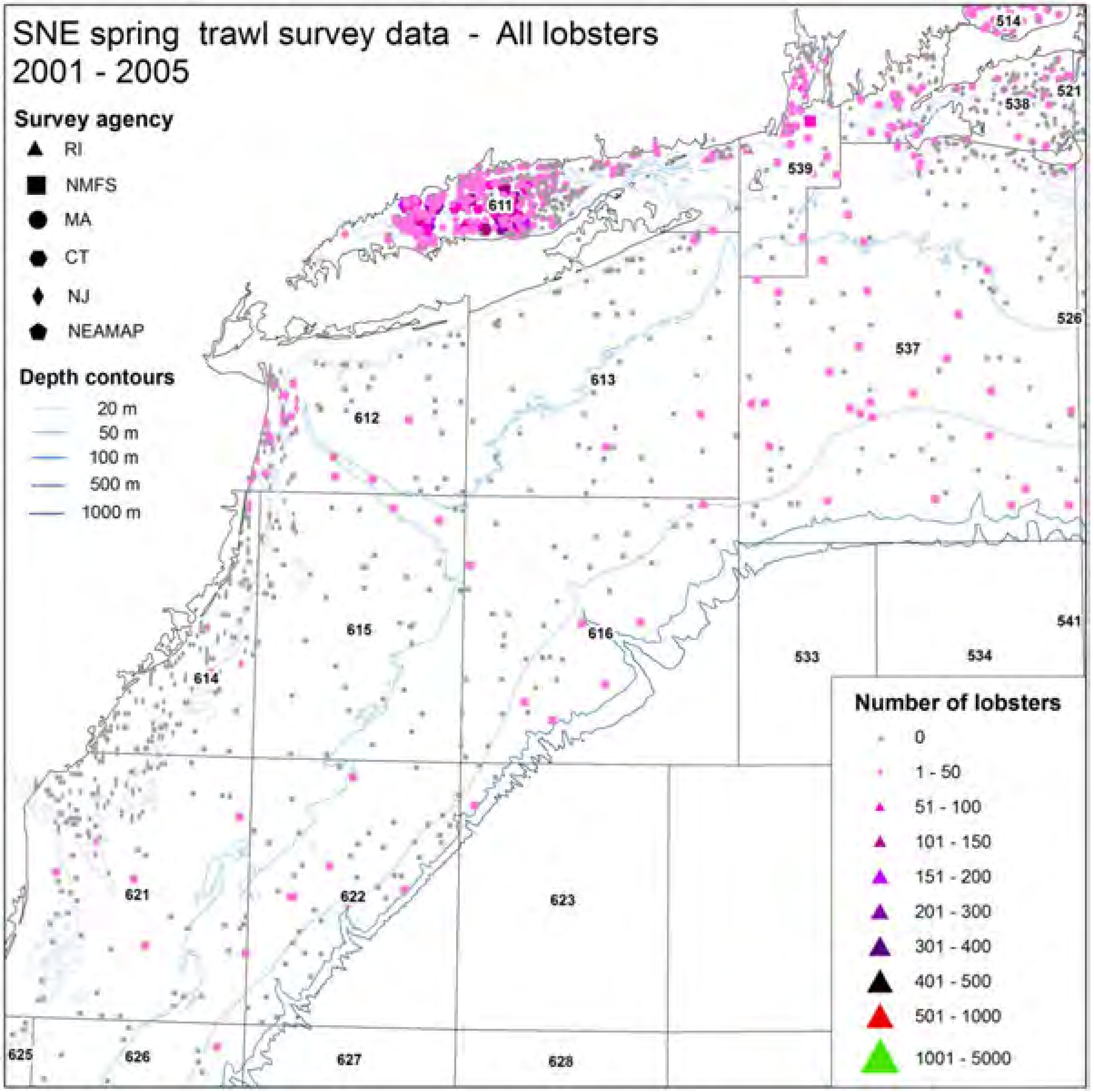
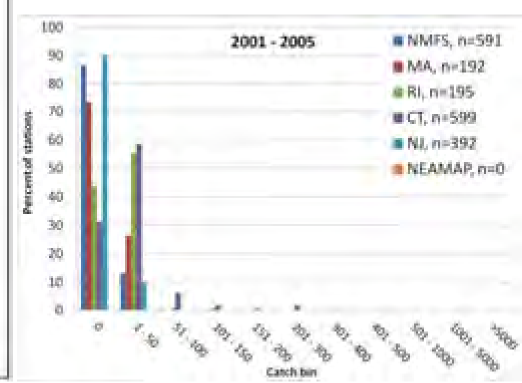


Figure 4.2.1.3.3.2 F



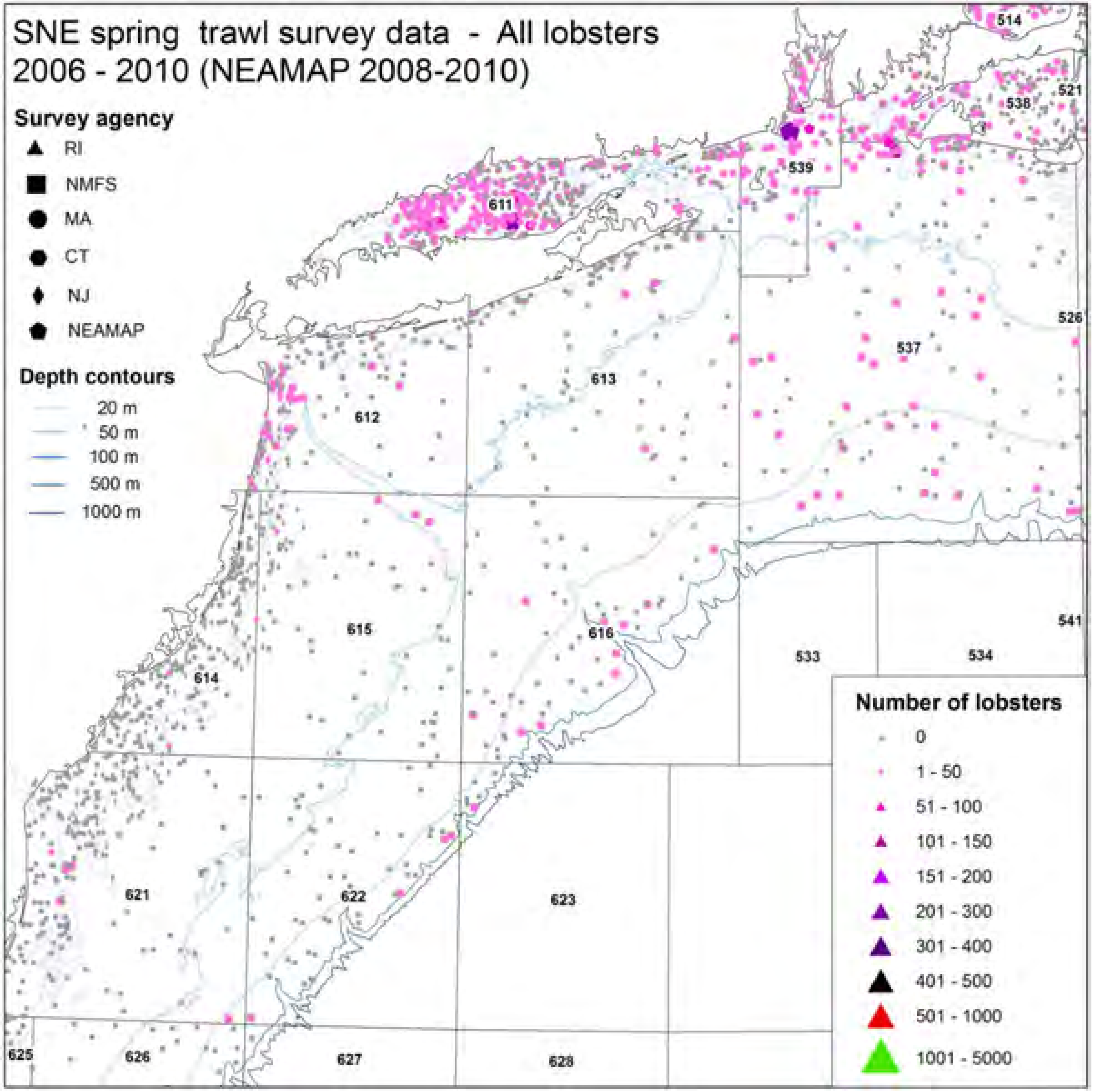
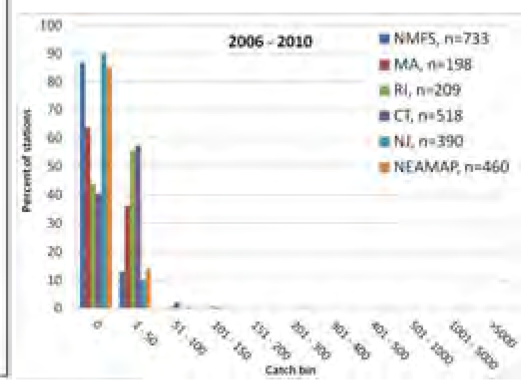


Figure 4.2.1.3.3.2 G



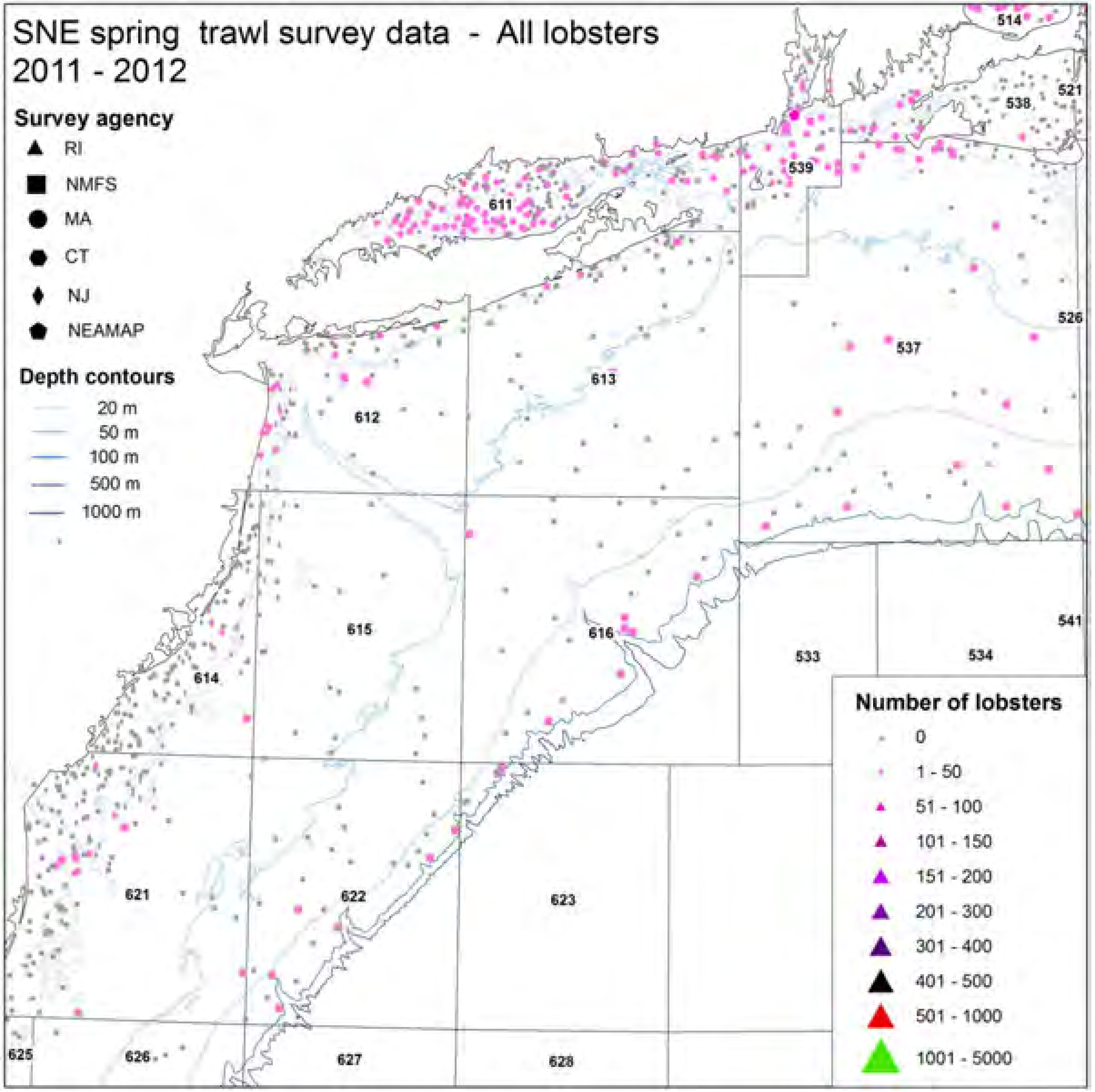
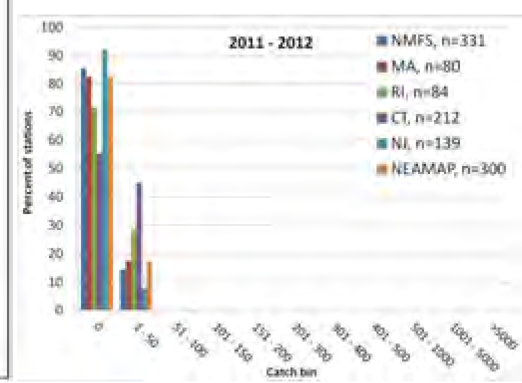


Figure 4.2.1.3.3.2 H



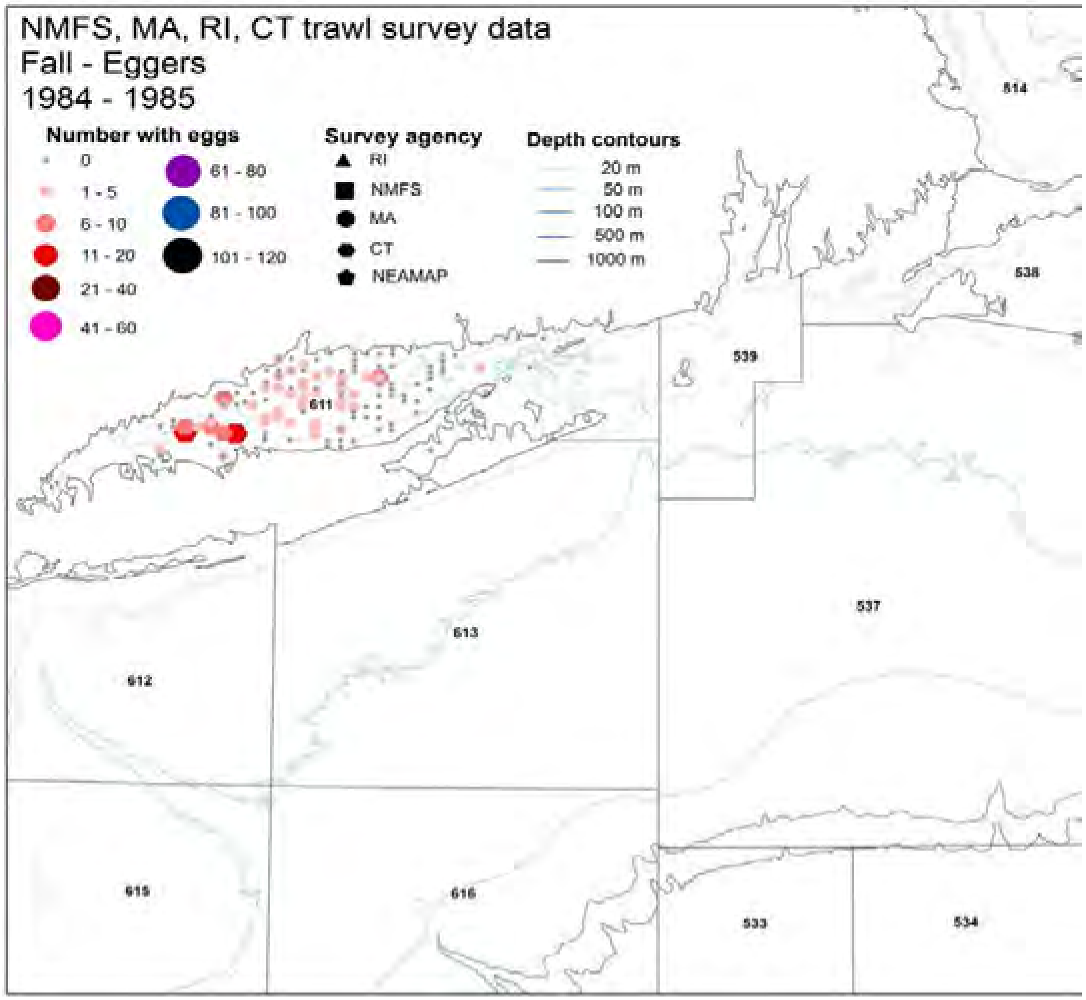


Figure 4.2.1.3.3.3 A

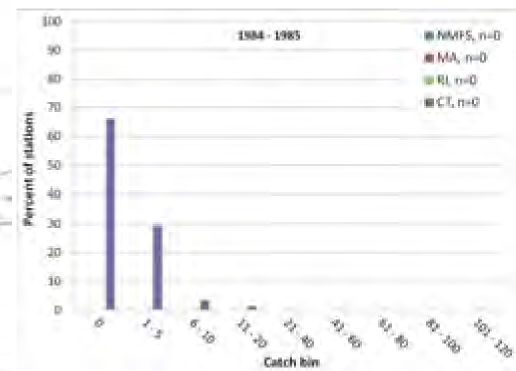


Figure 4.2.1.3.3.3 A – G. Mean catch per tow of ovigerous females (all sizes) at each fall sampling location from all SNE bottom trawl surveys (MA, RI, CT, NJ, NMFS, NEAMAP), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

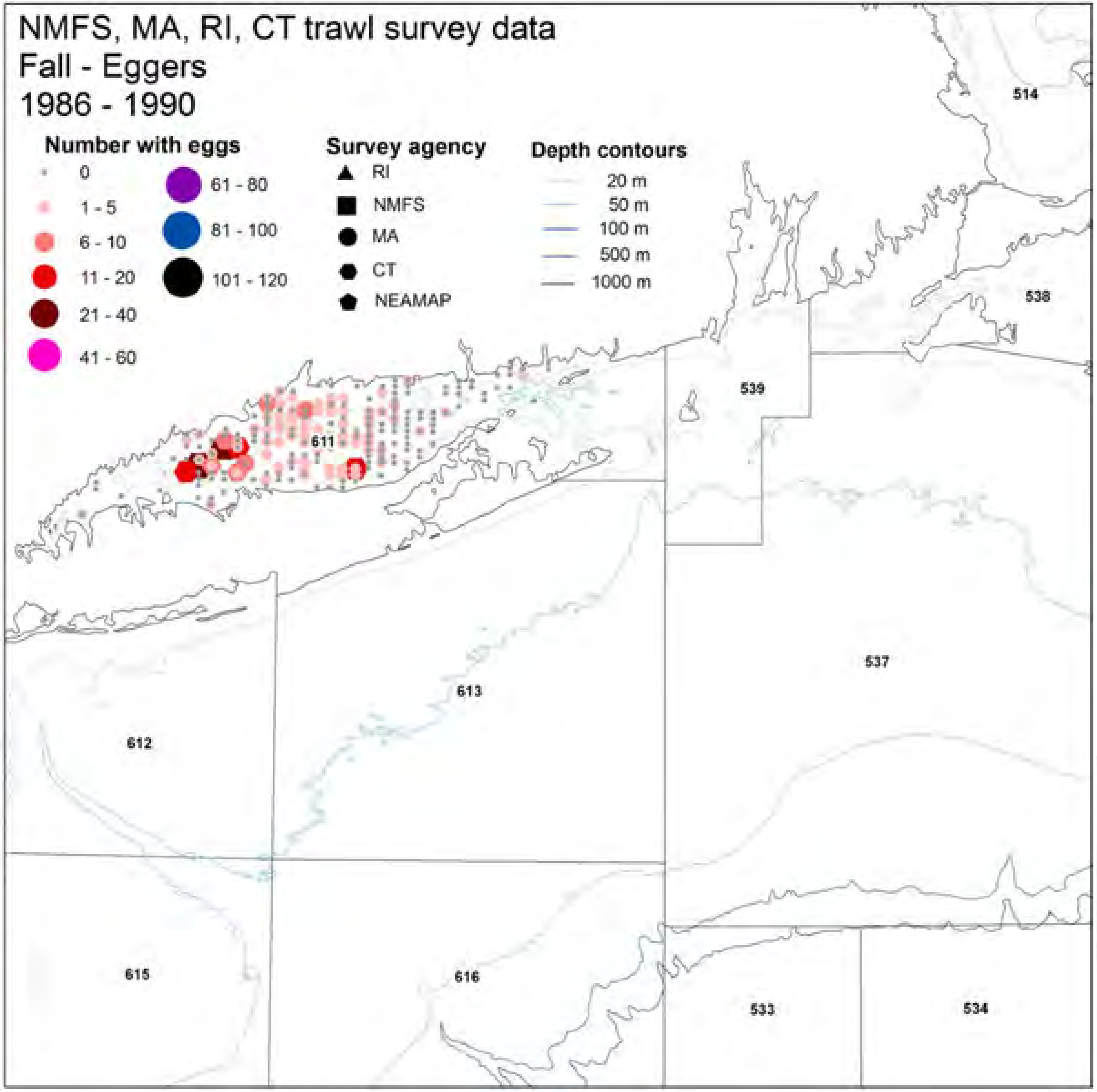
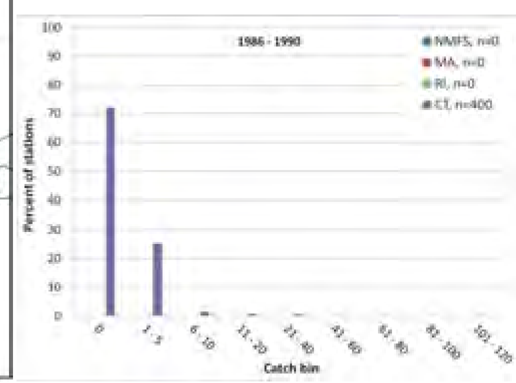
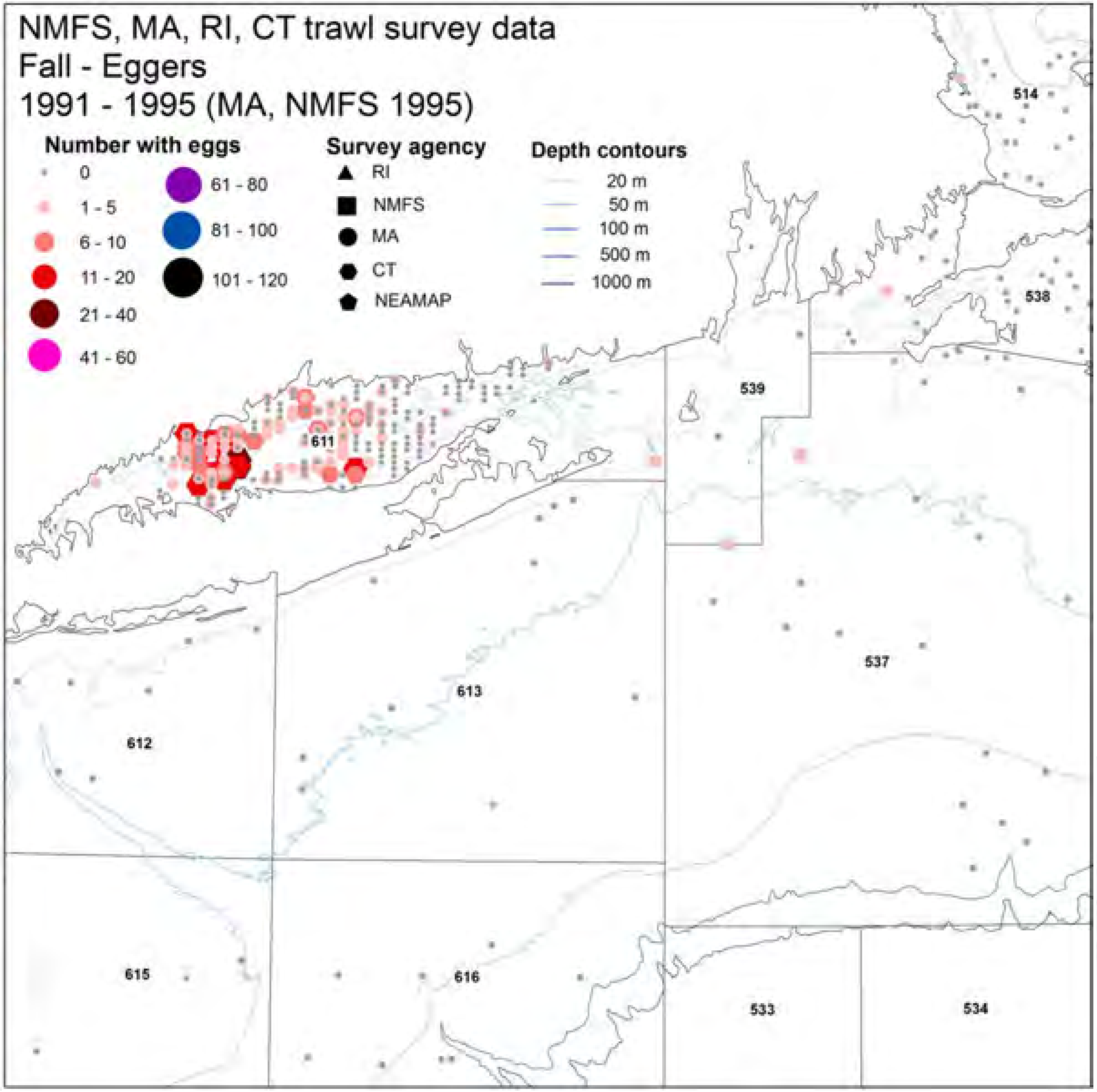


Figure 4.2.1.3.3.3 B





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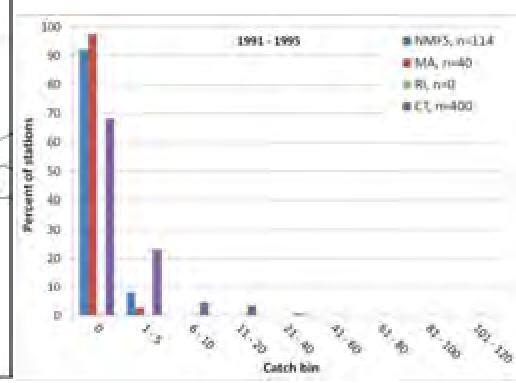

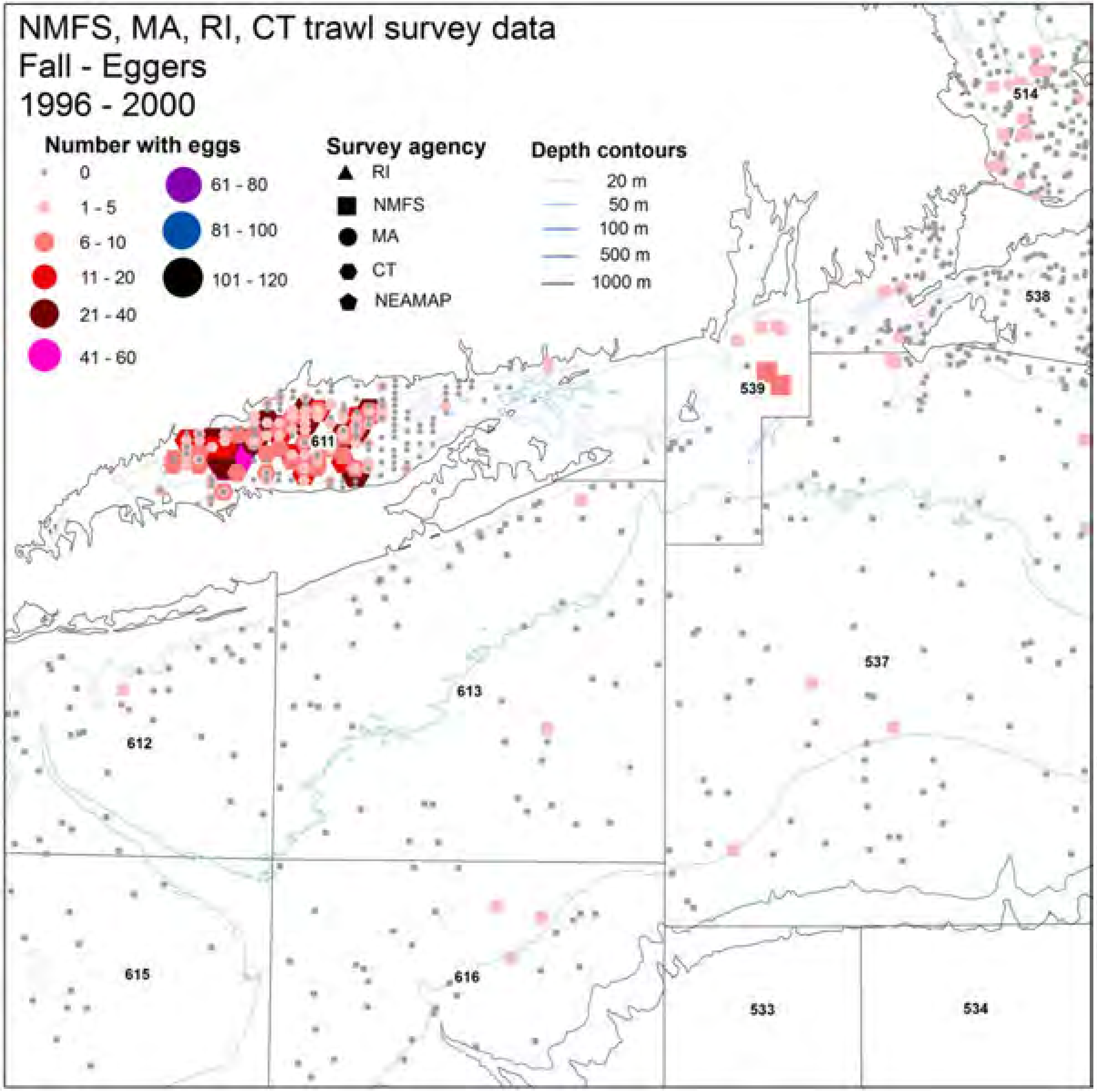

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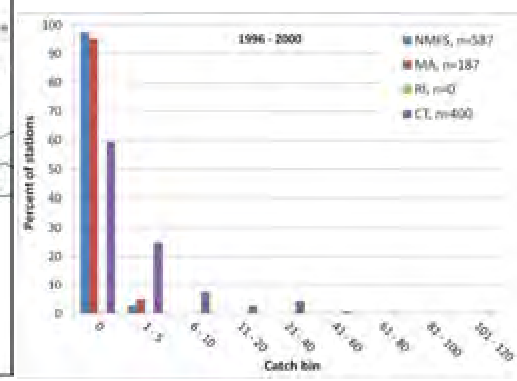

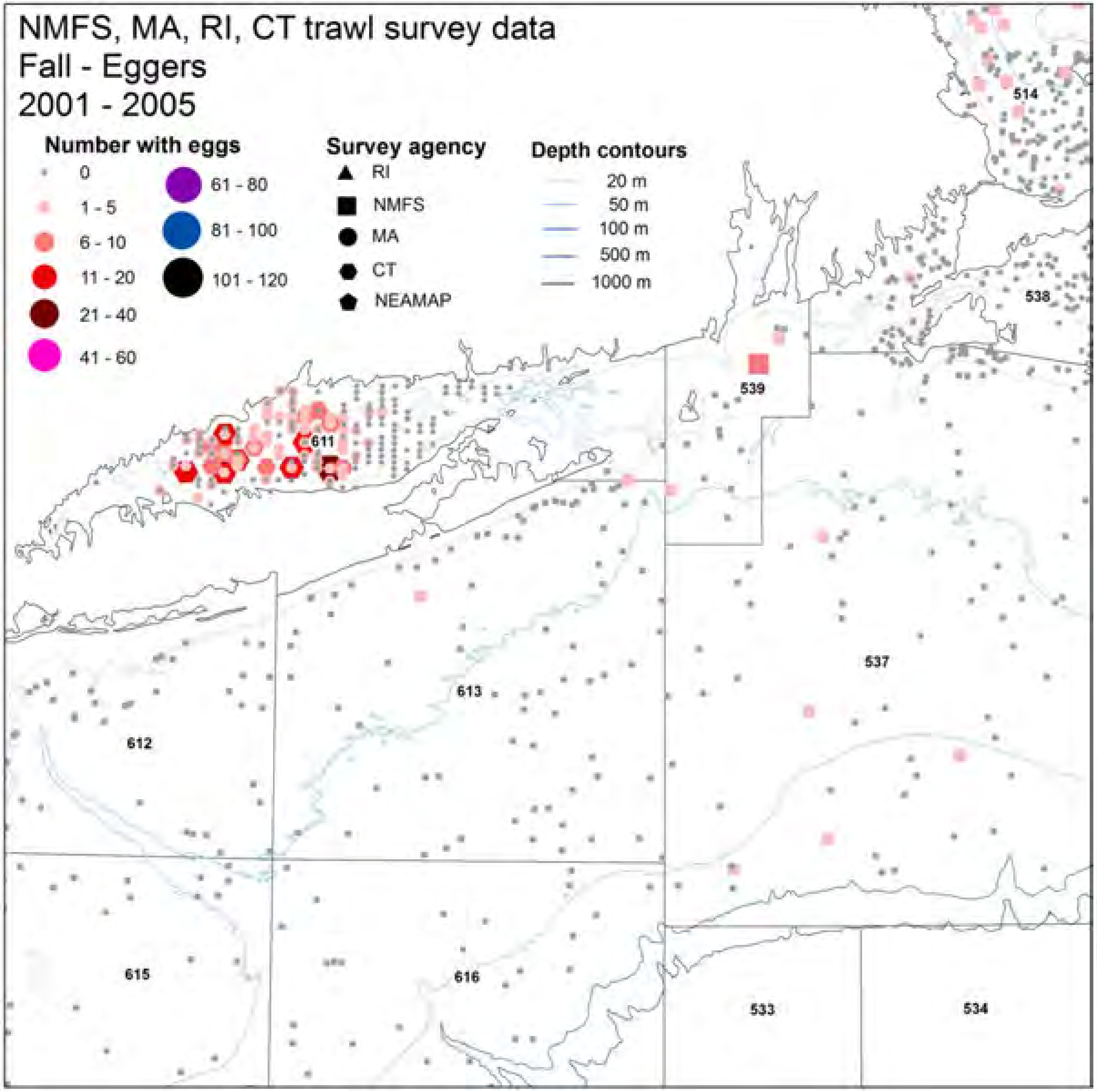

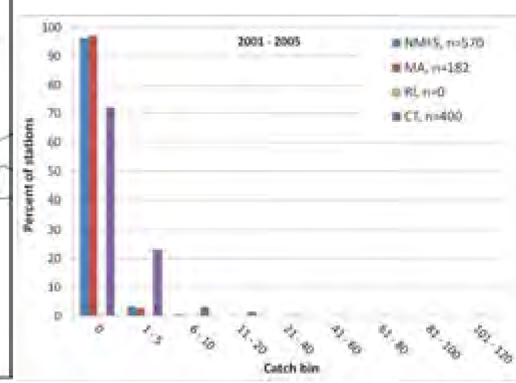

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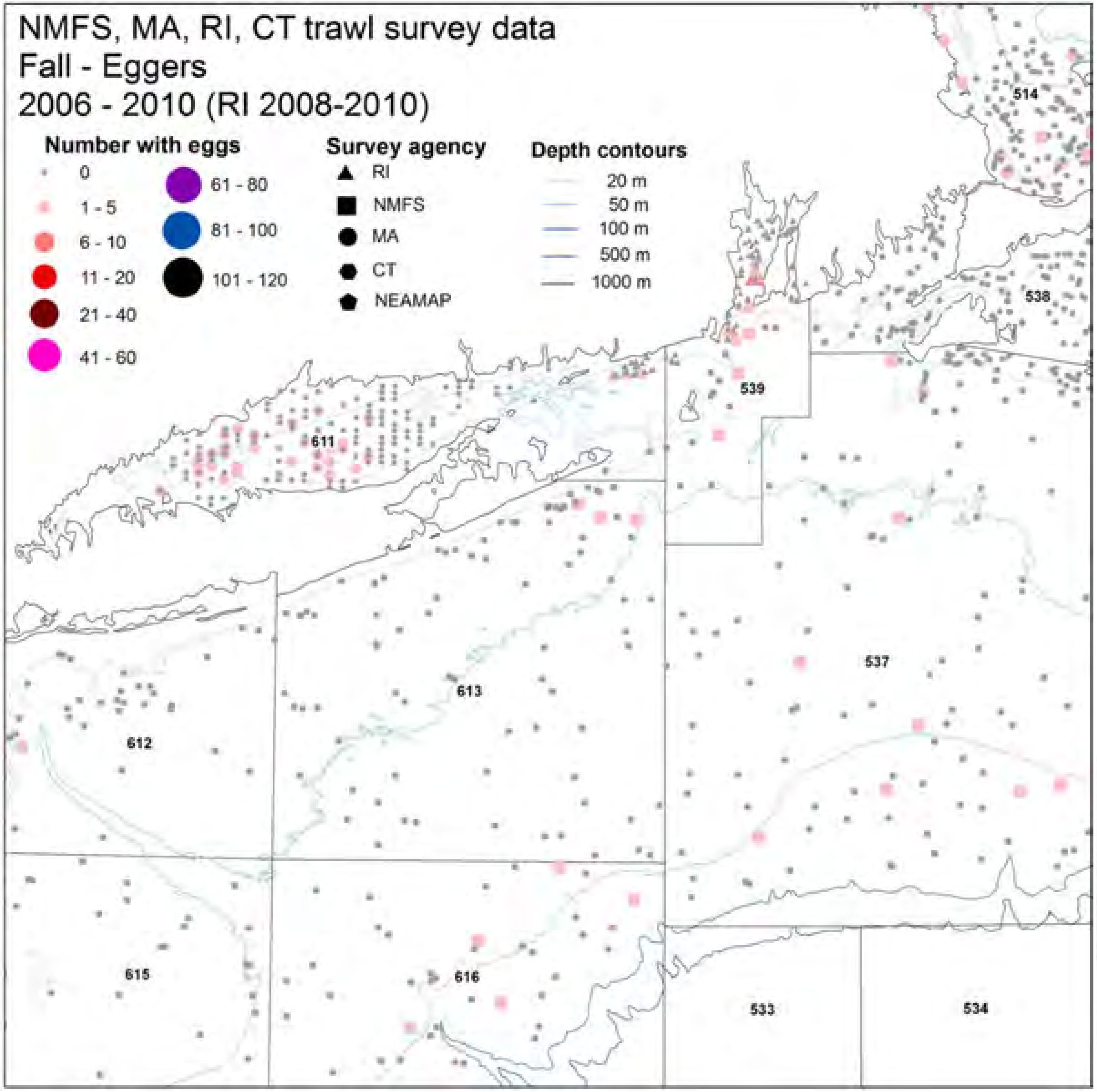

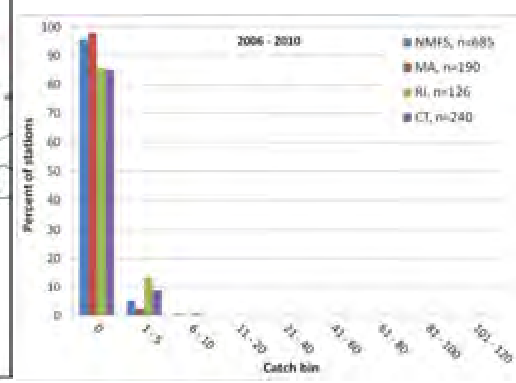

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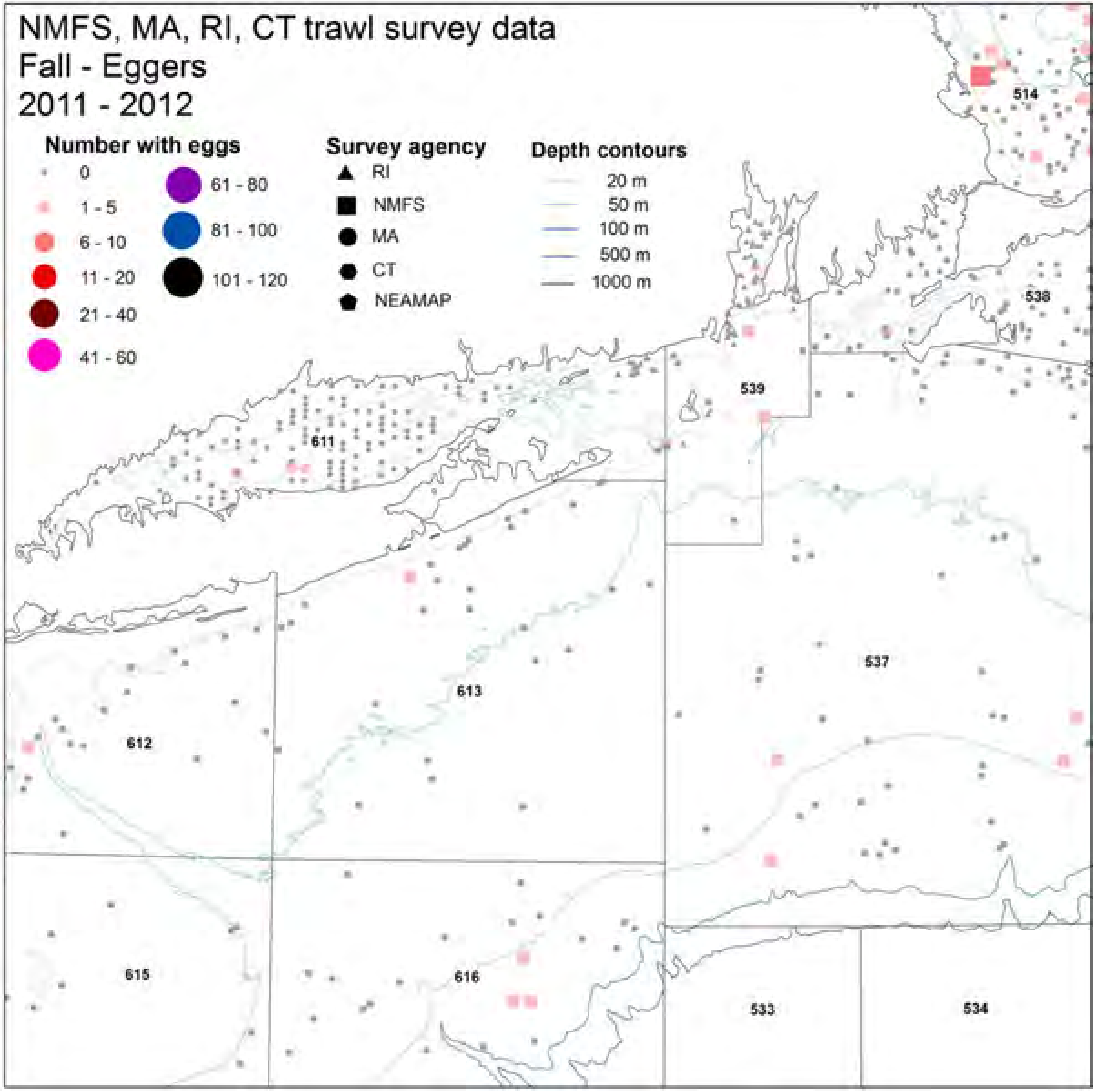
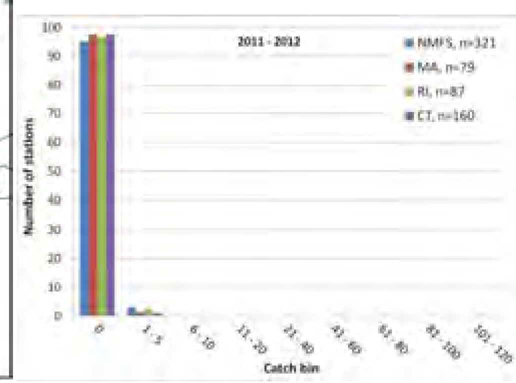


Figure 4.2.1.3.3.3 G



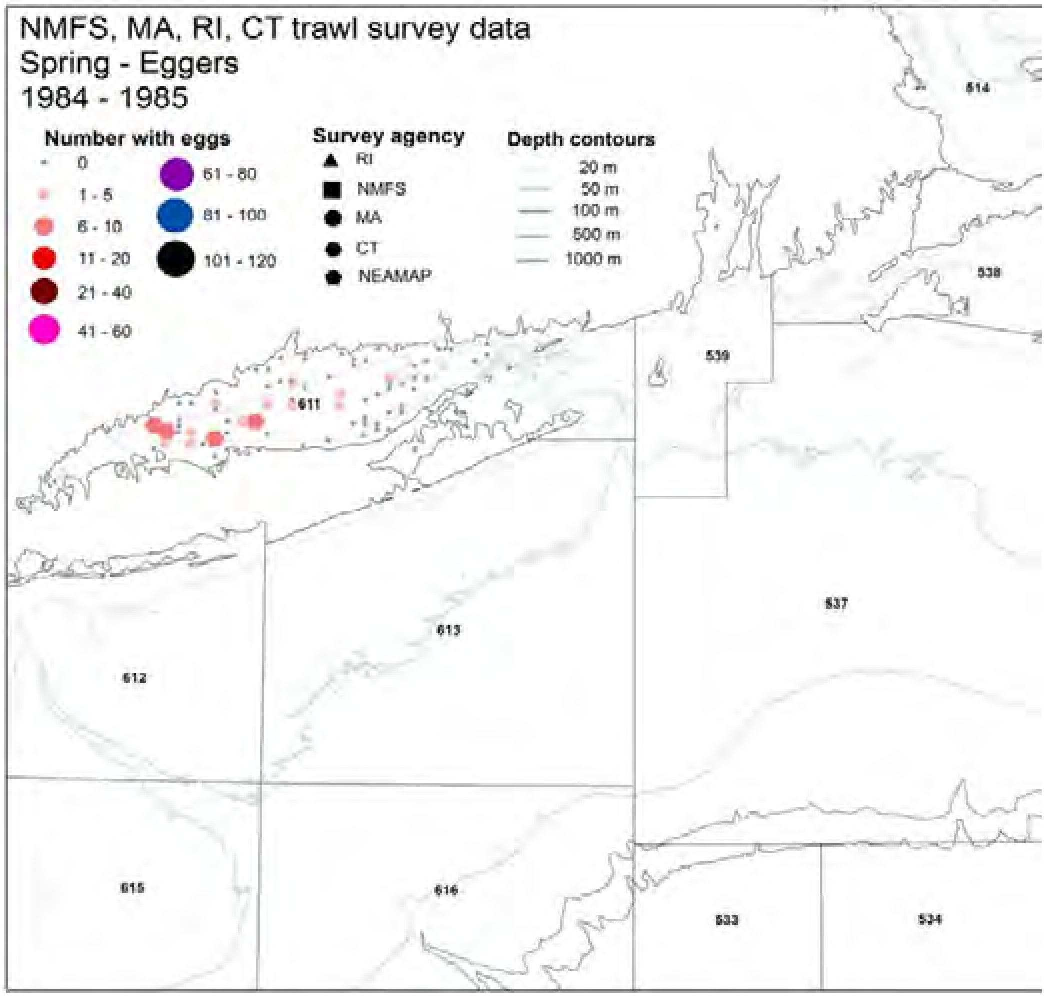


Figure 4.2.1.3.3.4 A

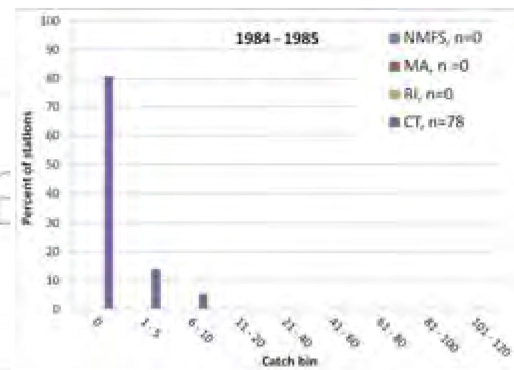
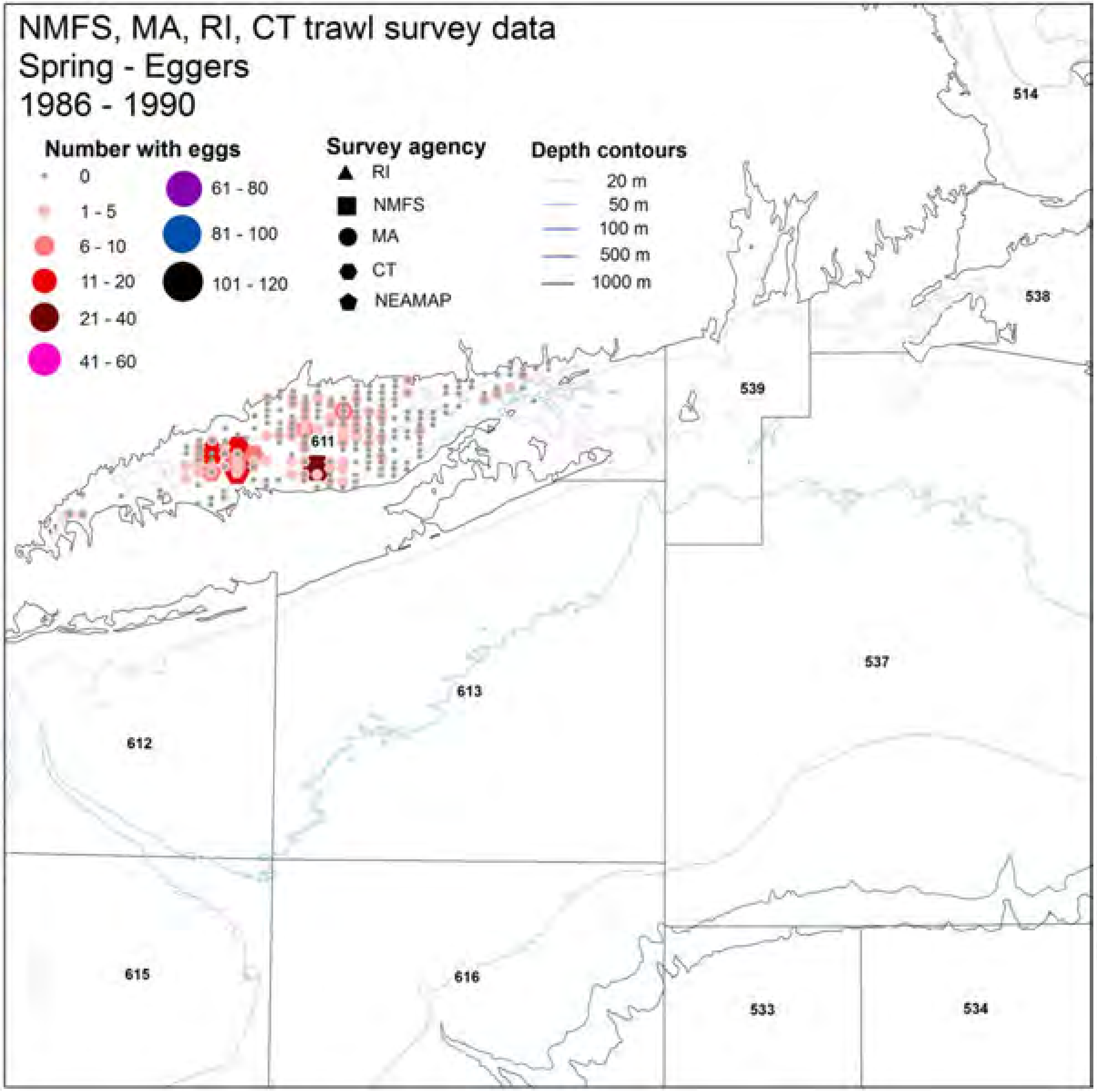


Figure 4.2.1.3.3.4 A – G. **Mean catch per tow of ovigerous females (all sizes) at each spring sampling location from all SNE bottom trawl surveys (MA, RI, CT, NJ, NMFS, NEAMAP), shown in 5 year time periods.** Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.



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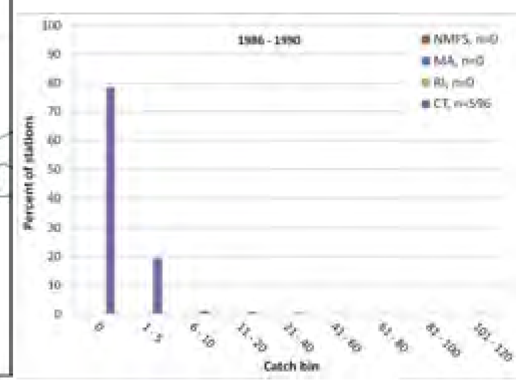

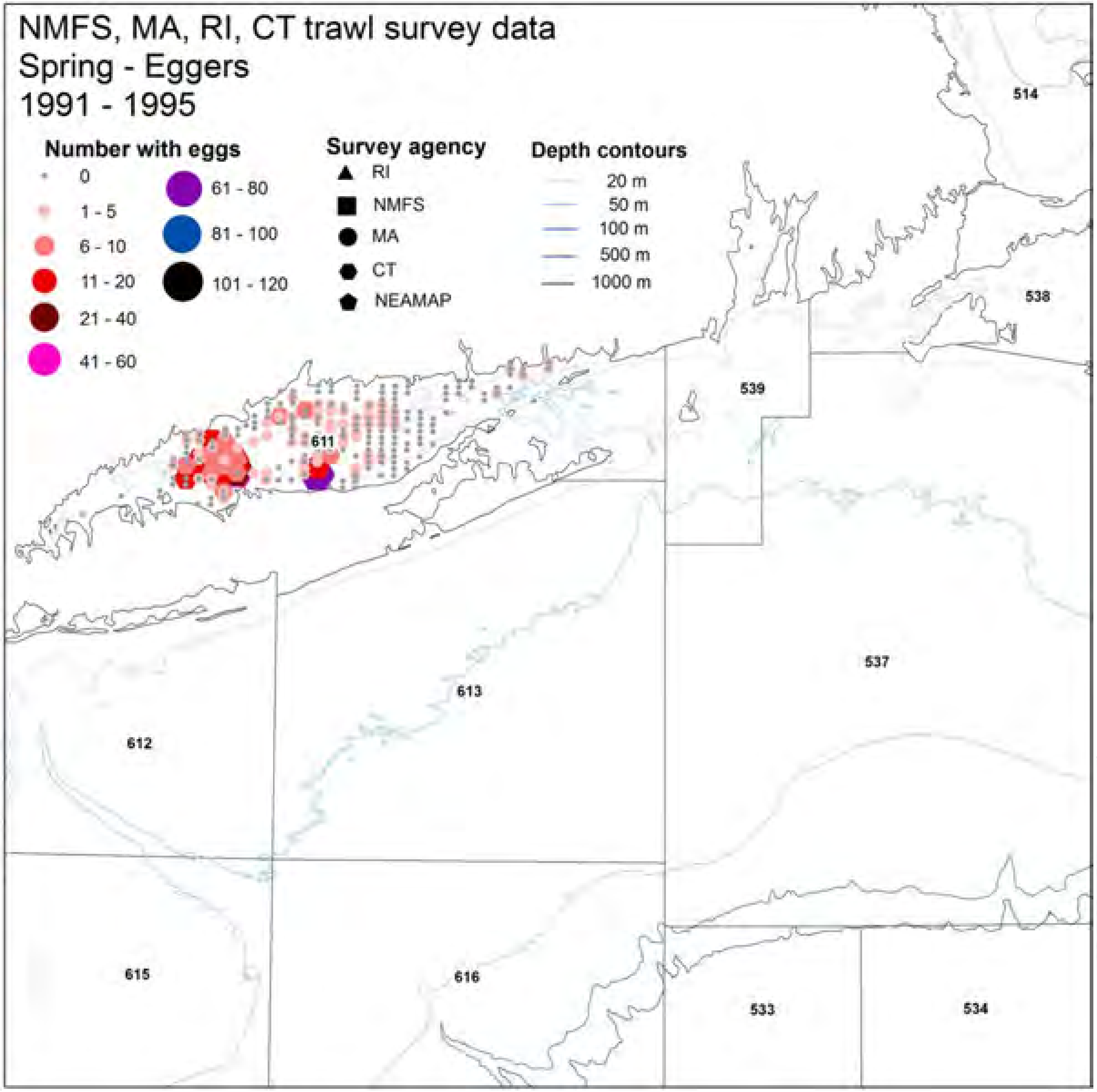

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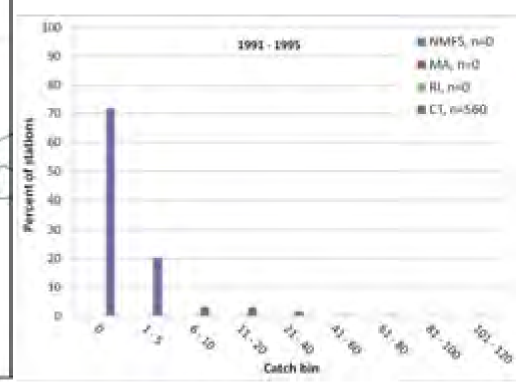

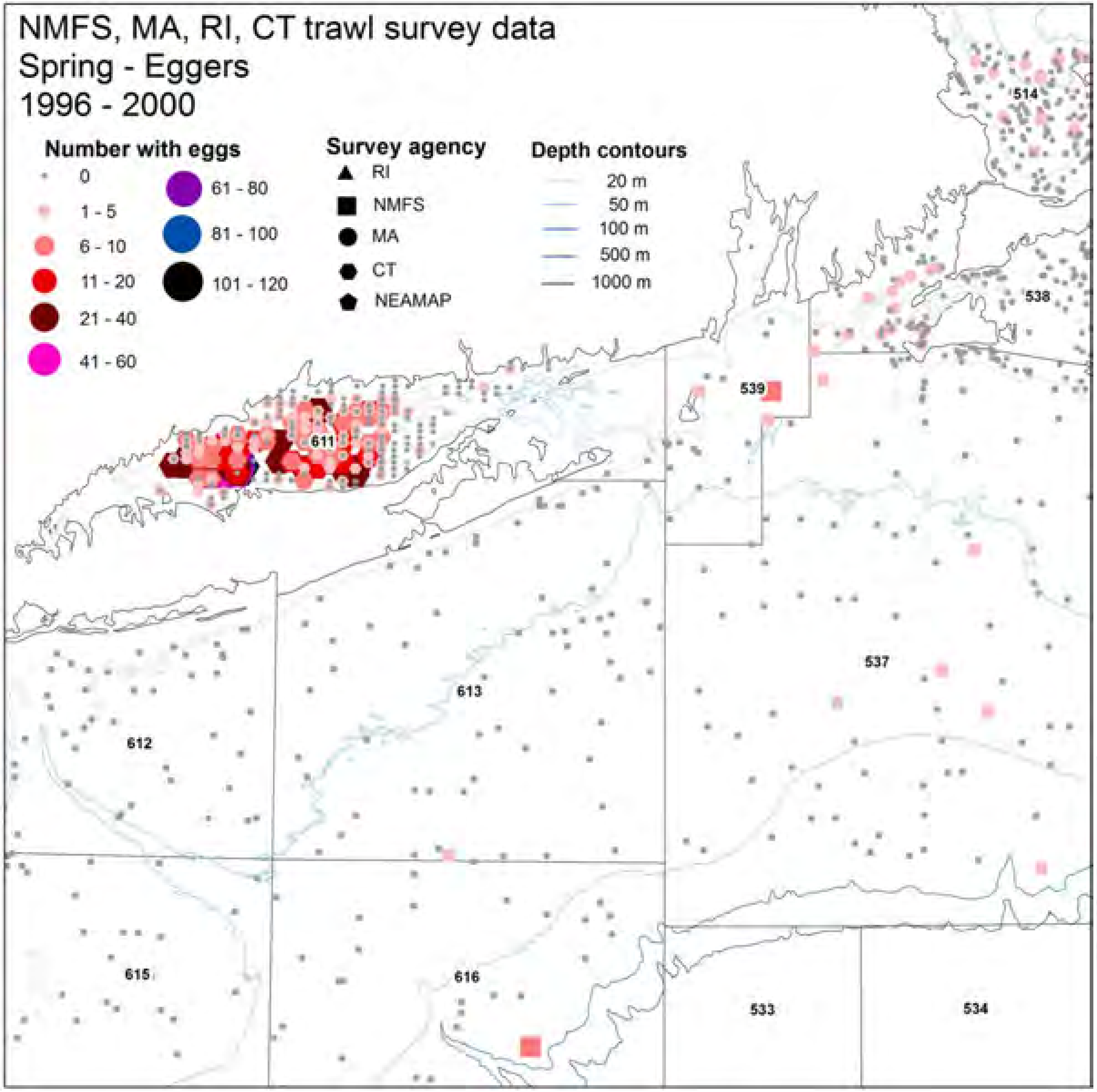

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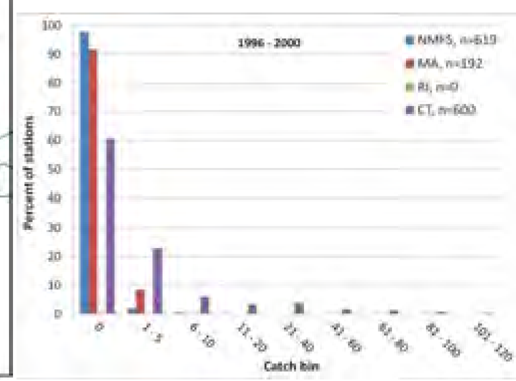

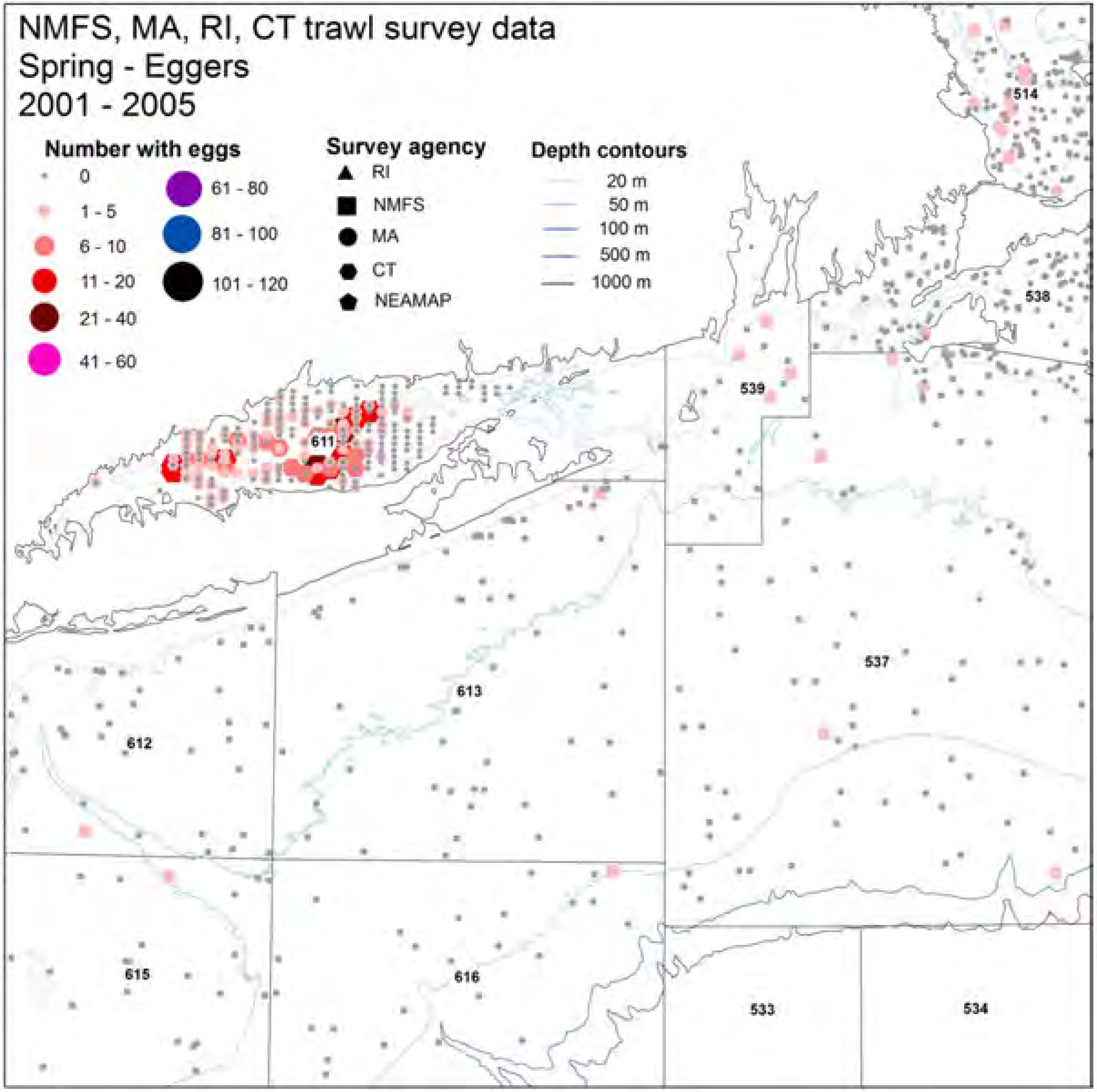

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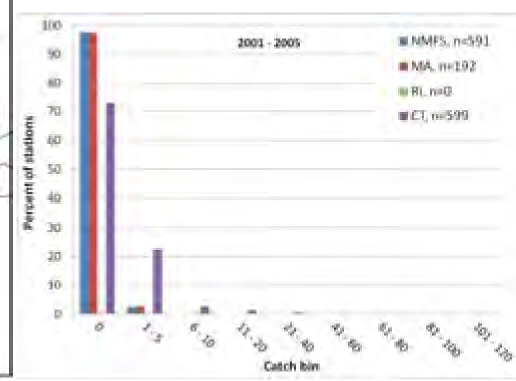


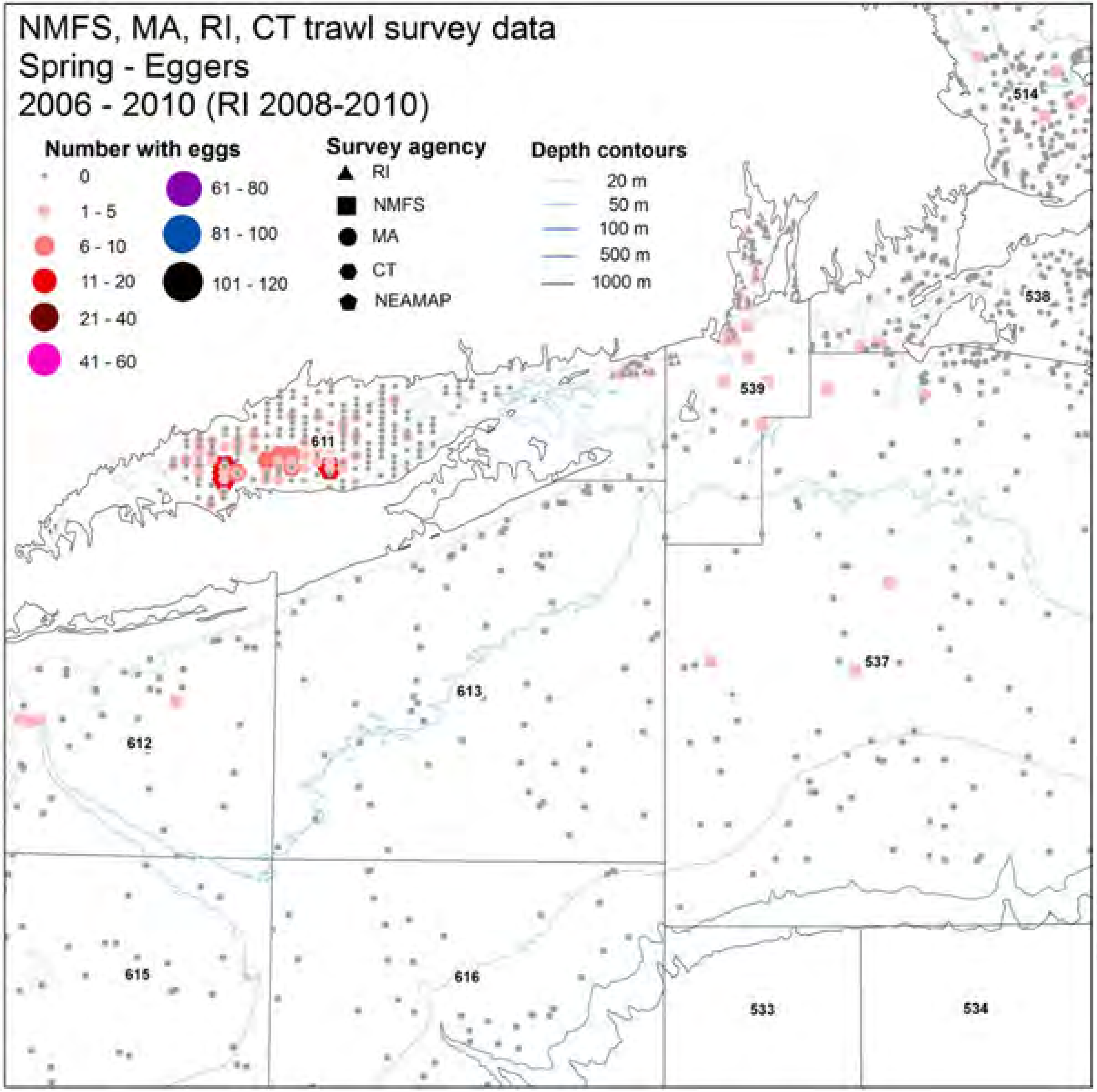
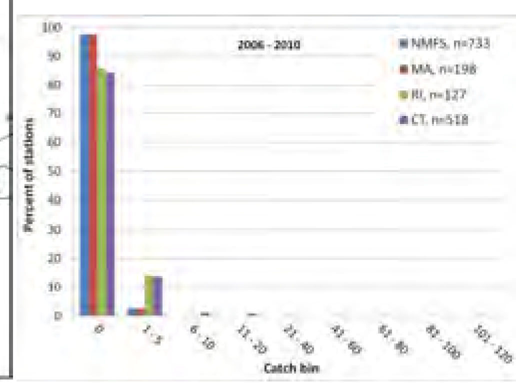


Figure 4.2.1.3.3.4 F



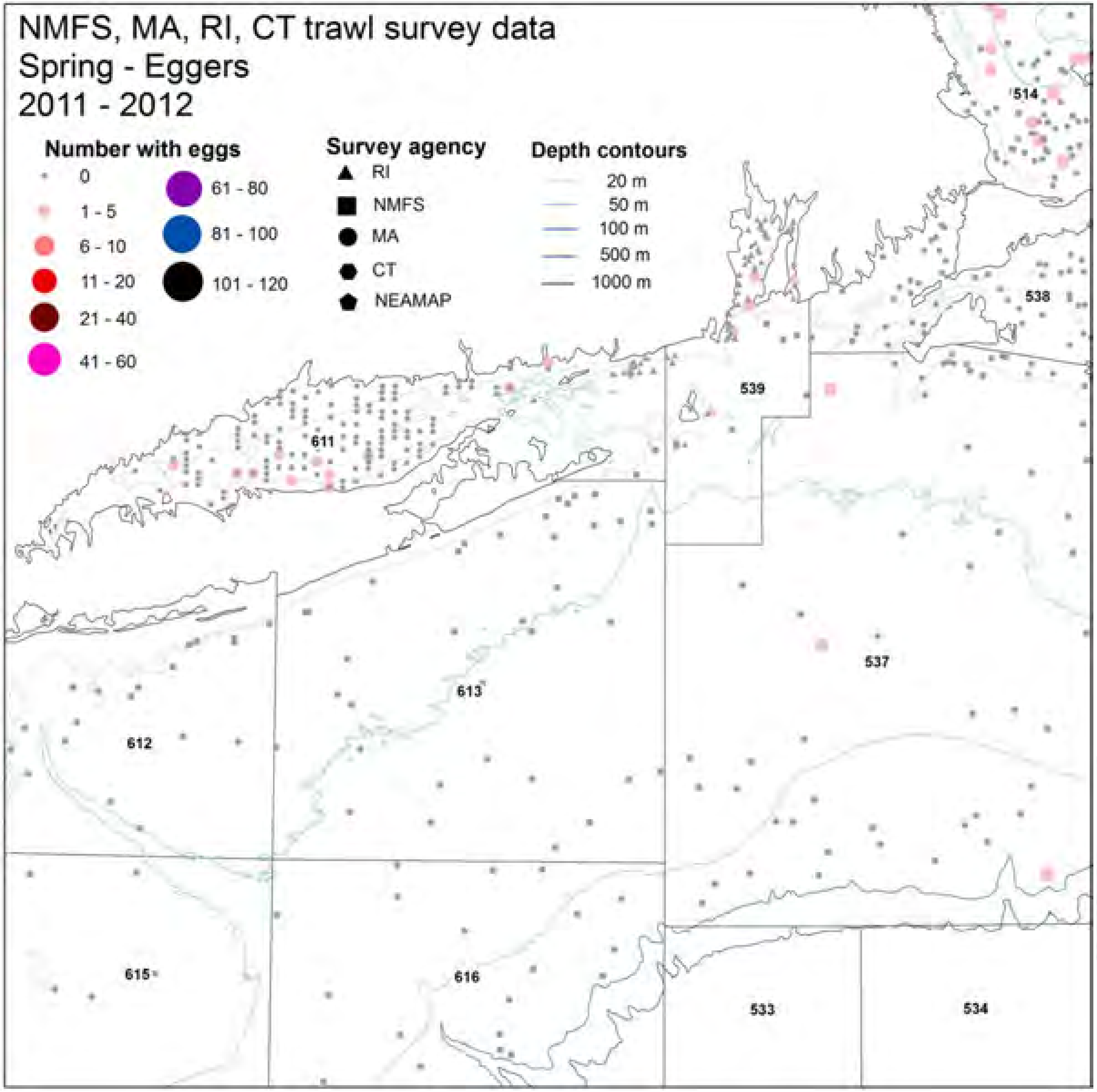
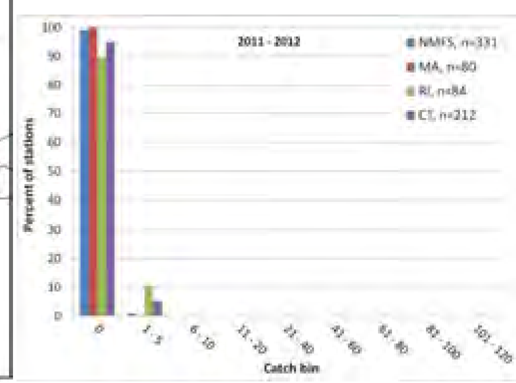


Figure 4.2.1.3.3.4 G



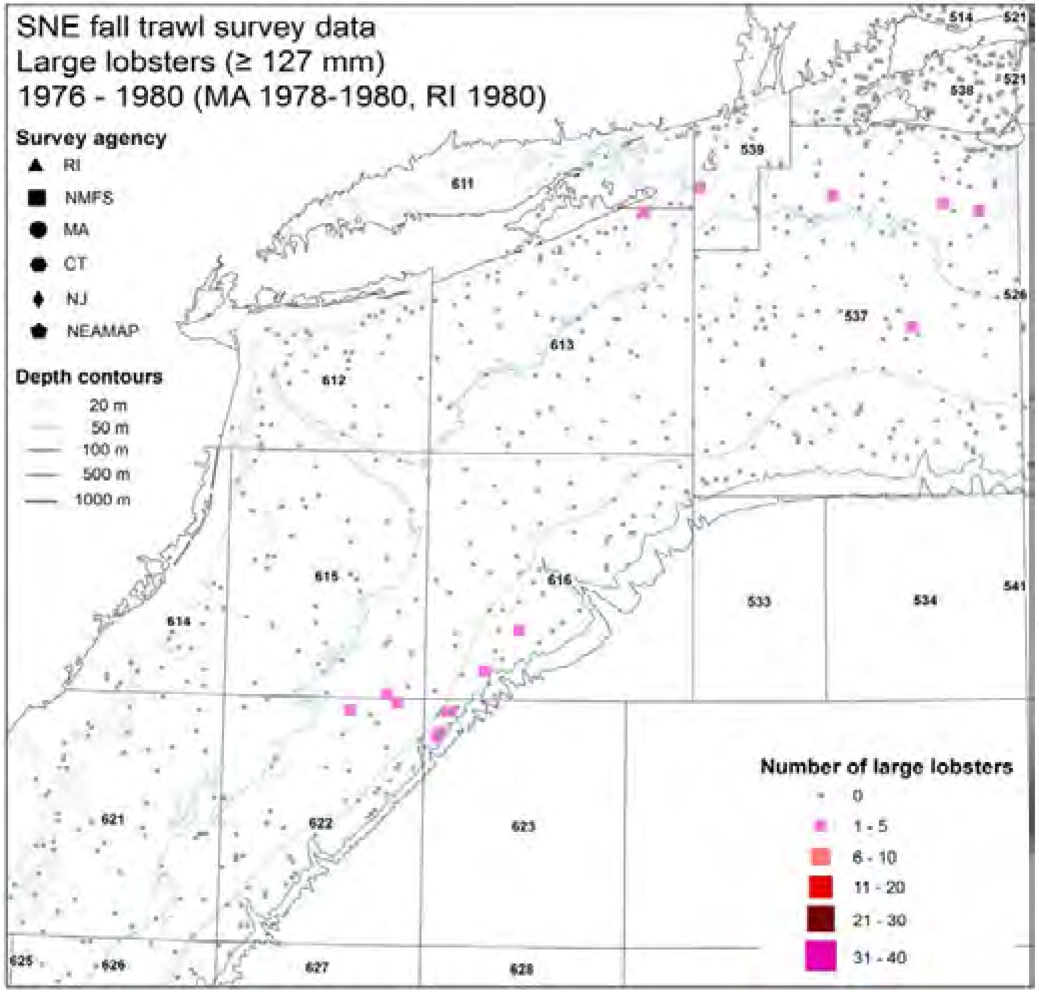


Figure 4.2.1.3.3.5 A

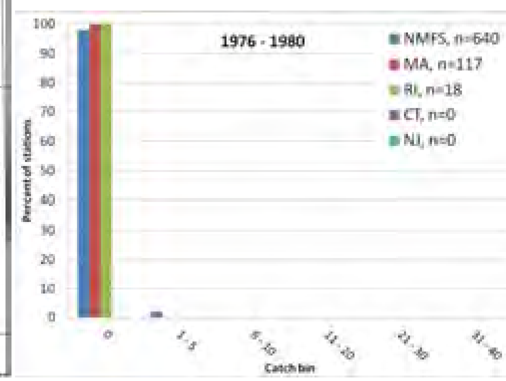
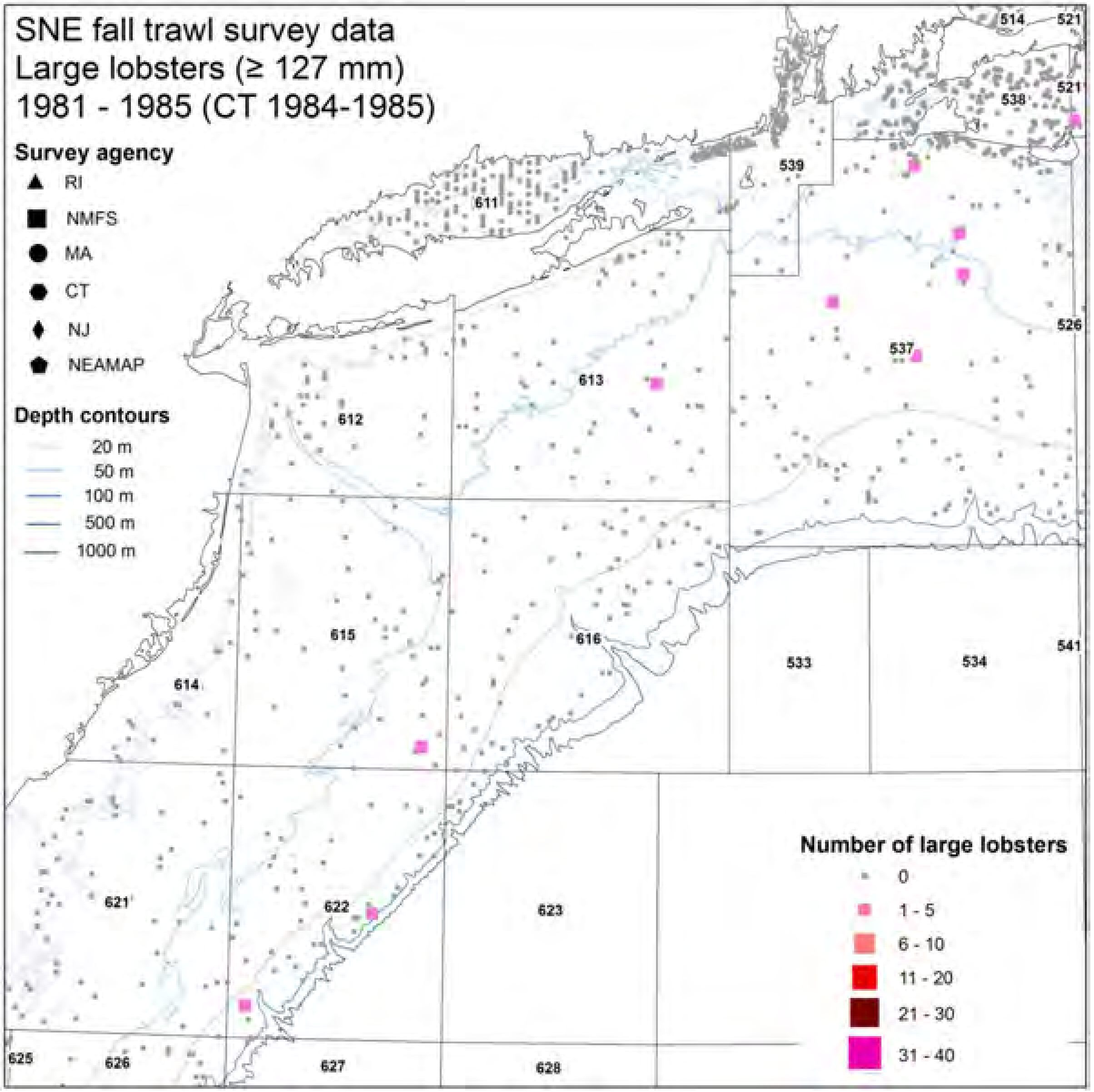


Figure 4.2.1.3.3.5 A – H. Mean catch per tow of "large" lobster (≥ 127 mm CL) at each fall sampling location from all SNE bottom trawl surveys (MA, RI, CT, NJ, NMFS, NEAMAP), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.



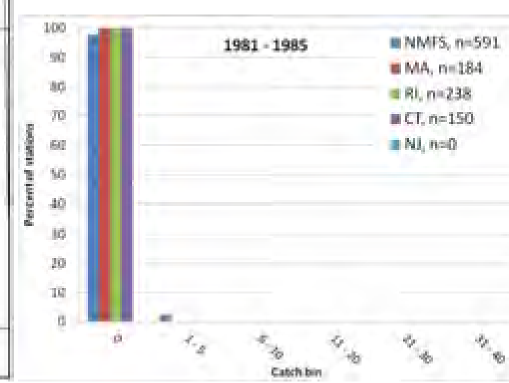
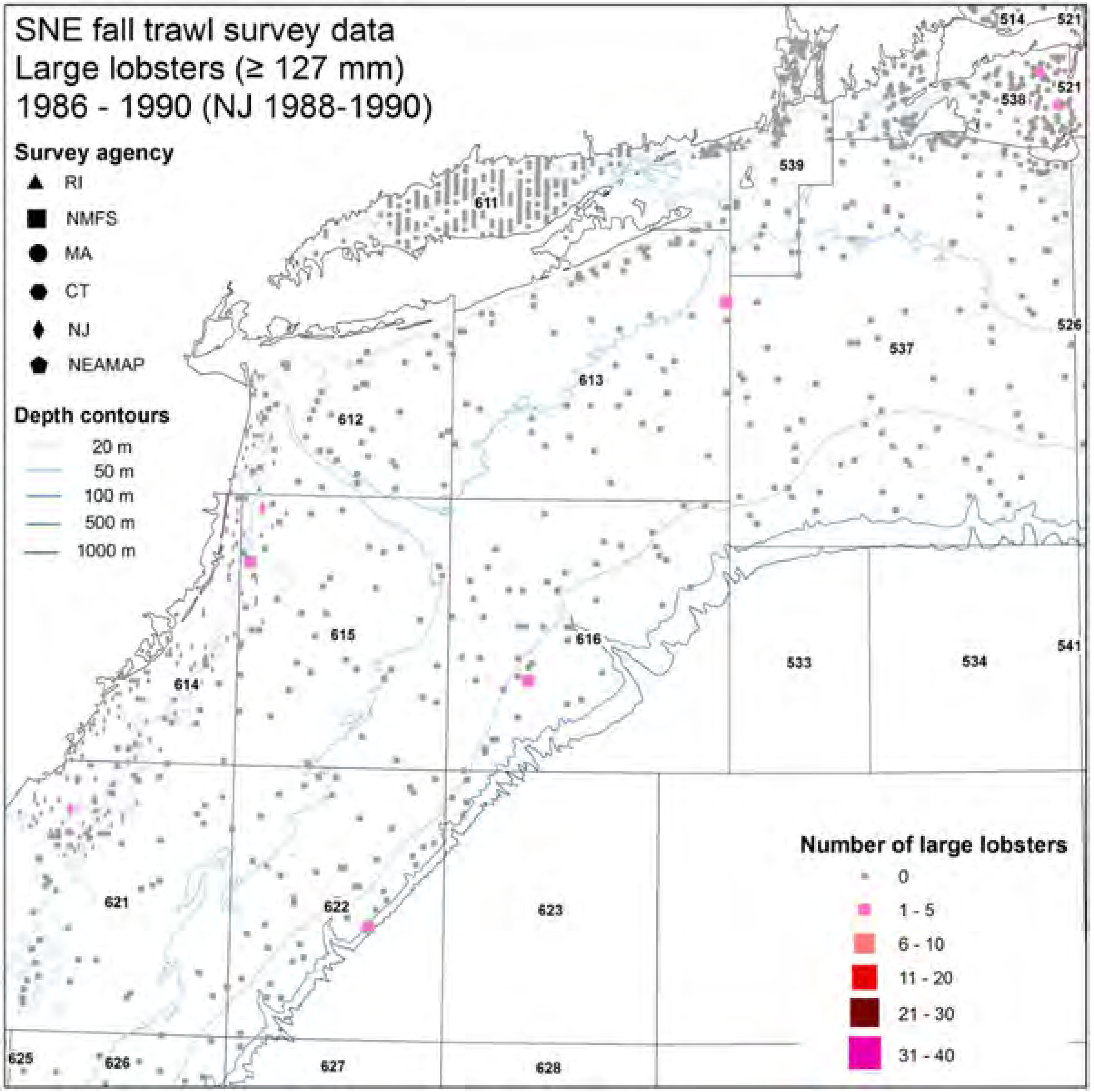
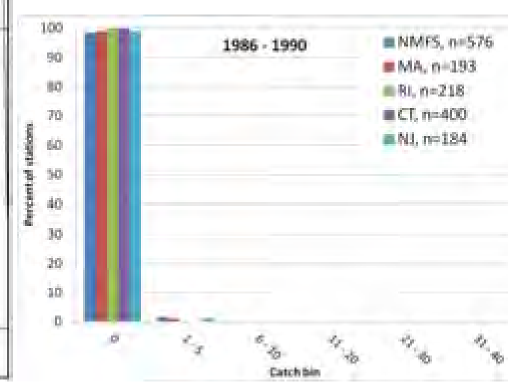


Figure 4.2.1.3.3.5 B





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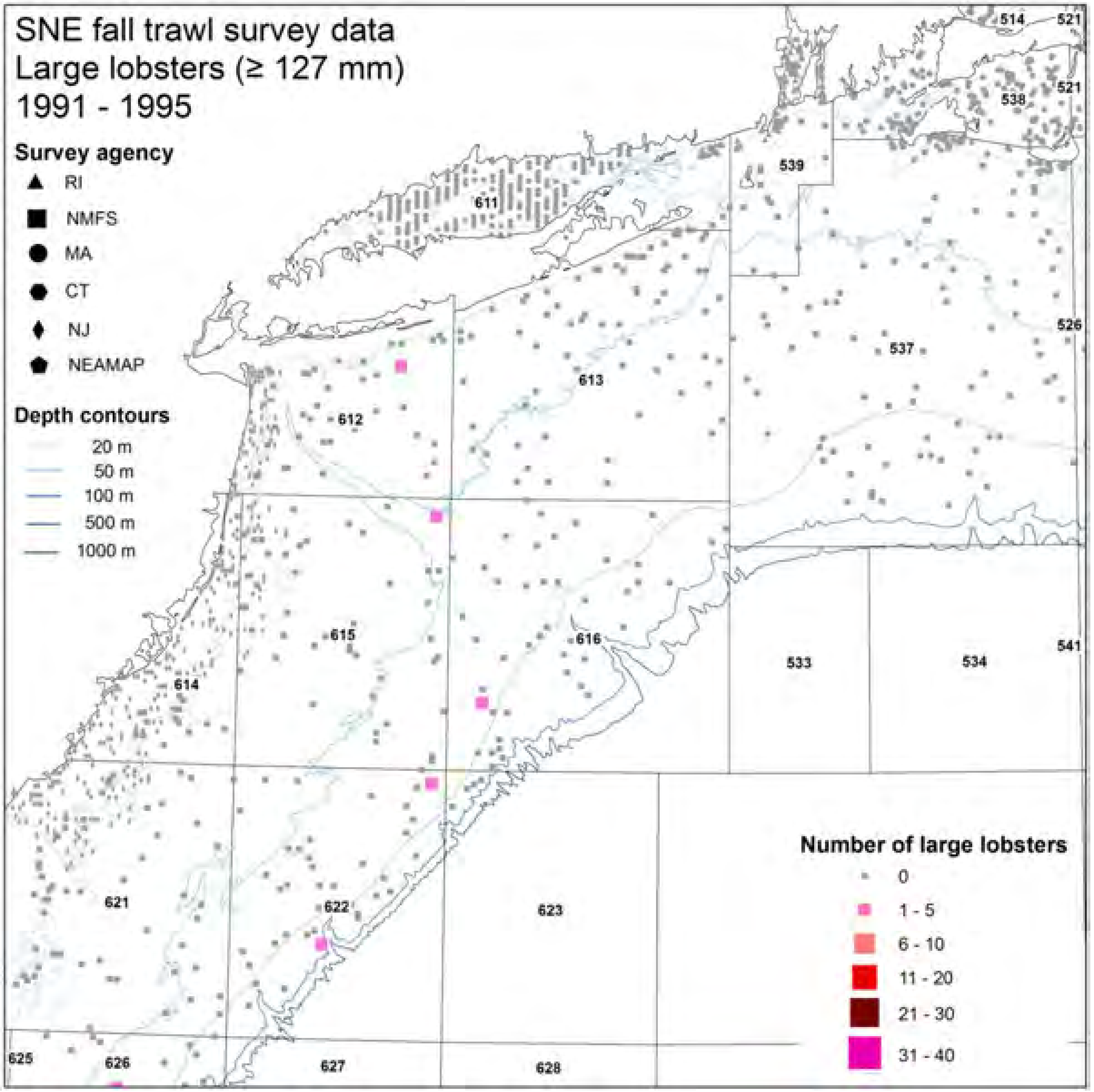
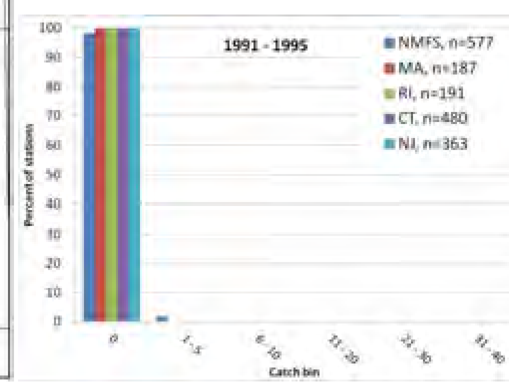
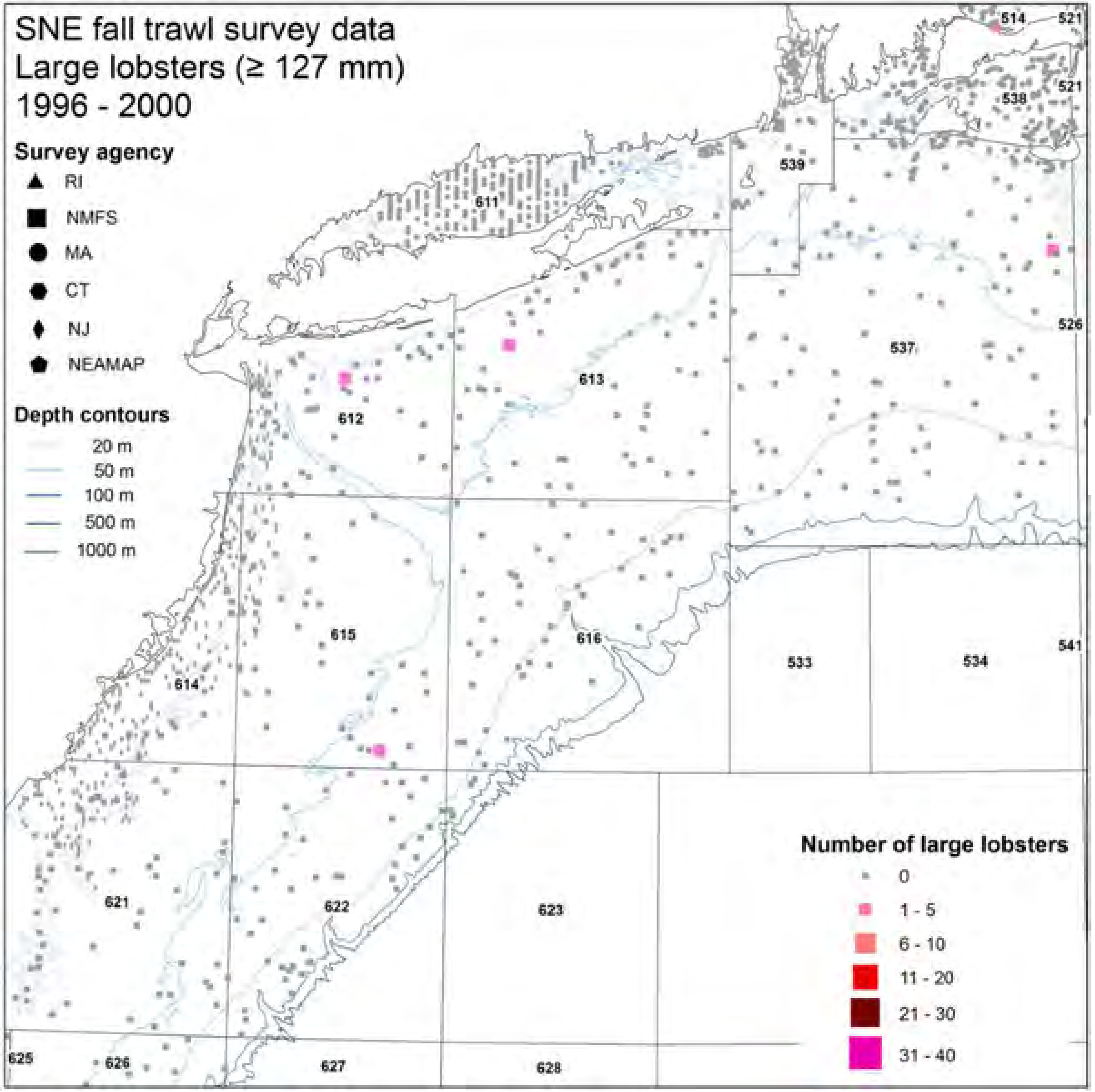
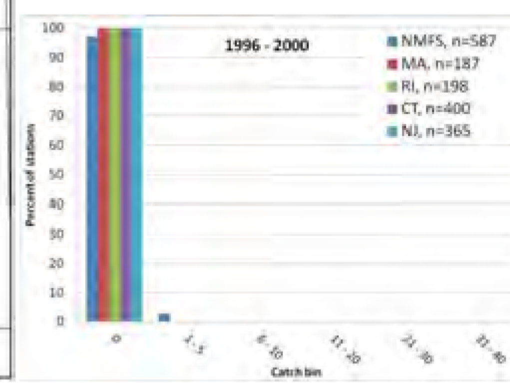


Figure 4.2.1.3.3.5 D







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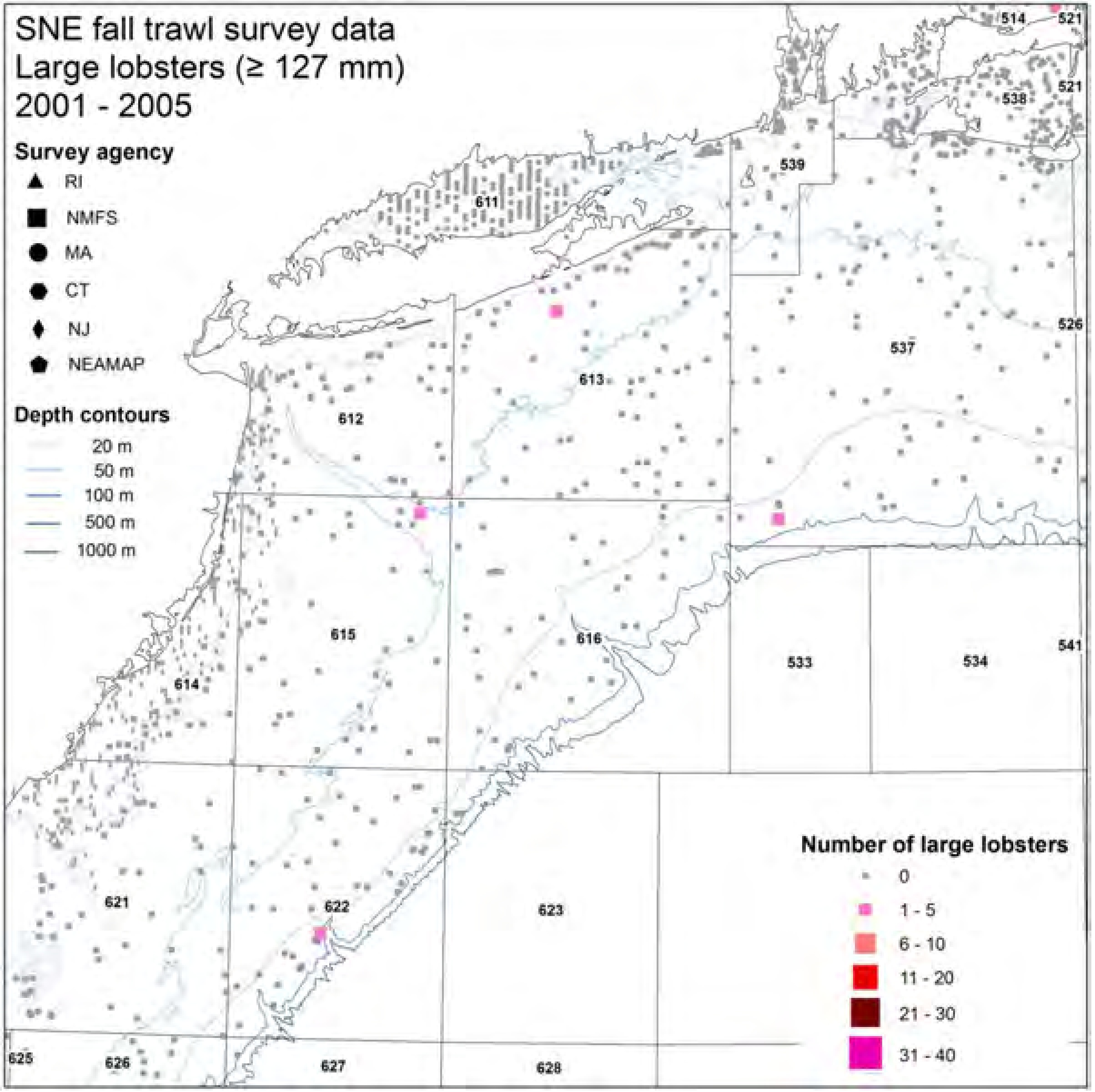

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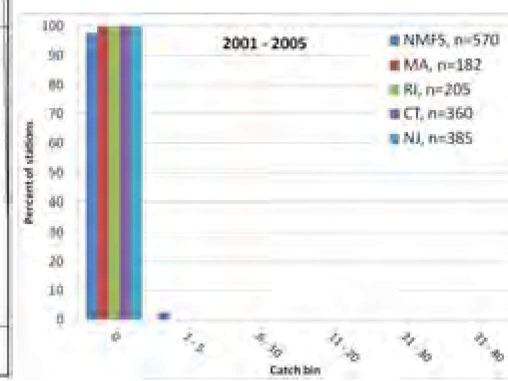


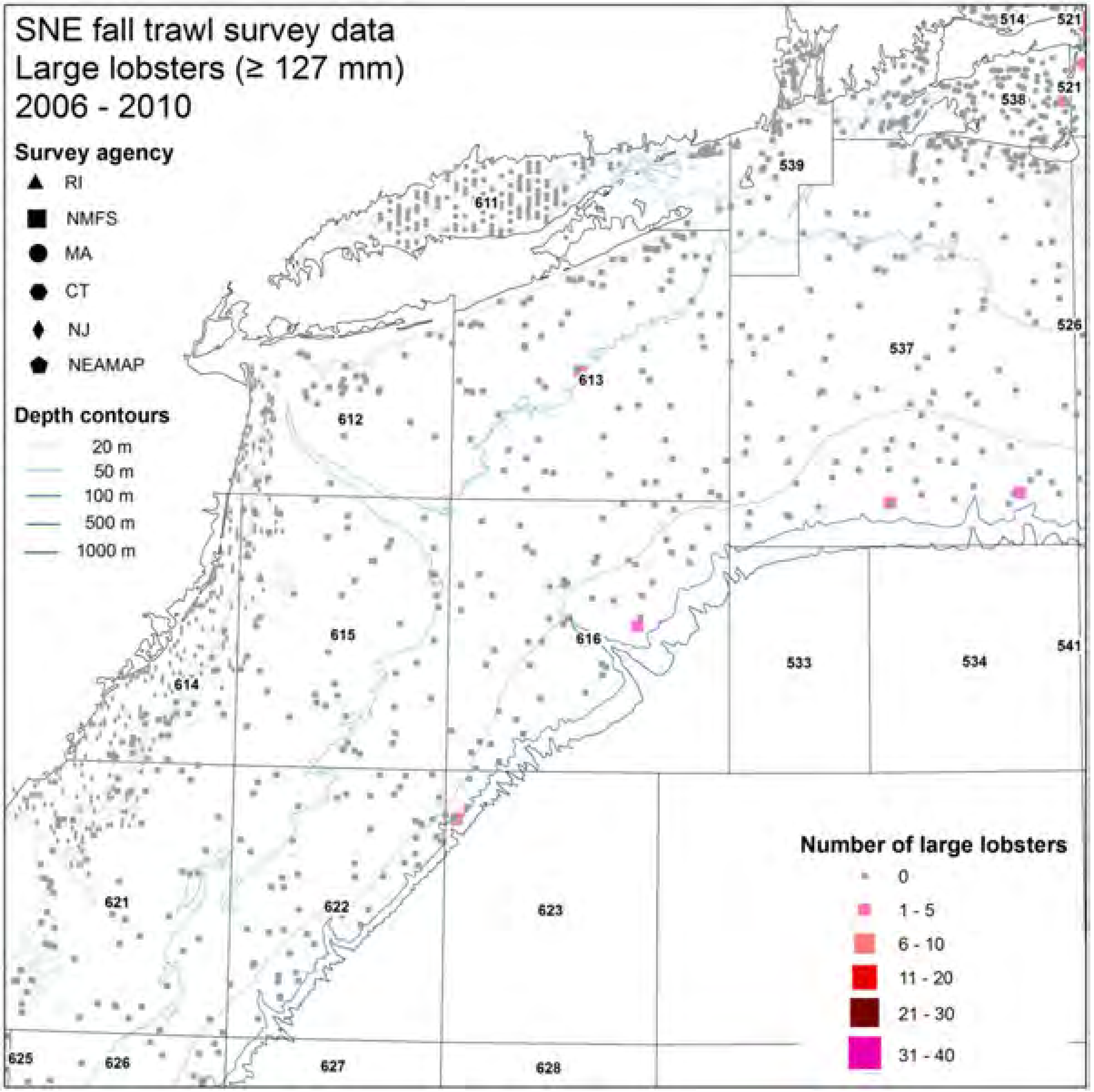
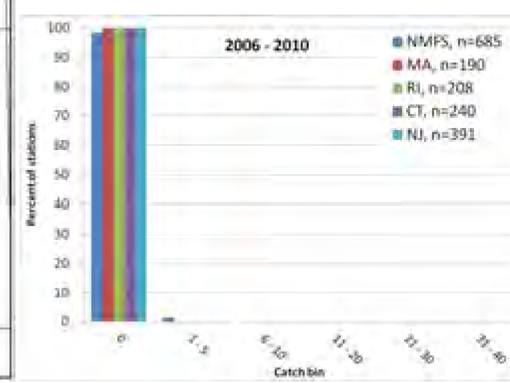


Figure 4.2.1.3.3.5 G



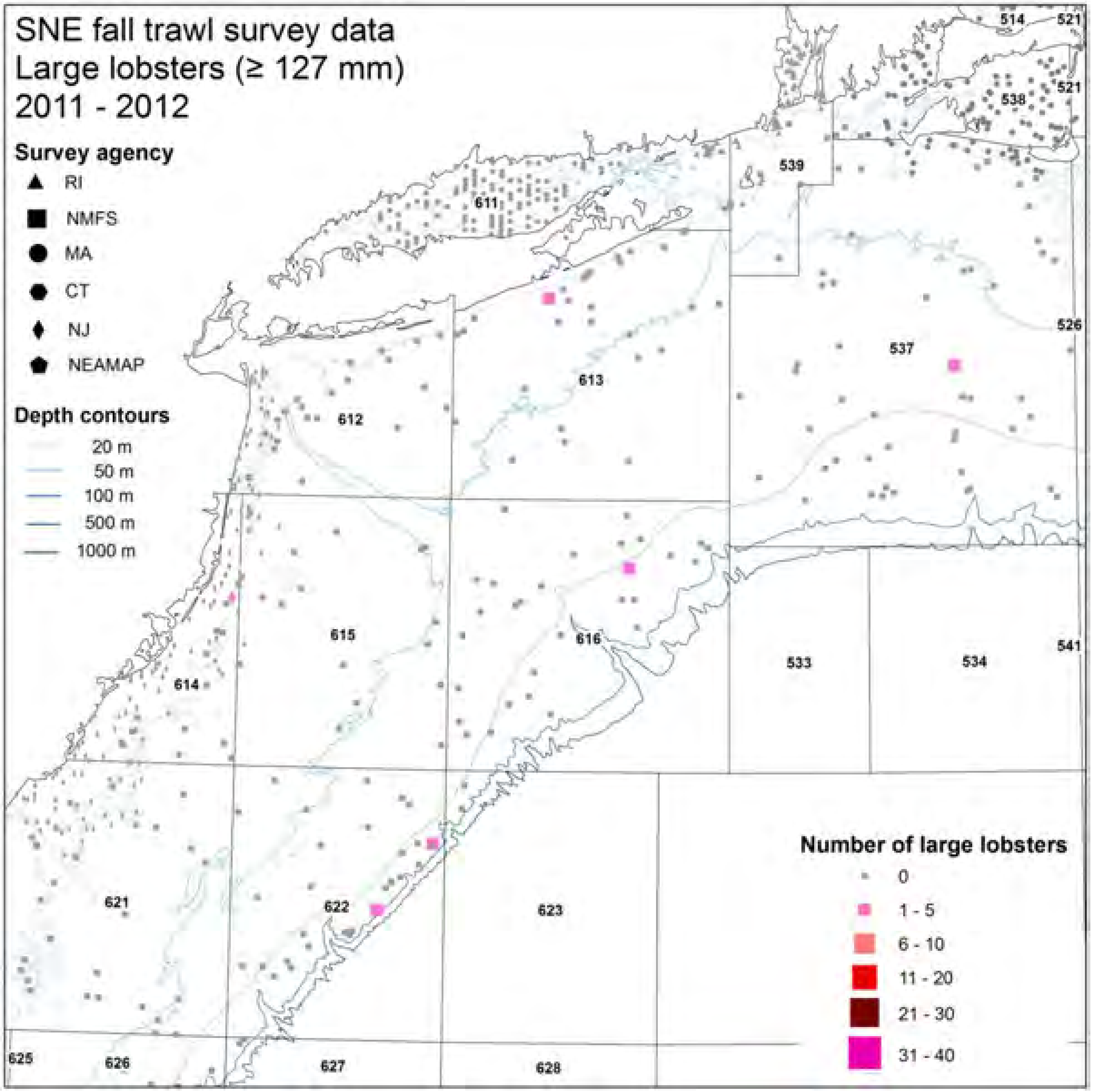
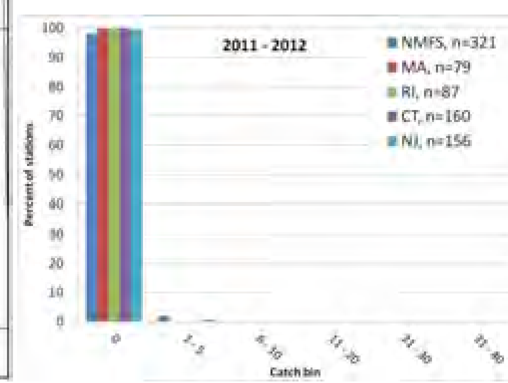


Figure 4.2.1.3.3.5 H



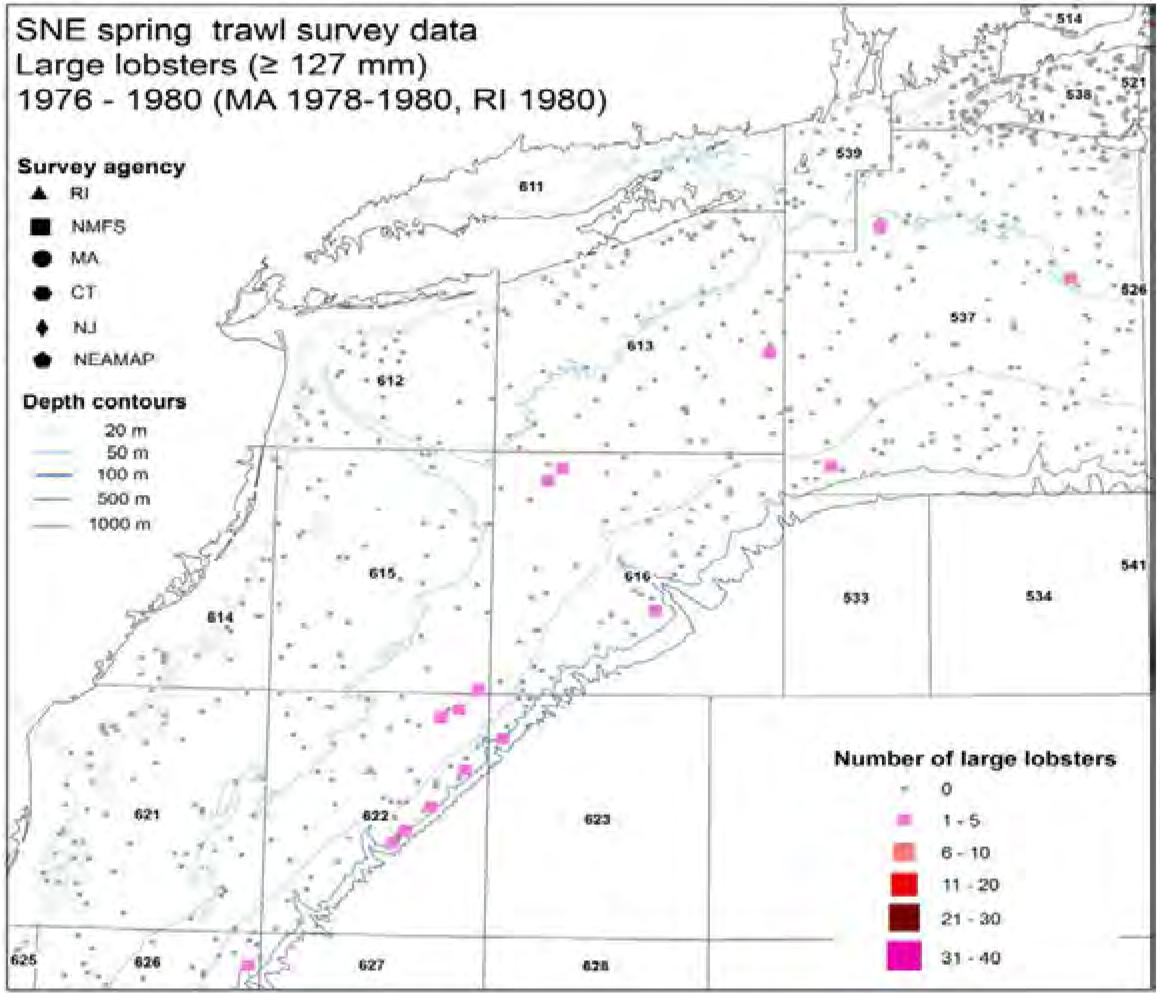


Figure 4.2.1.3.3.6 A

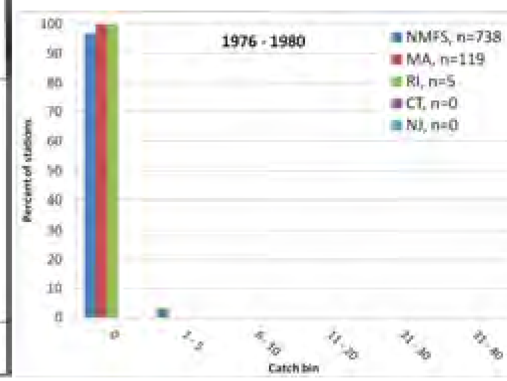


Figure 4.2.1.3.3.6 A – H. Mean catch per tow of "large" lobster (≥ 127 mm CL) at each spring sampling location from all SNE bottom trawl surveys (MA, RI, CT, NJ, NMFS, NEAMAP), shown in 5 year time periods. Histograms show the percent of stations that fell within each catch bin by survey agency for each 5 year time period.

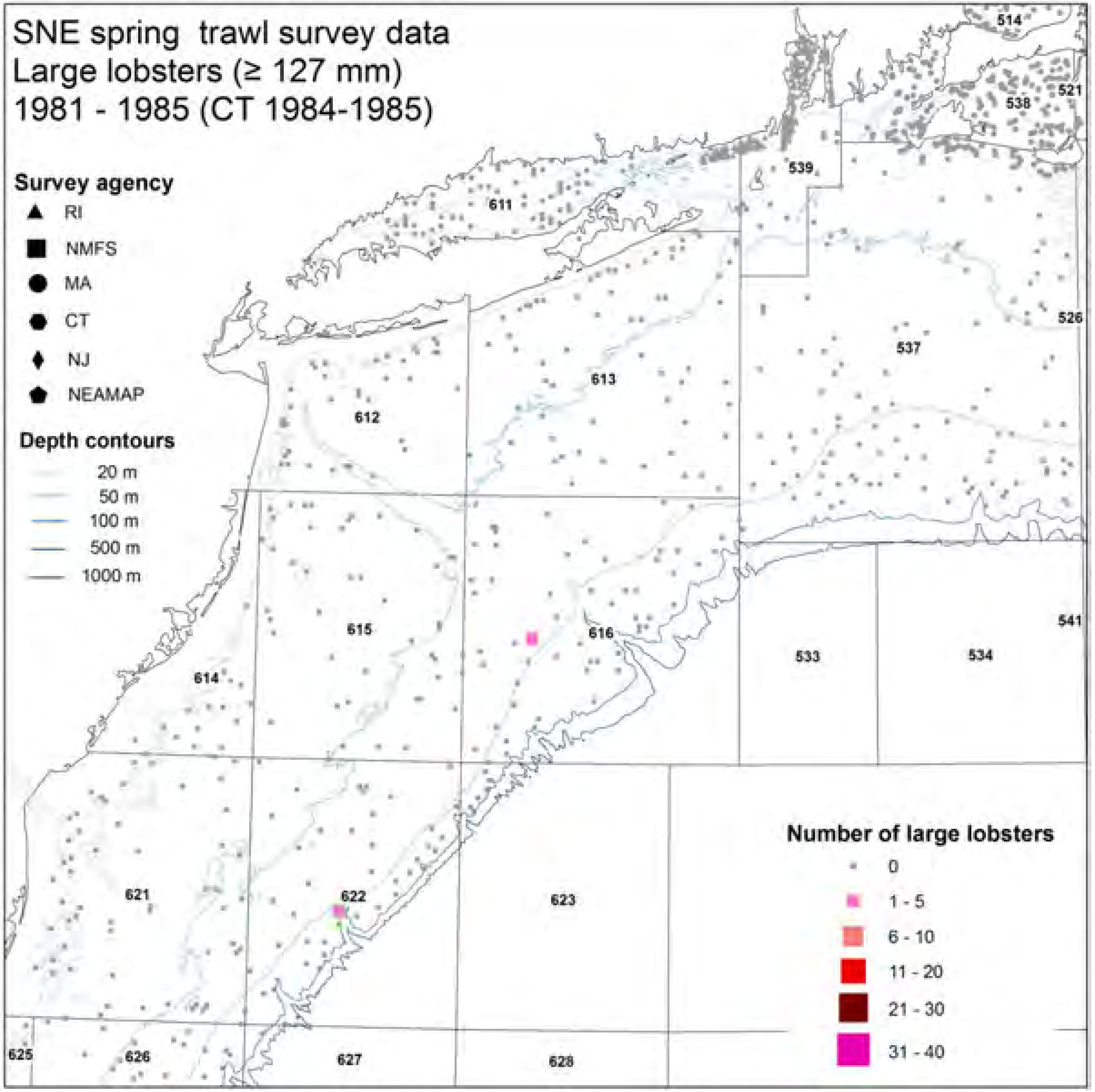
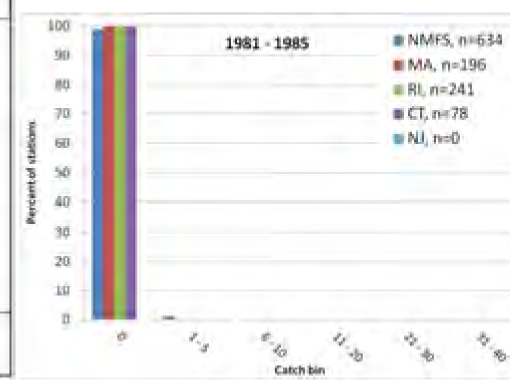
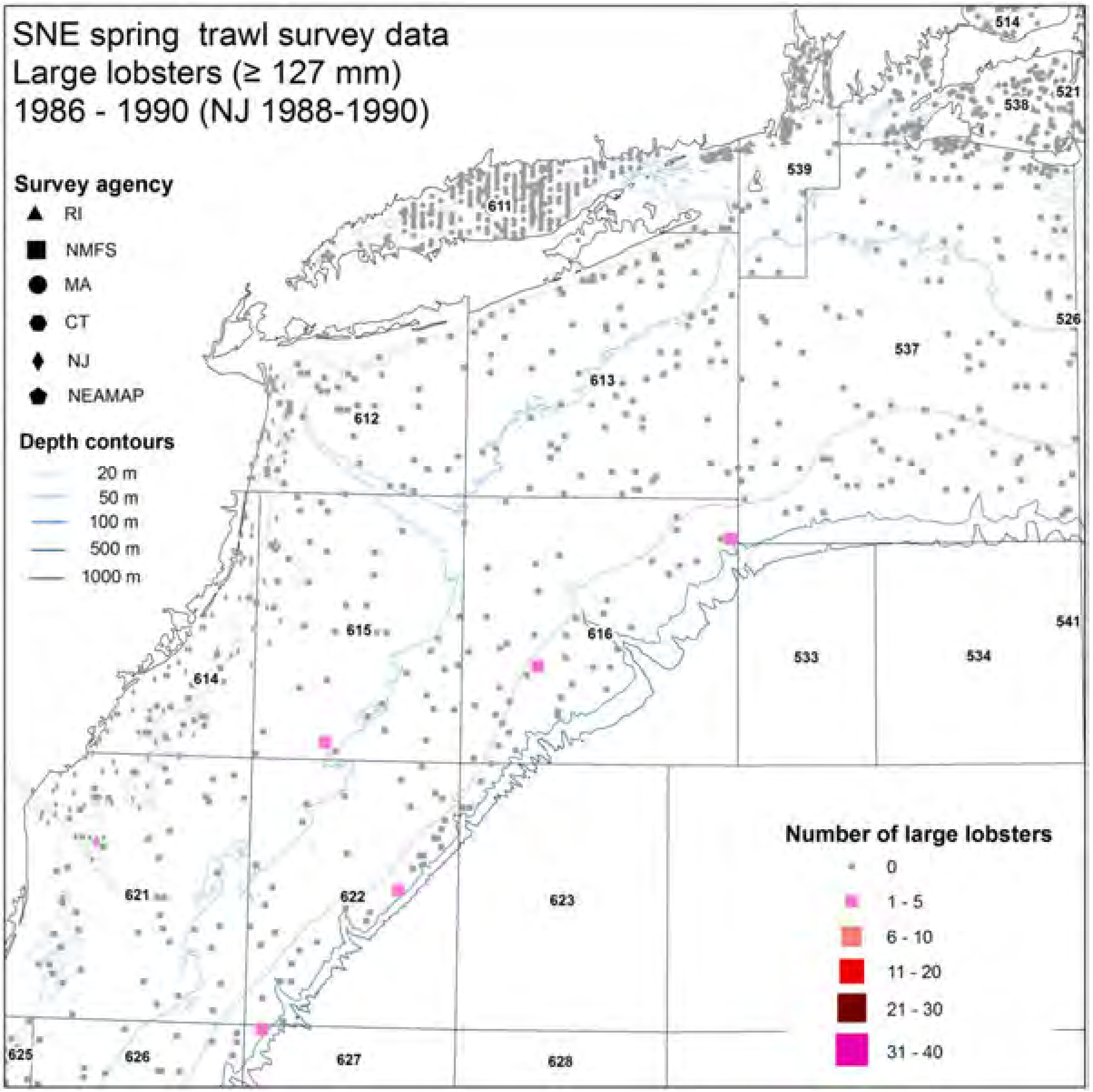


Figure 4.2.1.3.3.6 B





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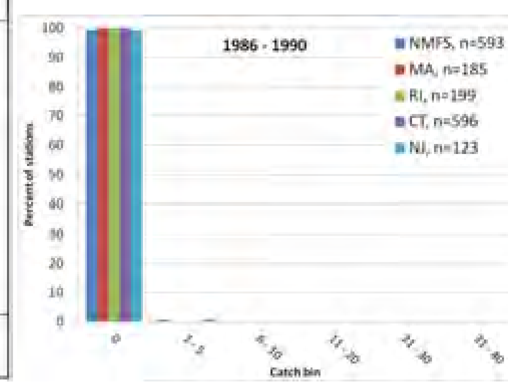

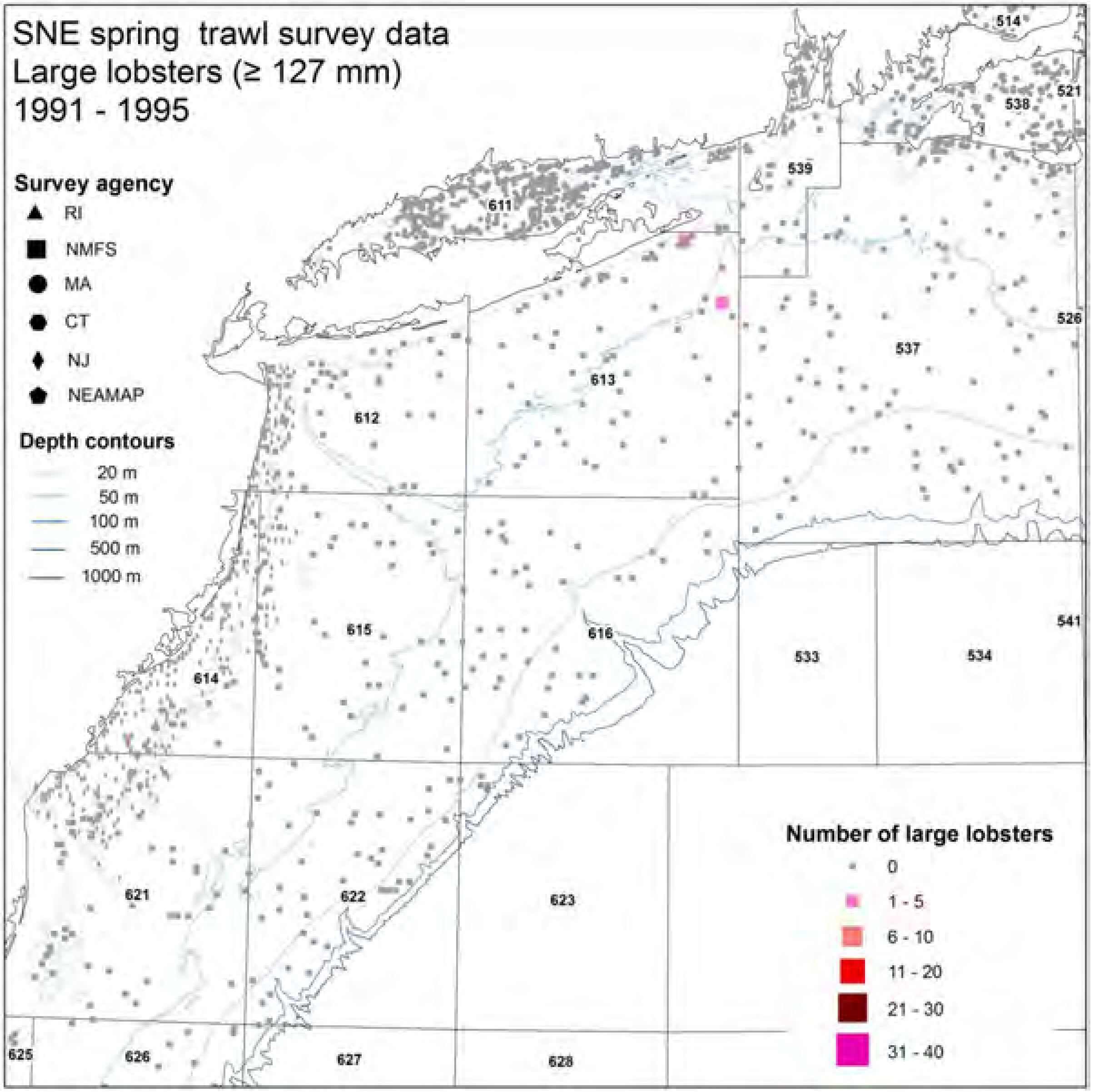

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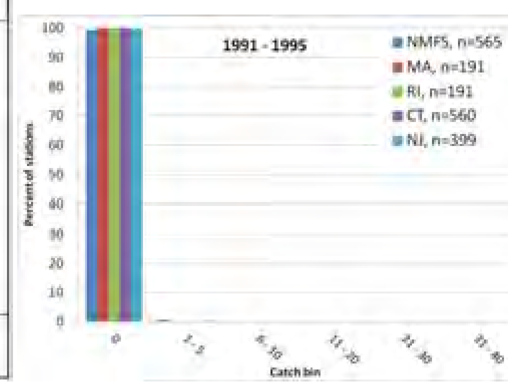


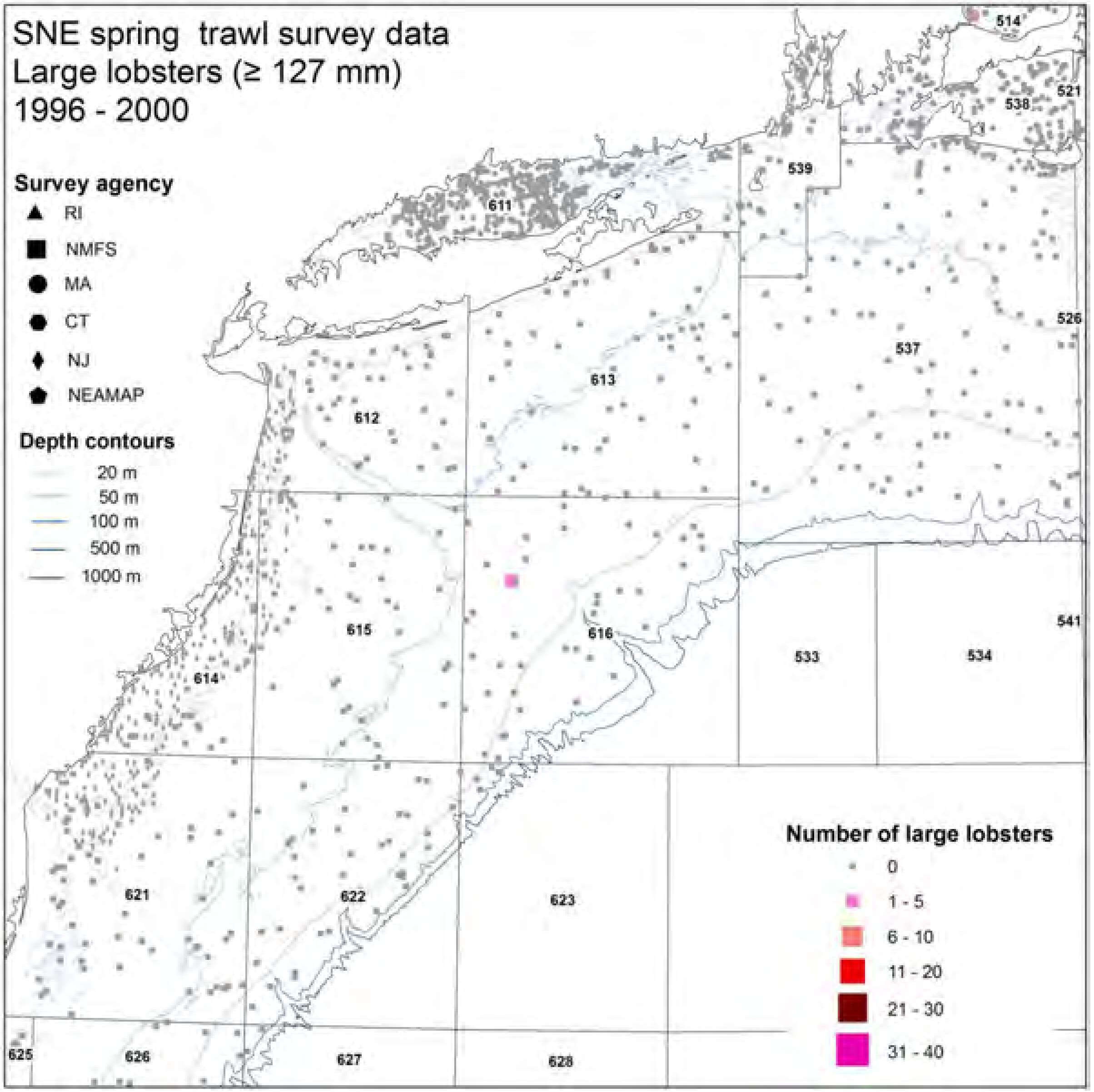
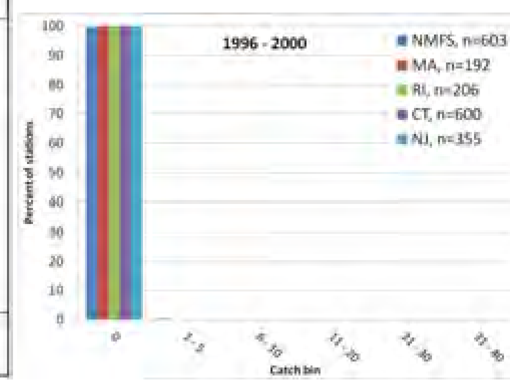
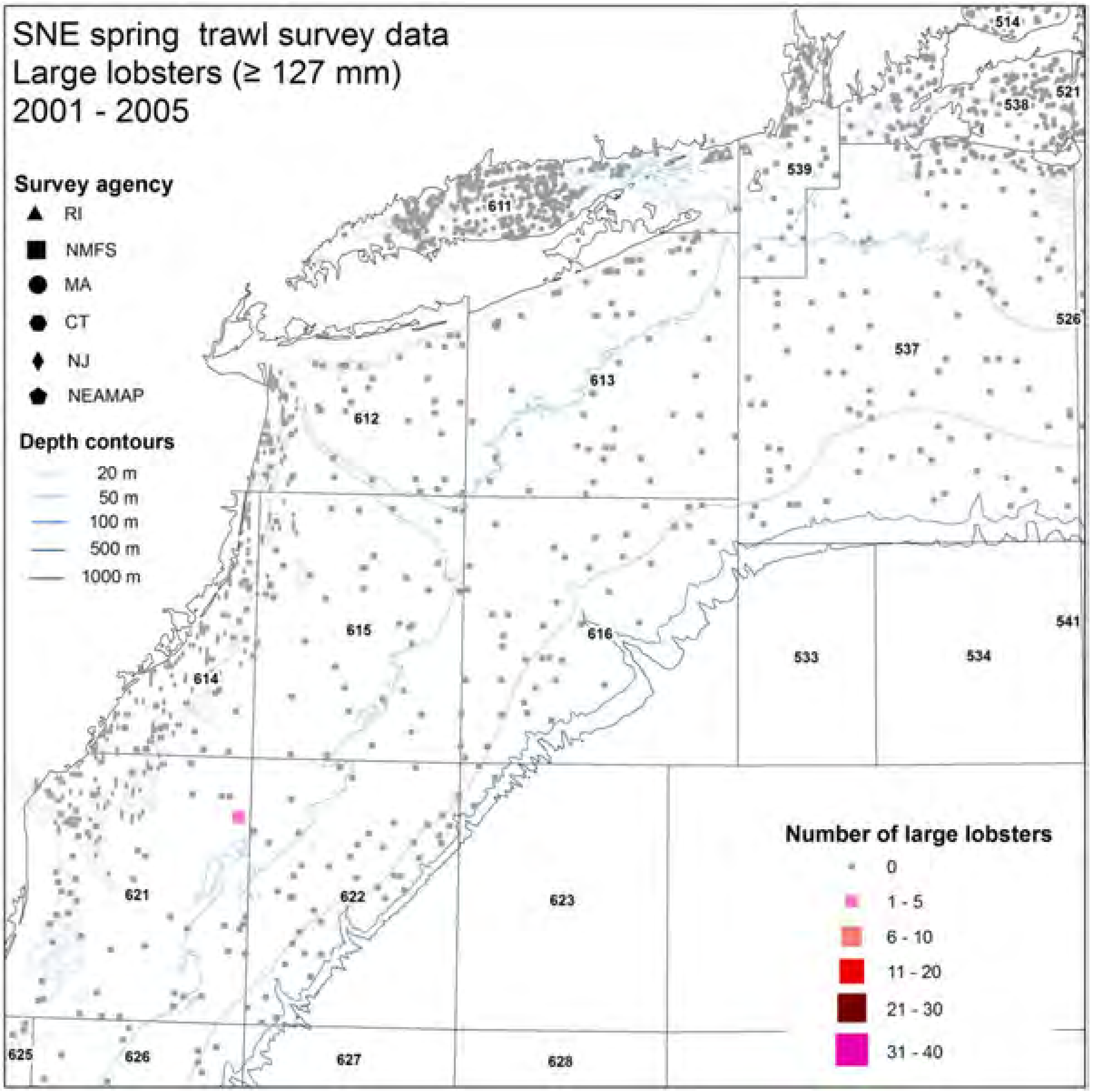


Figure 4.2.1.3.3.6 E





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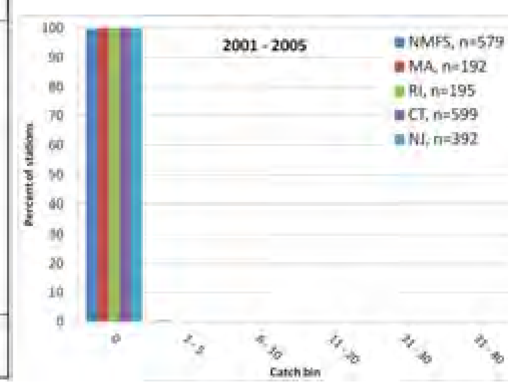


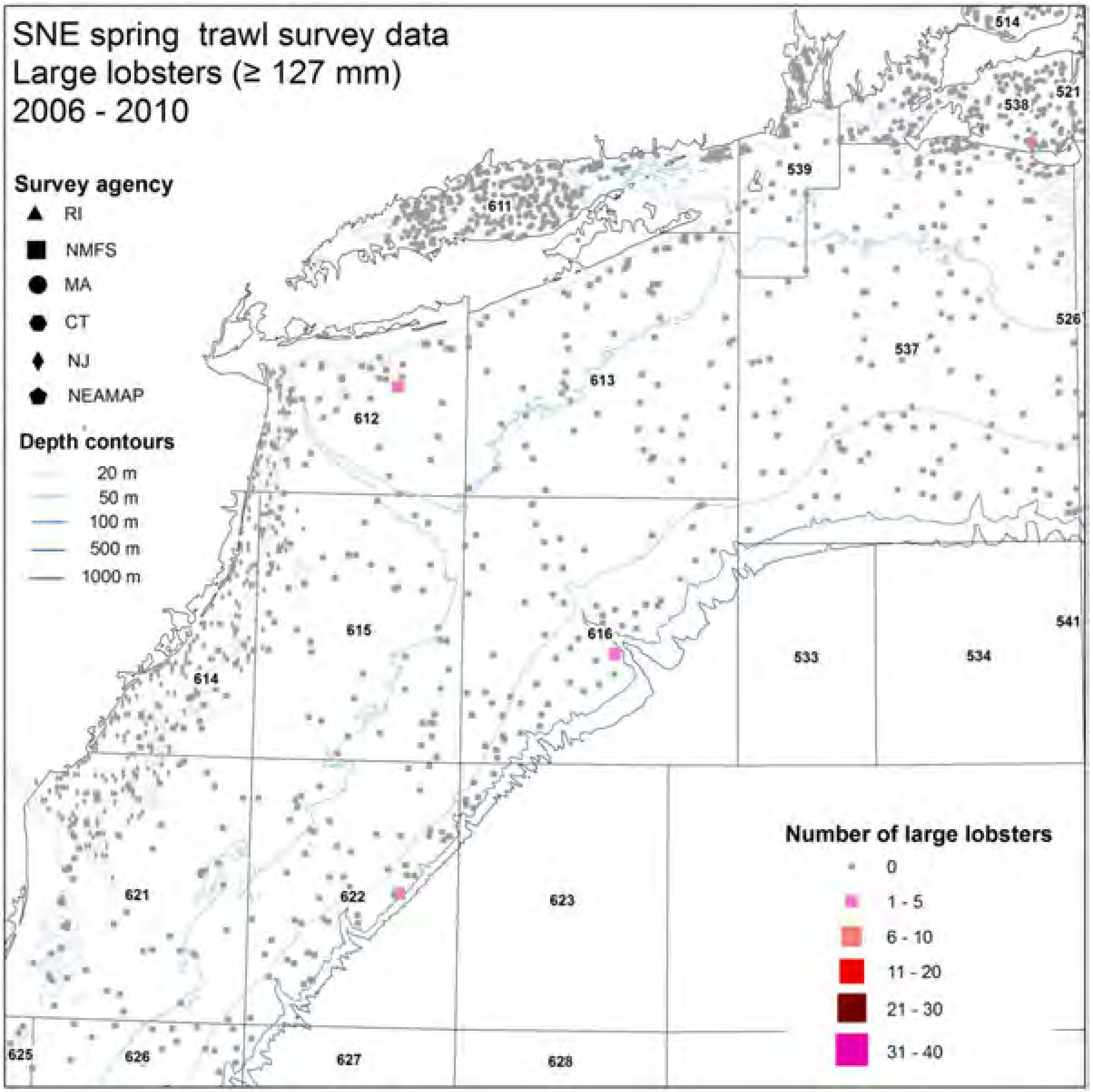
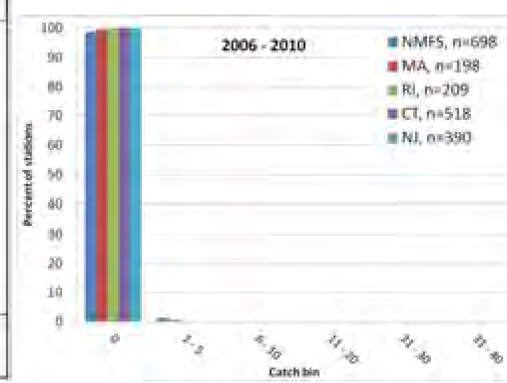


Figure 4.2.1.3.3.6 G



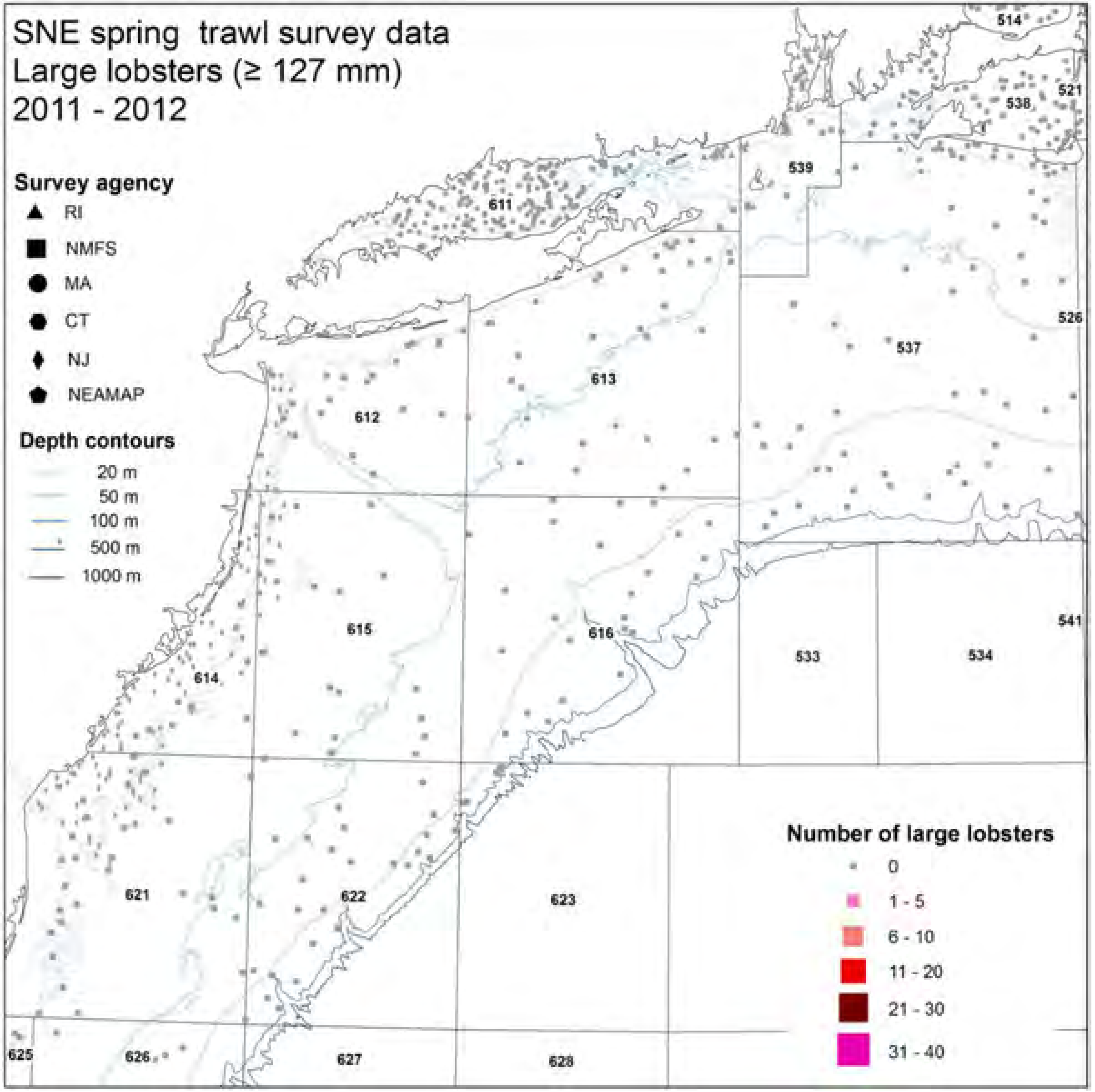
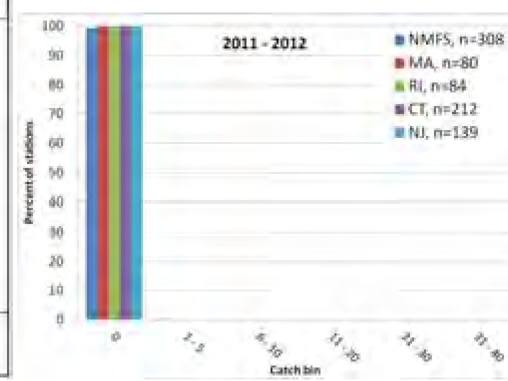
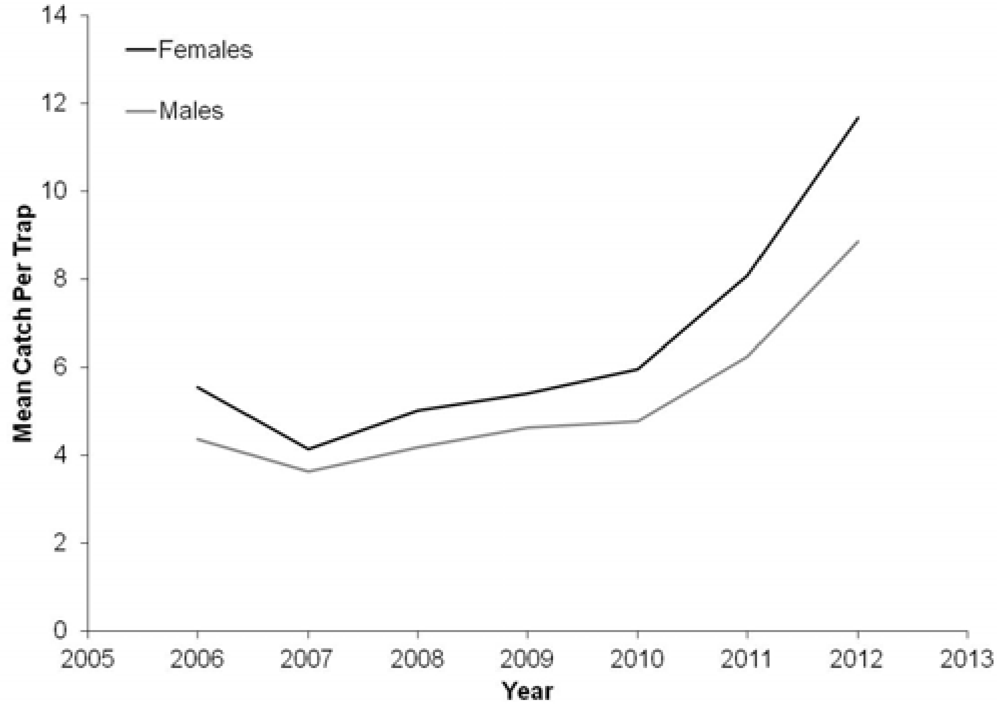


Figure 4.2.1.3.3.6 H



A



B

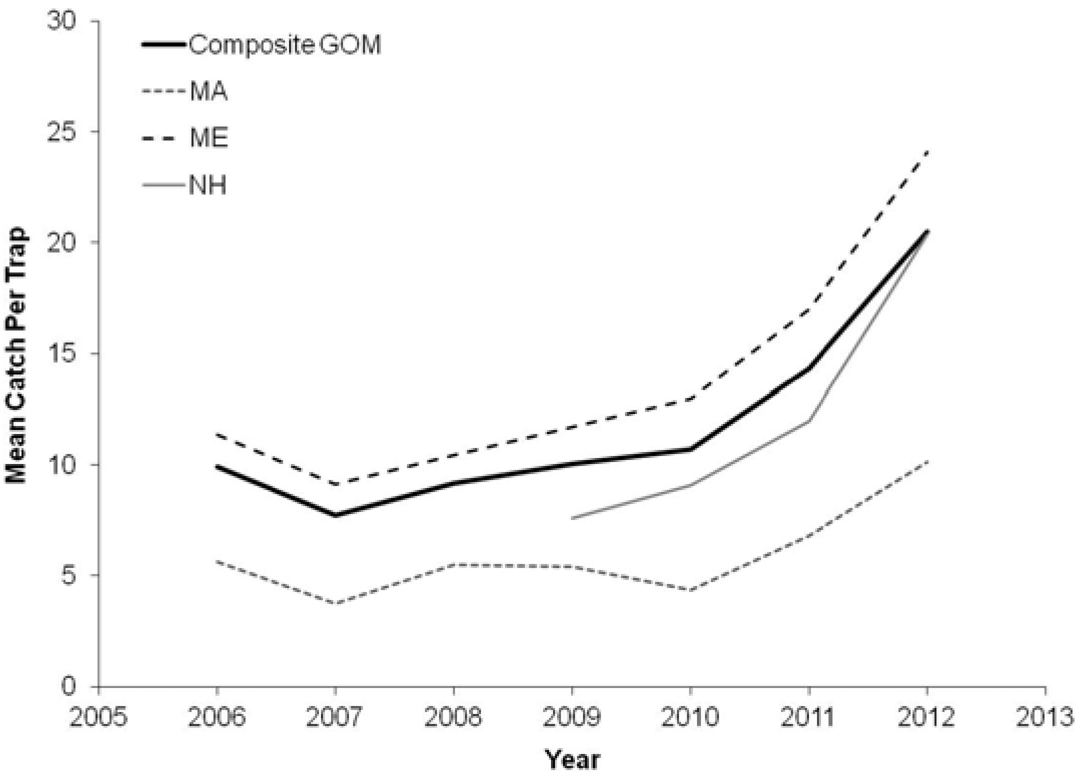


Figure 4.2.2.3.1. Gulf of Maine Ventless Trap Survey indices (A) **by sex and** (B) **by state.**

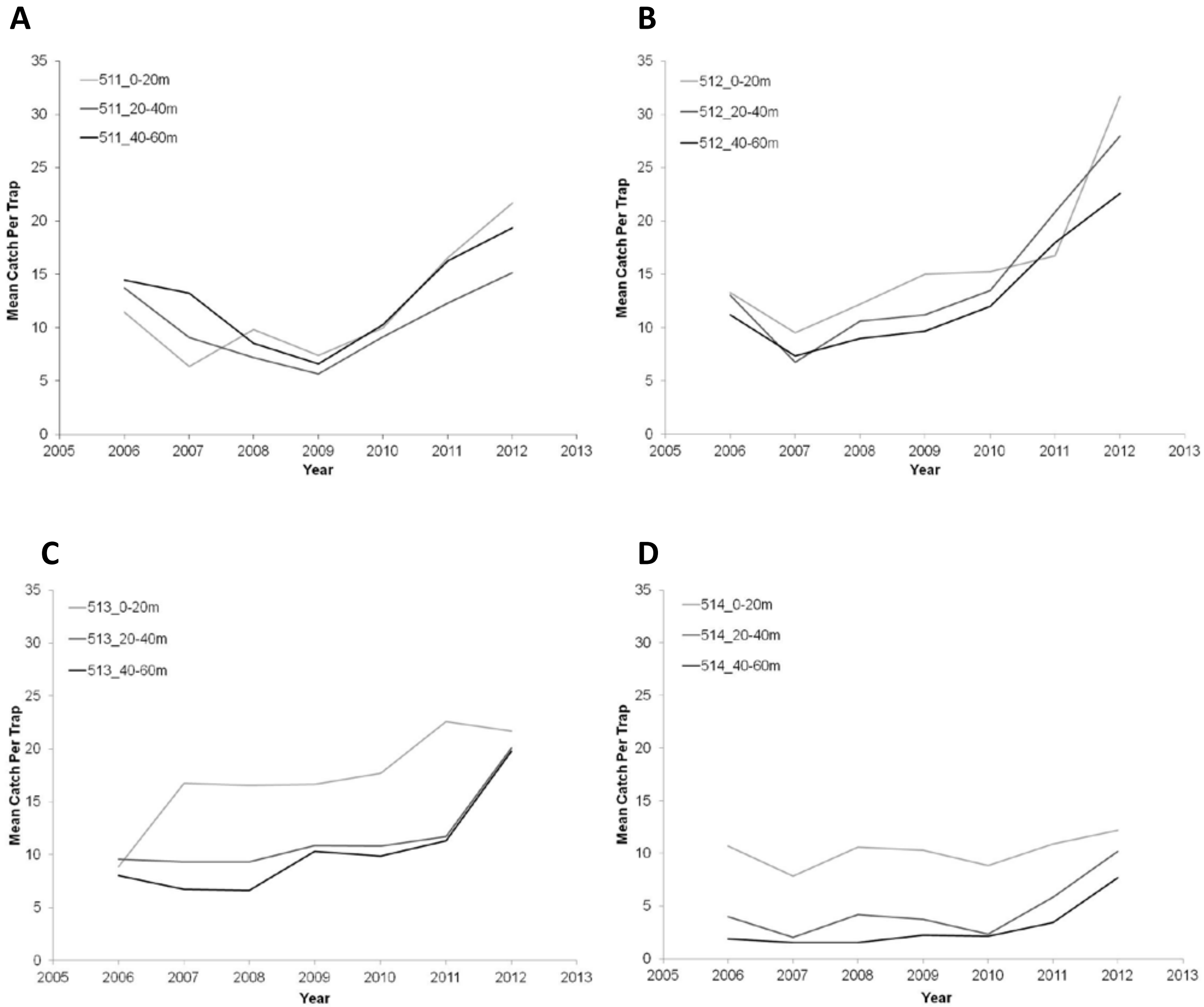


Figure 4.2.2.3.2. **Gulf of Maine Ventless Trap Survey indices by depth strata for statistical areas (A) 511, (B) 512, (C) 513 and (D) 514.**

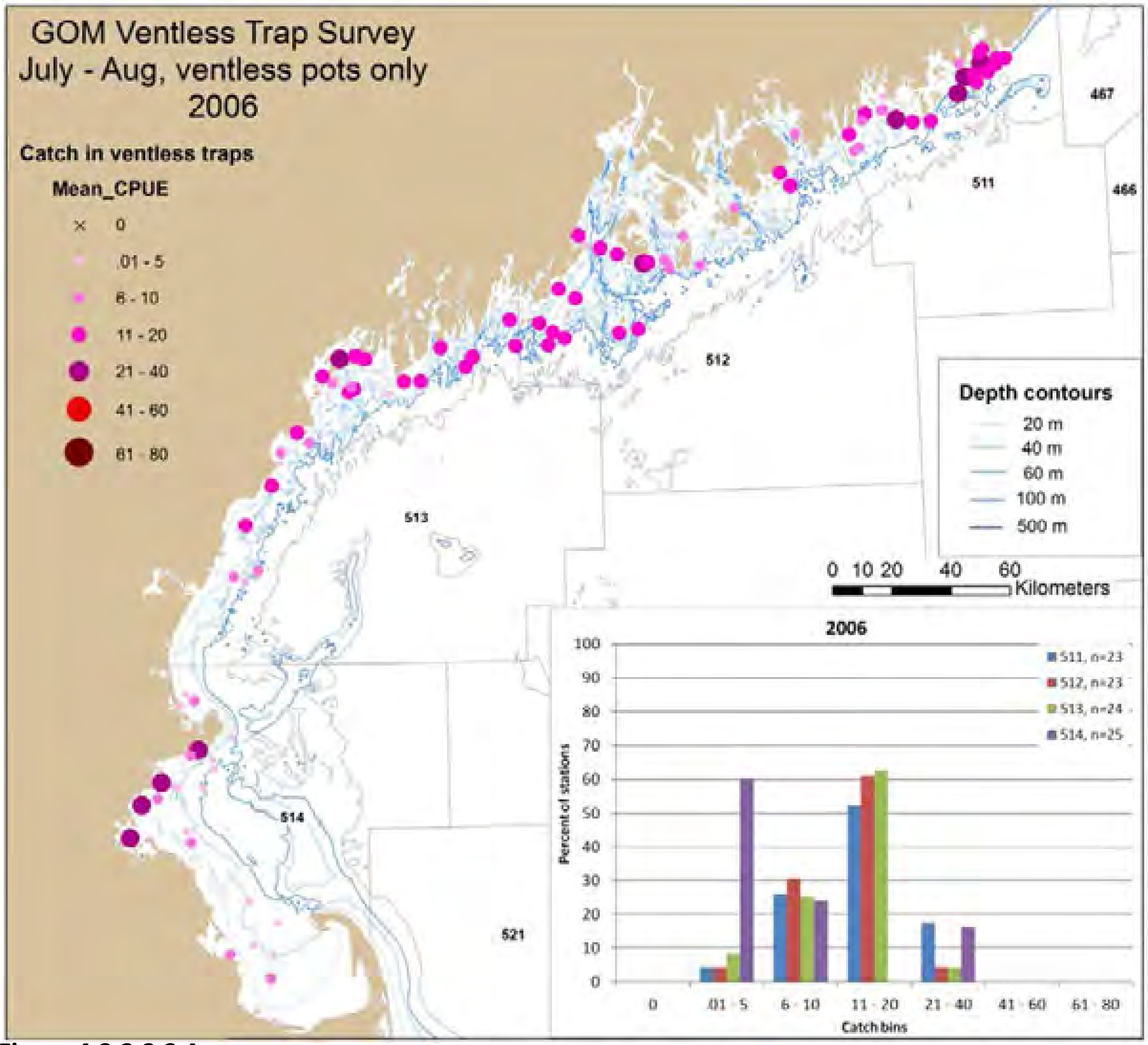


Figure 4.2.2.3.3 A

Figure 4.2.2.3.3 A - G. **Annual mean catch per trap haul of all lobsters in the GOM Coastwide Ventless Trap Survey (2006 – 2013).**

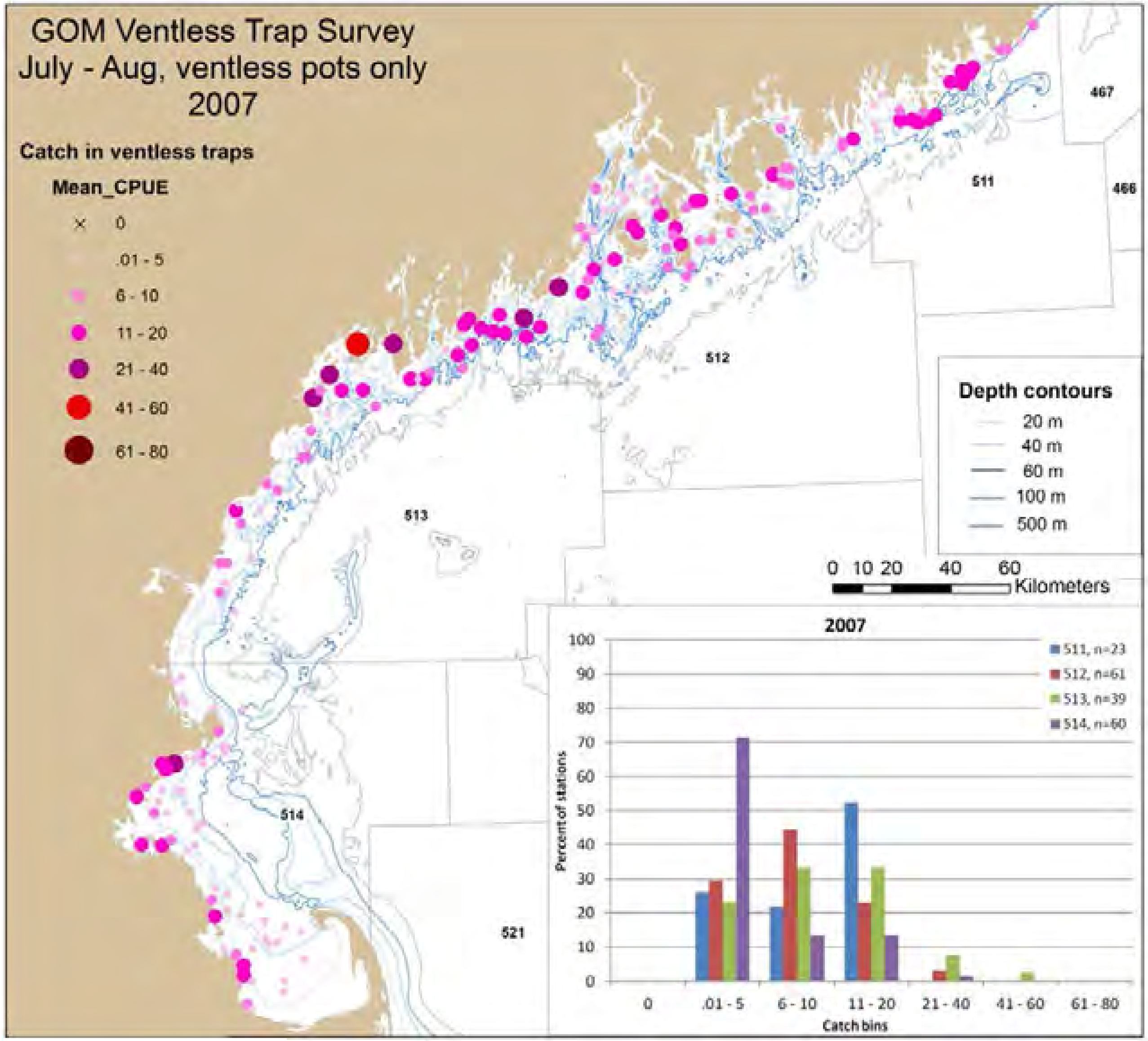


Figure 4.2.2.3.3 B

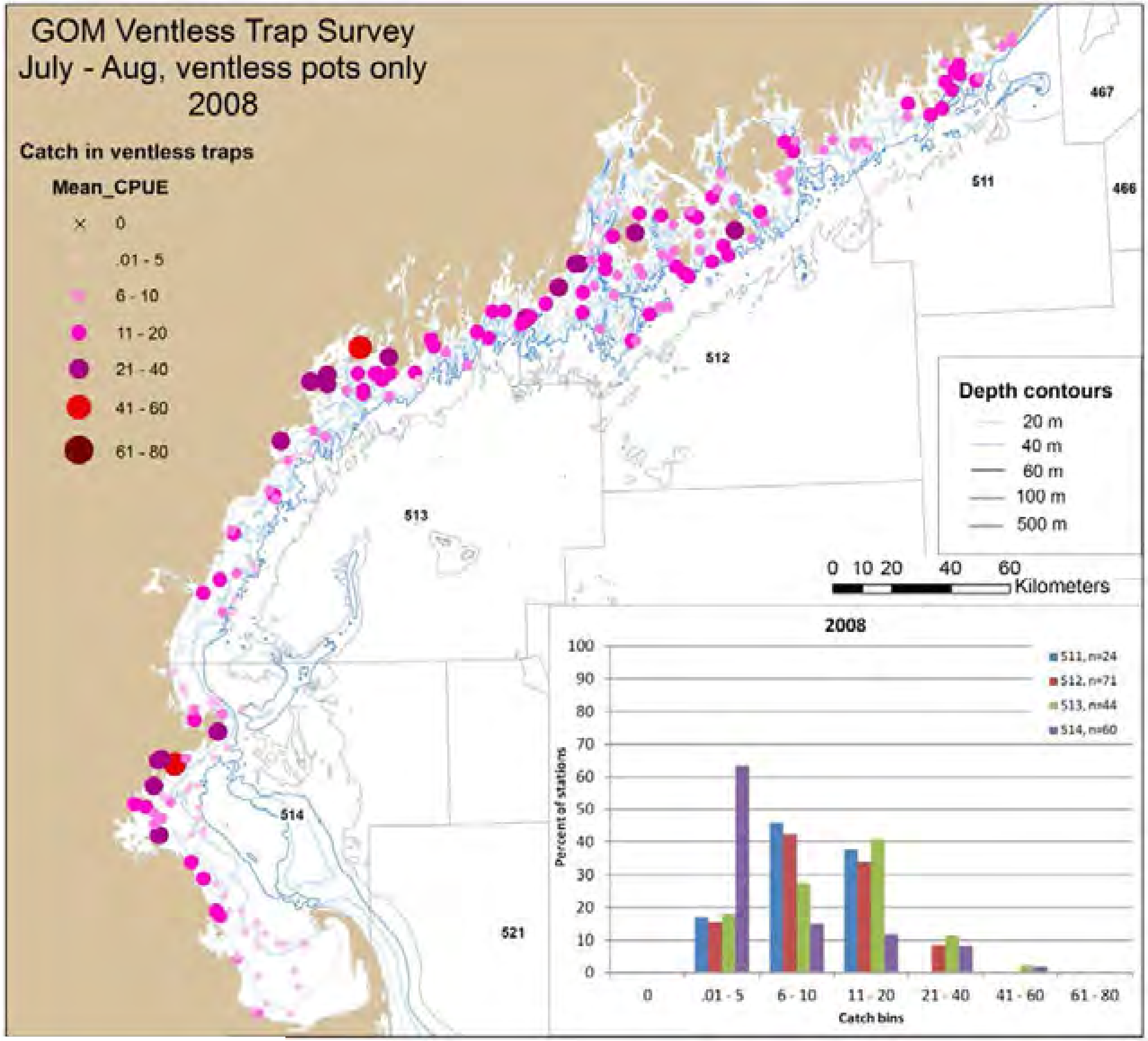


Figure 4.2.2.3.3 C

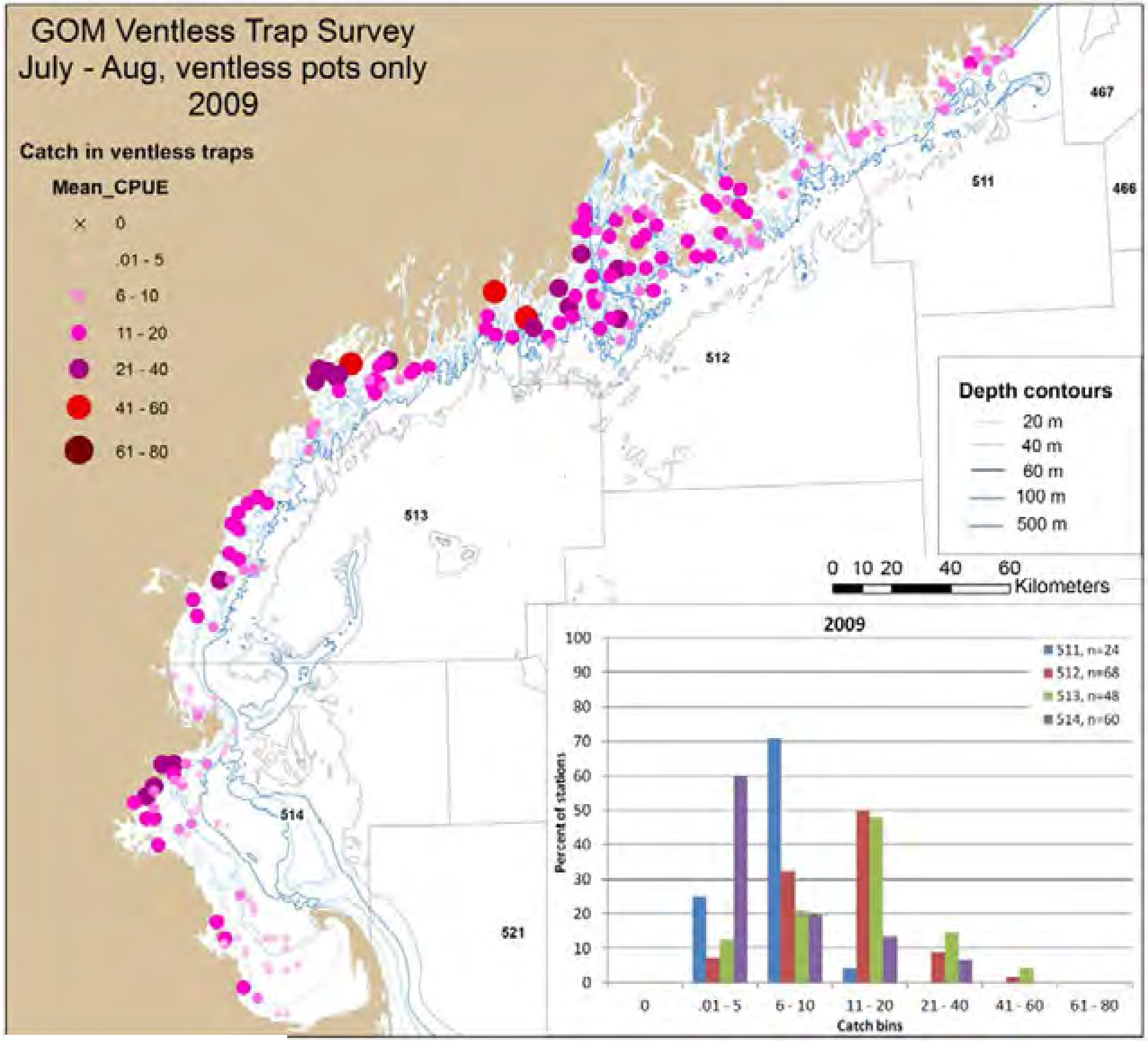


Figure 4.2.2.3.3 D

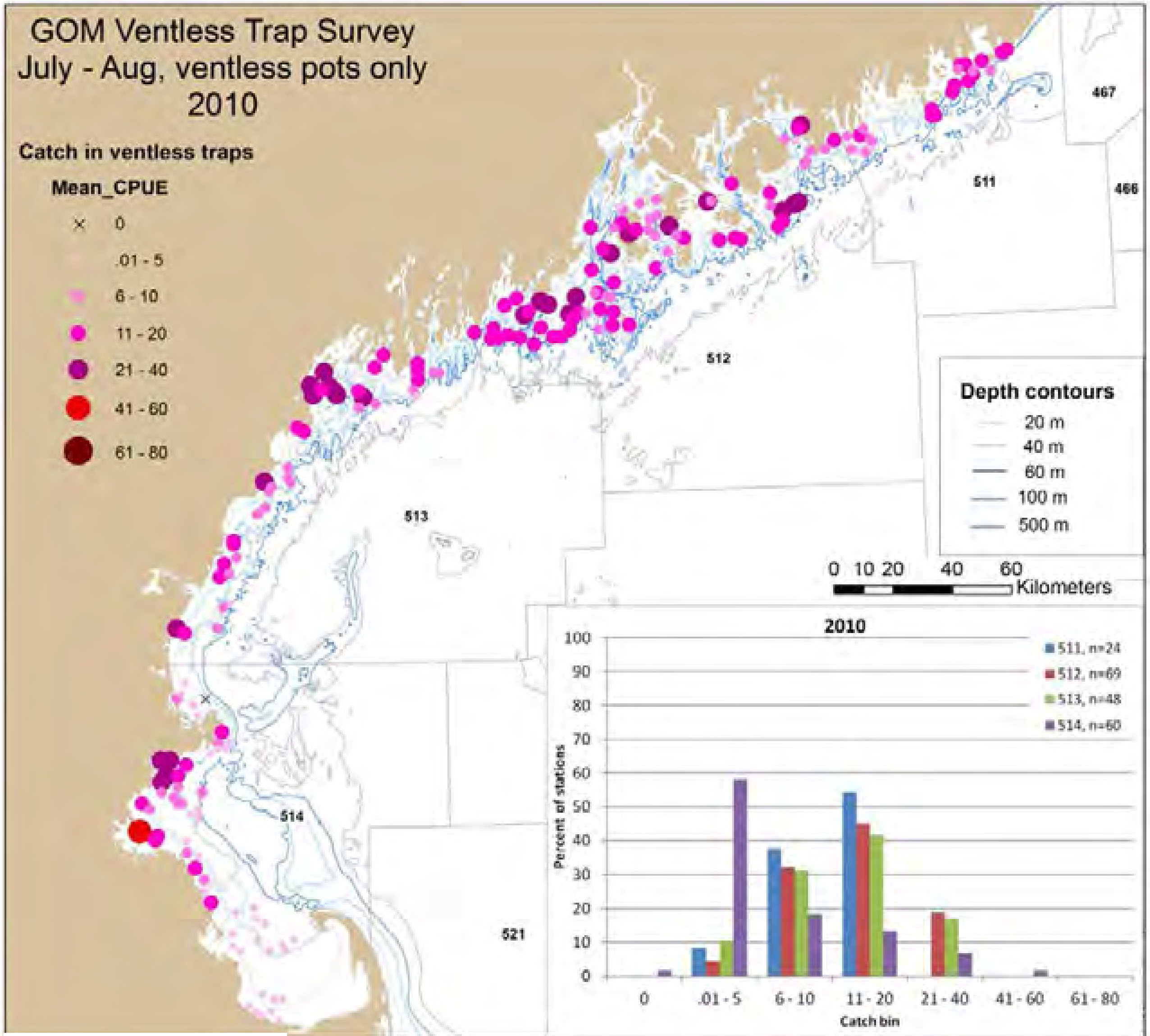


Figure 4.2.2.3.3 E

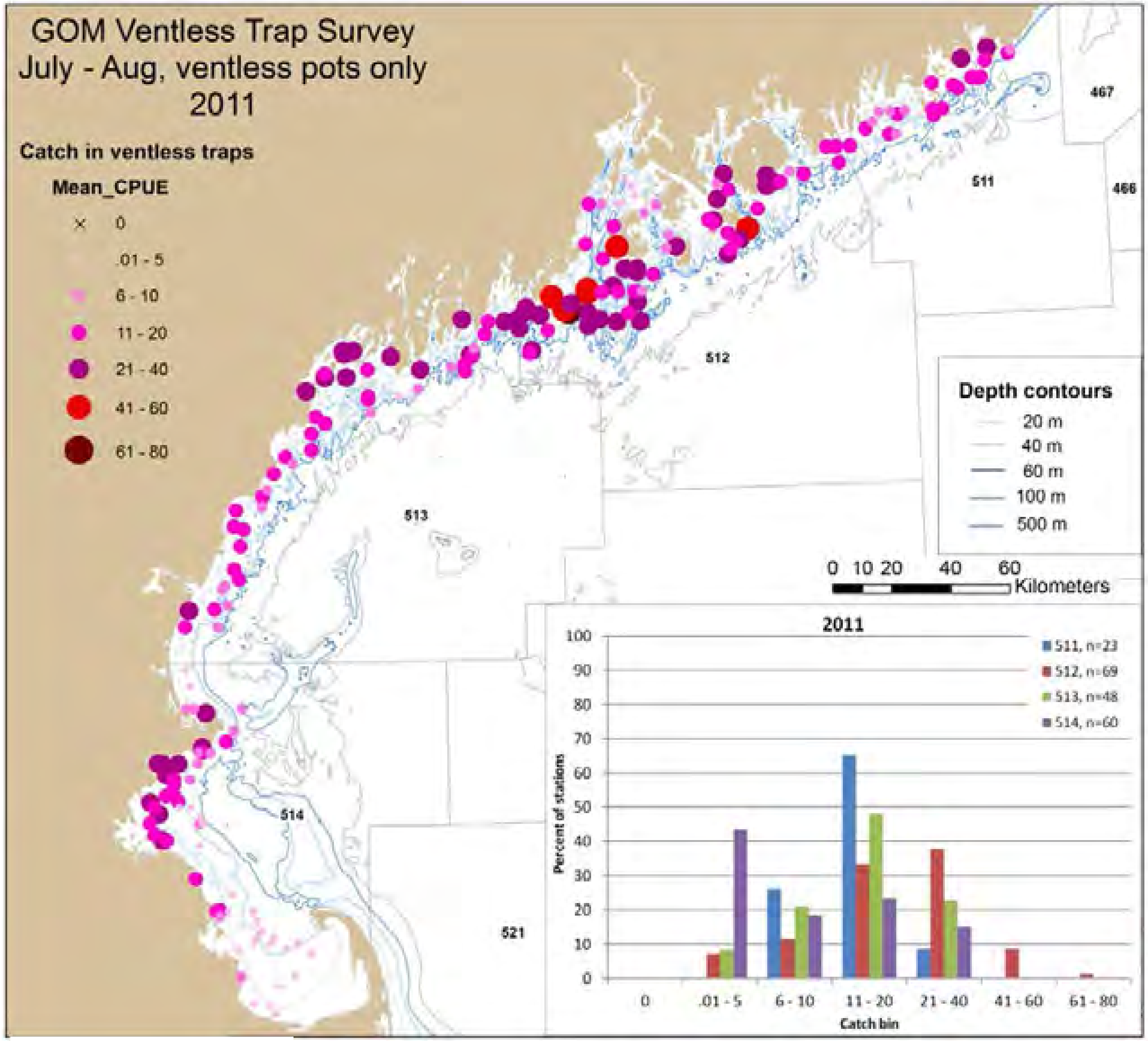


Figure 4.2.2.3.3 F

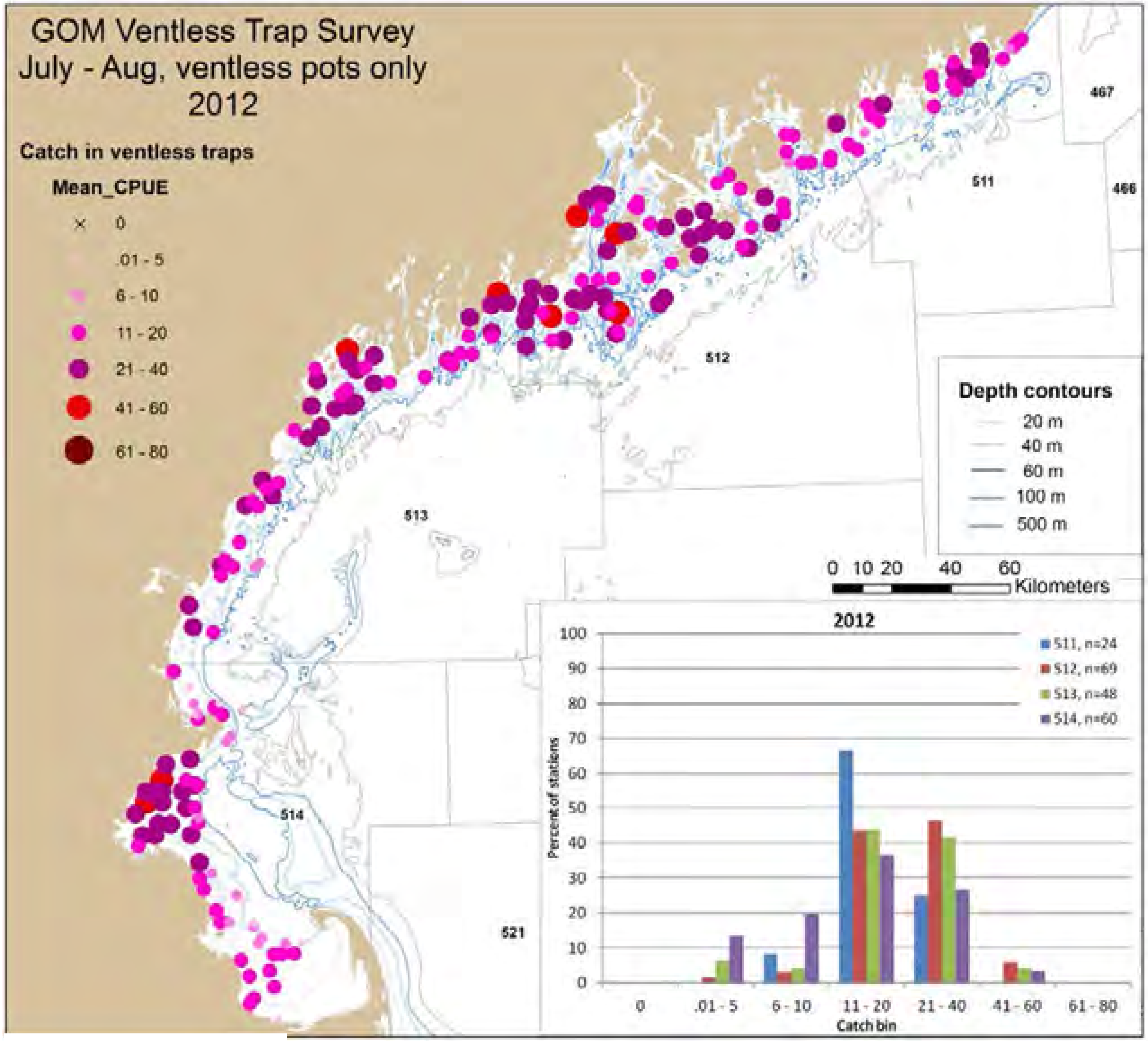


Figure 4.2.2.3.3 G

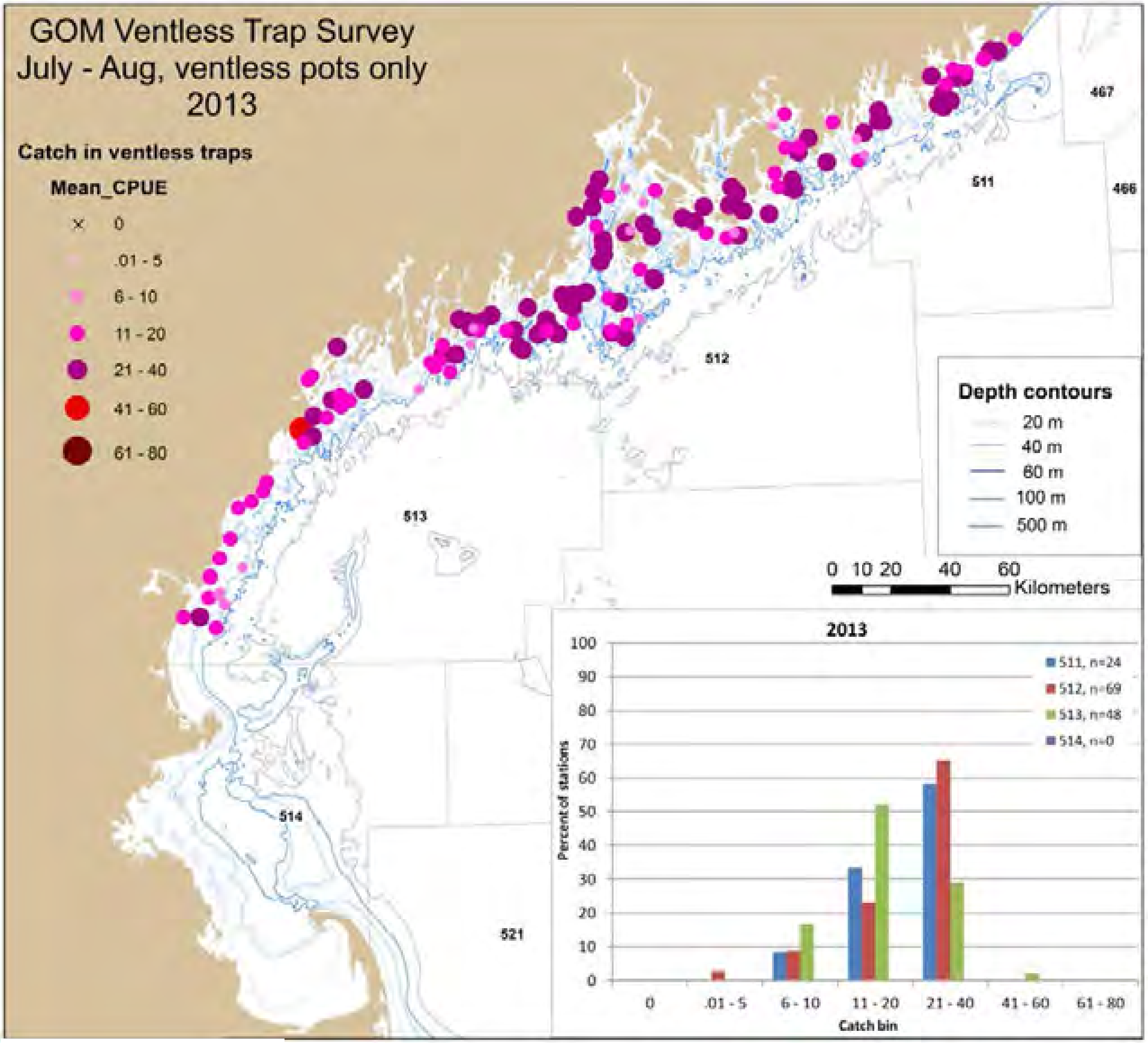


Figure 4.2.2.3.3 H

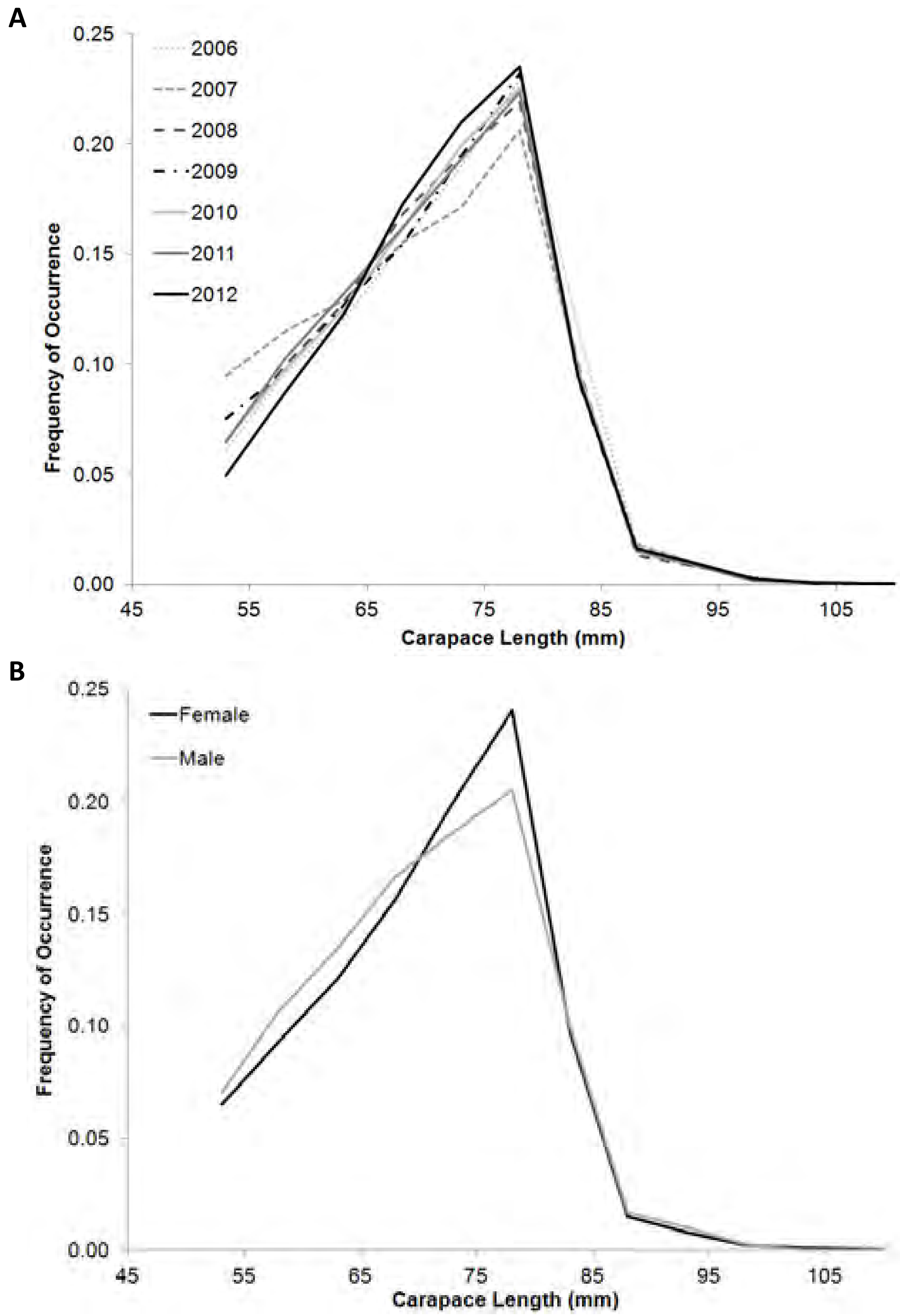
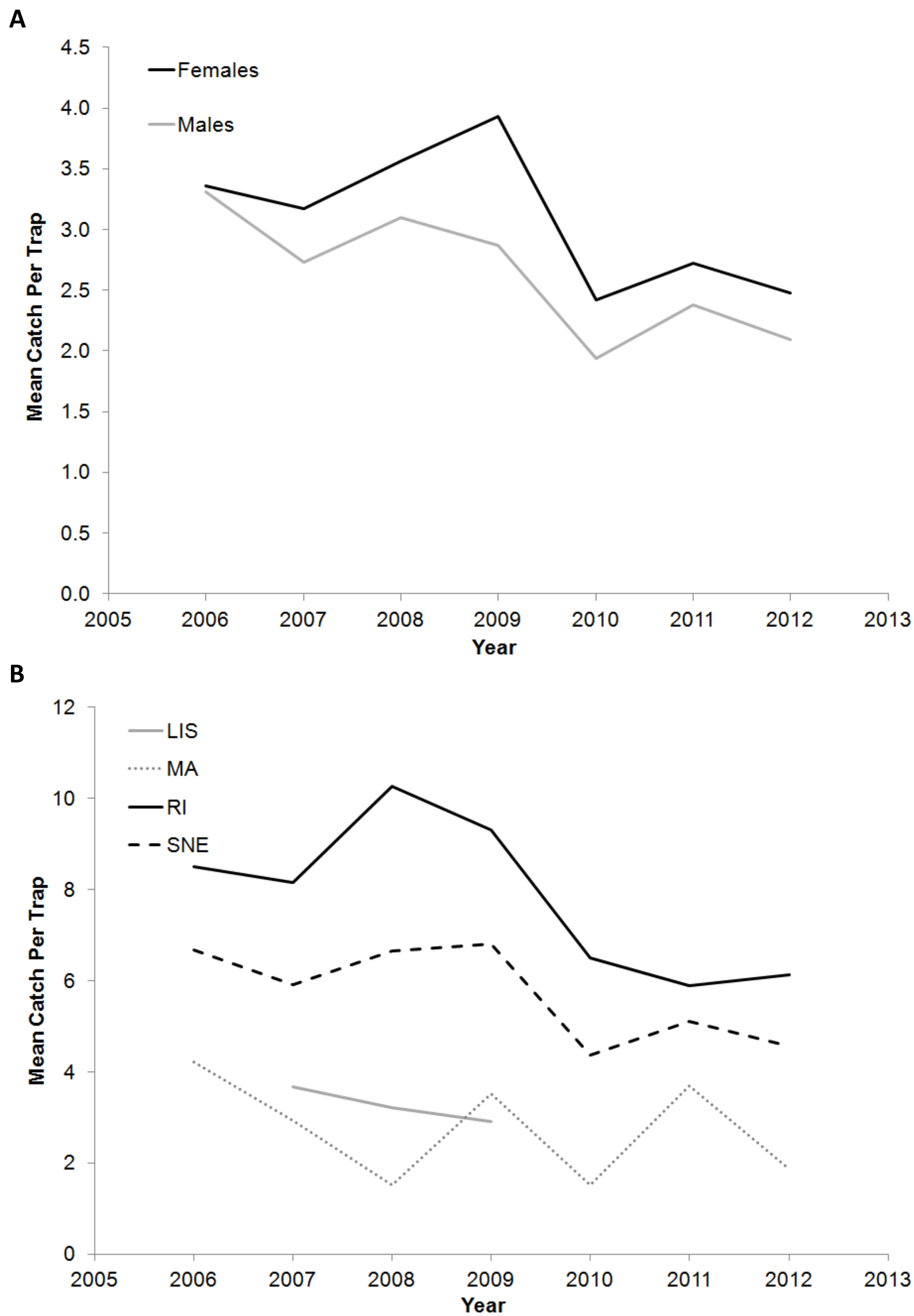
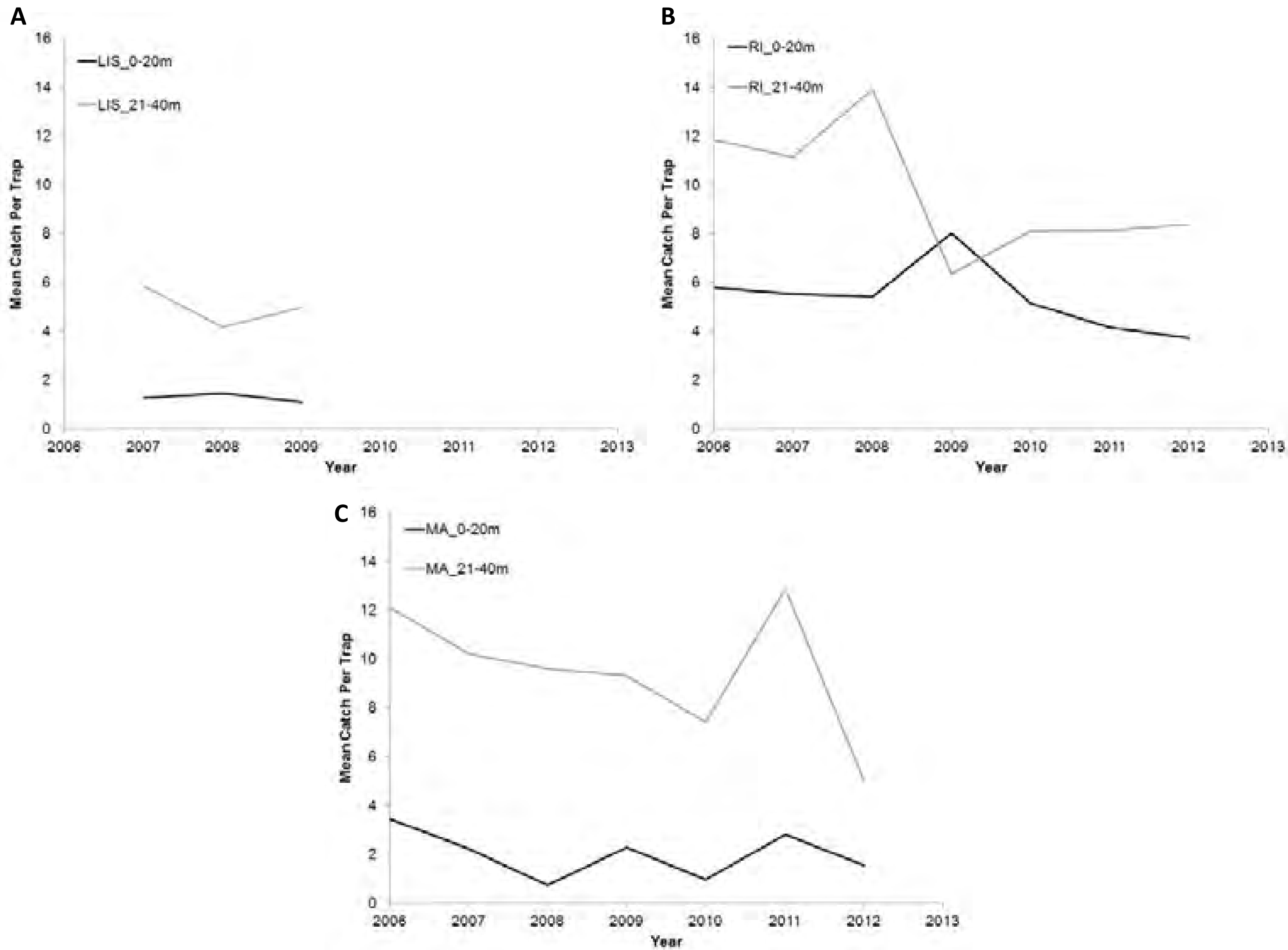


Figure 4.2.2.3.4. **Percent size frequency distribution by (A) year (sexes combined) and (B) sex (years combined) for lobsters from the Coastwide Ventless trap survey, GOM, 2006 – 2012.**



Figures 4.2.2.3.5. SNE Ventless Trap Survey indices (A) by sex and (B) by state.



Figures 4.2.2.3.6. SNE Ventless Trap Survey indices by depth strata for statistical areas (A) 611, (B) 539, and (C) 538.

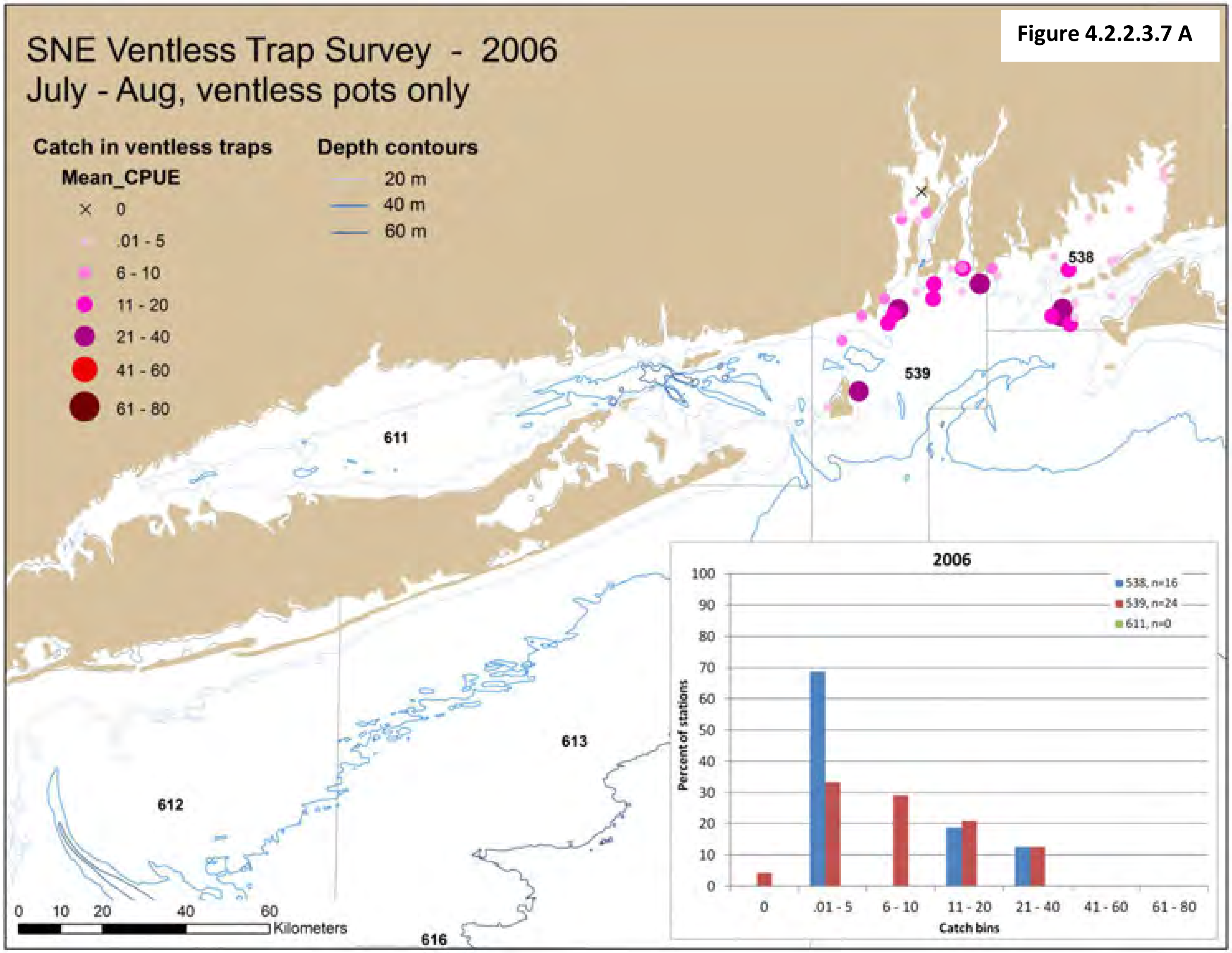


Figure 4.2.2.3.7 A - G. Annual mean catch per trap haul of all lobsters in the SNE Coastwide Ventless Trap Survey (2006 – 2012).

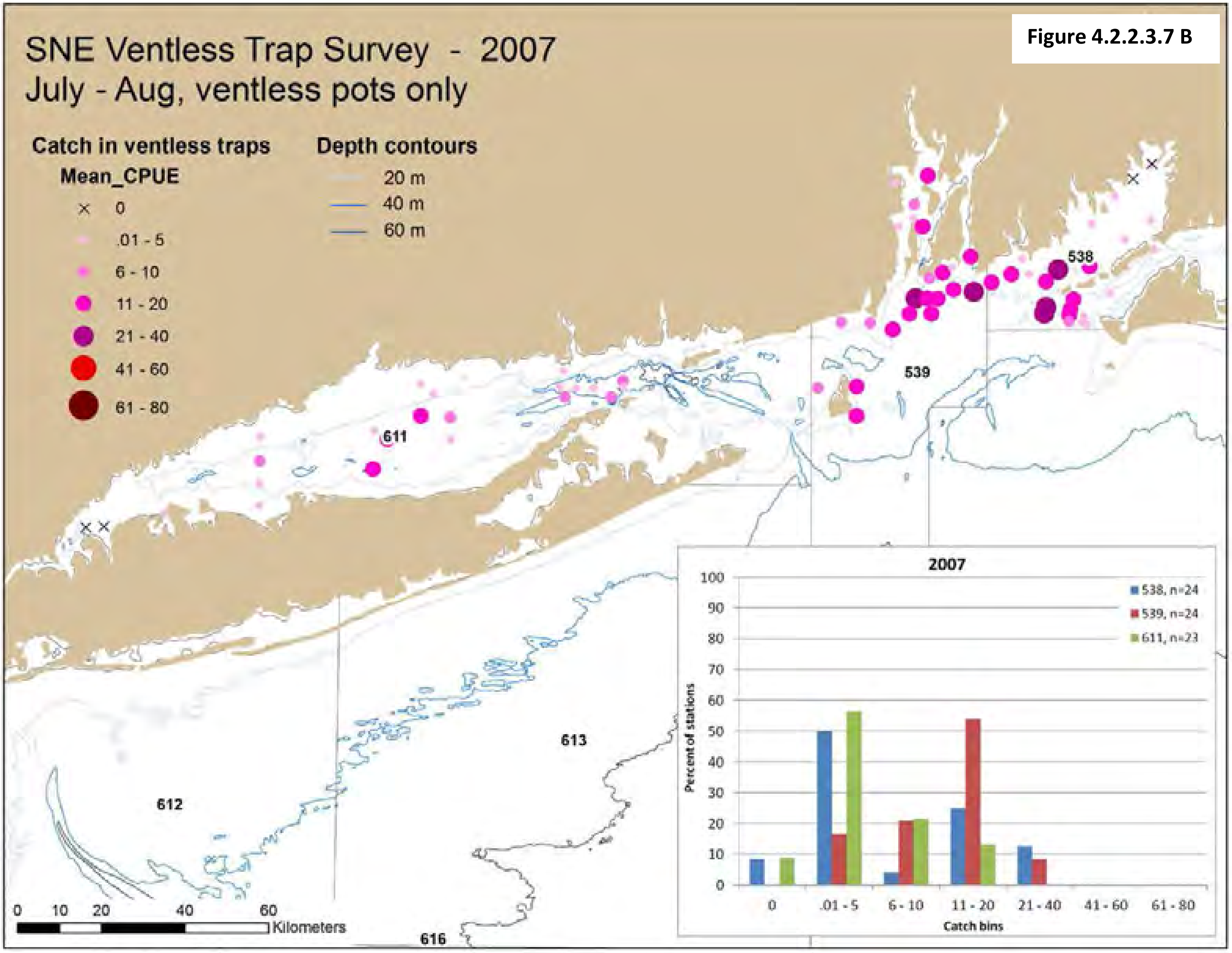


Figure 4.2.2.3.7 B
SNE Ventless Trap Survey - 2007
July - Aug, ventless pots only
Catch in ventless traps
Mean_CPUE
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80
Depth contours
20 m
40 m
60 m
538
539
611
612
613
616
0 10 20 40 60 Kilometers
2007
538, n=24
539, n=24
611, n=23
Percent of stations
Catch bins
0 .01 - 5 6 - 10 11 - 20 21 - 40 41 - 60 61 - 80

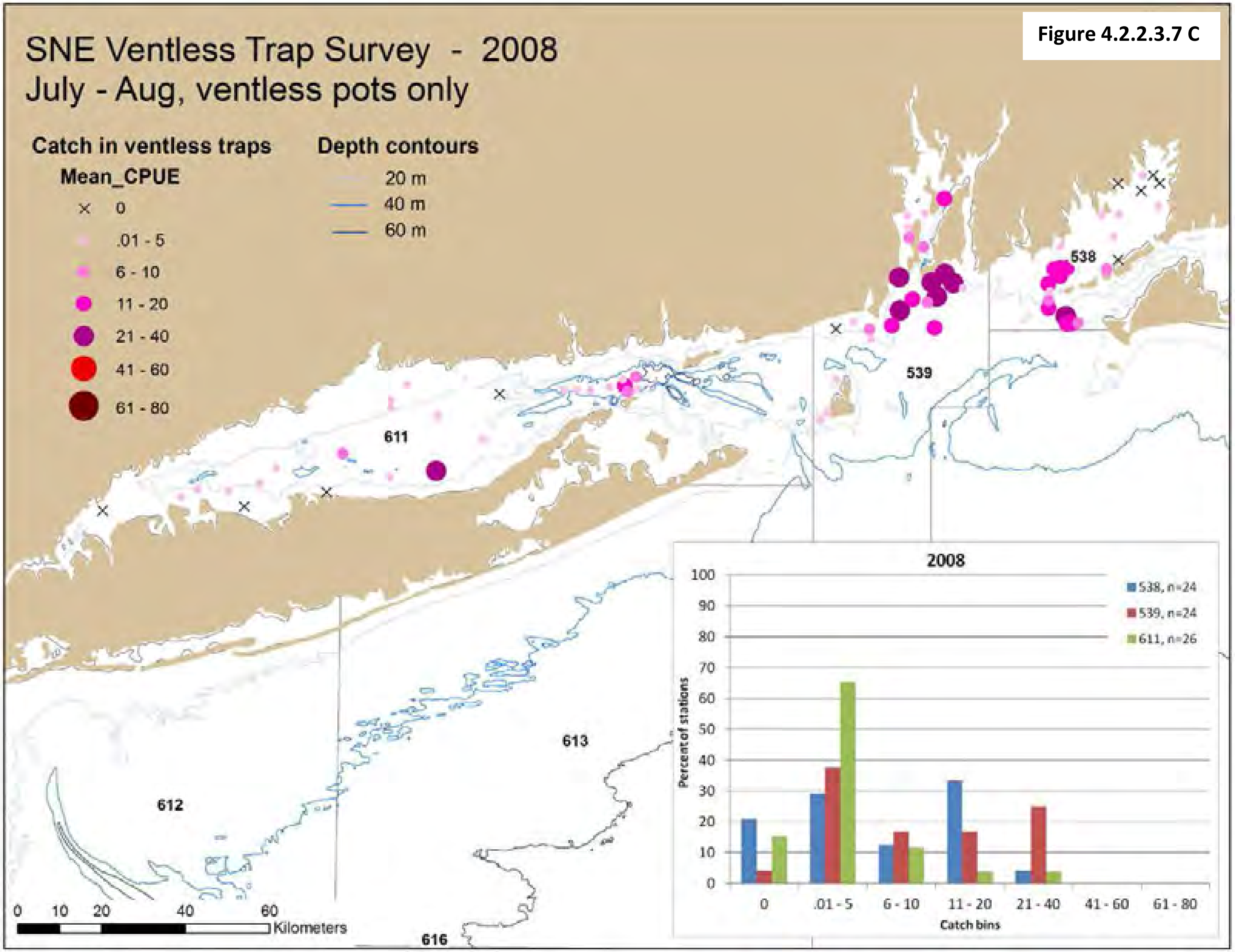


Figure 4.2.2.3.7 C
SNE Ventless Trap Survey - 2008
July - Aug, ventless pots only
Catch in ventless traps
Mean_CPUE
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80
Depth contours
20 m
40 m
60 m
538
539
611
612
613
616
0 10 20 40 60 Kilometers
2008
538, n=24
539, n=24
611, n=26
Percent of stations
Catch bins
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80

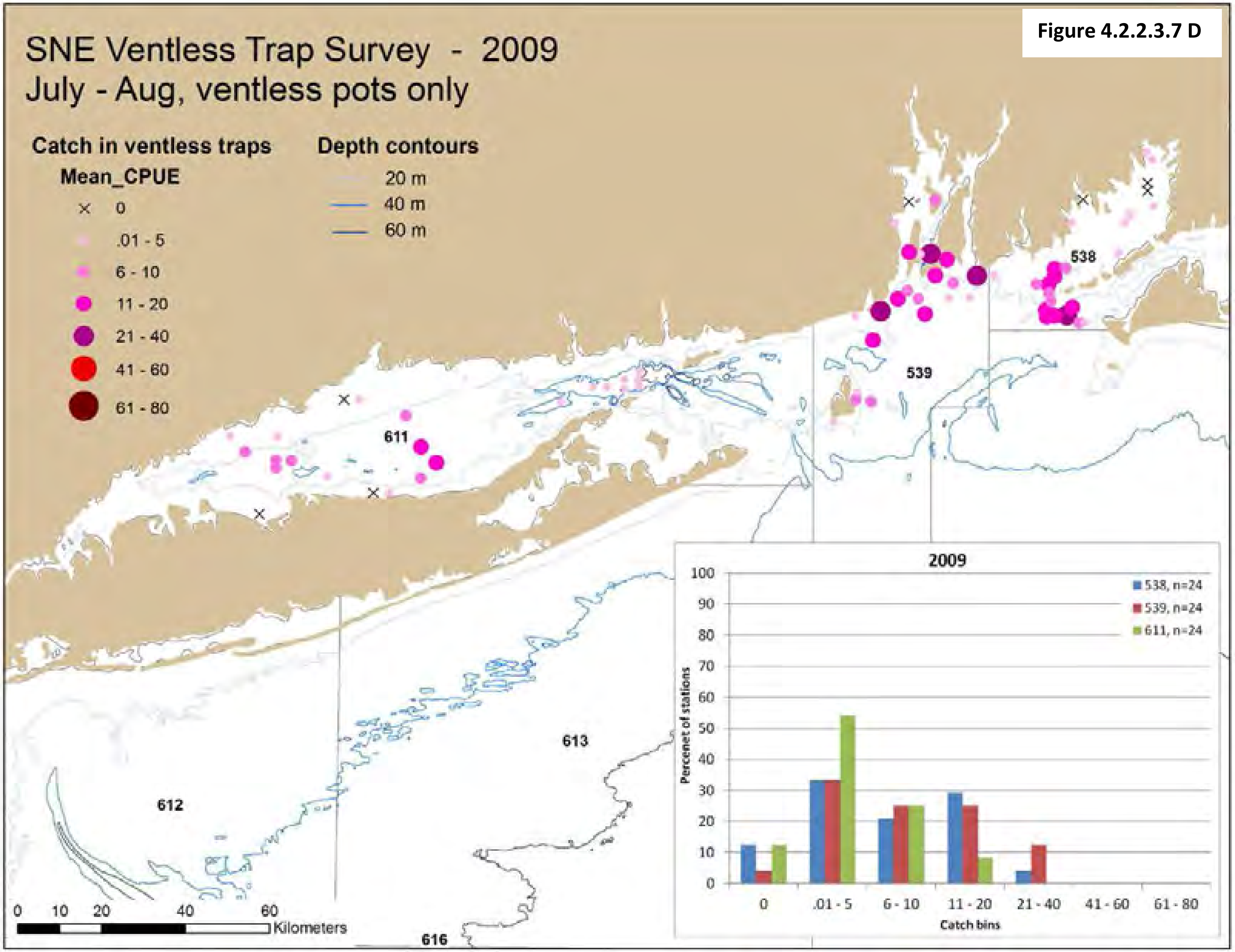


Figure 4.2.2.3.7 D
SNE Ventless Trap Survey - 2009
July - Aug, ventless pots only
Catch in ventless traps
Mean_CPUE
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80
Depth contours
20 m
40 m
60 m
538
539
611
612
613
616
0 10 20 40 60 Kilometers
2009
538, n=24
539, n=24
611, n=24
Percenet of stations
Catch bins
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80

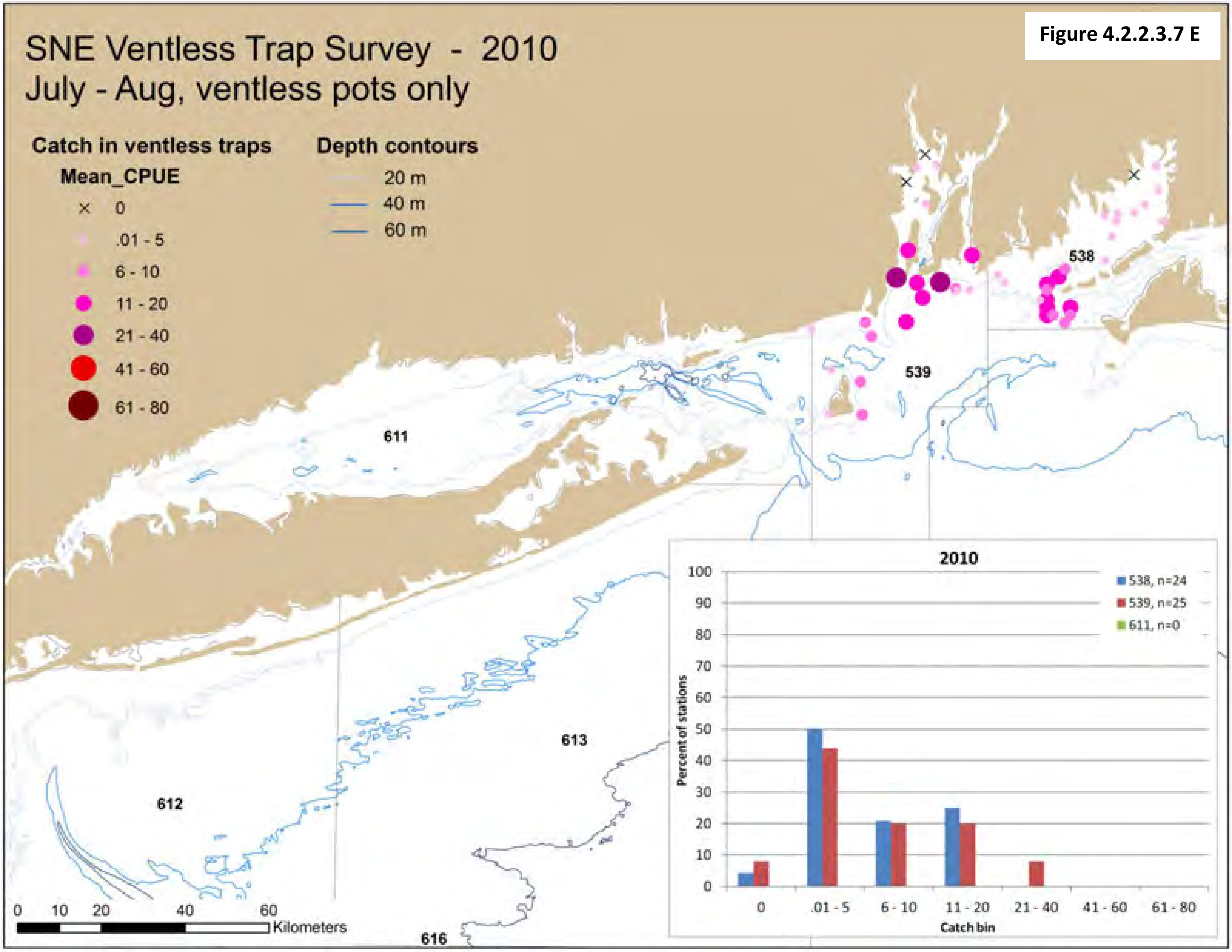


Figure 4.2.2.3.7 E
SNE Ventless Trap Survey - 2010
July - Aug, ventless pots only
Catch in ventless traps
Mean_CPUE
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80
Depth contours
20 m
40 m
60 m
538
539
611
612
613
616
0 10 20 40 60
Kilometers
2010
538, n=24
539, n=25
611, n=0
Percent of stations
Catch bin
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80

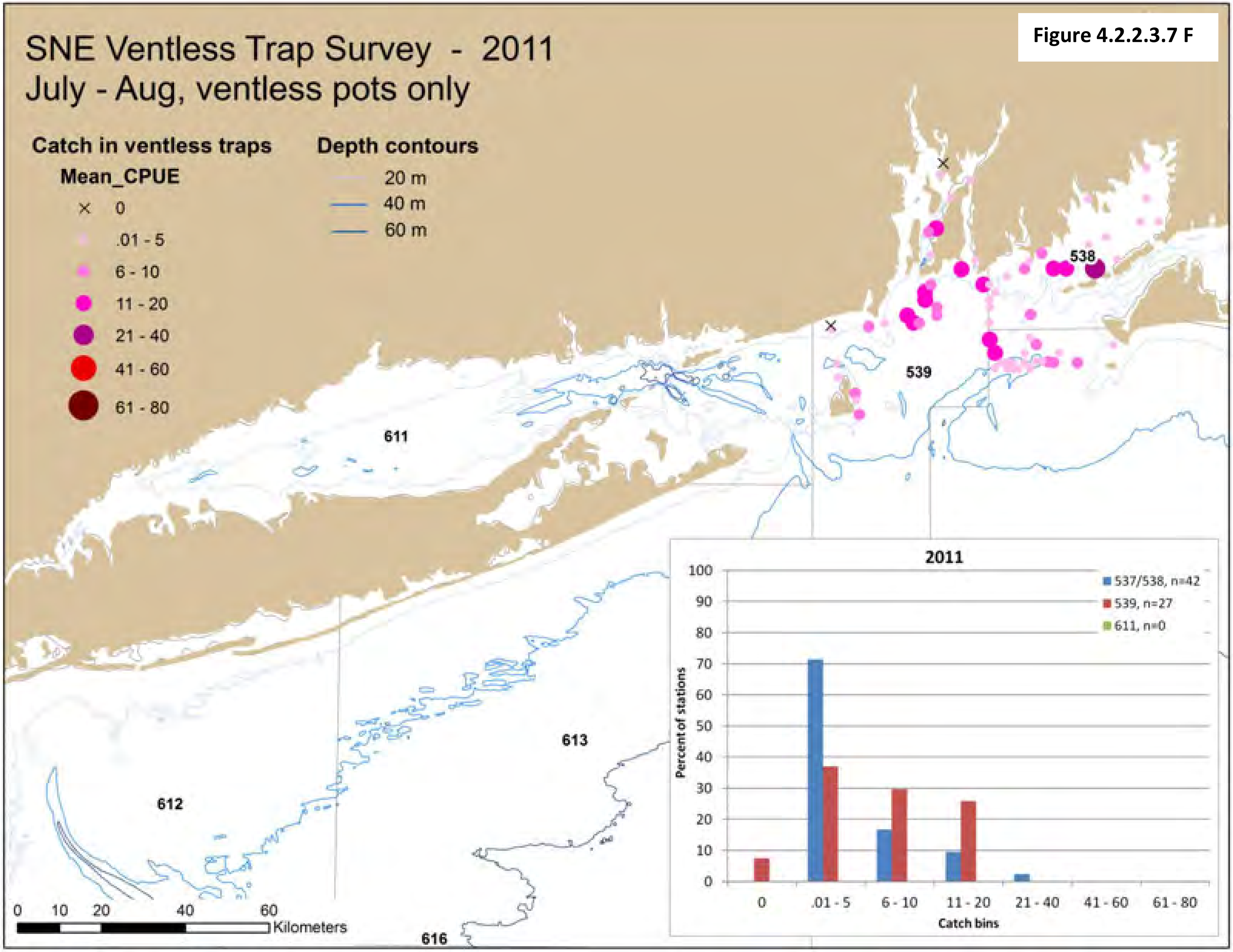


Figure 4.2.2.3.7 F
SNE Ventless Trap Survey - 2011
July - Aug, ventless pots only
Catch in ventless traps
Mean_CPUE
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80
Depth contours
20 m
40 m
60 m
538
539
611
612
613
616
0 10 20 40 60
Kilometers
2011
537/538, n=42
539, n=27
611, n=0
Percent of stations
100
90
80
70
60
50
40
30
20
10
0
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80
Catch bins

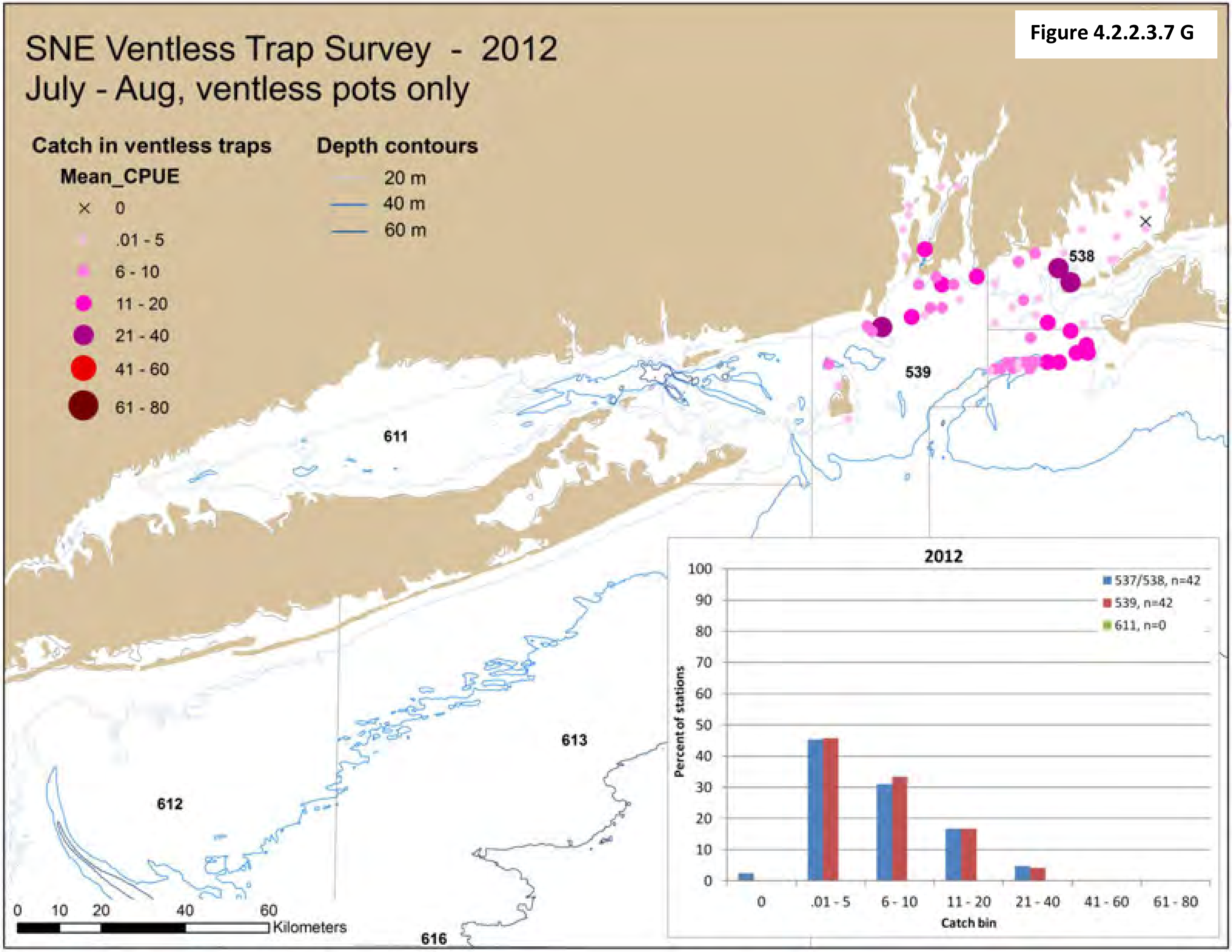


Figure 4.2.2.3.7 G
SNE Ventless Trap Survey - 2012
July - Aug, ventless pots only
Catch in ventless traps
Mean_CPUE
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80
Depth contours
20 m
40 m
60 m
538
539
611
612
613
616
0 10 20 40 60
Kilometers
2012
537/538, n=42
539, n=42
611, n=0
Percent of stations
Catch bin
0
.01 - 5
6 - 10
11 - 20
21 - 40
41 - 60
61 - 80
100
90
80
70
60
50
40
30
20
10
0

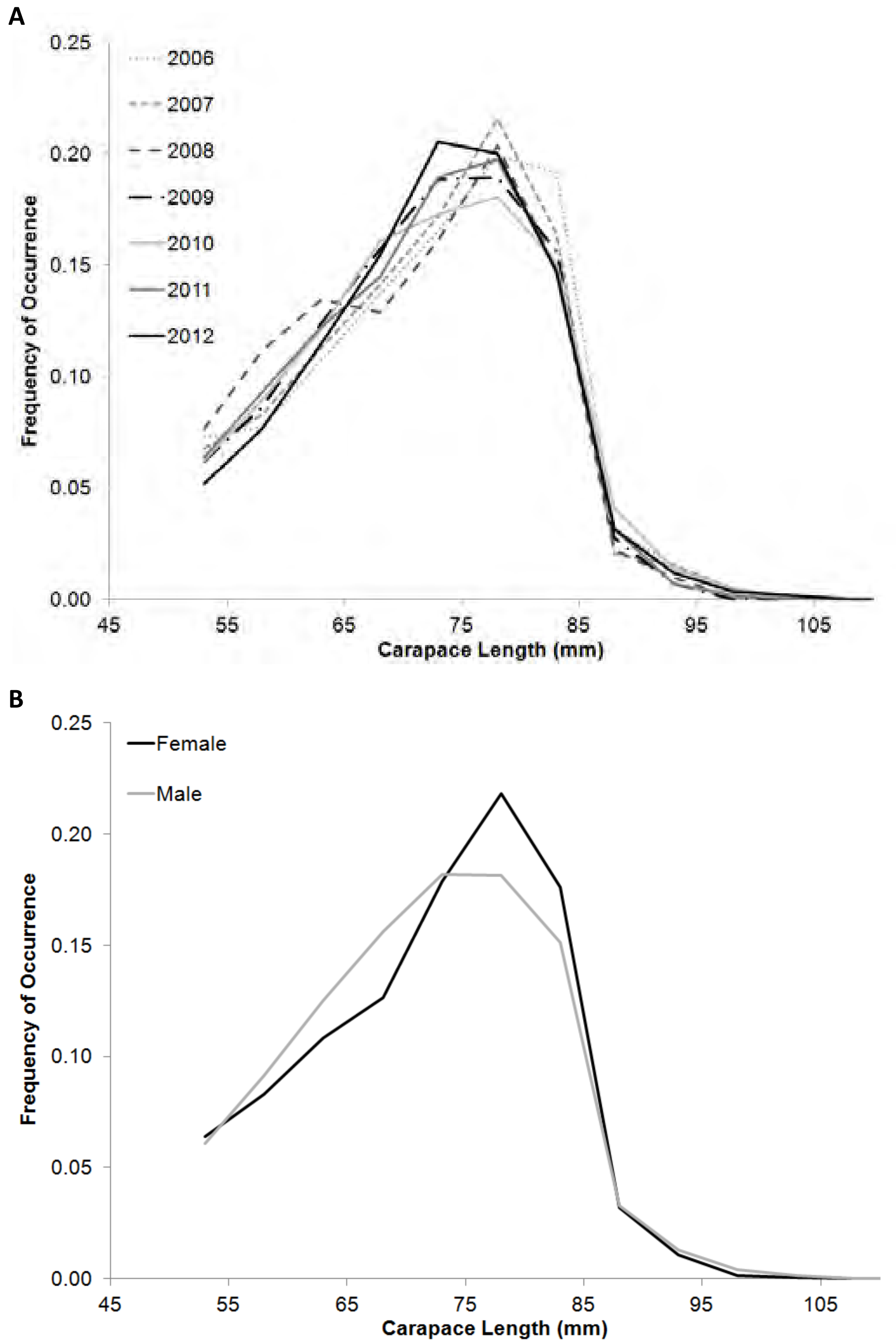


Figure 4.2.2.3.8. Percent size frequency distribution by (A) year (sexes combined) and (B) sex (years combined) for lobsters from the SNE Coastwide Ventless trap survey, 2006 – 2012.

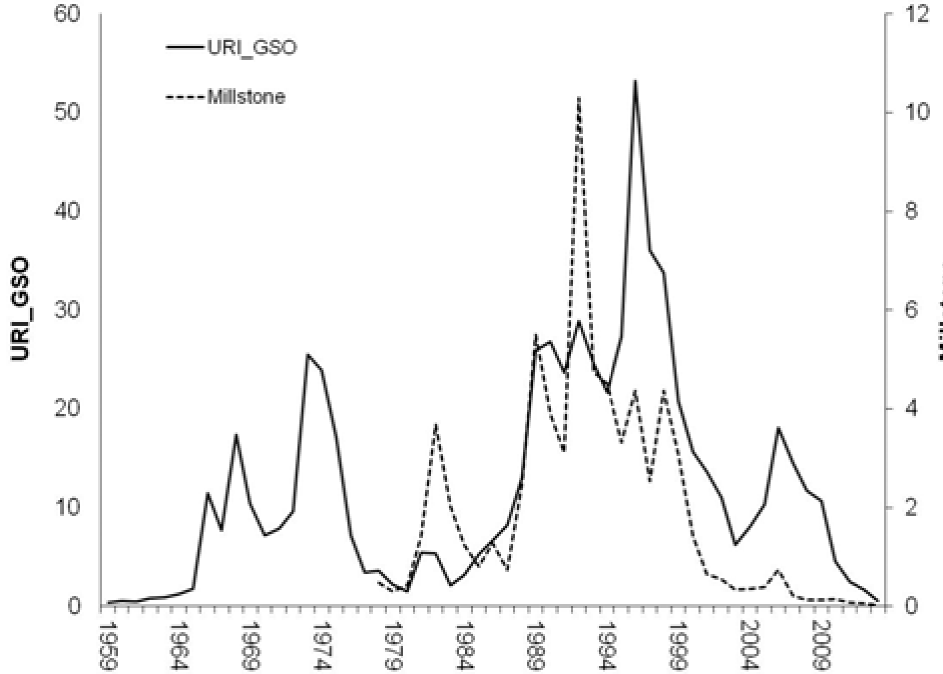


Figure 4.2.4.1. URI_GSO trawl survey index (Narragansett Bay, 1959 - 2013) and Millstone Power Station trawl survey index (Long Island Sound, 1978 - 2013).

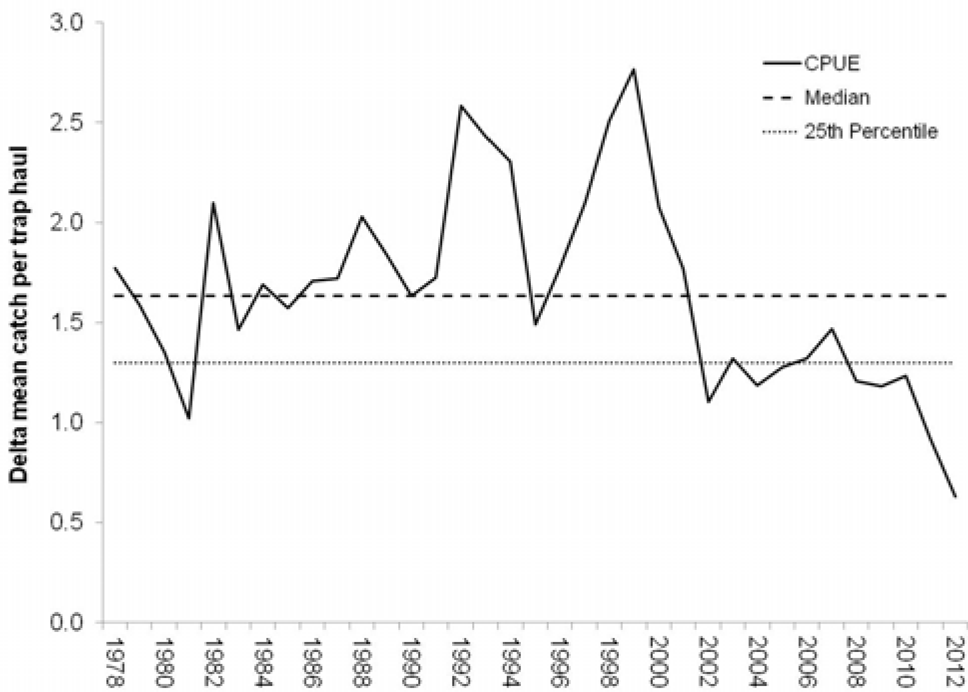


Figure 4.2.4.2. Average CPUE from the Millstone Power Station (Long Island Sound) ventless trap survey, 1978 to 2012. Time series median, and 25th percentile are also shown.

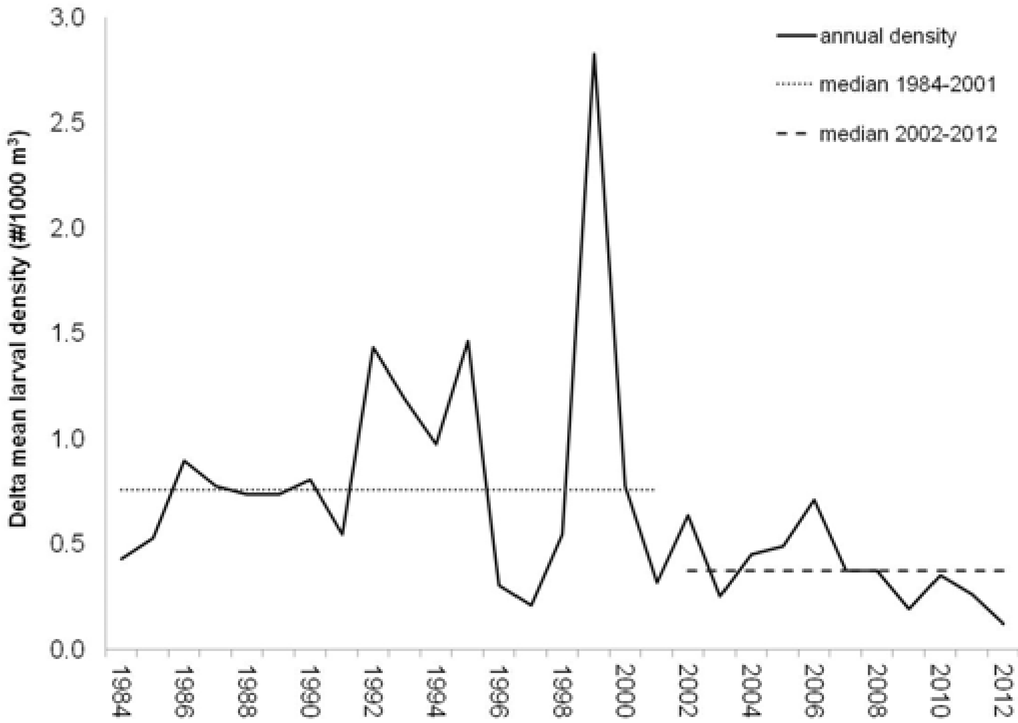


Figure 4.2.4.3. Average larval density (delta mean # larvae / 1000 m^3) from the Millstone Power Station (Long Island Sound) larval lobster entrainment index, 1984 to 2012.

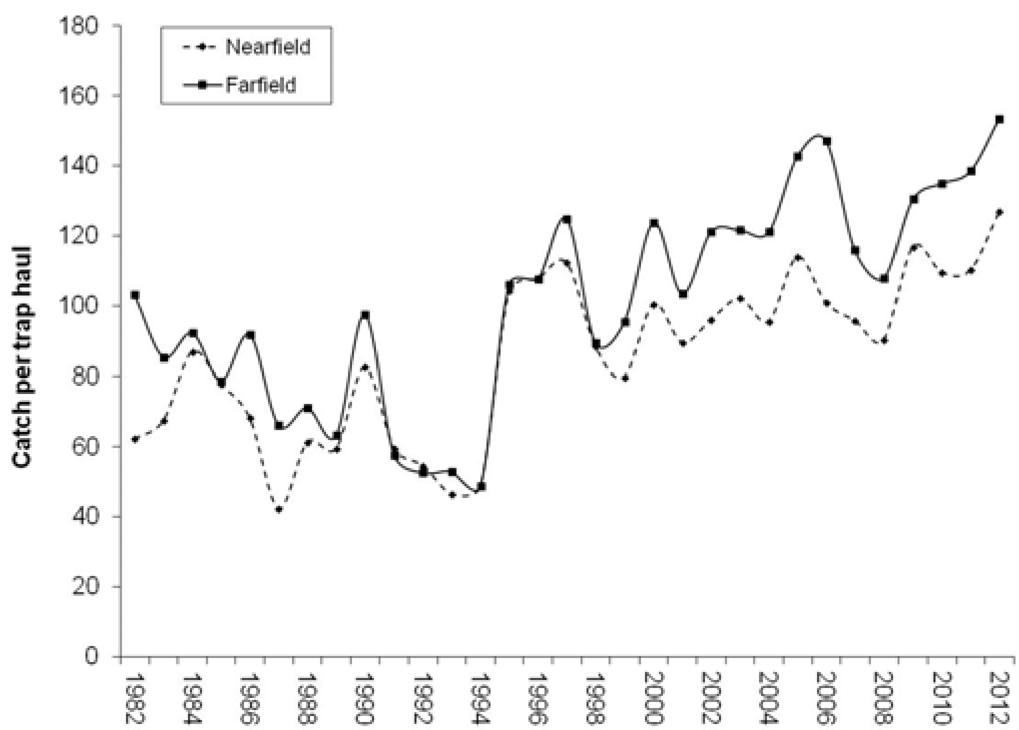


Figure 4.2.4.4. CPUE of lobsters from the Seabrook Power Station (SA 513) ventless trap survey, 1978 - 2012.

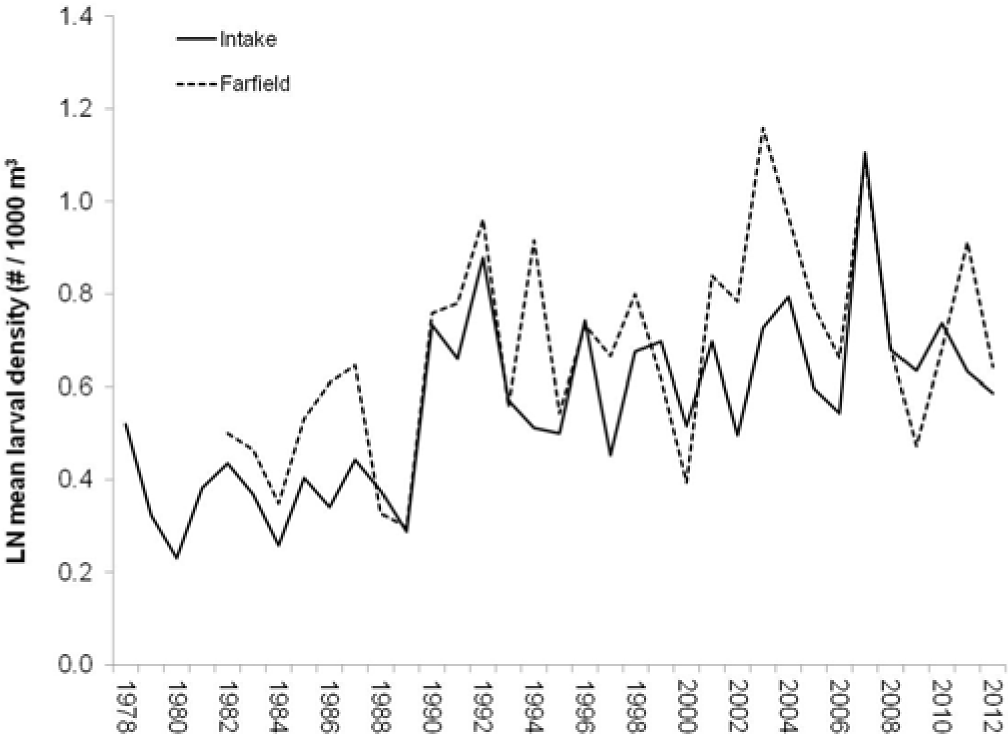


Figure 4.2.4.5. Larval lobster density (ln mean # / 1000 m^3) from the Seabrook Power Station (SA 513) neuston net survey, 1978 to 2012.

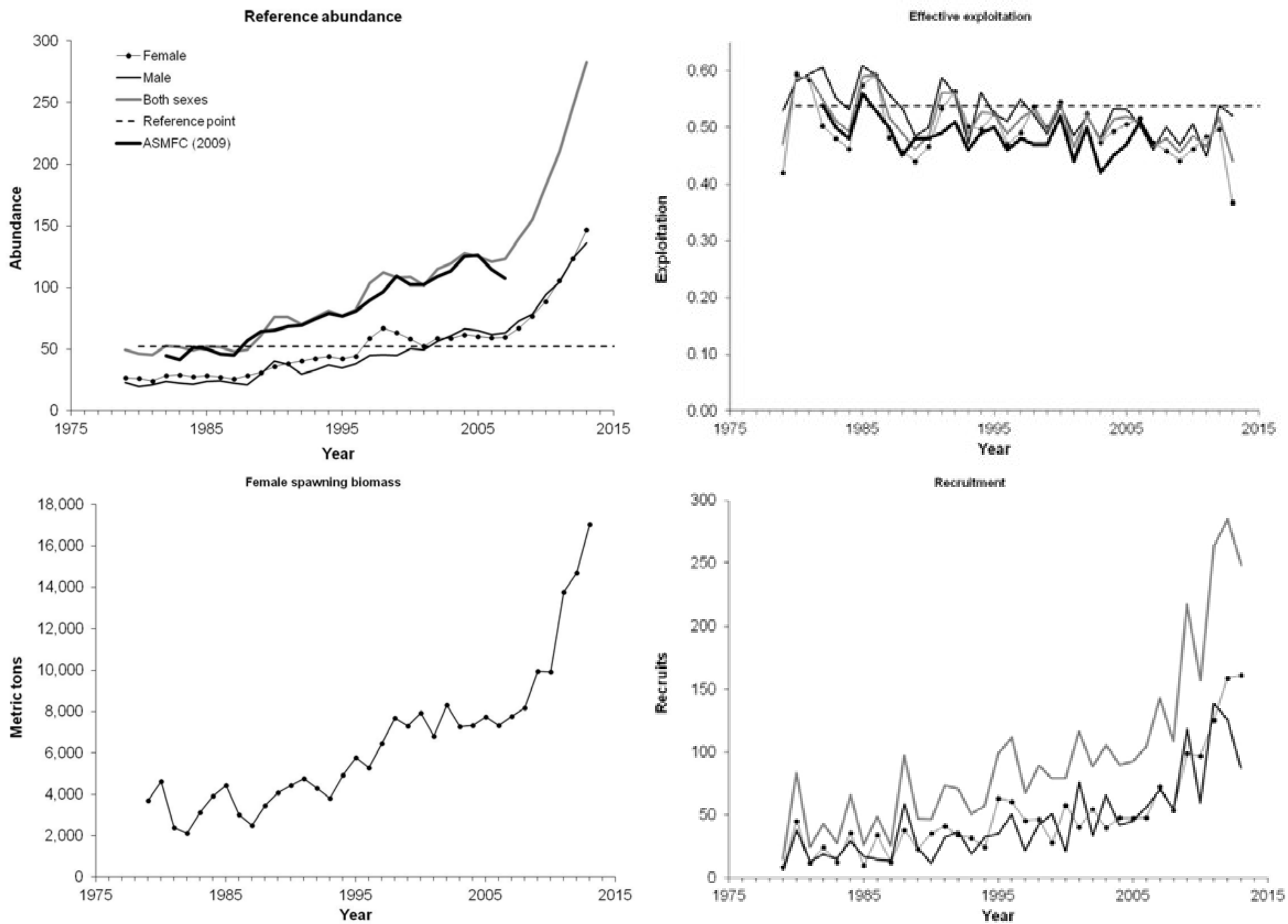


Figure 6.3.1.1. Annual reference abundance, effective exploitation, spawning biomass, and recruitment estimates for American lobster from 1979-2013 from the basecase model for GOM and from 1982-2007 from ASMFC (2009). Horizontal lines show threshold reference points at the 25th percentile (reference time period 1982-2003) for abundance and the 75th percentile for effective exploitation.

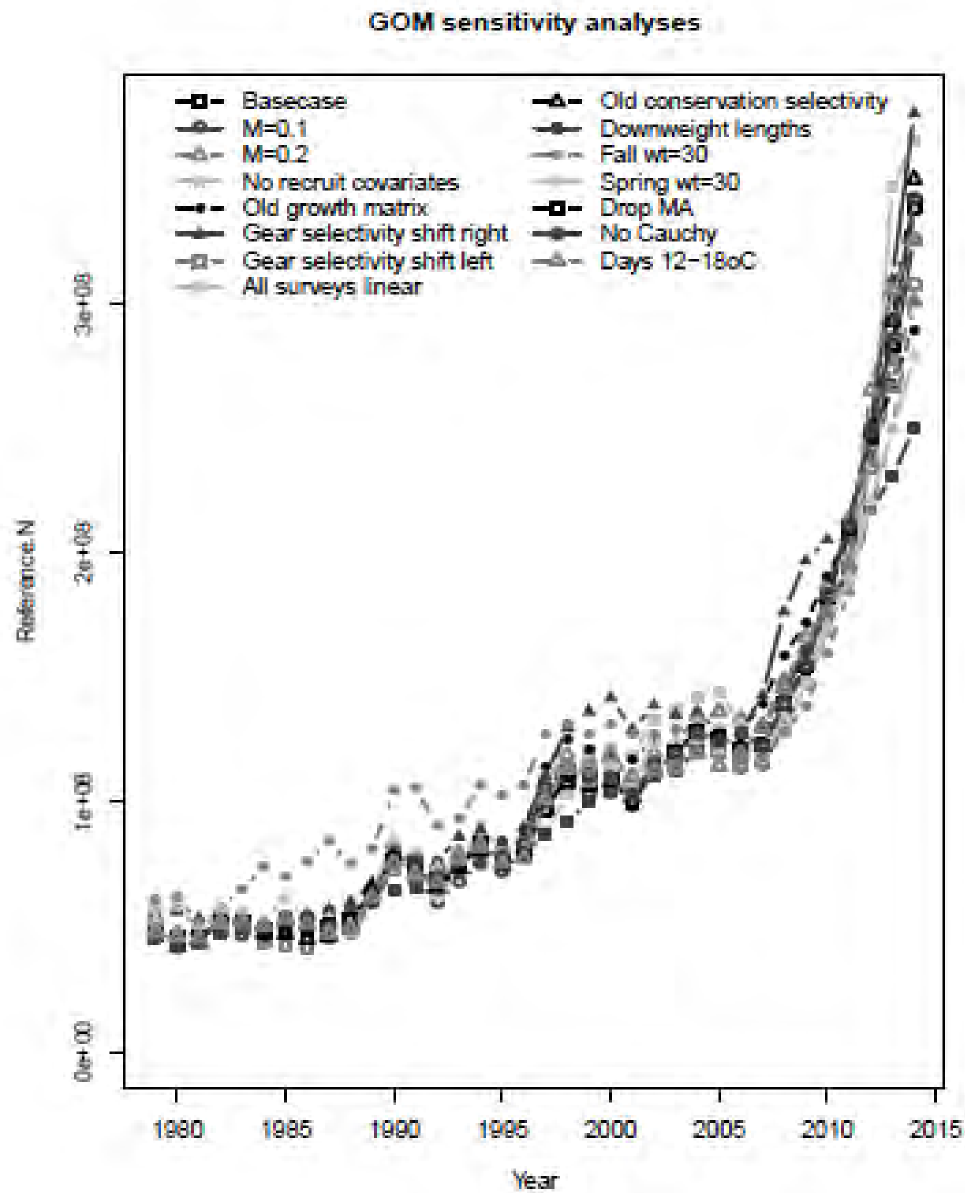


Figure 6.3.1.2. Annual reference abundance estimates for GOM lobster from 1979-2013 from the basecase and sensitivity model runs.

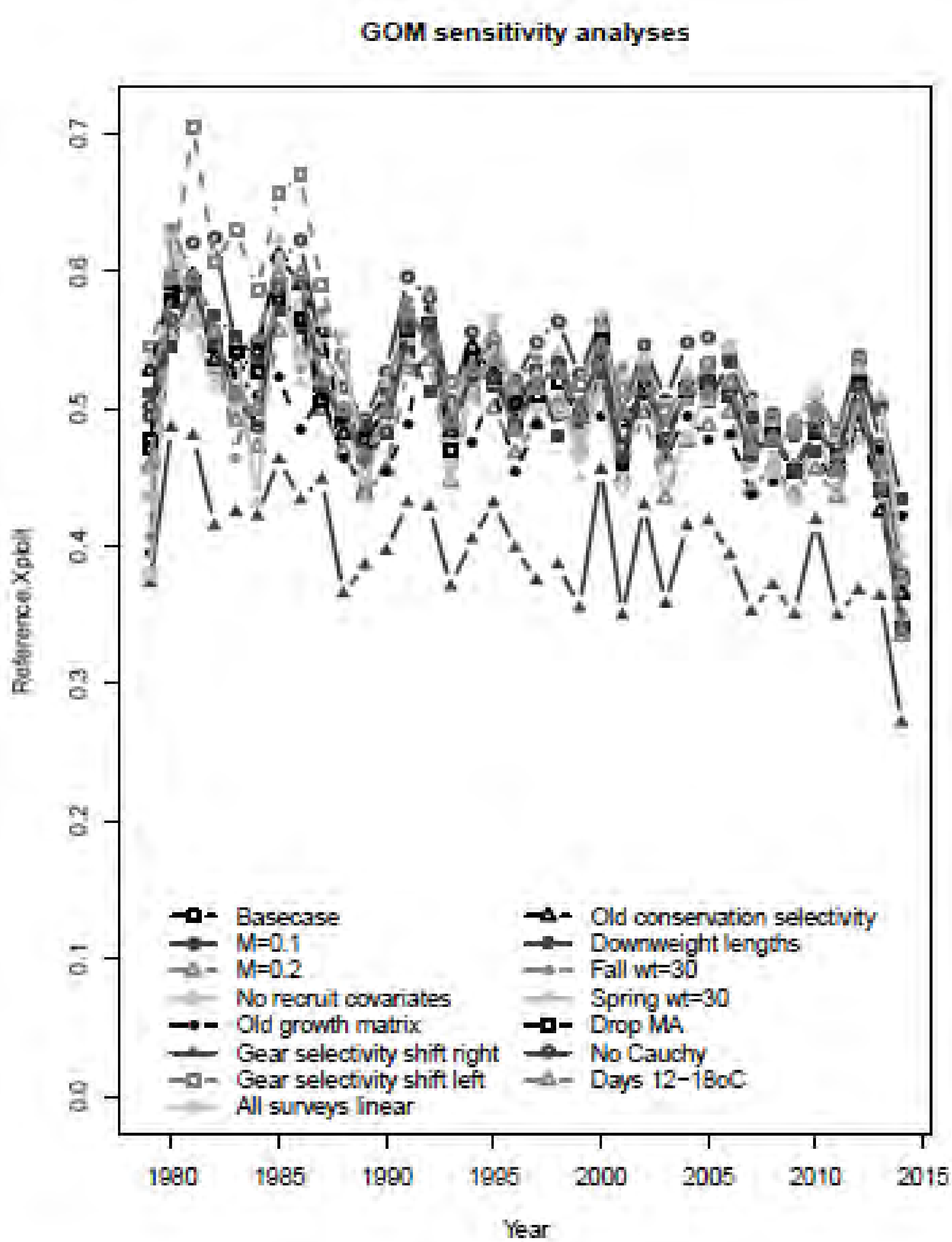


Figure 6.3.1.3. Annual effective exploitation estimates for GOM lobster from 1979-2013 from the basecase and sensitivity model runs.

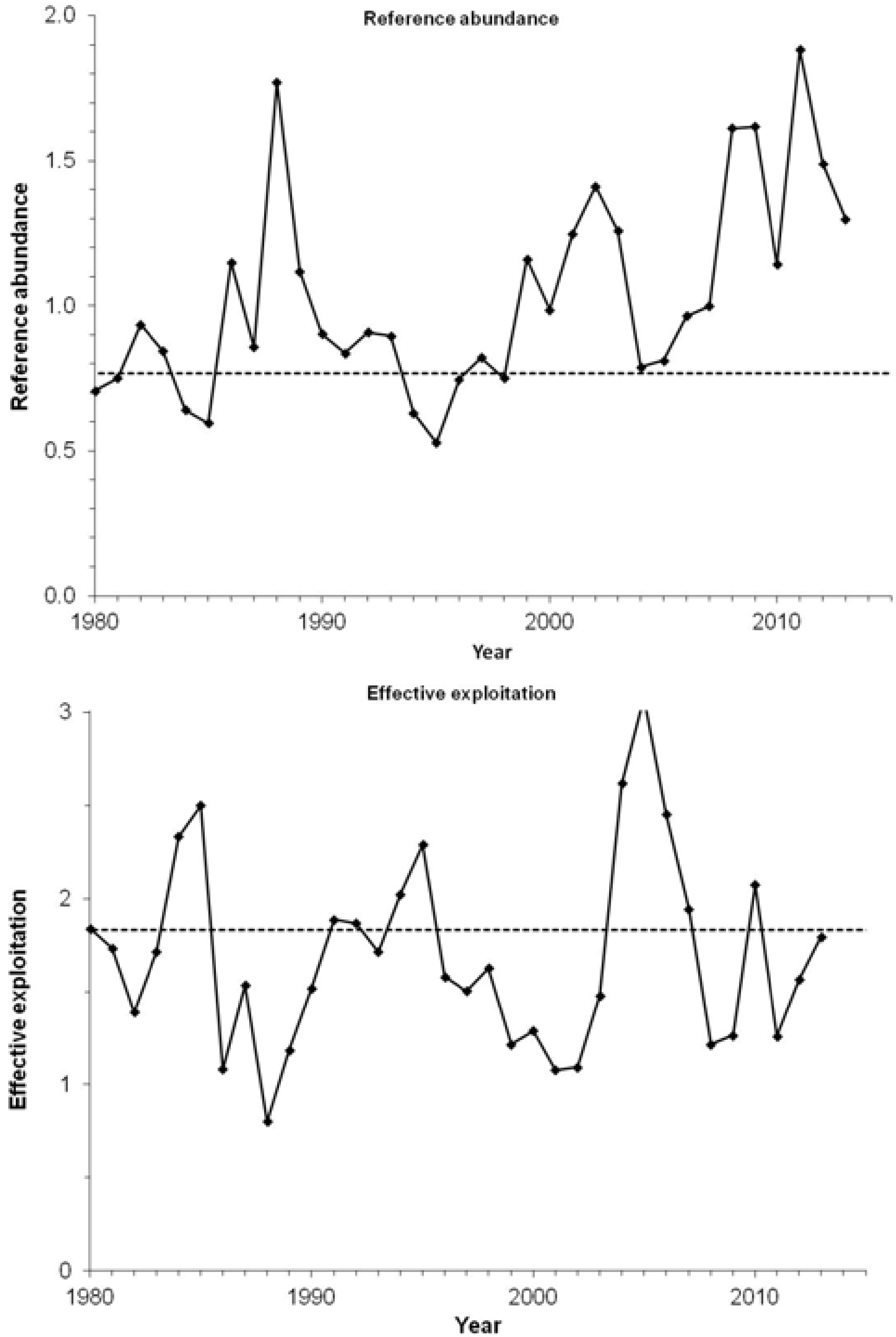


Figure 6.3.2.1. Trends in empirical basecase reference abundance and effective exploitation for GBK lobster (sexes combined) from 1982-2013. Horizontal lines show threshold reference points at the 25th percentile (reference time period 1982-2003) for abundance and the 75th percentile for effective exploitation.

Figure 6.3.2.2. Trends in empirical reference abundance and effective exploitation estimates for GBK lobster by sex from 1982-2013.

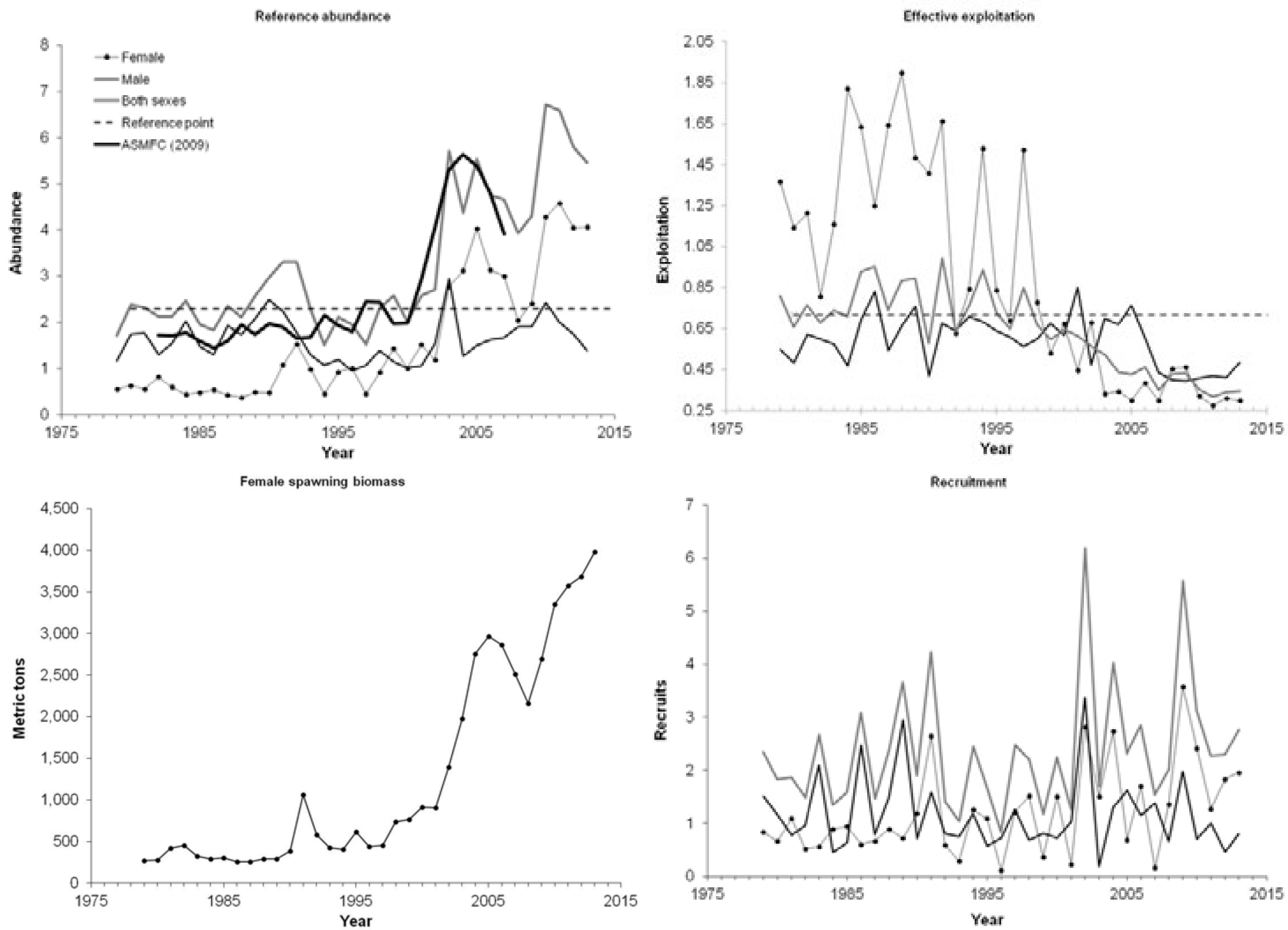


Figure 6.3.2.3. Annual reference abundance, effective exploitation, spawning biomass, and recruitment estimates for American lobster from 1979-2013 from the basecase model for GBK and from 1982-2007 from ASMFC (2009). Horizontal lines show threshold reference points at the 25th percentile (reference time period 1982-2003) for abundance and the 75th percentile for effective exploitation.. This model was not accepted by the American Lobster Technical Committee, should not be used for management purposes, and the figures are provided for diagnostic purposes only.

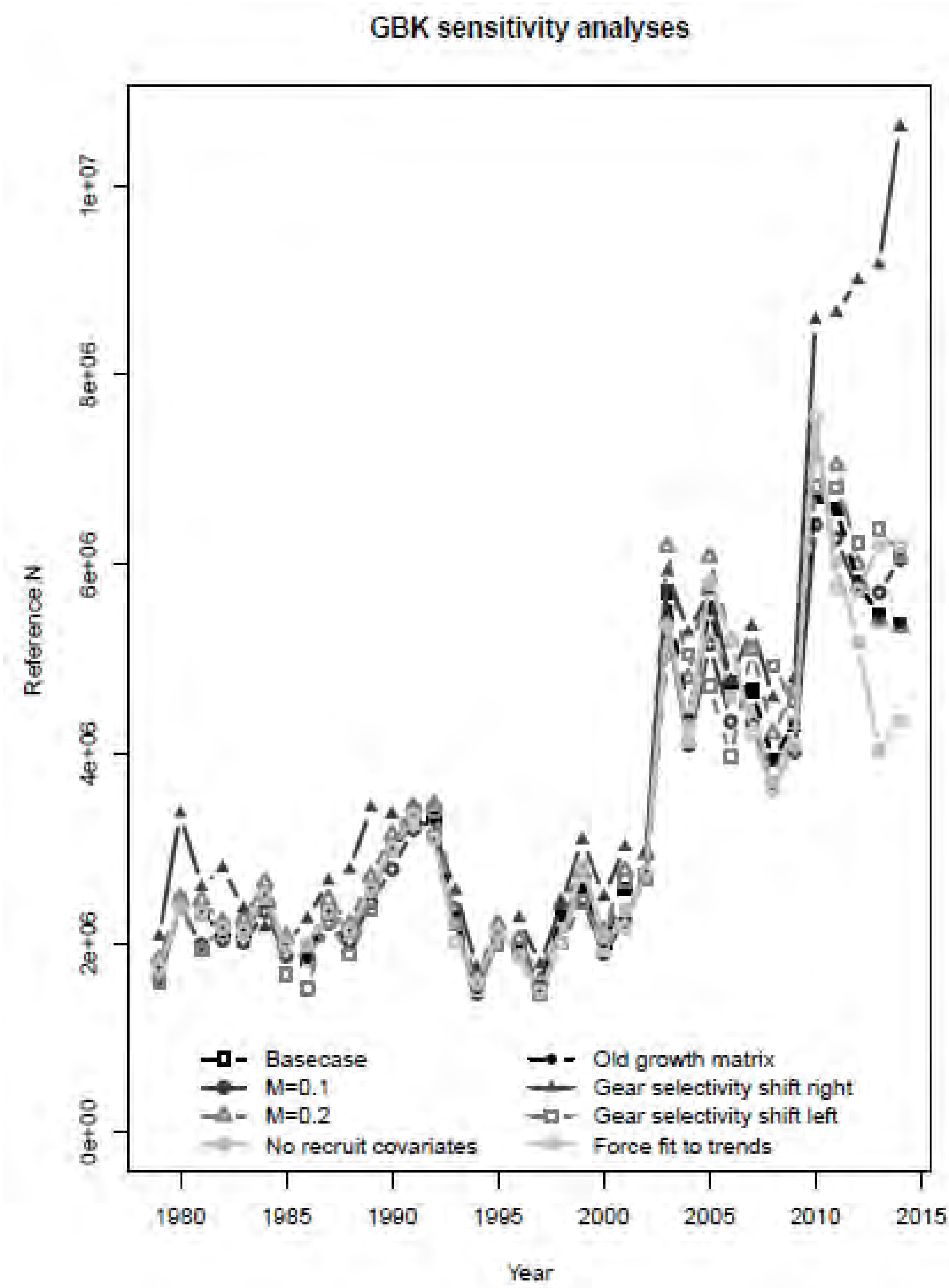


Figure 6.3.2.4. Reference abundance estimates for GBK lobster from 1979-2013 from the University of Maine model and sensitivity model runs. This model was not accepted by the American Lobster Technical Committee, should not be used for management purposes and the figures are provided for diagnostic purposes only.

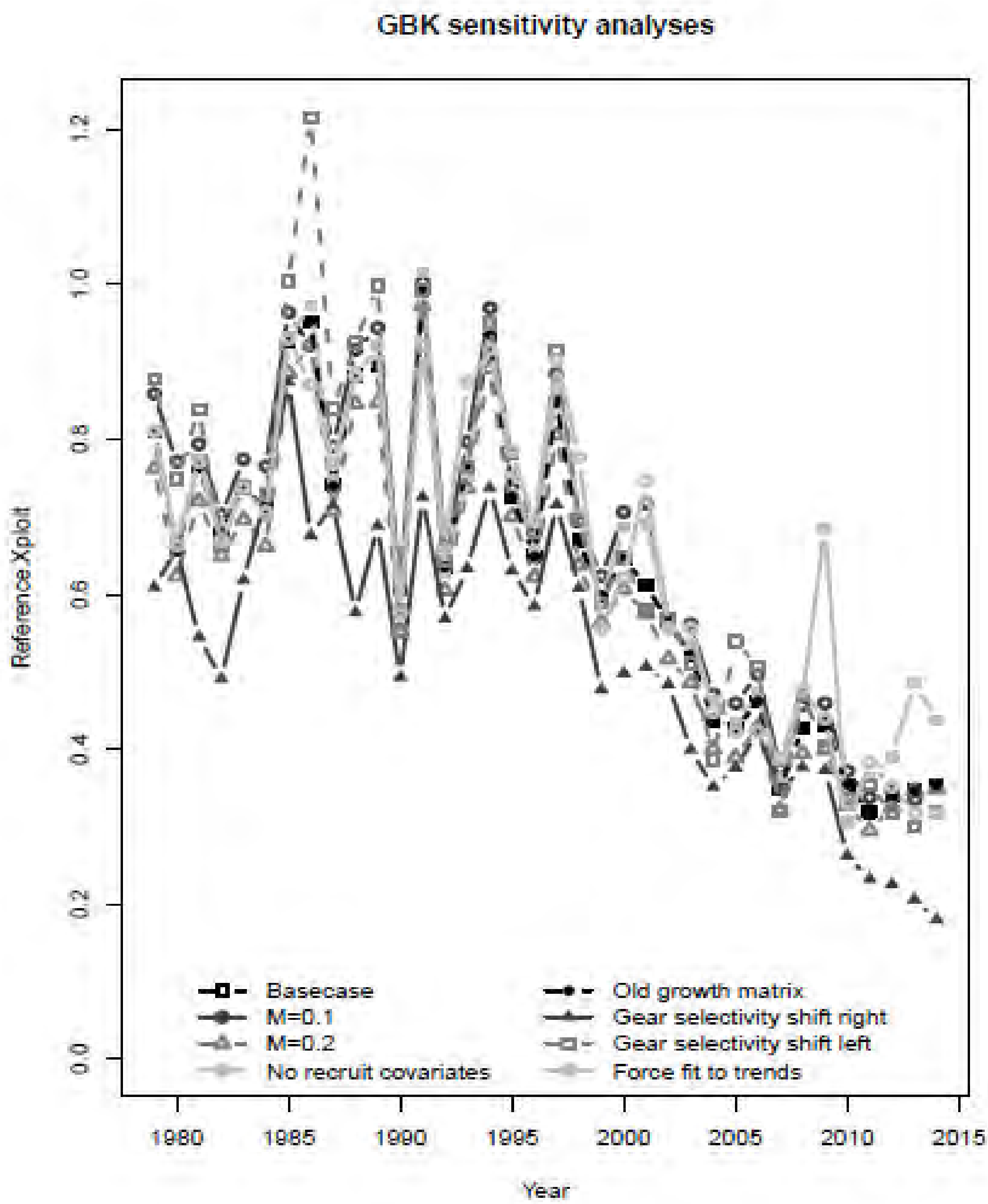


Figure 6.3.2.5. Effective exploitation estimates for GOM lobster from 1979-2013 from the University of Maine Model and sensitivity model runs. This model was not accepted by the American Lobster Technical Committee, should not be used for management purposes and the figures are provided for diagnostic purposes only.

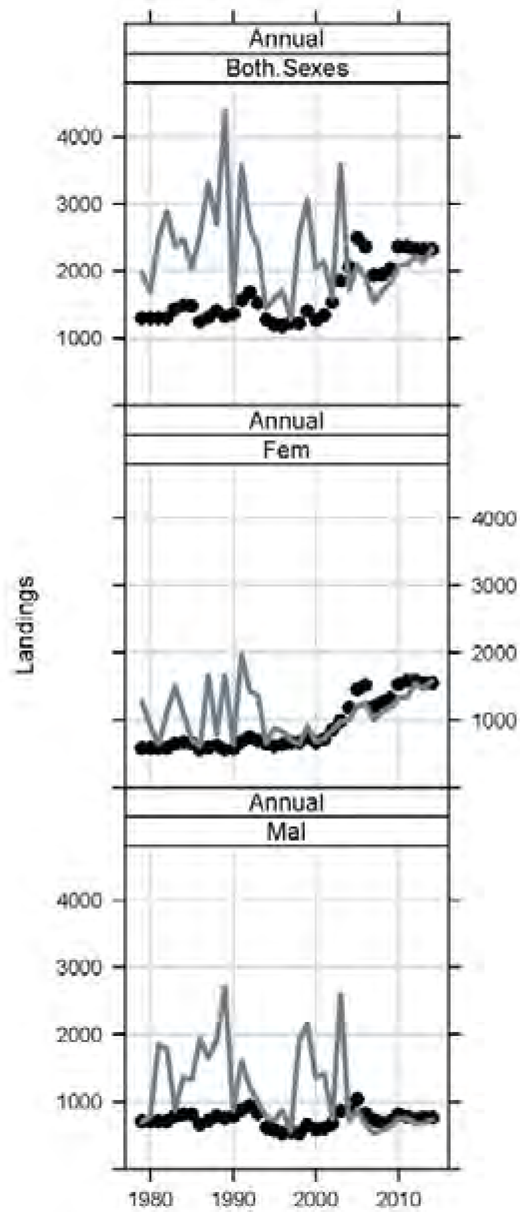


Figure 6.3.2.6. Observed (black circles) and predicted catches (grey line) in a sensitivity run where the likelihood weights for the NEFSC fall female and male surveys and the spring female survey were increased to 20. This model was not accepted by the American Lobster Technical Committee, should not be used for management purposes and the figures are provided for diagnostic purposes only.

Figure 6.3.3.1. Annual reference abundance, effective exploitation, spawning biomass, and recruitment estimates for 1979-2013 from the basecase model for GOM/GBK and for 1982-2007 from ASMFC (2009). Horizontal lines show threshold reference points (reference period 1982 - 2003) at the 25th percentile for reference abundance and the 75th percentile for effective exploitation.

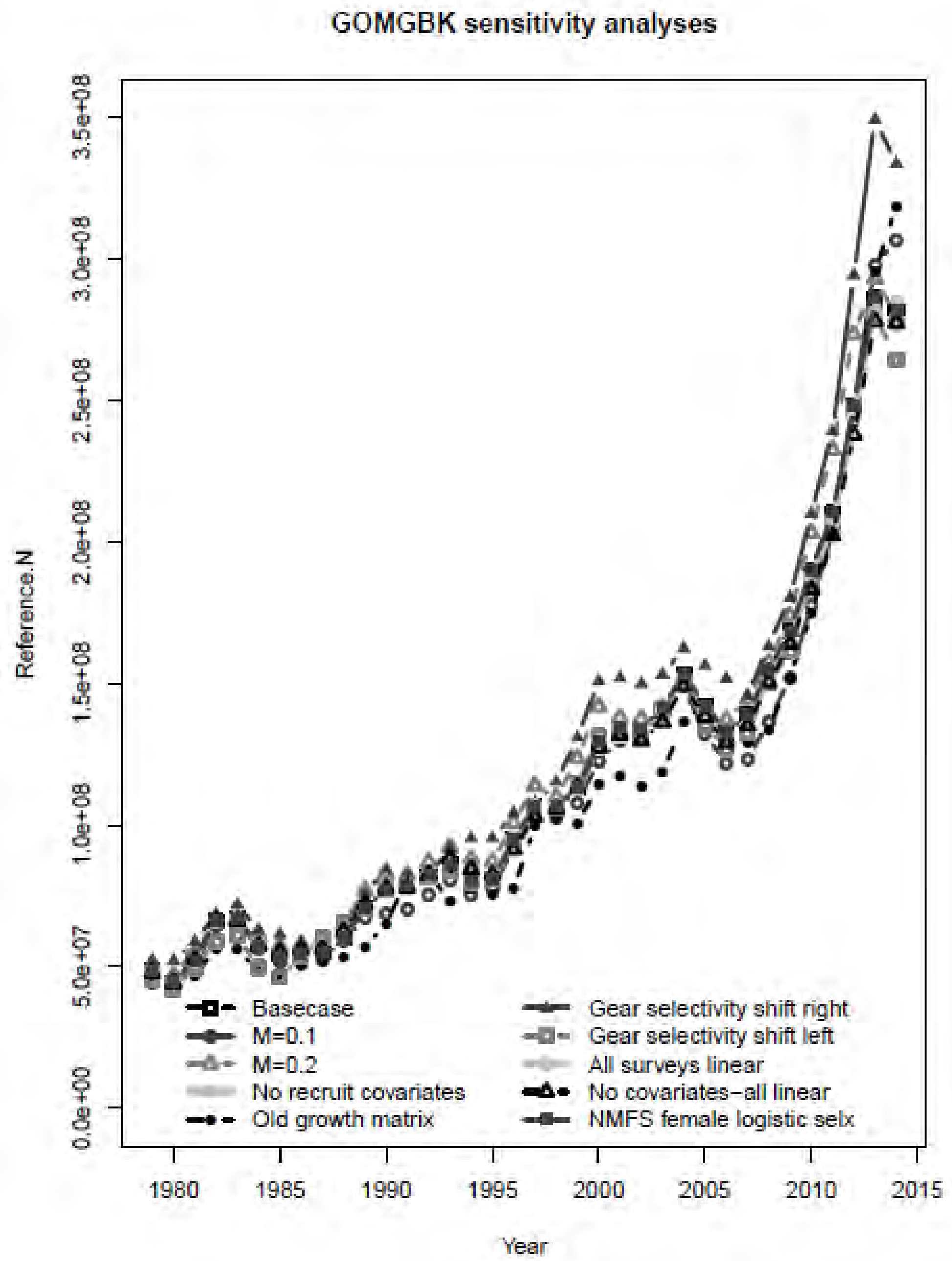


Figure 6.3.3.2. Annual reference abundance estimates for GOM/GBK lobster from 1979-2013 from the basecase and sensitivity model runs.

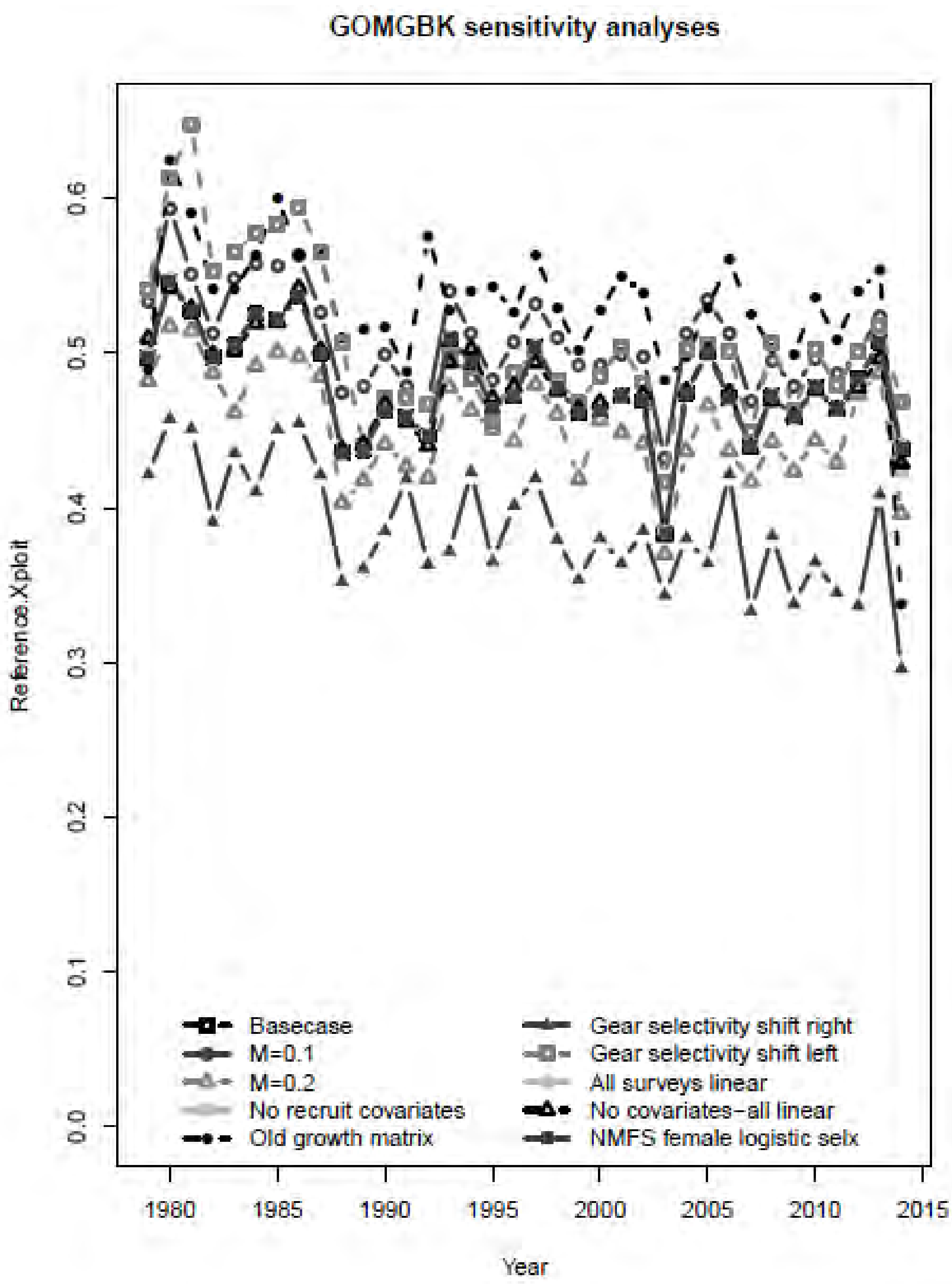


Figure 6.3.3.3. Annual effective exploitation estimates for GOM/GBK lobster from 1979-2013 from the basecase and sensitivity model runs.

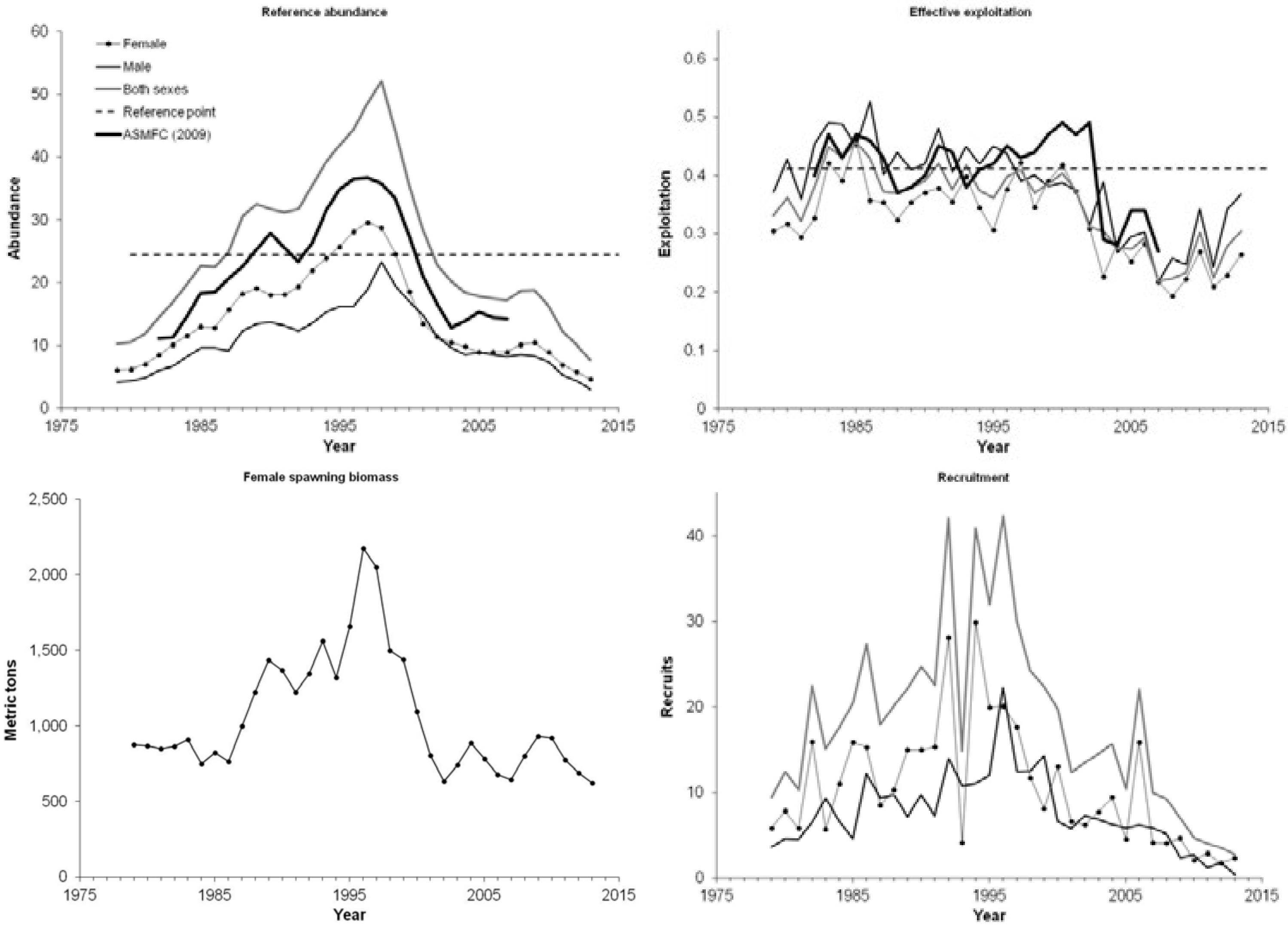


Figure 6.3.4.1. Annual reference abundance, effective exploitation, spawning biomass, and recruitment estimates for American lobster during 1979-2013 from the basecase model for SNE and for 1982-2007 from ASMFC (2009). Horizontal lines show threshold reference points (reference period 1984 - 2003) at the 25th percentile for reference abundance and the 75th percentile for effective exploitation.

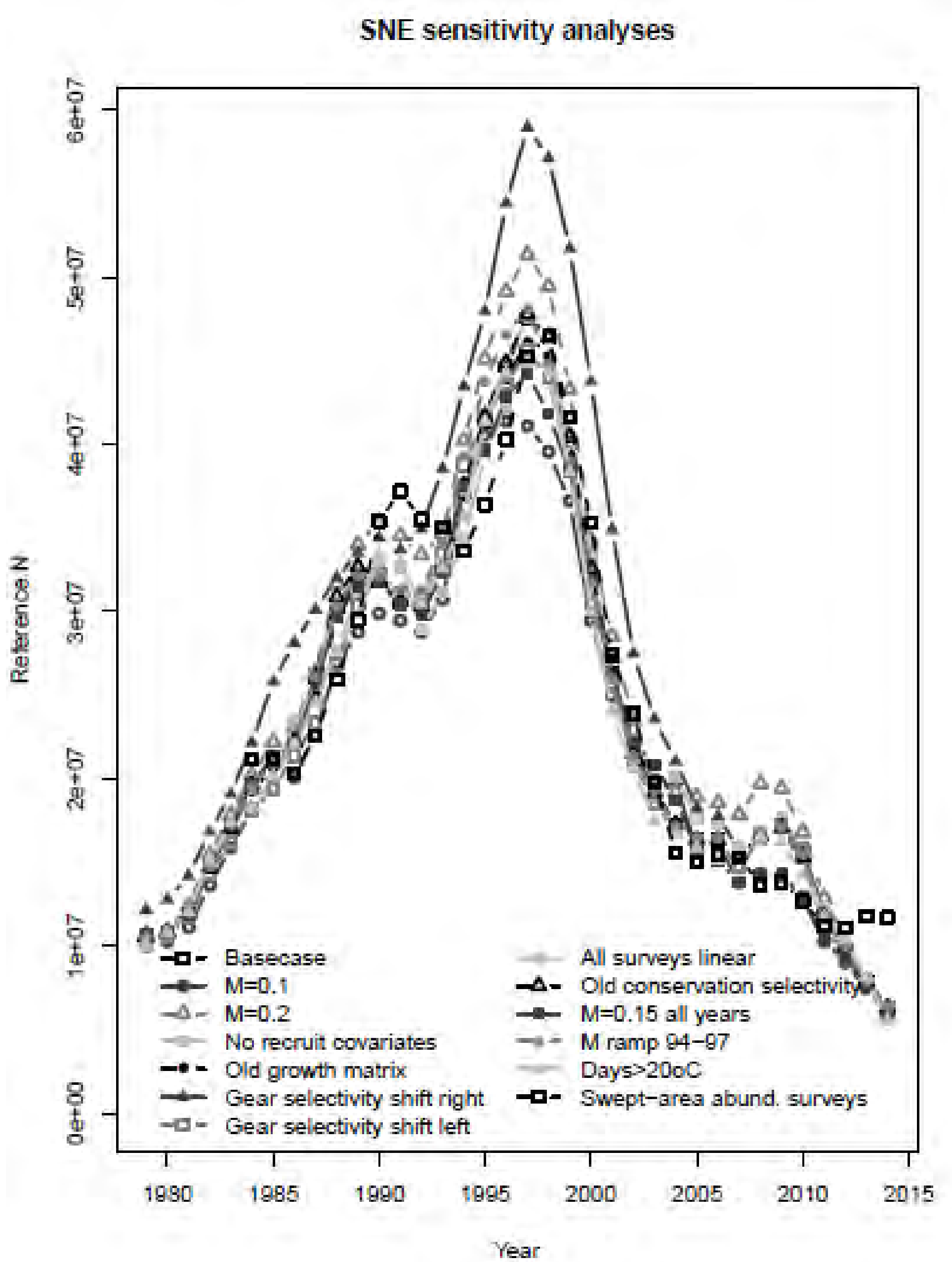


Figure 6.3.4.2. Annual reference abundance estimates for SNE lobster from 1979-2013 from the basecase and sensitivity model runs.

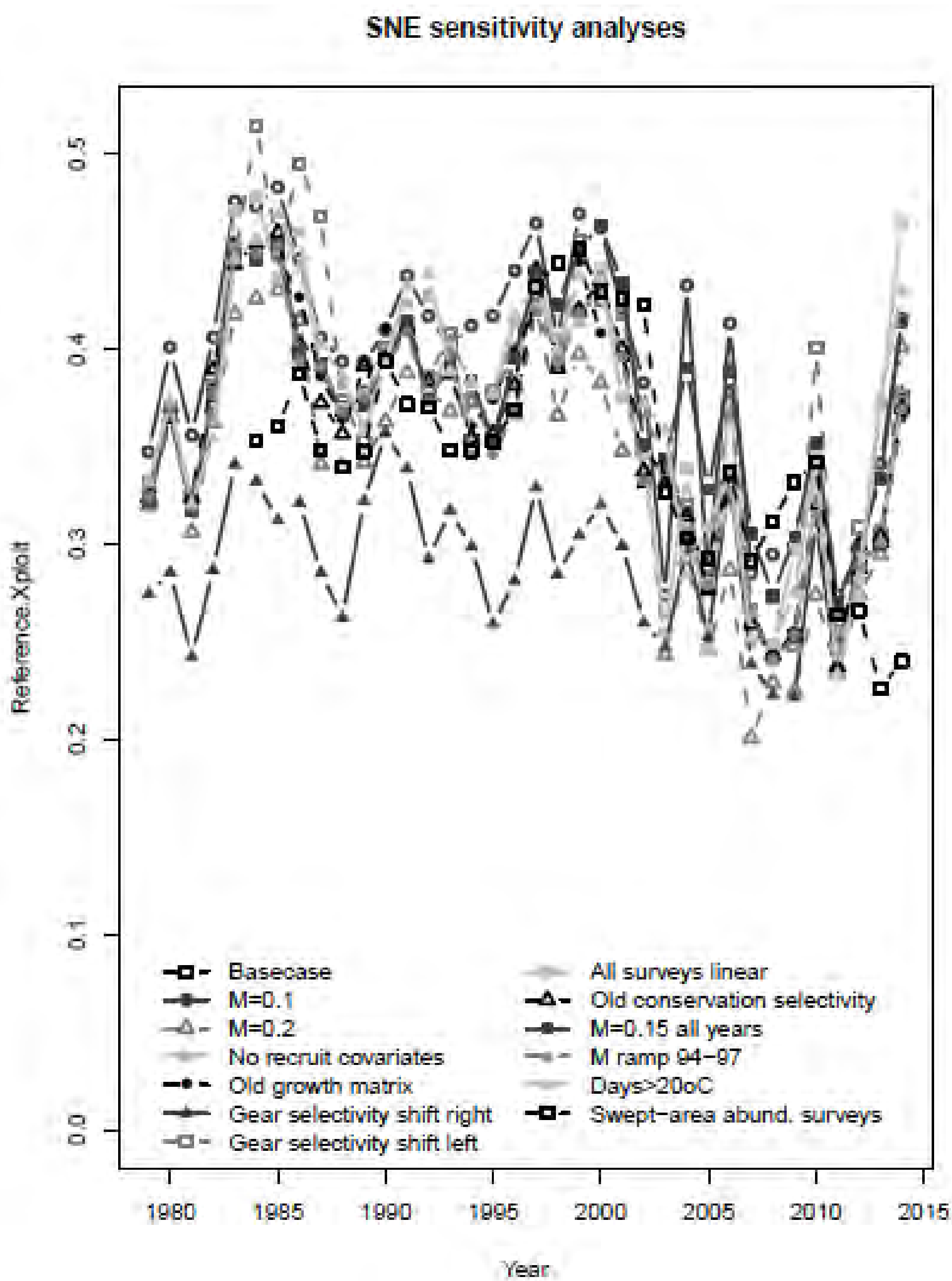
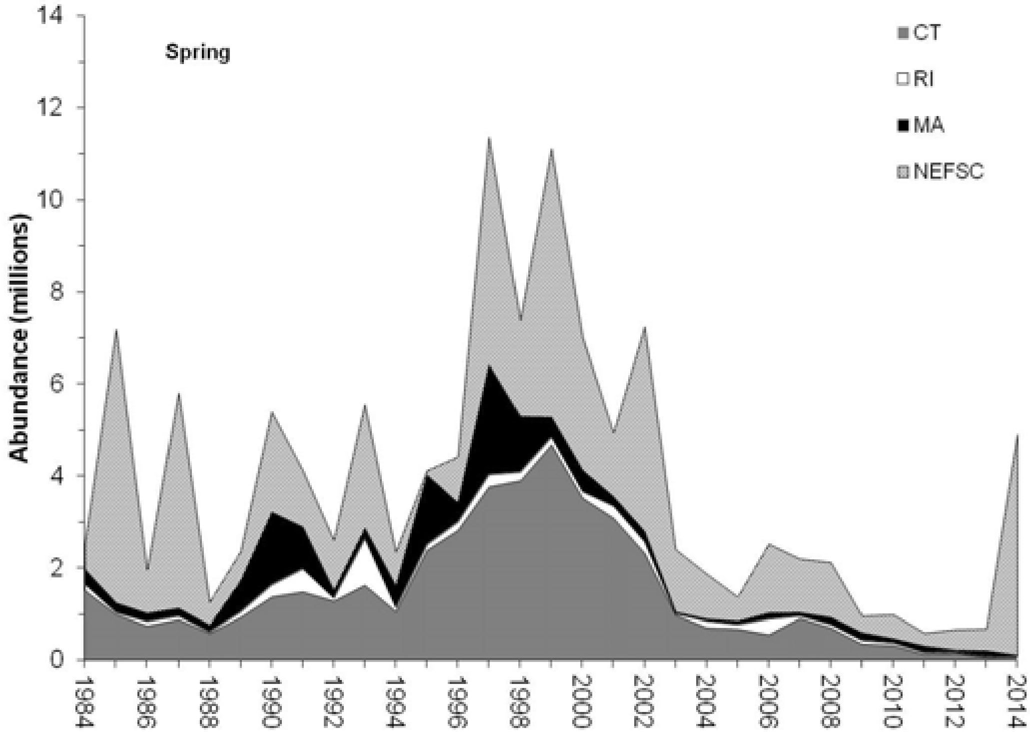


Figure 6.3.4.3. Annual effective exploitation estimates for SNE lobster from 1979-2013 from the basecase and sensitivity model runs.



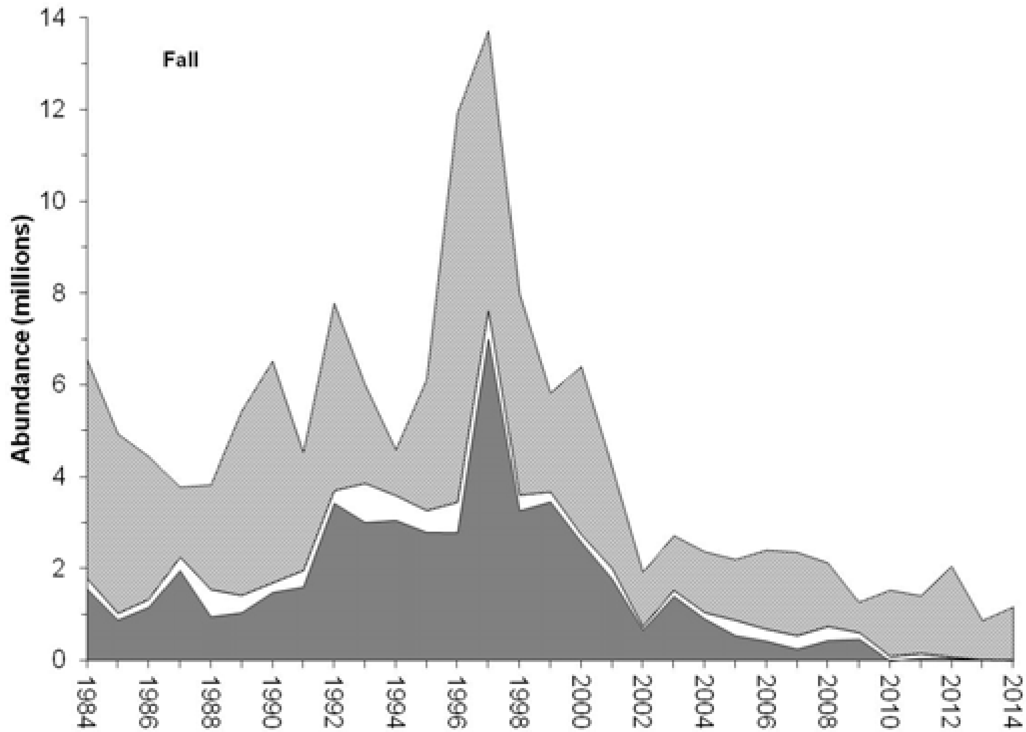


Figure 6.3.4.4. Spring (top) and fall (bottom) swept-area survey abundance data used in sensitivity analyses for SNE. The fall MA survey index was very low, noisy and not included.

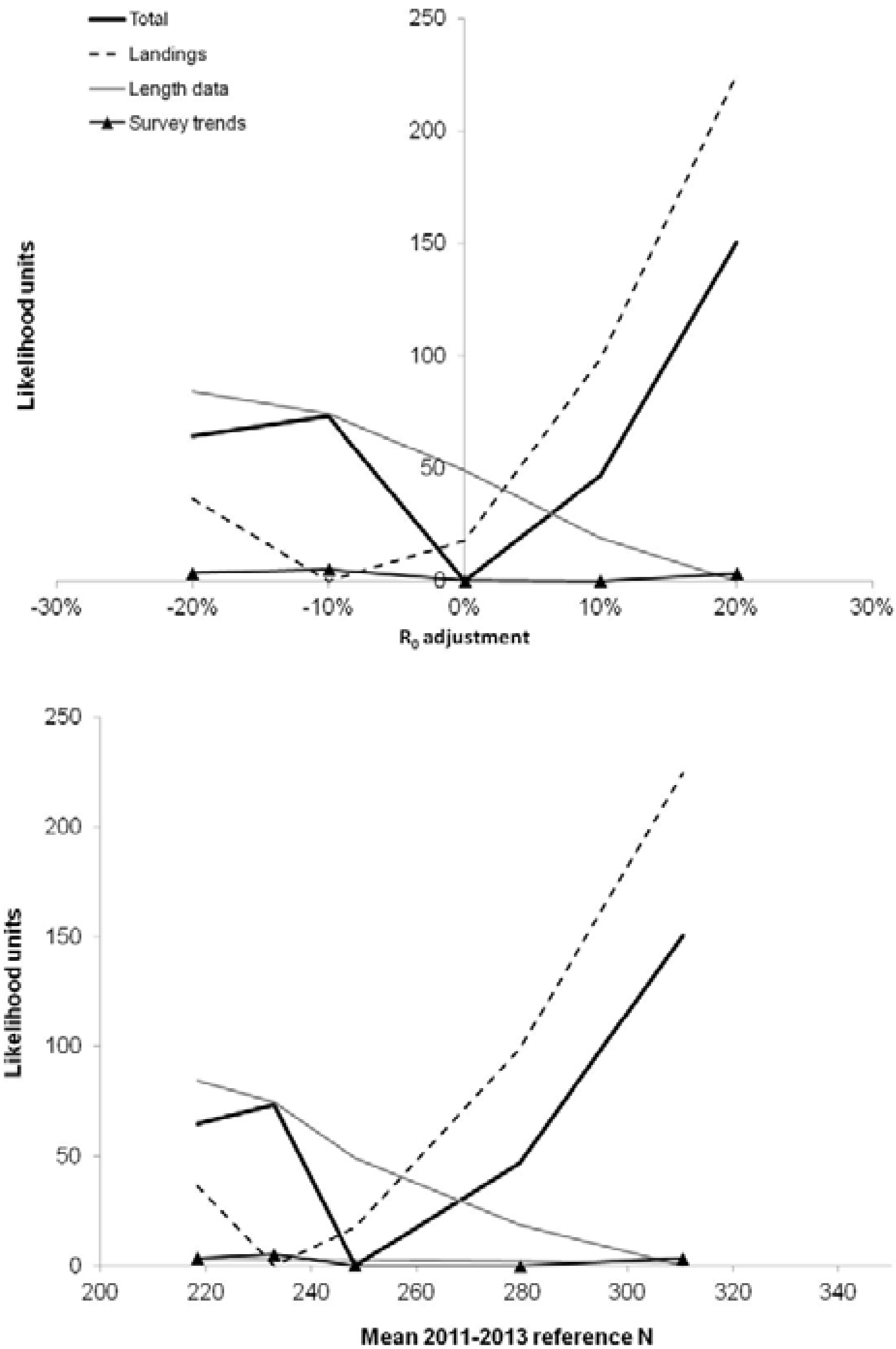


Figure 6.4.1.1. Summed likelihood profile results over a range of values for the mean log recruitment parameter (R_0) for female and male lobsters in the GOM stock area (top). An R_0 adjustment of 10%, for example, means that mean recruitment was fixed at a level about 10% higher than in the basecase model run. Mean reference N along the x-axis of the lower panel is the average reference abundance during 2011-2013 estimated from the corresponding run at the same position in the upper panel (bottom).

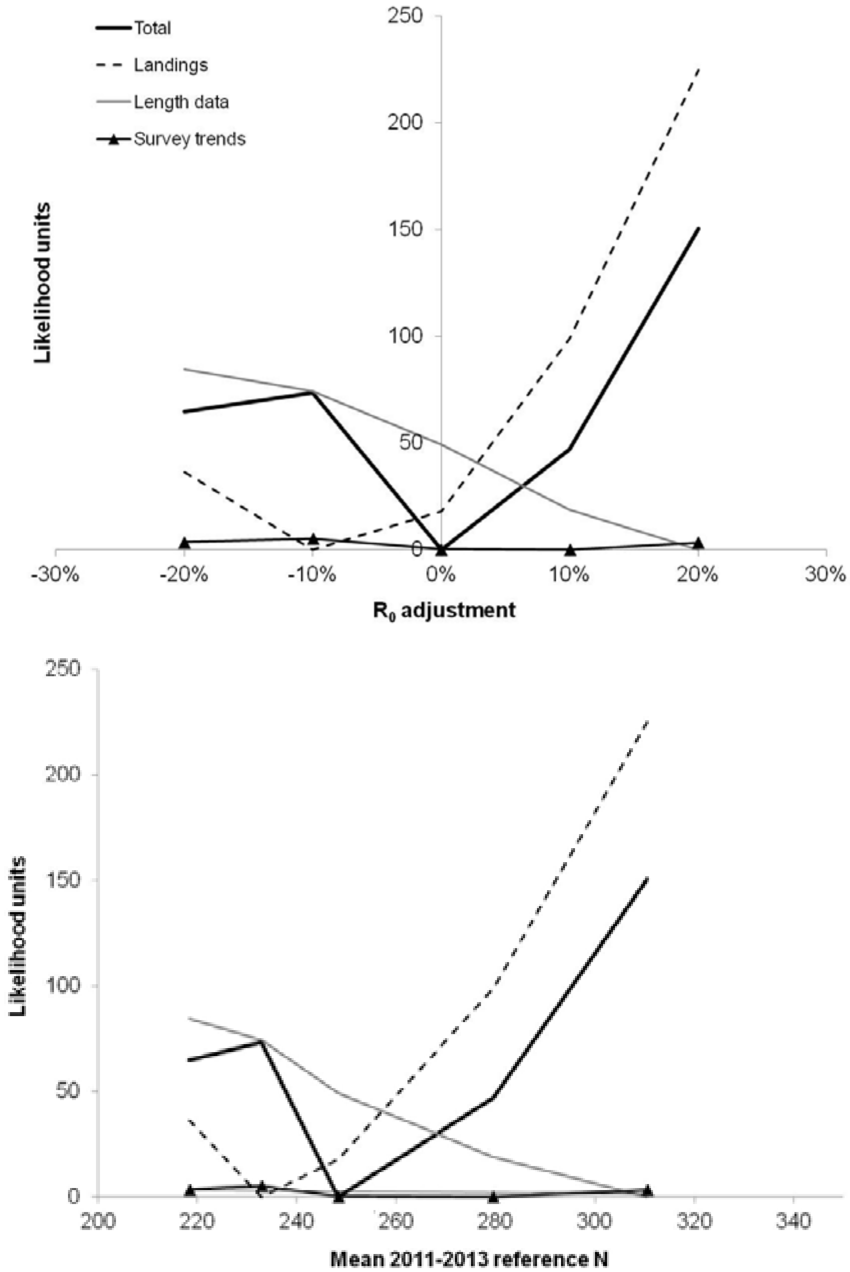


Figure 6.4.1.2. Summed likelihood profile results over a range of values for the mean log recruitment parameter (R_0) for female and male lobsters in the GOM/GBK stock area (top). An R_0 adjustment of 10%, for example, means that mean recruitment was fixed at a level about 10% higher than in the basecase model run. Mean reference N along the x-axis of the lower panel is the average reference abundance during 2011-2013 estimated from the corresponding run at the same position in the upper panel.

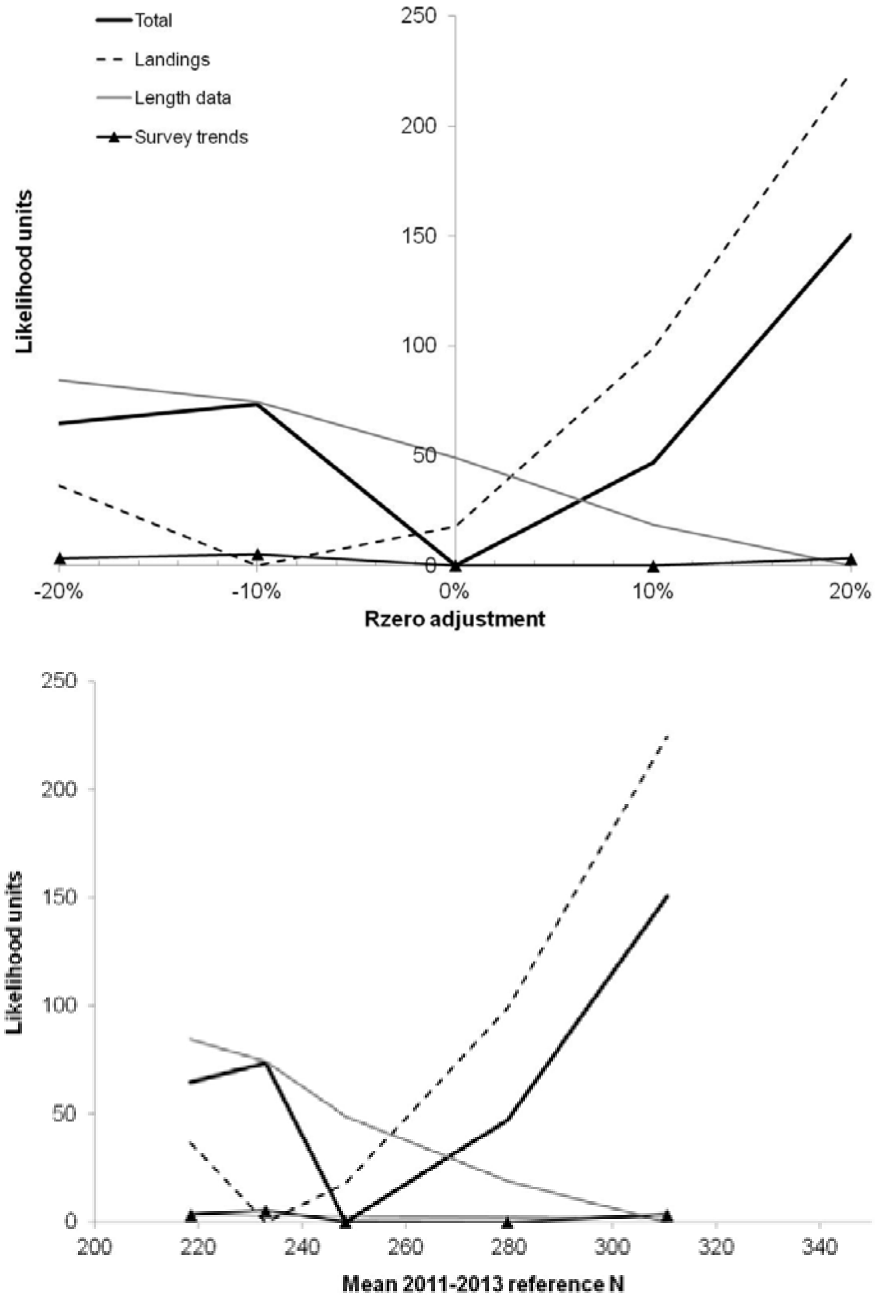


Figure 6.4.1.3. Summed likelihood profile results over a range of values for the mean log recruitment parameter (R_0) for female and male lobsters in the SNE stock area. An R_0 adjustment of 10%, for example, means that mean recruitment was fixed at a level about 10% higher than in the basecase model run. Mean reference N along the x-axis of the lower panel is the average reference abundance during 2011-2013 estimated from the corresponding run at the same position in the upper panel.

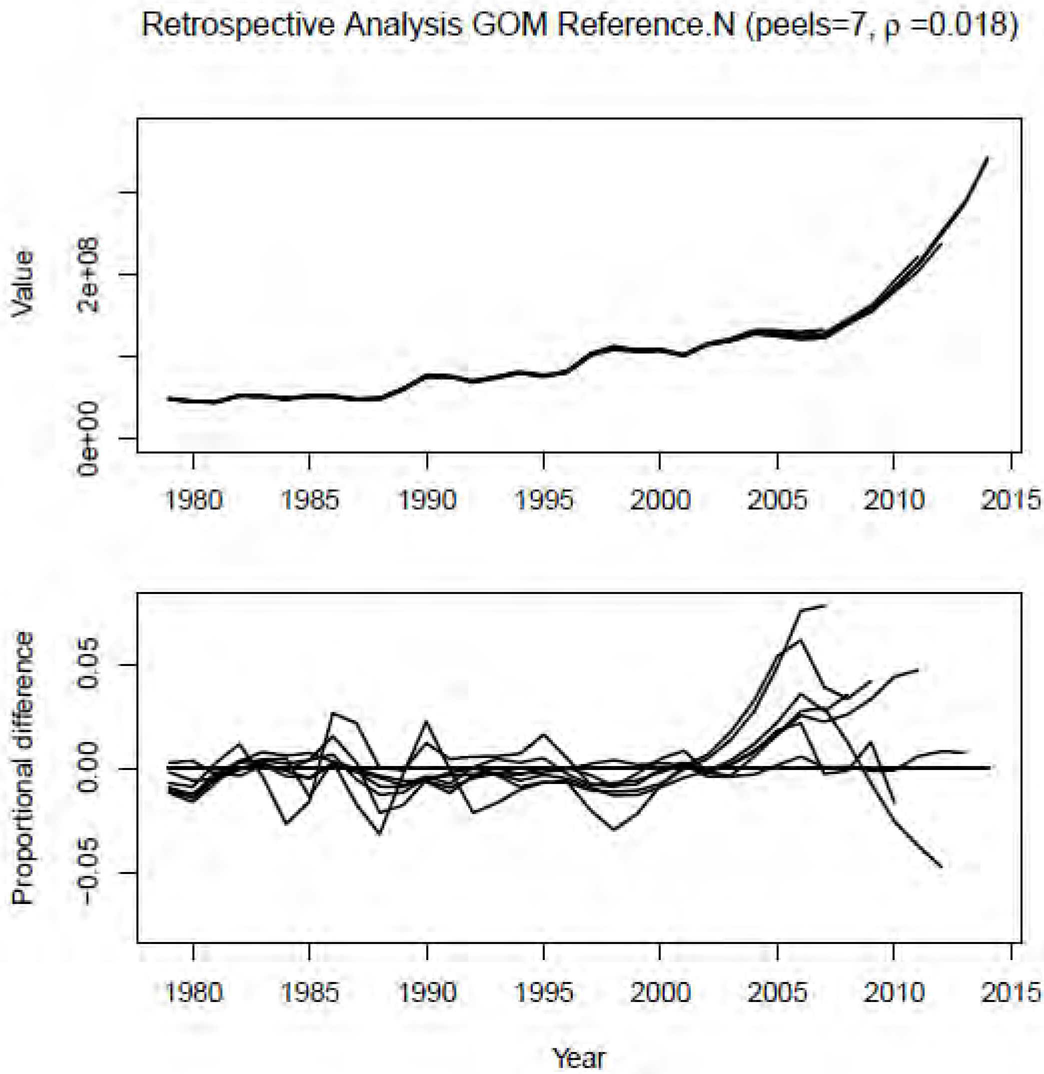


Figure 6.4.2.1. Retrospective analysis for GOM lobster reference abundance estimates from the preliminary basecase model.

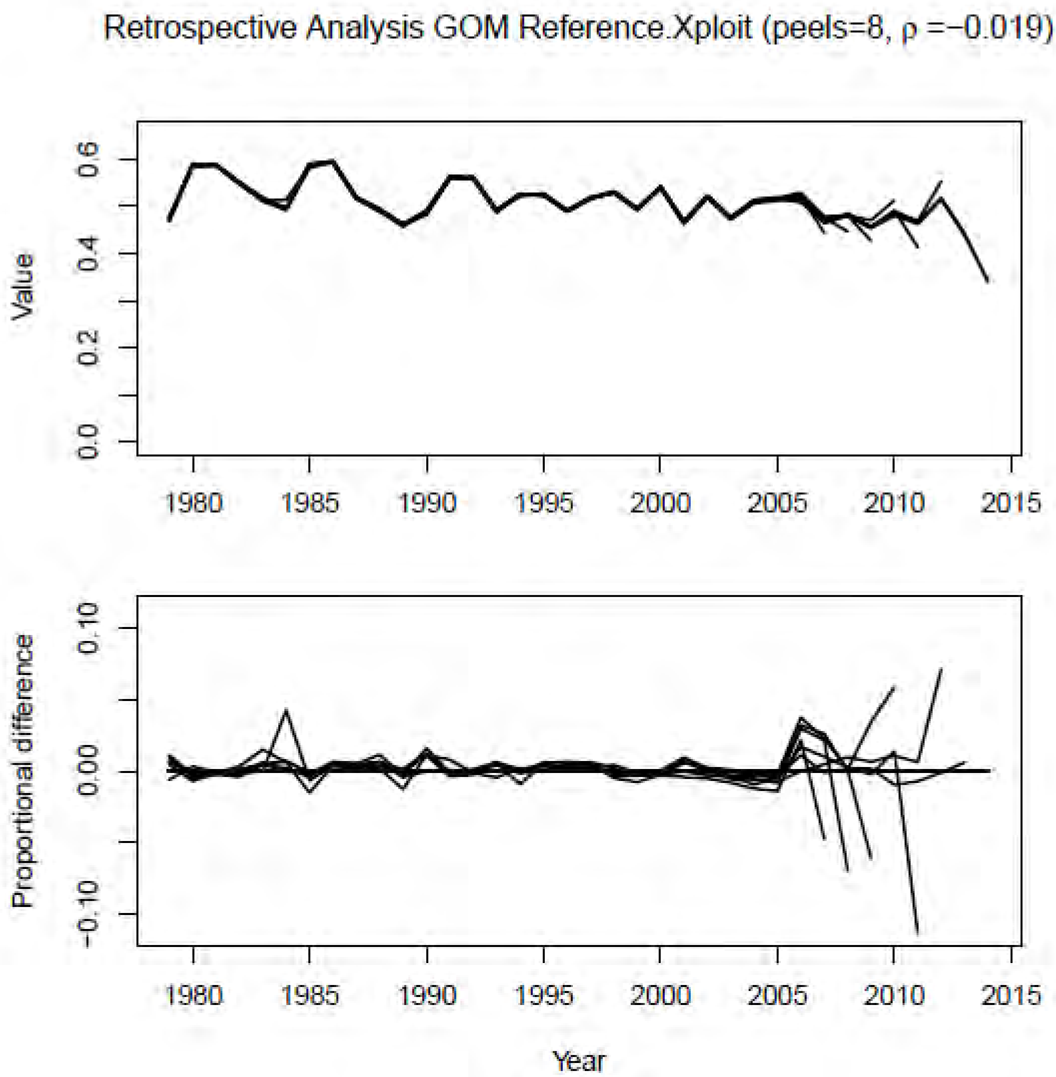


Figure 6.4.2.2. Retrospective analysis for GOM lobster effective exploitation estimates from the preliminary basecase model.

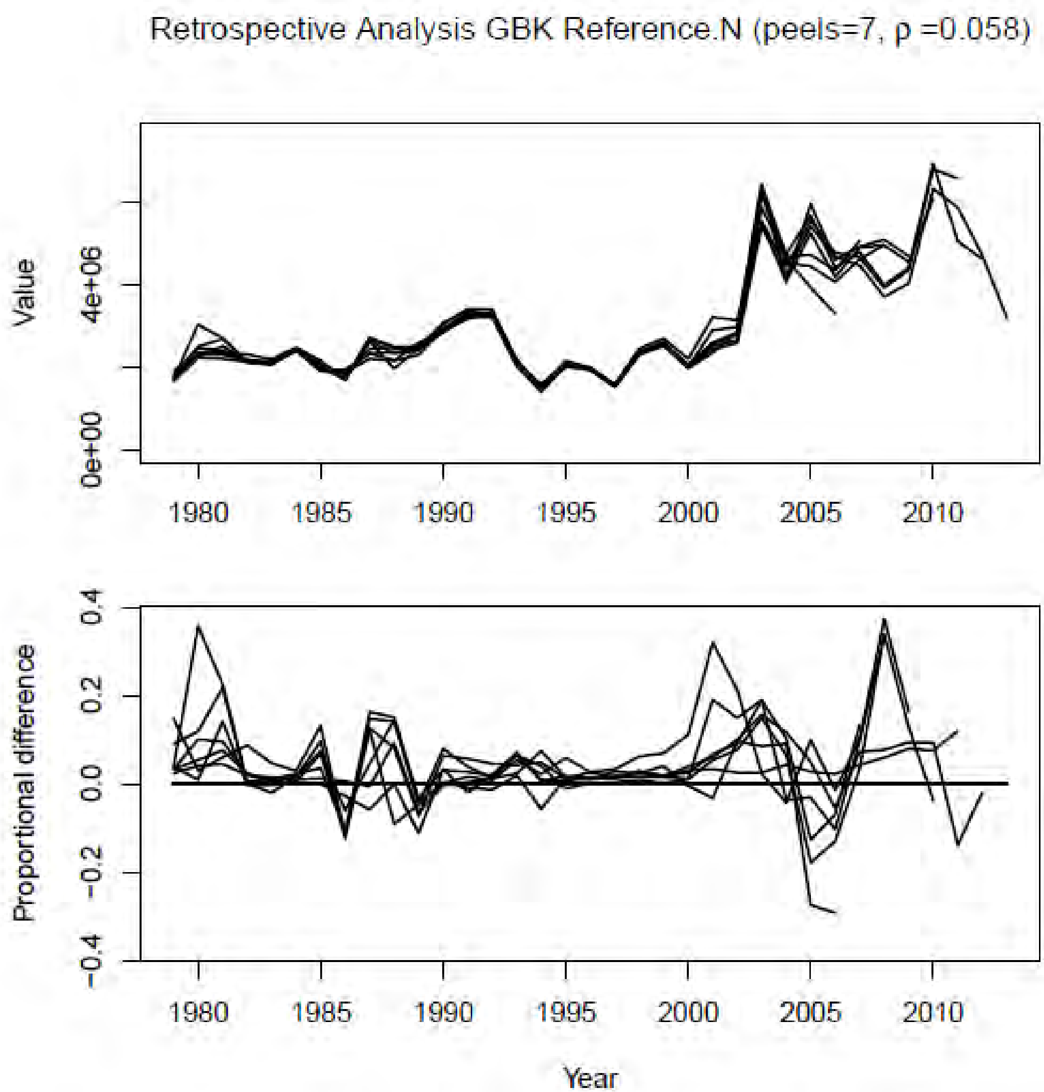


Figure 6.4.2.3. Retrospective analysis for GBK lobster reference abundance estimates from the basecase model. The American Lobster Technical Committee did not accept the basecase model for management use.

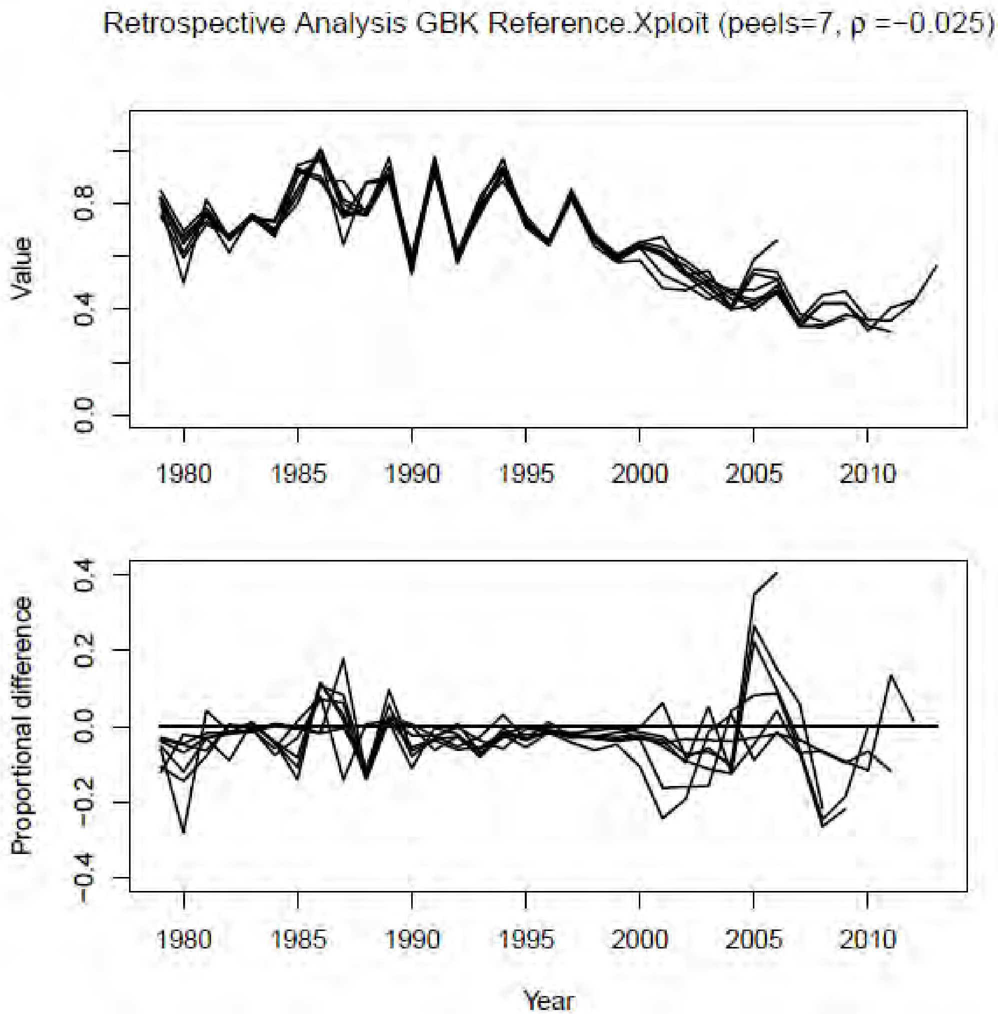


Figure 6.4.2.4. Retrospective analysis for GBK lobster effective exploitation estimates from the University of Maine model. This model was not accepted by the American Lobster Technical Committee, should not be used for management purposes and the figures are provided for diagnostic purposes only.

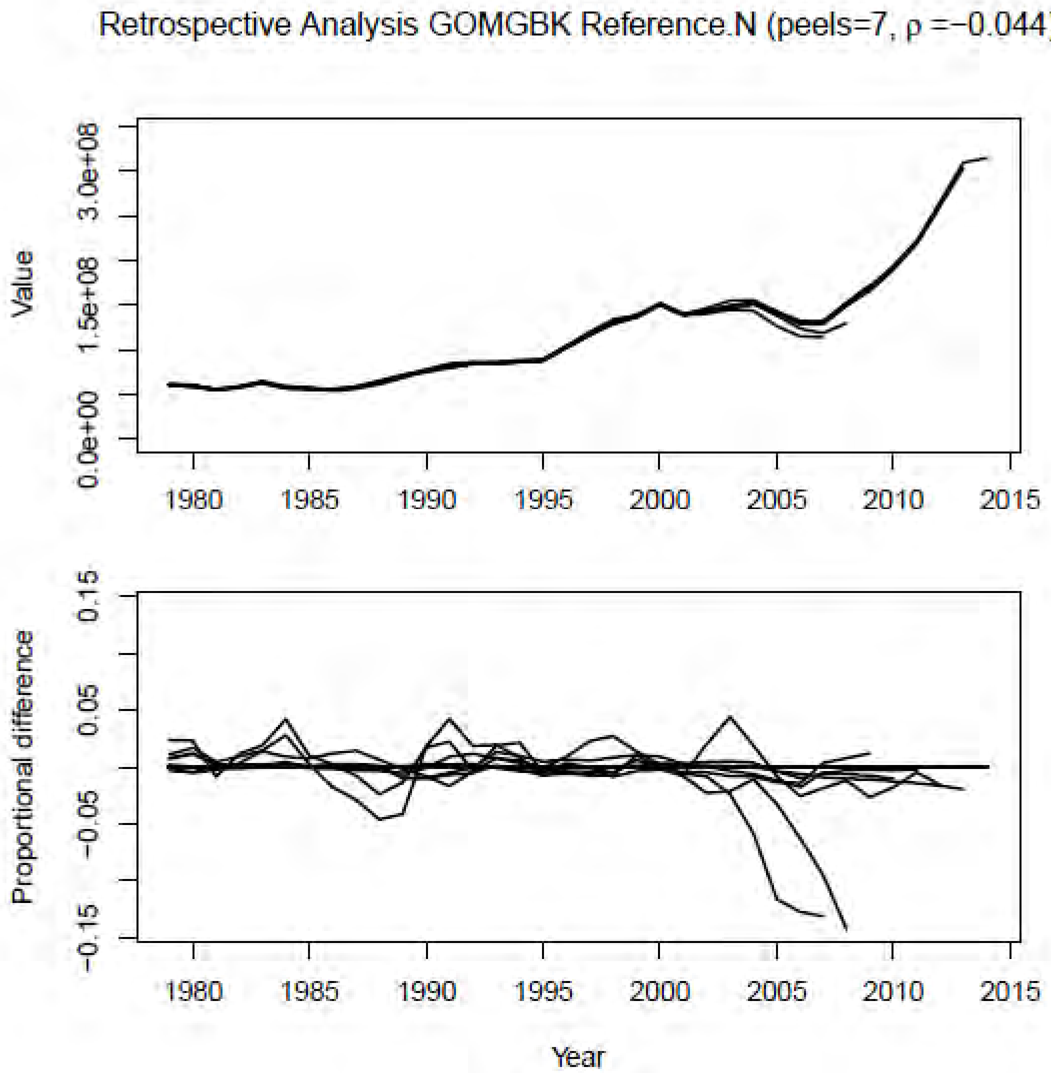


Figure 6.4.2.5. Retrospective analysis for GOM/GBK lobster reference abundance estimates from the basecase model.

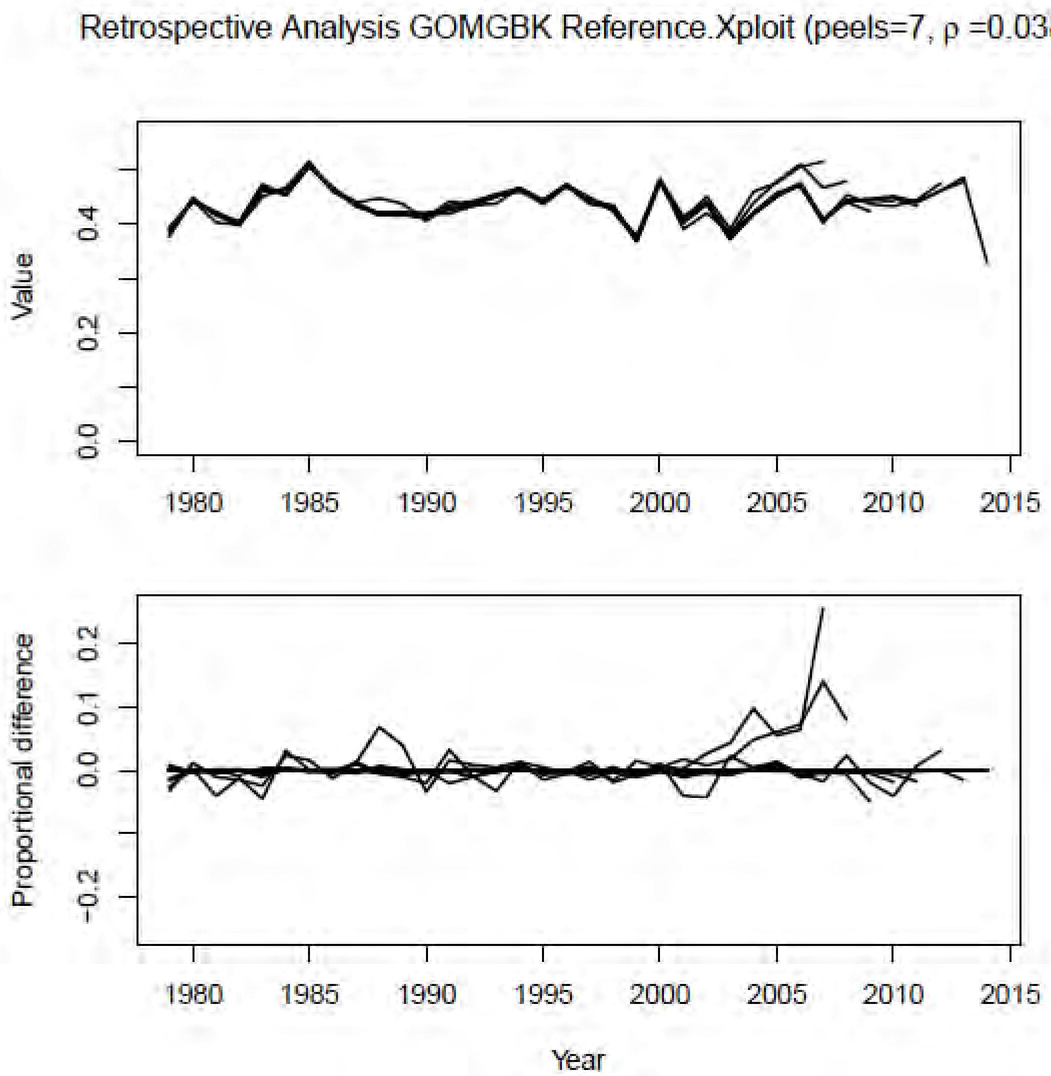


Figure 6.4.2.6. Retrospective analysis for GOM/GBK lobster effective exploitation estimates from the basecase model.

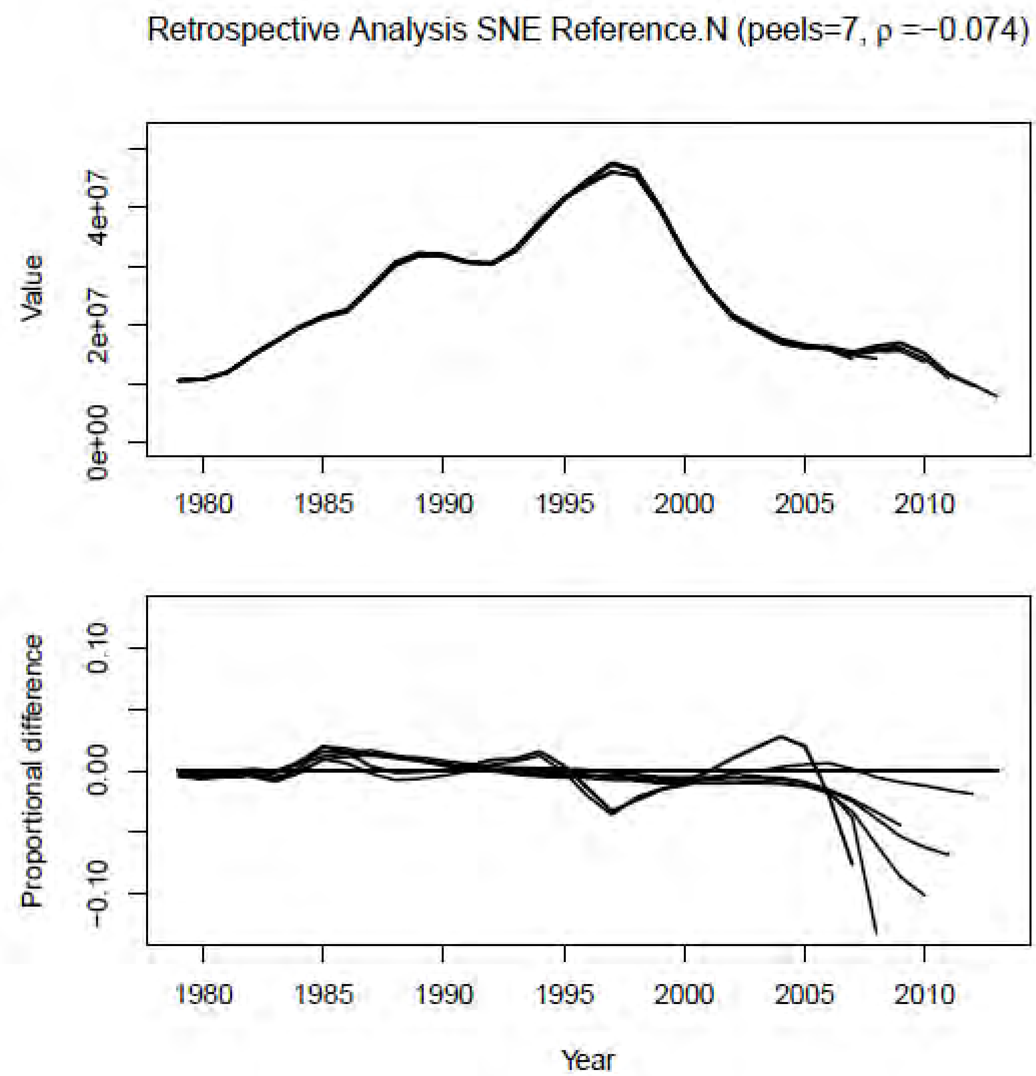


Figure 6.4.2.7. Retrospective analysis for SNE lobster reference abundance estimates from the preliminary basecase model.

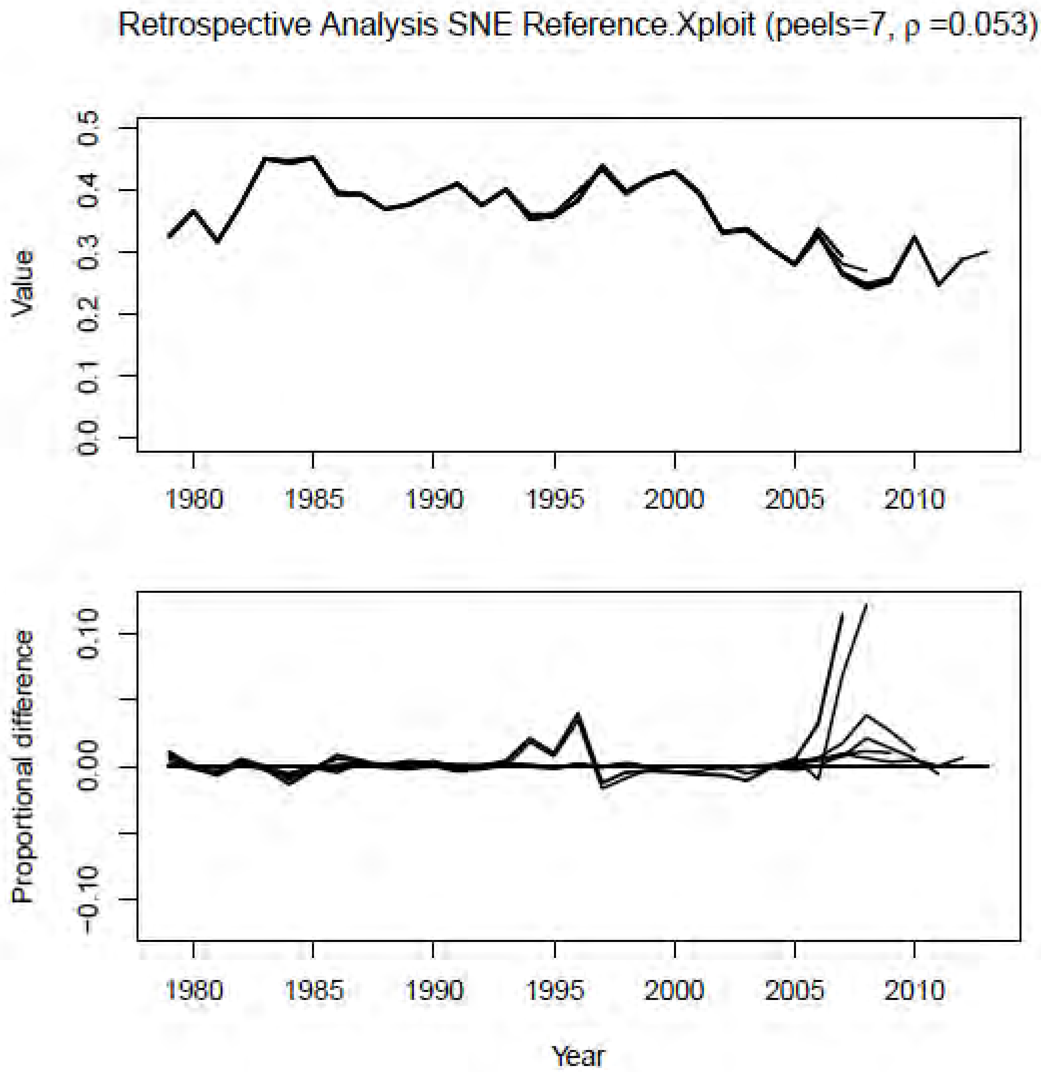


Figure 6.4.2.8. Retrospective analysis for SNE lobster effective exploitation estimates from the preliminary basecase model.

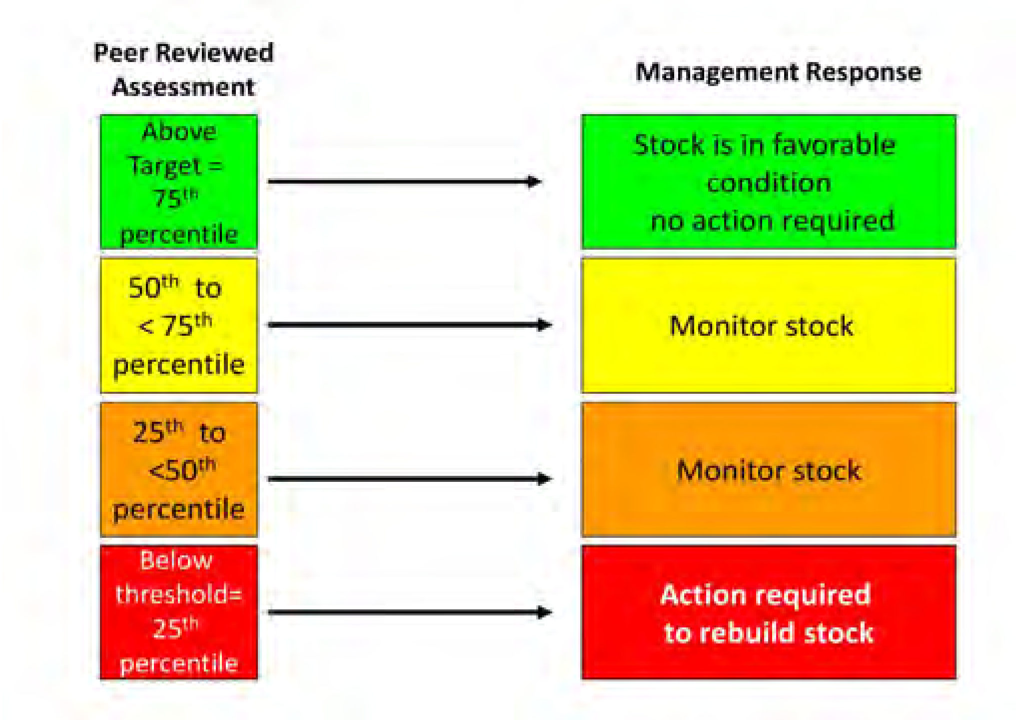


Figure 7.1.1.1. Diagram of the abundance reference point threshold, target, and management responses for the Gulf of Maine and Georges Bank stocks.

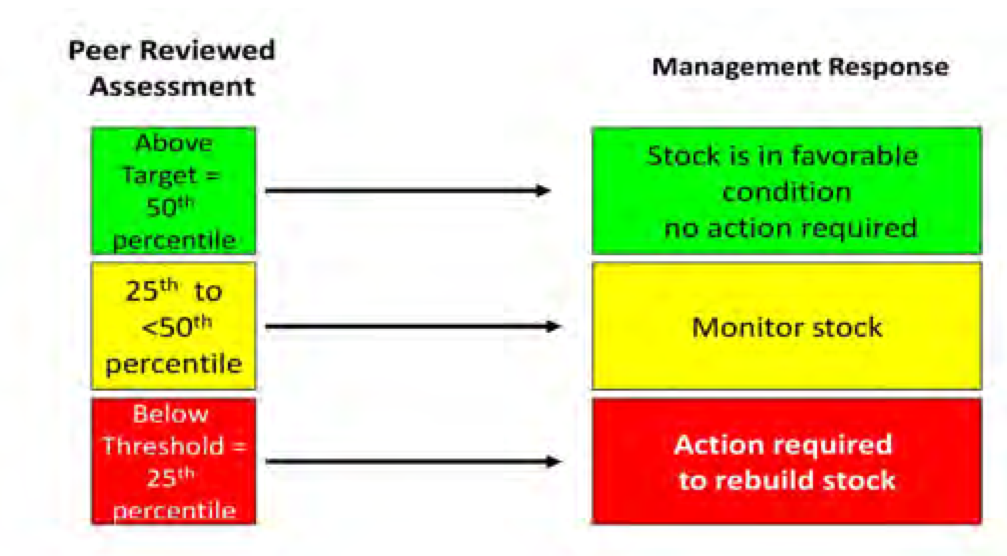


Figure 7.1.1.2. Diagram of the abundance reference point threshold, target, and management responses for the Southern New England stocks.

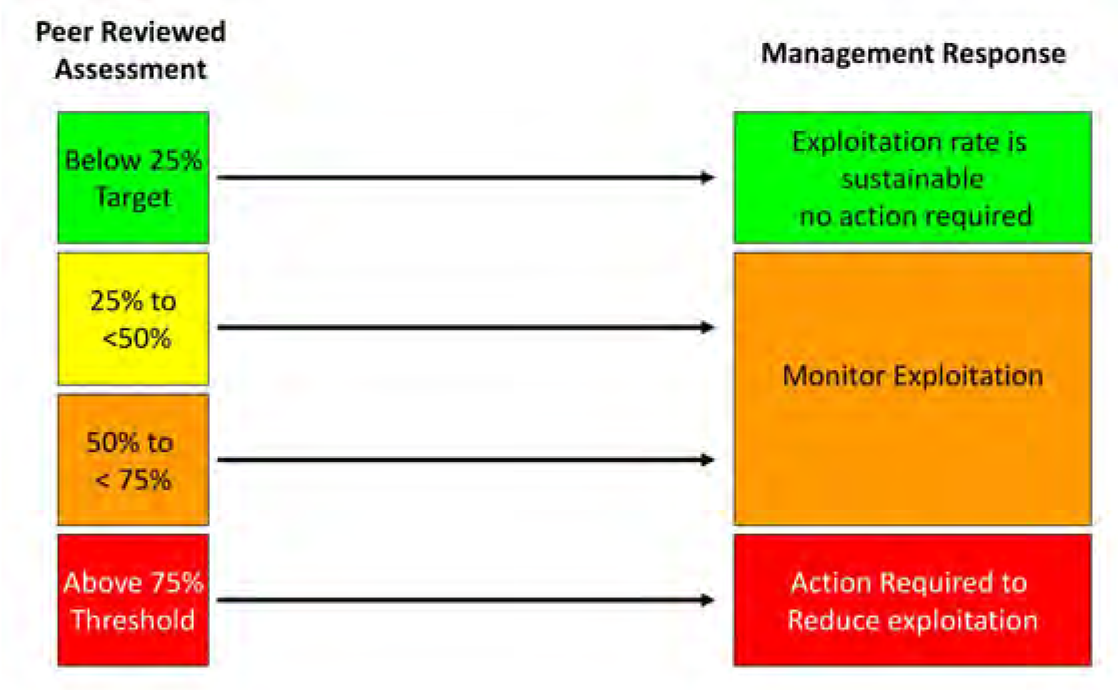


Figure 7.1.1.3. Diagram of the mortality based reference point threshold, target, and management responses for the GOM, GBK, and SNE stocks.

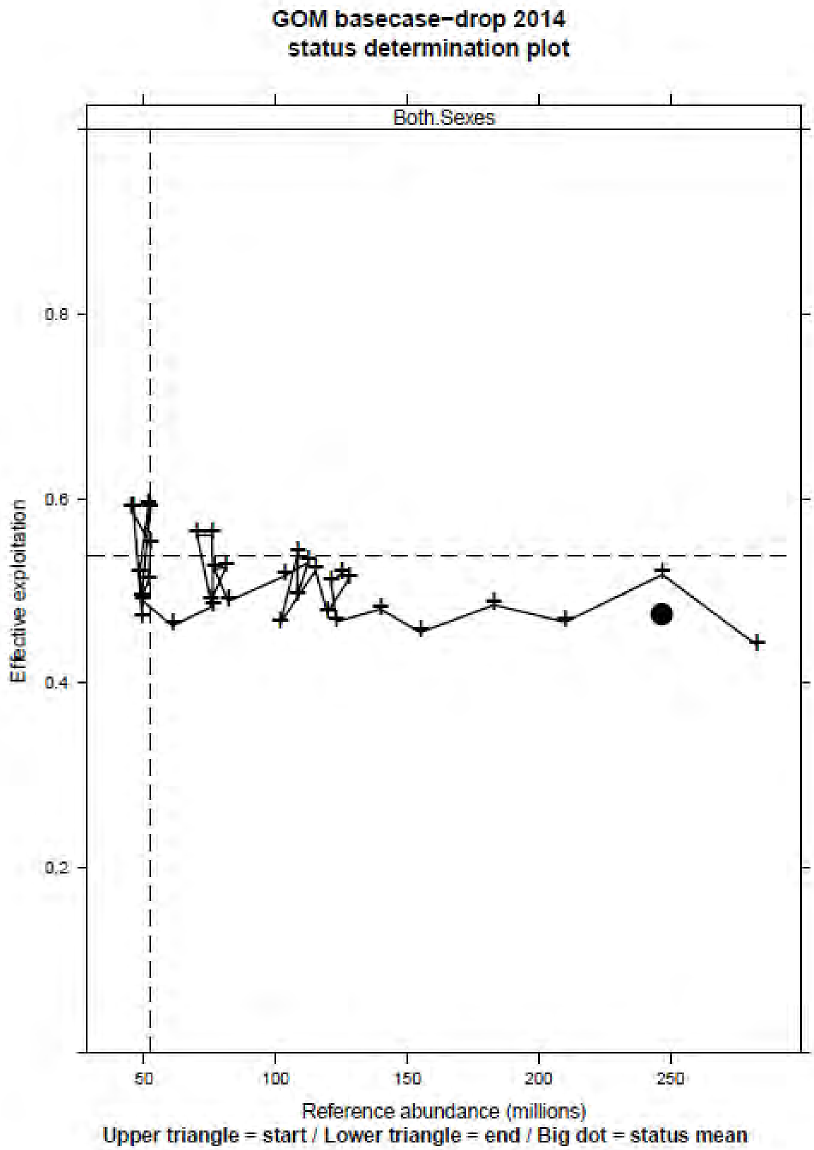


Figure 7.3.1.1. Reference abundance and effective exploitation estimates for 1979-2013 from the basecase University of Maine assessment model for GOM lobster. The dashed lines show the current reference points calculated as the 25th percentile of reference abundance and the 75th percentile of effective exploitation based on the 1982-2003 reference period. The circle shows mean reference abundance and effective exploitation during 2011-2013.

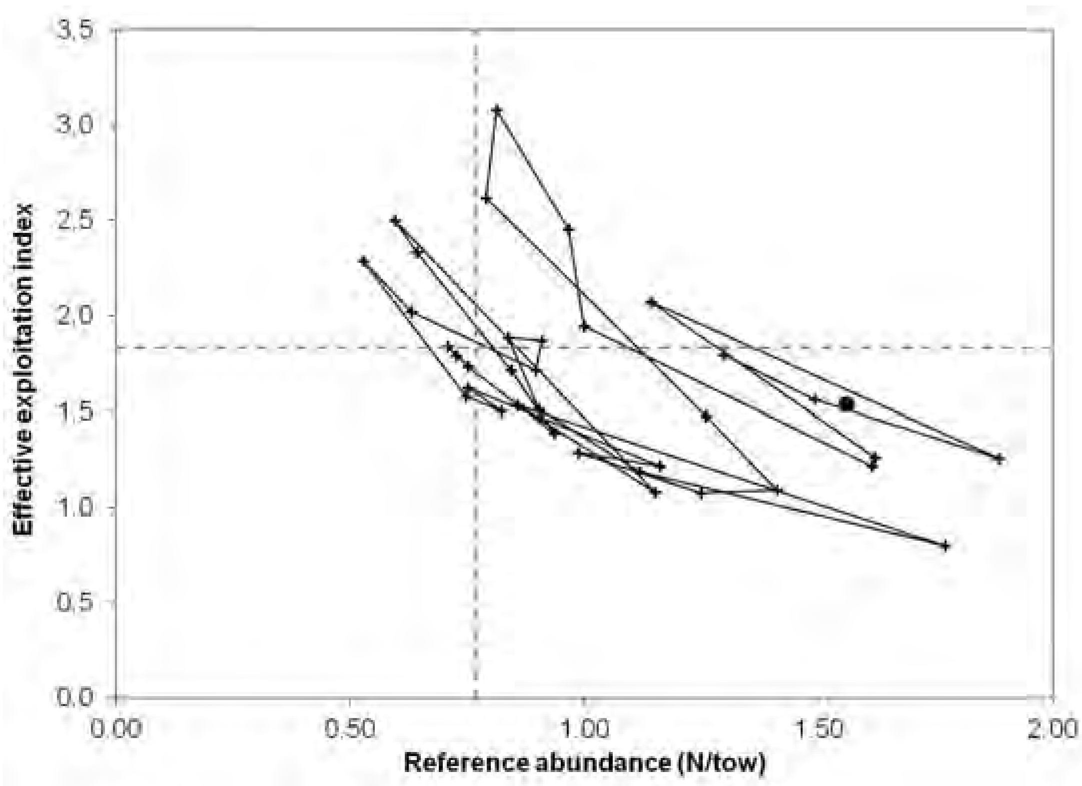


Figure 7.3.2.1. Reference abundance and effective exploitation estimates for 1979-2013 from an empirical trend based assessment based on survey and landings data for GBK lobster. The dashed lines show the current reference points calculated as the 25th percentile of reference abundance and the 75th percentile of effective exploitation based on the 1982-2003 reference period. The circle shows mean reference abundance and effective exploitation during 2011-2013.

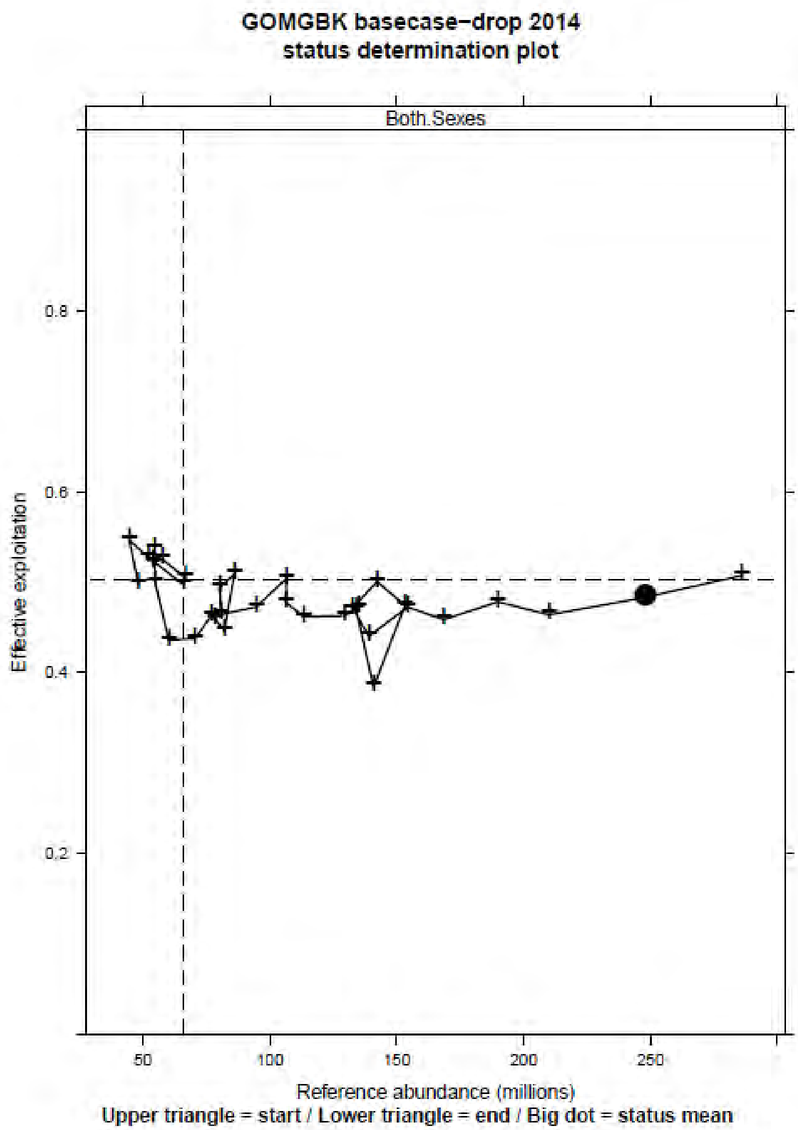


Figure 7.3.3.1. Reference abundance and effective exploitation estimates for 1979-2013 from the basecase University of Maine assessment model for GOM/GBK lobster. The dashed lines show the current reference points calculated as the 25th percentile of reference abundance and the 75th percentile of effective exploitation based on the 1982-2003 reference period. The circle shows mean reference abundance and effective exploitation during 2011-2013.

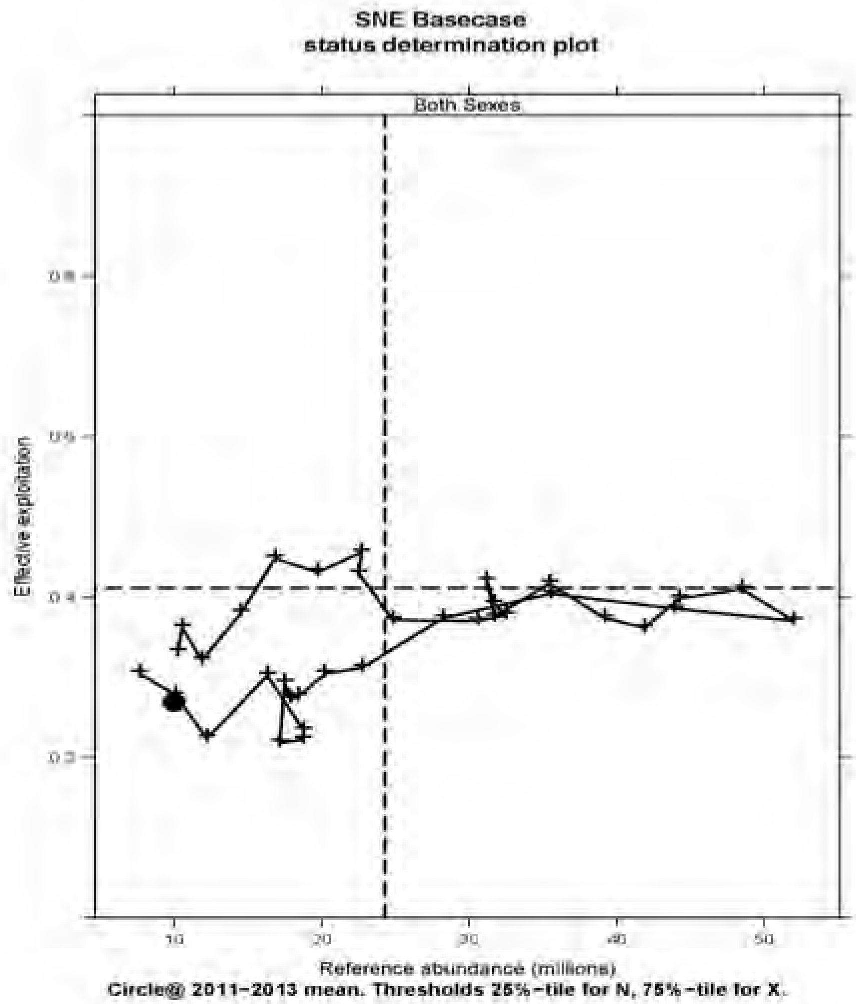
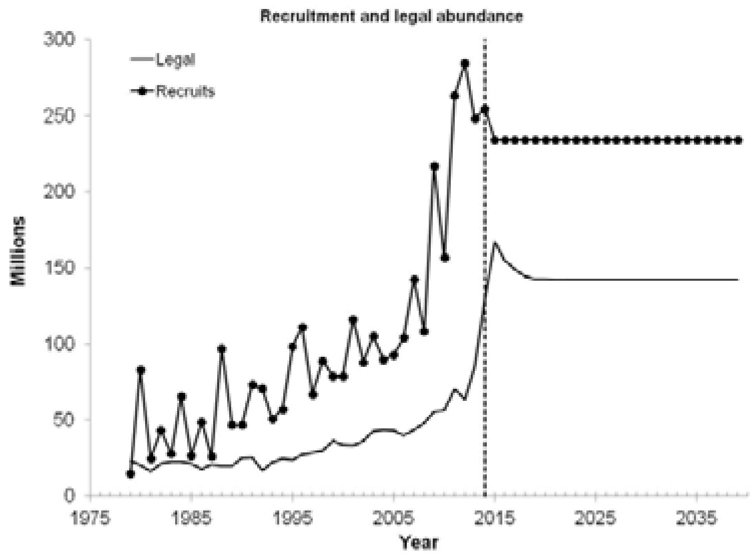
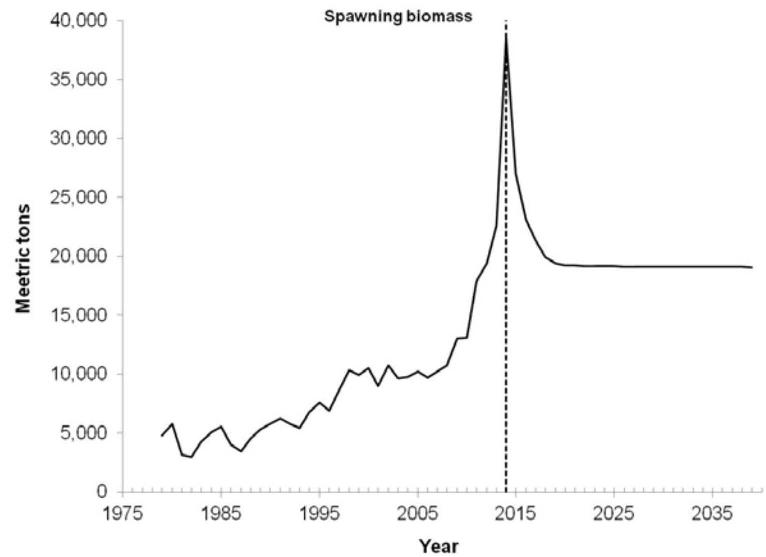


Figure 7.3.4.1. Reference abundance and effective exploitation estimates for 1979-2013 from the basecase University of Maine assessment model for SNE lobster. The dashed lines show the current reference points calculated as the 25th percentile of reference abundance and the 75th percentile of effective exploitation based on the 1984-2003 reference period. The circle shows mean reference abundance and effective exploitation during 2011-2013.





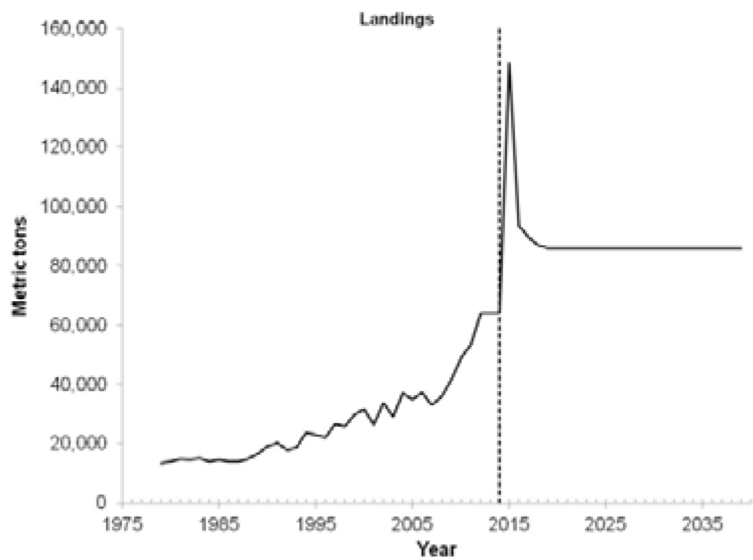
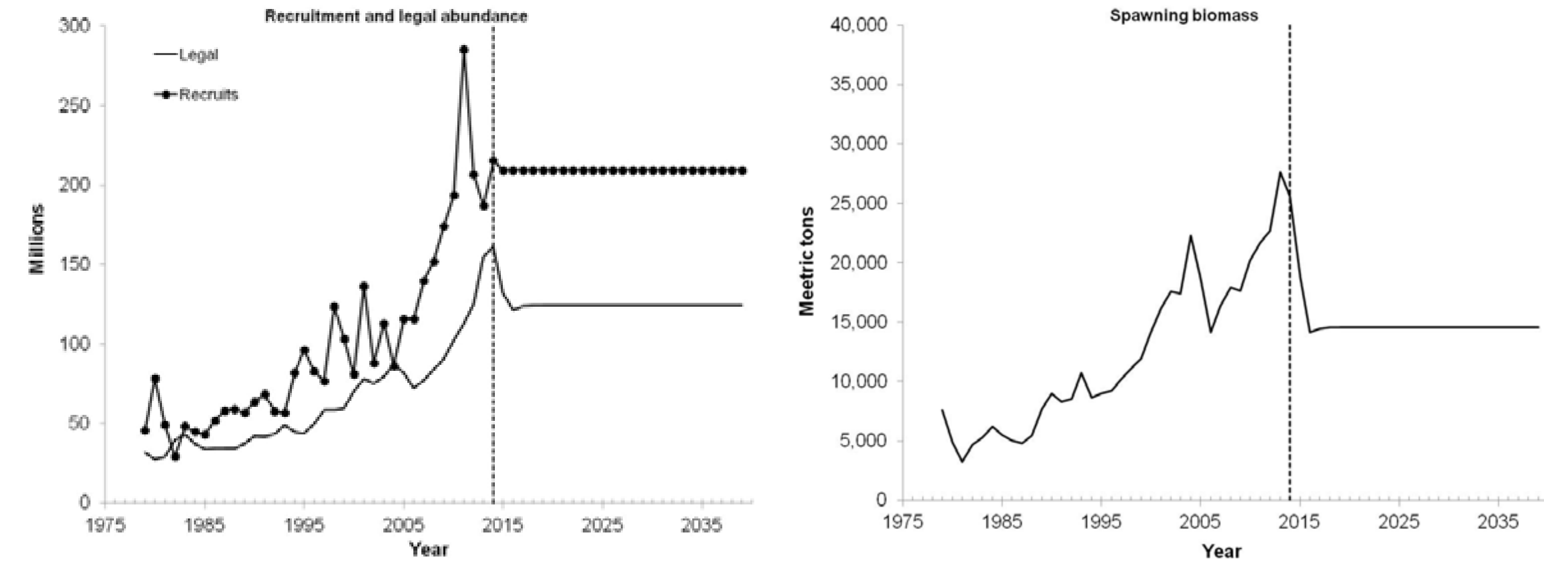


Figure 7.5.1. Basecase assessment model estimates for 1979-2014 with projected recruitment, legal abundance, spawning biomass and landings for GOM lobster from 2015-2039. This scenario is designed to provide a rough idea of equilibrium average productivity levels that might exist if current recruitment and fishing mortality levels continue into the future. The projections assume that natural mortality and fishery selectivity during 2015-2039 are the same as in 2014 and that fishing mortality and recruitment are the same as averages during 2009-2013. Basecase estimates for 2014 are not reliable so projected dynamics from 2014 through about 2020 should be ignored (only equilibrium levels after 2020 are of interest). Vertical lines separate basecase estimate and projections. These results are for demonstration purposes only and should not be used for management.



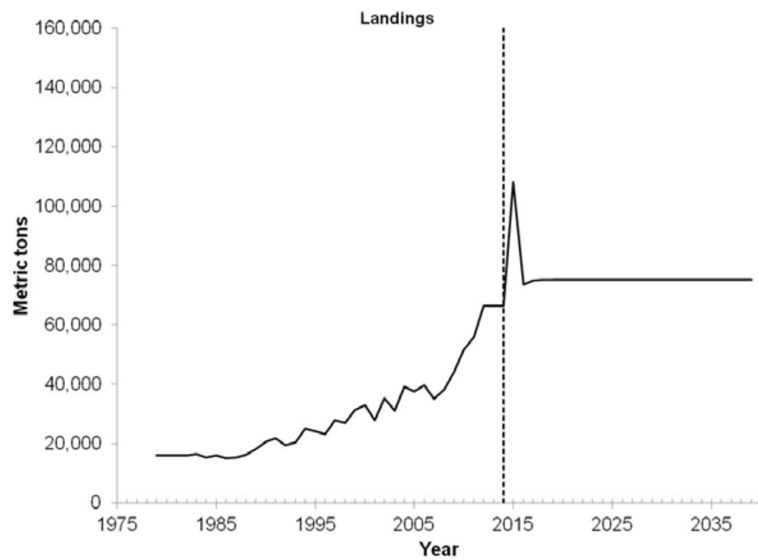
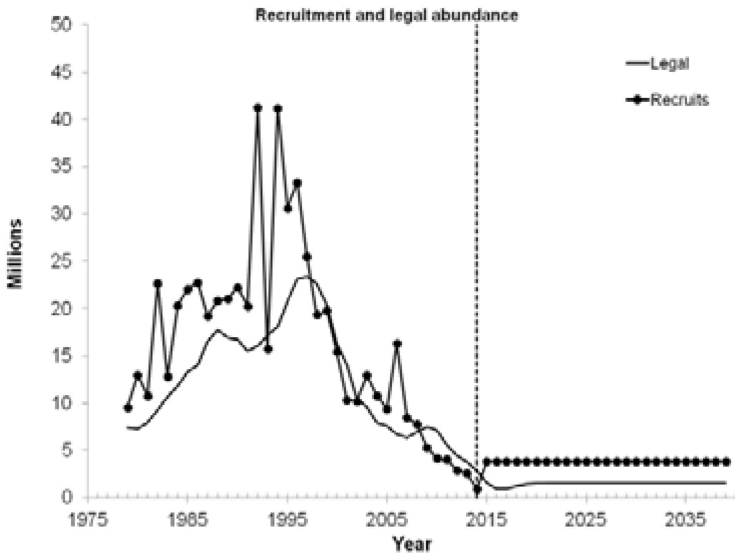
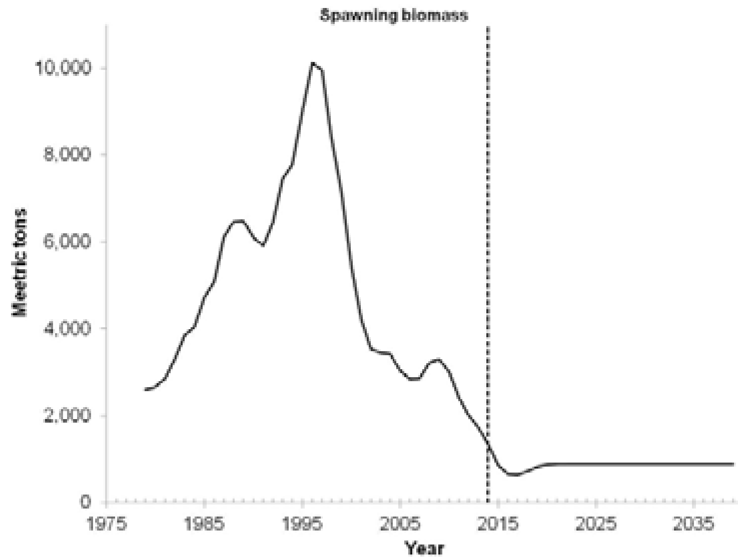


Figure 7.5.2. Basecase assessment model estimates for 1979-2014 with projected recruitment, legal abundance, spawning biomass and landings for GOMGBK lobster from 2015-2039. This scenario is designed to provide a rough idea of equilibrium average productivity levels that might exist if current recruitment and fishing mortality levels continue into the future. The projections assume that natural mortality and fishery selectivity during 2015-2039 are the same as in 2014 and that fishing mortality and recruitment are the same as averages during 2009-2013. Basecase estimates for 2014 are not reliable so projected dynamics from 2014 through about 2020 should be ignored (only equilibrium levels after 2020 are of interest). Vertical lines separate basecase estimate and projections. These results are for demonstration purposes only and should not be used for management.





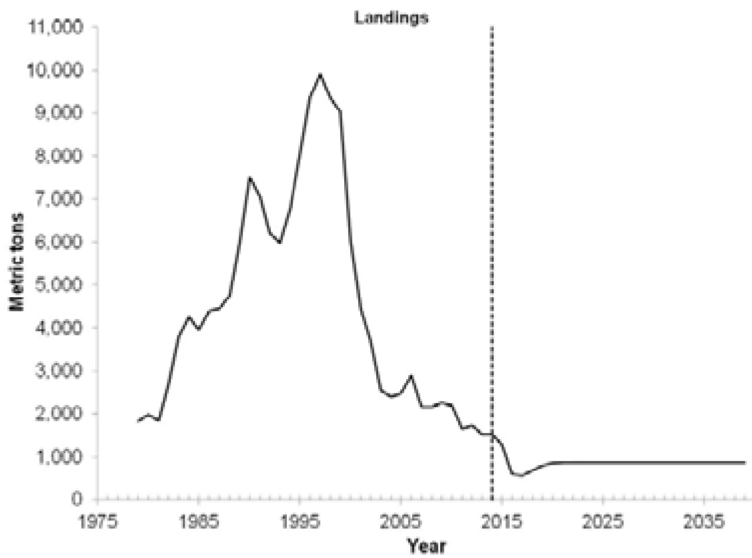


Figure 7.5.3. Basecase assessment model estimates for 1979-2014 with projected recruitment, legal abundance, spawning biomass and landings for SNE lobster from 2015-2039. This scenario is designed to provide a rough idea of equilibrium average productivity levels that might exist if current recruitment and fishing mortality levels continue into the future. The projections assume that natural mortality and fishery selectivity during 2015-2039 are the same as in 2014 and that fishing mortality and recruitment are the same as averages during 2009-2013. Basecase estimates for 2014 are not reliable so projected dynamics from 2014 through about 2020 should be ignored (only equilibrium levels after 2020 are of interest). Vertical lines separate basecase estimate and projections. These results are for demonstration purposes only and should not be used for management.

APPENDIX 1: DERIVATION OF ASSESSMENT MODEL INPUTS FROM FISHERY-DEPENDENT BIOSAMPLES AND RAW LANDINGS DATA

Fishery-dependent data, typically collected by state or federal port- and sea-sampling programs, are used for multiple inputs to the University of Maine stock assessment model including:

1. the catch length composition by sex, quarter, and year
2. landings by sex, quarter, and year
3. percent of the catch that is legal by size, sex and year
4. conservation discards (probability of discarding for egg-bearing and v-notched females) by size, quarter, and year (only applicable to females)

While all of these are important inputs to the assessment model, it is worth noting that the catch length composition and landings by sex are treated as estimates with error that the model attempts to fit given the other inputs. However, the legal percentage and conservation discards are specified constraints that the model has to accept and work around, similar to the gear selectivity. Calculations of these inputs are necessarily complex due to spatial variations in the length composition and sex ratios of lobster and different minimum and maximum size limits associated with each LMA. Additionally, these size compositions change seasonally due to molting and seasonal migrations. Statistical areas (SAs) are the finest spatial scale to which the landings data can be attributed, setting the finest scale at which other inputs can be estimated. Thus, it is most appropriate to estimate the above inputs by year, quarter, and SA, and then aggregate them across SAs and quarters as is appropriate. This often results in requiring data at finer resolution than has been historically collected, necessitating the estimation of data for year / quarter / SA combinations where data are otherwise lacking, commonly called gap-filling. Because this process can be subjective but the resulting inputs are important to the outcome of the assessment model, we decided it was appropriate to produce a single, reproducible and rule-based, computational routine to calculate these inputs from the raw data. This process is performed within an R computer script ("script Lobster_CALF_Landings_ConservDisc_1.6.R") and detailed below.

Biosampling data require some pre-processing, standardization, and thinning before being used for estimating model inputs. For each agency, ovigerous status and v-notch data are standardized and data from gear other than lobster traps are excluded. Given the variety of conditions that biosampling data are collected under, it is difficult to define replicate samples (i.e. all lobster from one trawl of traps, one vessel's catch for a day, multiple vessel's catch for a day port-sampled at a single dock, or a vessel's catch from a multi-day trip, etc.). Further, not all data can be assigned to a specific vessel and sampling session. For lack of a better identifier of sampling units, data are treated as replicates based on trip identifiers composed of available data on Stock, Sample Type (port vs sea), Agency (state, federal ,etc.), Date, Port, SA, Supplier Trip Id and Observer Trip Id, though not all fields are available for all data from all agencies. These replicate sampling bouts, considered "Trips" generally represent samples from one vessel trip but also include a day's port-sampling across multiple vessels at a port or one day's sea-sampling from a multi-day cruise and further study and refinement of the definition of replicates is probably justified. Trips are further assessed for having sampled a minimum of 20 lobsters and having sexed a minimum of 90% of the individuals, and data from trips not meeting these requirements are discarded.

Investigation on the spatial and temporal variability of catch lengths and sex ratios indicate that catch composition is generally more stable across years within a season and SA, than across seasons within a SA and year or across SAs within a year and season. Thus, gap-filling of model inputs were generally performed by finding comparable data across years within a season and SA. The exceptions to this are offshore SAs that are infrequently sampled but have comparable SAs where data may be shared and SAs that have very little sampling, are outdated, or have very little reported landings, which were lumped with an appropriate neighboring SA (Appendix Table 1.1).

To apply appropriate length regulations to data from SAs, individual SAs were assigned the regulations from their most appropriate LMA based on spatial overlap and knowledge of the spatial distribution of landings within the LMA. Such assignments were reasonably intuitive with the exceptions of Areas 521 and 537. Stat Area 521 was finally assigned to the Outer Cape Cod LMA based on primarily inshore landings. Stat Area 537 has significant landings from both inshore and offshore LMA's with some overlap of the LMAs and historically more landings from the inshore area. We found SNE model results to be robust in a sensitivity run with Area 537 assigned to either the inshore or offshore LMA, so 537 was left assigned to the inshore LMA2.

To characterize a length composition for a year, quarter and SA, a minimum of 10 Trips were generally required. Further, offshore SAs were required to have data from at least two different years to avoid having length compositions characterized by a small number of multi-day sea-sampling trips. Length composition data were first extracted for a SA and any comparable SAs and assessed if the minimum number of trips and years were represented. If not, the data set was iteratively expanded across years, including comparable SAs, until the minimum requirements were achieved. Two different sets of length compositions were extracted; one for characterizing commercial landing compositions and one characterizing commercial catch compositions, the latter used to provide relative weighting factors for legal proportions and conservation discards calculations. The iterative process of searching across years for minimum adequate data sets is different for the two data sets.

Commercial landings length compositions and sex-specific landings

Commercial landings length compositions were characterized using both port- and sea-sampling data (without v-notched or ovigerous lobsters) for legal-sized individuals only. Minimum and maximum length regulations often changed across years which affected the catch proportions.

To account for this, years were assigned to management regimes where the length regulations were consistent across years and management regimes were ordered according to how restrictive their regulations were. Where data from two or more years were necessary to characterize a length composition, the process first searched across adjacent years symmetrically (future and past years) within its appropriate management regime. If the entire management regime was included without reaching the minimum sampling requirement, the process next searched temporally through less-restrictive management regimes (usually backwards in time). Only if all less-restrictive management regimes had been searched without reaching the minimum sampling requirement did the process search forward into more-restrictive management regimes for data. If all management regimes from the time series were included without reaching the sampling requirement the process was stopped and the length composition estimated based on the available data. Once a minimum sample of trips had been determined, the raw data from the appropriate trips were further constrained to the legal length requirements for the target year before calculating compositions.

Because the final landings length composition was weighted across SAs by landings, the landings length composition for each year, quarter and SA is calculated by tracking the proportion of the catch represented by each size bin and later transformed back into a relative abundance estimate. Mass for each lobster is calculated for each of the appropriate trips using the length/mass relationships derived for this assessment for males and non-ovigerous females. The proportion of the mass represented by each bin within a trip is then calculated as:

$$pLbM_{b,t,s} = \frac{\sum_{b,s} M_{b,t,s}}{\sum M_t} \qquad \text{(Eq. 1)}$$

Where $pLbM_{b,t,s}$ is the proportion of the landings by mass for bin b, trip t and sex s, $M_{b,t,s}$ is the mass of all lobster for a bin from a trip and M_t is the mass of all lobster from a trip. From the appropriate trips, we then calculate the proportion of mass by bin for a given year (y), quarter (q), sex (s) and SA (a) by averaging $pLbM$ across trips within bins, sexes and years, then averaging across years within bins and sexes

$$pLbM_{b,y,q,s,sa} = \frac{\sum_y \frac{\sum_t pLbM_{b,t,s}}{N_{t_y}}}{N_y} \qquad \text{(Eq. 2)}$$

where N_{t_y} is the number of trips in a year and N_y is the number of years in the set of trips. The proportion of mass by sex is calculated as the sum across bins within a sex divided by the total sum across bins:

$$pLbM_{y,q,s,sa} = \frac{\sum_b pLbM_{b,y,q,s,sa}}{\sum_{b,s} pLbM_{y,q,sa}} \qquad \text{(Eq. 3)}$$

The landings by year, quarter and sex are then calculated from the raw landings and the proportion by sex as:

$$Landings_{y,q,s} = \sum_{sa} Landings_{y,q,sa} \times pLbM_{y,q,s,sa} \qquad \text{(Eq. 4)}$$

The proportional mass for each bin, year, quarter and sex are then calculated across statistical areas as:

$$pLbM_{b,y,q,s} = \sum \frac{\sum_{sa} pLbM_{b,y,q,s,sa} \times Landings_{y,q,sa}}{Landings_{y,q,s}} \qquad \text{(Eq. 5)}$$

These mass proportions are then converted to proportions of landings by number as:

$$pLbN_{b,y,q,s} = \frac{\frac{pLbM_{b,y,q,s}}{\widehat{M_b}}}{\sum_b \frac{pLbM_{b,y,q,s}}{\widehat{M_b}}} \qquad \text{(Eq. 6)}$$

Where $\widehat{M_b}$ is the estimated mean mass for a lobster of length b.

Finally, we calculate the effective sample size for each year and quarter based on the number of trips that actually occurred in a year and quarter across SAs. While this is an imperfect proxy for sample size, as not all SAs have equal biosampling coverage, it provides an initial representation of how sampling effort occurred in a given year.

Legal proportions and conservation discards

Both the calculation of legal proportions and conservation discards require an estimate of the proportion of the raw catch.

Commercial catch compositions represent the raw length composition of the catch and were calculated using only sea-sampling data since port sampling data represent the catch after minimum and maximum size requirements and other regulations have been applied to them. The search process for a minimally acceptable data set involves iteratively including adjacent years (future and past) until the minimum sample requirements or the limits of the time series are reached. Once the data set has been discovered, the calculation of proportions proceed similar to Eq.1 except that proportions within a sex sum to one rather than across sexes as in the landings proportions.

$$pCbM_{b,t,s} = \frac{\sum_{b,s} CbM_{b,t,s}}{\sum M_{t,s}} \qquad \text{(Eq. 7)}$$

Where *CbM* is Catch by Mass and $M_{t,s}$ is the mass of all lobster from a trip for a sex. Proportions are then similarly aggregated up to trip and year resolution and averaged across years as:

$$pCbM_{b,y,q,s,sa} = \frac{\sum_y \frac{\sum_t pCbM_{b,t,s}}{N_{t_y}}}{N_y} \quad \text{(Eq. 8)}$$

For both legal proportions and conservation discards it is important to get estimates of catch rates of larger lobsters where observations are relatively sparse, resulting in volatile estimates. To address this, we estimate a single smoothed catch proportion across years for each sex, quarter, and SA using a General Additive Model (GAM) with the form:

$$pCbM_{b,y,q,s,sa} \sim s\big(Bin, by = c(Sex, Quarter, SA)\big), family = Binomial) \quad \text{(Eq. 9)}$$

For legal proportions we estimate the mass of lobster caught for each year, quarter, sex, SA. The smoothed proportion caught by mass ($\widehat{pCbM}_{b,q,s,sa}$ from Eq.9) is predicted at 1 mm increments over the range of the size bins, and the minimum and maximum legal sizes are applied for each sex, quarter, SA and year before being aggregated back to 5mm to determine the percentage of the catch that is legal for each bin ($\widehat{pLegalCbM}_{b,q,s,sa}$). The reciprocal of the proportion of all catch that was of legal size for each SA, sex, quarter and year is used as an expansion factor that is applied to the landings to get the estimated total catch:

$$Catch_{y,q,s,sa} = \frac{Landings_{y,q,s,sa}}{\sum_b \widehat{pLegalCbM}_{b,q,s,sa}} \quad \text{(Eq. 10)}$$

The legal proportions by bin are then calculated across SAs from the proportions of the catch by bin, proportion legal for the bin, and the expanded catch for the SA.

$$pLegal_{b,y,s} = \frac{\sum_{b,q,sa} (\widehat{pCbM}_{b,q,s,sa} \times pLegalCbM_{b,y,q,s,sa} \times Catch_{y,q,s,sa})}{\sum_{q,sa} Catch_{y,q,s,sa}} \quad \text{(Eq. 11)}$$

Appendix Figure 1.1 shows a example output for the percent legal for the GOM/GBK combined stock area. The lines from the 1980's stand out on the right from the period before minimum sizes were increased. The drop at 128 mm is due to the maximum size restriction inshore and the differences among years in the larger size classes reflect the proportions of the landings from the inshore and offshore where larger lobsters are legal. Legal proportions for very large lobsters drop to zero for the recent years when the maximum size went into effect for the offshore LMA.

The conservation discards are the probability that a captured female lobster is ovigerous and / or v-notched and therefore released. The data are constrained to females from sea sampling so data for many size classes, particularly larger individuals, are again very sparse. As a result, we also modeled the probability of discarding with a GAM, using only data for 43 mm – 153 mm CL individuals, with the 153+ mm treated as a plus-group. The model was built in a forward stepwise manner, based on AIC's and model diagnostics. The best model for all stocks had the final form:

$$pDisc_{b,y,q,sa} \sim s(Bin, by = factor(Quarter), k = K) + s(Year, by = factor(Quarter), k = 2) + factor(SA) + factor(Quarter), family = Binomial) \quad \text{(Eq. 12)}$$

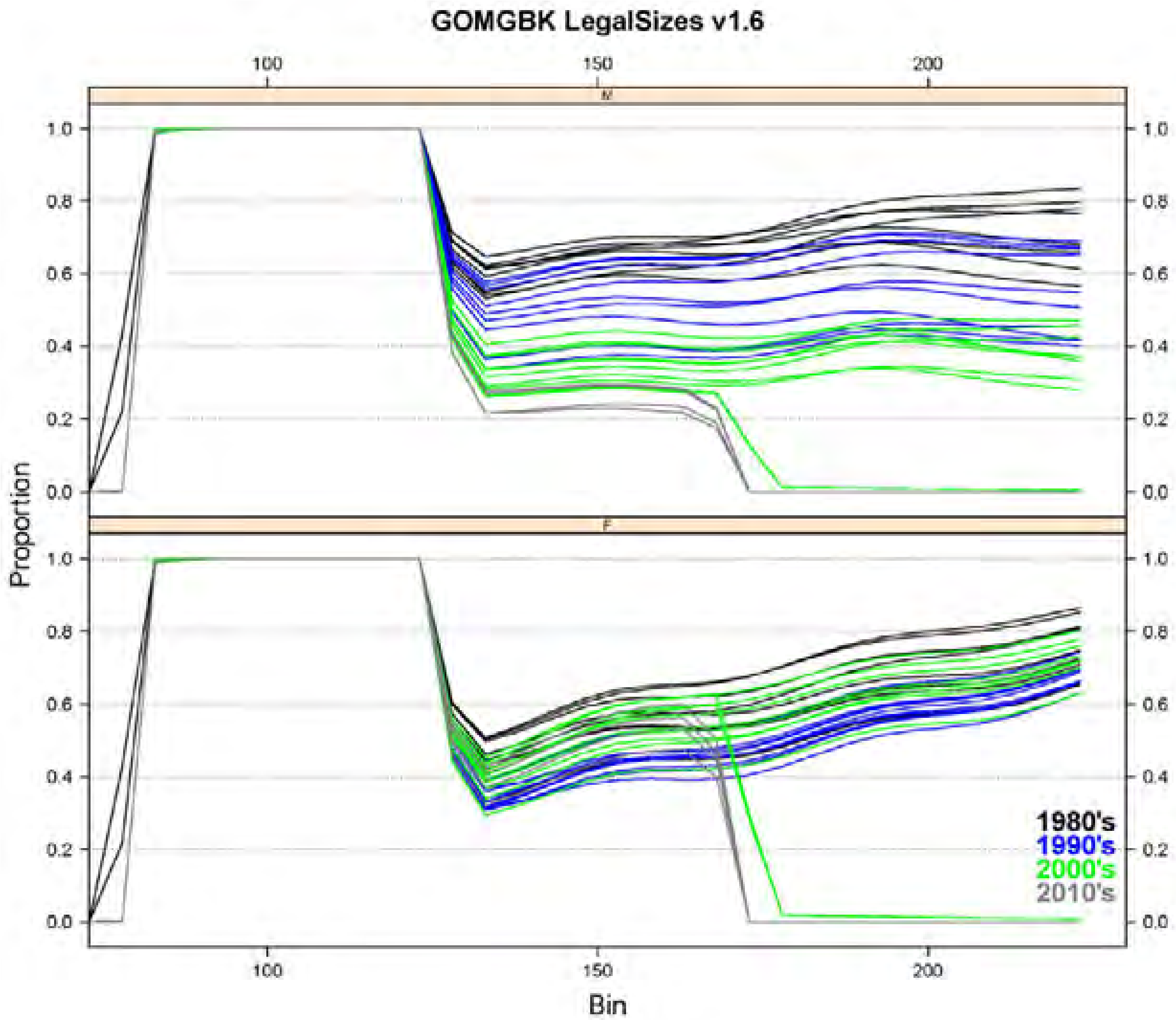
Where $pDisc_{b,y,q,sa}$ is the probability of discard by bin, year, quarter, and SA and K is the number of knots allowed in the Bin spline (K=2 for SNE, K=4 for other stock areas). The number of knots on the smoothers was constrained as splines with sparse data can yield unrealistic results. Interestingly, there is strong evidence for the temporal shift in discard rates and inclusion of the year term, based on model AIC scores. The terminal value at 153 mm was used to fill in all larger size classes. Appendix Figure 1.2 shows the model-based discard probabilities for GOM. The model finds insufficient data to produce a smoother for the first quarter so returns a fixed line. For the second quarter, the discard rate increases with length throughout the range while the model for the third and fourth quarter finds a maximum around 120 mm. For the second through fourth quarter, the model finds an increase in the probability of discard across years.

The final stock-level retention rates by bin, year and quarter are calculated from the product of the retention rate (1- discard rate), and the catch proportion, weighted by the catch.

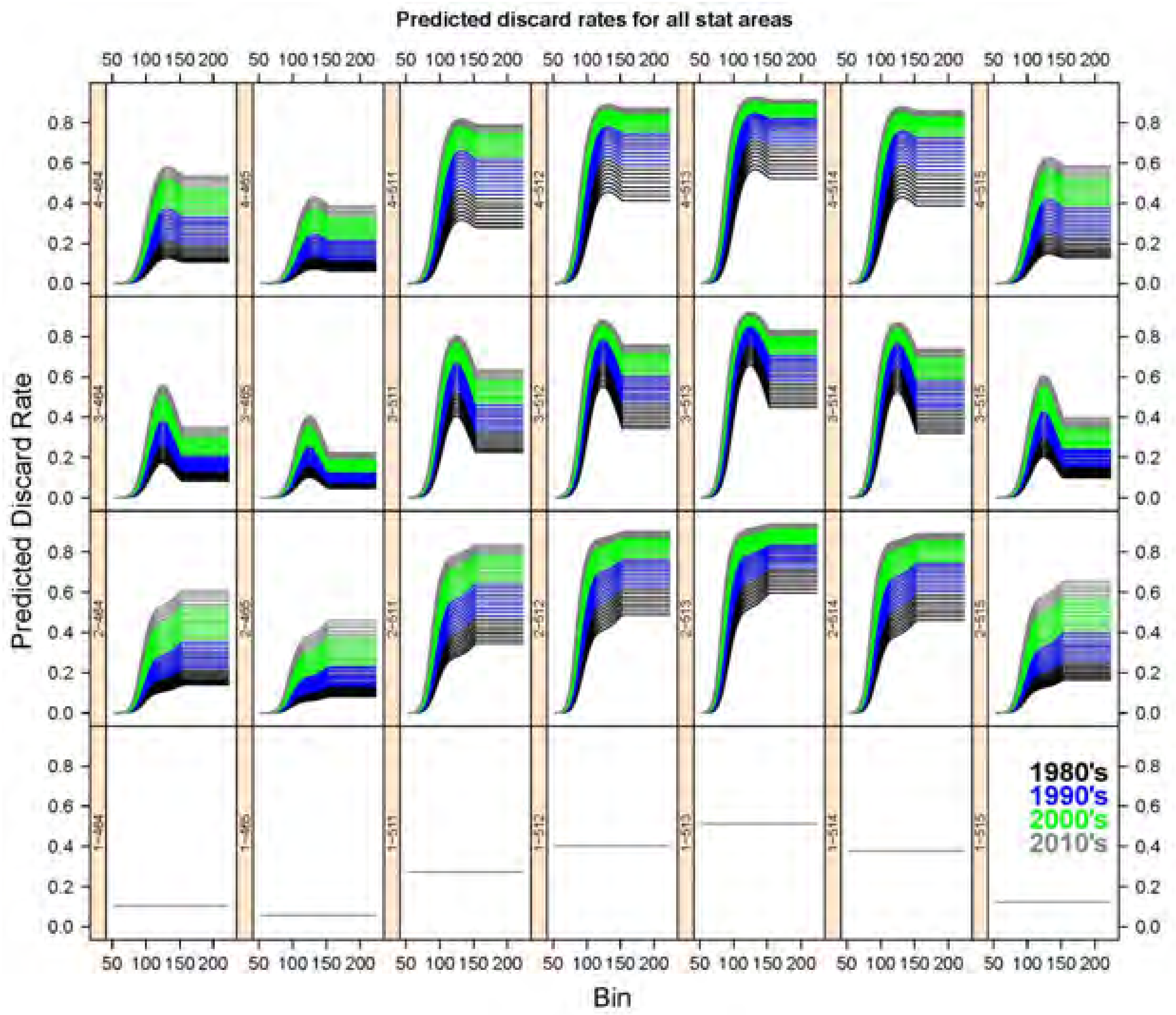
$$pRetention_{b,y,q} = \frac{\sum_{b,q,sa}((1-pDisc_{b,y,q,sa}) \times \widehat{pCbM}_{b,q,sa} \times Catch_{y,q,sa})}{\sum_{sa} Catch_{y,q,sa}} \quad \text{(Eq. 13)}$$

Appendix Table 1.1. Data-poor and comparable statistical areas. Length data and landings from statistical areas with Method=1 were reassigned to their comparable area while statistical areas with Method=2 borrowed length data from comparable areas for characterizing length compositions.

Statistical Area	Method	Comparable Area
464	2	465, 515
465	2	464, 515
467	1	511
515	2	464, 465
521	2	526
522	2	525
523	1	561
524	1	562
533	1	537
534	1	537
538	2	539
541	1	526
542	1	525
543	1	525
551	1	561
561	2	562
613	2	616
614	2	612
615	2	616
621	2	612
622	2	616
623	2	616
624	1	623
625	1	621
626	2	616
627	1	626
628	1	626
631	1	621
632	2	616
635	2	612
636	2	616



Appendix Figure 1.1 Estimated percent of catch that is legal by size bin, sex, and year for the GOM/GBK combined stock.



Appendix Figure 1.2. Model-based discard rate of ovigerous or v-notched females for GOM by size, quarter, SA, and year.

APPENDIX 2:

Responses to the 2009 Lobster Stock Assessment Peer Review Research Recommendations and the 2010 CIE Review Recommendations of the TC Report on SNE Recruitment Failure

2009 LOBSTER STOCK ASSESSMENT PEER REVIEW RECOMMENDATIONS: research recommendations to improve future assessments. *(SAC responses follow research recommendations and are presented in italics).*

The investment in lobster fishery research is out of balance with the lobster fishery's value (>$400 M). Thus, we strongly urge substantially increased investment in acquiring stock assessment and biological research to ensure sustainability of this valuable fishery. We put forth the following research recommendations with respect to data, model, and management reference points, respectively.

Recommendations regarding data

Good performance of assessment models depends heavily on the quality of all input data, including biological parameters (growth, mortality, and reproduction), fishery-dependent catch, effort, size distributions, and fishery-independent abundance indices and size samples.

HIGH PRIORITY: The growth process is the heart of the length-based model at the core of the assessment. The 2009 Panel recommends continued effort and funding to support growth research, including 1) recasting the growth matrix in a probabilistic context and resampling the growth matrix in the MCMC runs; 2) using the extensive Canadian tag database for obtaining better estimates of growth and molt frequency; and 3) applying biochemical assessment of lipofuscin content to help estimate growth. Natural mortality influences greatly the dynamics of lobster stocks, yet understanding of M is poor because this parameter is difficult to estimate. Much like growth, both intra- and inter-annual variation in natural mortality may occur. We identified three research areas that can potentially help refine our understanding of M and improve the stock assessment: 1) using the Canadian tag database for estimating M; 2) exploring environmental factors (e.g., temperature) which may be incorporated as independent variables in the stock assessment to explain abundance and recruitment variation; and 3) incorporating M with a prior distribution in the length-based model rather than as a fixed value.

- *All available tag data were included in the updated growth matrix, including the Canadian data.*
- *MCMC simulations were done for the assessment and provided similar results to uncertainty estimates from other approaches.*
- *Alternative aging methods are being developed and tested in Maine. A five year, $250,000, contract was initiated with the University of Maine in 2013 using the ageing techniques developed by Kilada et al. (2012). This study is ongoing and results will be*

made available to future assessments.

- *Long-term continuous temperature data were added as a covariate to natural mortality and recruit estimates in the SNE and GOM model runs.*

HIGH PRIORITY: While improvements such as mandatory dealer reporting have been made, the 2009 Panel feels commercial landings and fishing efforts continue to be recorded piecemeal over the stock range. We recommend that they be standardized. The Panel recommends a statistically-designed survey (rather than current ad hoc approach) be implemented for collection of biological characteristics of the catch. The Panel commends the improvement in the spatial coverage of sea and port biological sampling from commercial landings since the last stock assessment, but stresses the need to continue this sampling so as to achieve representative coverage of all segments of the fishing fleet. These data were especially helpful in evaluating Georges Bank stock status in the 2009 stock assessment. In particular, the Panel recommends annual reporting by state agencies of the data needed for the assessment model be implemented so that data are readily available for annual updates of stock indicators to be presented to the Lobster Management Board and for assessment model updates every five years.

- *A federal sea sampling program has been initiated and federal port sampling has increased. There are continued funding issues to support both sea and port sampling. State and federal agencies have increased coordination to make sampling more efficient. Finally the committee did an analysis of the existing sampling program to determine where more sampling was needed. The Committee revised the approach of estimating catch by length and sex to address the issue of inadequate sampling, but uncertainty still remains in offshore areas.*
- *This would require states to make sea sampling mandatory which is a management decision and logistically unrealistic at this time due to the scale and complexity of the fishery.*
- *Additional funds are needed to address the staffing needed to complete annual data reporting due to the scale and complexity of the fishery.*
- *A first cut of sampling power was attempted in this assessment, and has identified statistical areas in need of sampling and others that are adequately sampled.*

HIGH PRIORITY: While fishery-independent data are important for monitoring stock status, the Panel urges exploring the reliability of the fishery-independent trawl surveys even in areas where lobster are less common. One recommendation is to map catch rates to determine if consistent spatial patterns exist and that would also suggest, to some extent, survey reliability. The Panel strongly recommends ventless trap surveys be continued to obtain good abundance indices of the inshore areas where the fishery primarily occurs. Additionally, the Panel believes it will be helpful to include information on the stock status of the adjoining Canadian stock in future analyses and presentations.

- *The ventless trap survey has been continued from Maine to Rhode Island.*
- *We used data from Canada for growth.*

- *The committee examined a series of bubble plots in 5-year intervals that demonstrate the distributional changes of lobster in SNE for the assessment. Maps were generated separately for demographic groups (i.e. eggers, 'large' sizes) to examine specific distributional trends.*
- *The states of Maine and Massachusetts have secured near permanent funding for ventless trap surveys through dedicated surcharges on licenses or other dedicated funding mechanisms.*

MEDIUM PRIORITY: While growth and mortality are key factors influencing population dynamics, recruitment often is the driver behind population resilience. The lobster stock assessment models define recruitment as entry into the fishery and thus bypass the early life stages. Nevertheless, we think research into larval mortality and distributions should be carried out. In particular, the biophysical coupled modeling approach (Xue et al. 2008) that simulates the patterns of egg production, temperature-dependent larval growth, stage-explicit vertical distributions of larvae, and mortality in a realistically simulated physical environment should be extended to other areas to understand recruitment sources for the U.S. lobster stocks. It will likely provide insight for the assessment team with regard to stock connectivity and shed some light on the conundrum of unusual stock resilience. In particular, the Panel recommends use of the model to understand whether larval sources are the same for below average and strong year classes. Identifying sources of recruits may provide managers with options to help ensure the continued resilience of this stock.-

- *A long-term stock-wide larval study would be necessary to complete this, which requires funding and research.*
- *Sensitivity runs were completed on recruitment.*
- *A recent paper by Annis et al. (2013) suggests that small differences in water temperature may shape settlement patterns through either behavioral avoidance of colder settlement sites or elevated postsettlement mortality of postlarvae settling at colder sites.*

Recommendations on models

The 2009 Panel concluded the length-based model provided a reliable, scientifically-sound foundation for assessment work. On the other hand, the CSM has a simple structure and few assumptions, with potential as a resilient and reliable assessment model. The Panel concluded the CSM continues to provide a useful, aggregate summary of patterns in lobster stocks and thus recommends continued use of the CSM.

The Panel agrees the length-based model has reached a sufficient level of development to provide management advice. A next step is to estimate a stock-recruitment relationship within the model so that population projections can be carried out. The Panel recommends continued funding to support model refinement and performance evaluation. For future modeling, the Panel identified the following crucial research areas.

- *The UM model used in this assessment is the best approach at this time. It uses all the available information, is biologically realistic, and stable.*

HIGH PRIORITY: Include an option to estimate a stock-recruitment relationship within the length-based model.

- *This research recommendation was not completed because attention was focused on implementing recruit covariates to deal with environmental effects on recruitment, which appear more important in all stock areas during recent years. Interested users can use preliminary spawning biomass estimates as recruit covariates until these modifications are made to achieve nearly the same effect.*

HIGH PRIORITY: Explore sensitivity to assumptions of model structure and parameter values (such as catchability, selectivity).

- *A standard set of sensitivity analyses were carried out for each stock area that evaluated sensitivity of the model to assumptions about natural mortality, environmental effects on recruitment, growth and commercial gear selectivity. Stock-specific sensitivity analyses were carried out as well.*

HIGH PRIORITY: Implement MCMC and in particular resample the growth matrix in the MCMC runs in order to fully evaluate parameter uncertainties, which now are unrealistically narrow.

- *R software and MCMC features in the model for MCMC analysis have been enhanced but additional CODA capabilities for estimating thinning rates should be added in R. ADMB libraries allow likelihood profile estimation for any parameter in the existing program. The R and ADMB software for manual profile analysis have been enhanced. These enhancements were used in the current assessment and results for recent reference abundance and effective exploitation are presented.*

HIGH PRIORITY: Examine the implications of varying the weightings on components of the overall likelihood on model fits. Such exploration is considered good practice in assessment modeling. With respect to model output presentation, the Panel also would have liked to have seen the actual likelihood values from the base case and alternative model runs, rather than just relative differences.

- *The assessment team used relative differences which are presented in the report and neglected to provide absolute values as requested.*

LOW PRIORITY: Use “un-filled” data rather than “gap-filled” data in all stock area models.

- *Approaches to dealing with inadequate sampling of the commercial fishery, particularly offshore, was a major area of work in this assessment. Gap-filling (borrowing sample data from other areas or time periods to fill holes in the sample data for areas and quarters where landings occurred) is the traditional approach for lobster but may be problematic because sampling rates are very low in some cases and a great deal of borrowing is required. Preliminary model runs with partially unfilled data through 2007 showed small to modest changes in results. However, it was necessary to fill gaps in sample data and to calculate gap-filled commercial catch at length in order to update input data used to model gear, legal size and conservation selectivity which must be available for every year, quarter, sex and stock. These input data are assumed known without error and it was decided that some sort of gap-filling was required to make them as accurate as possible.*
- *Assumptions and procedures for gap-filling were refined after discussion and experimentation. In particular, the process was automated and borrowing was from the same areas and quarters in different years, rather than from different areas because size-composition data in the same area and quarter tend to be similar. Sample data were smoothed with GAM models where appropriate and gear/legal size/conservation selectivity data for large lobster used in modeling were smoothed where necessary. Landings data use in modeling were in weight, rather than numbers, to reduce reliance on gap-filled sample data although separation of landings into female and male components involved gap-filled data.*

LOW PRIORITY: Allow more surveys as input.

- *The structure of the current code prevents reprogramming to allow an arbitrary number of surveys. It would be easier to reprogram the model than to make this type of change to the existing code. For this assessment, the model was modified to accommodate up to sixteen surveys which can be broken down by sex and season for efficient use of the available slots. The updated model sufficed for this assessment but the model should be reprogrammed for the next assessment.*

Recommendations on management reference points and MSE

The 2009 Panel strongly recommends the development of reference points that are not based on trend analysis but rather have a sound biological basis.

HIGH PRIORITY: The success of MSE relies heavily on the assumed stock-recruitment relationship. The Panel recommends completing a meta-analysis of stock-recruitment relationships for long-lived crustaceans so that some reasonable parameter estimates for the stock-recruitment relationship may be identified for the lobster stock, and then be implemented in the MSE.

- *Funding and research is needed to complete a MSE.*

2010 CIE REVIEW OF THE TC REPORT ON SNE RECRUITMENT FAILURE

Recommendations from Bell:
(B1) The TC should be given the opportunity to conduct a comprehensive analysis of distributional patterns in the survey data in order to make more robust inferences about any changes in spawning distribution. Suggestions for these analyses are given on p.7 and should include: survey indices stratified by depth and distance offshore; extraction of dominant survey trends using dynamic factor analysis or similar; fuller presentation of results from the Massachusetts Sea Sampling program; and tables or graphs of Ventless Trap Survey catch rates stratified by depth and region.

- *The assessment examined a series of bubble plots in 5-year intervals that demonstrate the distributional changes of lobster in SNE. Maps were generated separately for demographic groups (i.e. eggers, 'large' sizes) to examine specific distributional trends.*
- *Trends in percent positive tows in all state and federal trawl surveys were added as a model-free indicator of distributional changes*

(B2) Any new analyses of lobster trends distribution should attempt to make an explicit linkage of lobster habitat with environmental conditions by incorporating sea temperature (and/or other environmental or climatic variables such as the North Atlantic Oscillation Index) as model covariates.

- *Long-term continuous temperature data were added to the assessment as a covariate to natural mortality and recruit estimates in the SNE and GOM model runs.*
- *A recent paper by Annis et al. (2013) suggests that small differences in water temperature may shape settlement patterns through either behavioral avoidance of colder settlement sites or elevated postsettlement mortality of postlarvae settling at colder sites.*

(B3) If there exist sea temperature data that have not been considered in the TC's report, these should be collated and analyzed in a similar way. Attempts should be made to collate a comprehensive spatio-temporal overview of bottom temperatures (possibly including physical modeling results) that could be used to map the thermal boundaries of lobster habitat within SNE.

- *All available temperature data sets were reviewed and analyzed.*

(B4) A modeling study of lobster larval transport in SNE should be undertaken in an attempt to improve the understanding of the spatial scales over which recruitment occurs and the relationship between the abundance and location of the parental lobster stock and subsequent recruitment. Such a study is likely to have a strong modeling component, e.g. particle tracking within hydrographic models, but should also be supported by satellite tracking of drifter deployments as appropriate.

- *A drifter study was completed which demonstrated a majority of female lobster in southern MA waters were dispersing eggs in deeper offshore waters than had been previously documented where their survivorship is compromised. A new project was* *recently funded to model the relationship between the location of spawning females and the fate of settling larvae. Results of this work should be available by 2016.*

(B5) Lobster recruitment surveys should be continued into the future, and if possible their sampling intensity should be increased to enhance their power to detect changes in larval or young-of-year abundance. New surveys are also recommended to give a spatially comprehensive picture of spawning patterns across SNE. Deployment of passive postlarval collectors is a promising methodology for such surveys. These surveys should be used (a) to improve understanding of recruitment processes, (b) to provide early feedback on the success of management measures aimed at protecting spawning potential, and (c) to allow forecasts of recruitment and landings for both inshore and offshore area.

- *MA has added 4 new YOY sampling stations; RI has done additional sampling at 2 existing YOY stations. Additional sampling requires more funding, current state fiscal resources are limiting.*

(B6): The scope for instituting a sentinel fishery monitoring program should be investigated in the event that a harvest moratorium is imposed. The focus should be on plugging any gaps that will be left by the absence of fishery-dependent information during any moratorium

- *A moratorium was not imposed*

(B7) Feasible management alternatives to a harvest moratorium should continue to be investigated, particularly as new information comes in on the spatial dynamics of the SNE lobster stock. This should include consideration of v-notching, spatio-temporal input controls and technical measures. Discard mortality should be adequately characterized when technical measures are considered – this may involve the collection of new data.

- *These are management considerations.*

(B8) The projection methodology should be improved along the lines suggested on p.18. This includes incorporation of spatial structure, improved information about natural mortality, improved information on stock-recruitment relationships, incorporation of environment-recruitment linkages and stochastic projections based on MCMC.

- *Long-term continuous temperature data were added as a covariate to natural mortality and recruit estimates in the SNE and GOM model runs.*

(B9) Qualitative and model-based information should be collated in evidence of a change in patterns of natural mortality. As suggested on p.19, this might include an account of mortality factors for lobster in SNE, consideration of trade-offs between *M* and other factors (such as growth uncertainty and spatial heterogeneity) in the fit of the length-based model, examination of weighting factors for model likelihood components and consideration of sex-specific *M*.

- *Information on temperature, recruitment, predation and disease trends in SNE and how they may relate to increased natural mortality and/or decreased recruitment is discussed in Sections 2.2-2.4. Temperature anomaly data from SNE indicate that the number of days with water temperatures above 20° C has increased since the late 1990's. The timing is also co-incident with a lobster die off in Long Island Sound (Howell et al., 2005) and increases in shell disease (Figure 2.4.1). This assessment utilized information from the last assessment, and subsequent analyses (see Section 6.3.4) that indicated the SNE model fit the data better with a higher M starting in the late 1990's. This assessment included a number of sensitivity runs to examine effects of M and recruitment covariates (See Section 6.3.4).*

(B10) Finally, it is strongly recommended that the TC be given the opportunity to undertake a longer review of lobster stock and recruitment patterns in SNE, including consideration of evidence for alternative scenarios (e.g. return to lower productivity levels) in addition to strengthening the evidence for the environmentally---driven recruitment failure scenario

- *New initiatives using Ecosystem-based Modeling have begun at NEFSC and may be helpful for such a larger-scale review.*

Recommendations from Frusher

(F1): It is recommended that increased temperature stations be established and that temperature measurements be routinely collected as part of fishery dependent and independent surveys. Consideration should be given to ways of encouraging fishers to also link bottom temperature with catch (e.g. volunteer logbook).

- *Temperature data are currently being recorded in several long-term data sets. Additional data would not be usable without an associated historical context.*

(F2): It is recommended that a more formal analysis of catch rates at depth be undertaken and that future surveys be depth stratified. Consideration should be given to ways of encouraging fishers to record depth with catch (e.g. volunteer logbook). Although there are concerns over the use of trap lifts as effort, catch rate (catch per unit of effort [CPUE]) data is an important metric for standardizing and interpreting catch data.

- *Sea sampling data are gathered opportunistically and cannot be statistically stratified by depth. Therefore we are unable to examine catch trends by depth strata or distance from shore in any meaningful way.*

(F3): It is recommended that CPUE data be used as an additional metric in assessing the fishery;
(F9): It is recommended that the regional CPUE data used in this review is updated to 2009.

- *CPUE in the lobster fishery, as well as other passive gear fisheries, has repeatedly been demonstrated as hyperstable and not reflective of changes in abundance; therefore it is not a useful measure of abundance trends.*

(F4): It is recommended that the UMM model and the model used in the report be investigated to determine which estimates of female abundance are most likely.

- *This recommendation was not directly addressed but female abundance estimates and trends for SNE were similar in the basecase and a range of sensitivity analyses.*

(F5): It is recommended that YOY be prioritized as the preferred recruitment index for the fishery. Further effort should be directed to expanding this index to other regions and that the MA YOY survey sites are altered to a region where improved numbers of YOY are encountered.

- *MA has added 4 new YOY sampling stations; RI has done additional sampling at 2 existing YOY stations. There is not sufficient funding for new surveys.*

(F6): It is recommended that a study be undertaken to determine why there is a weaker correlation between recruits of a year and the legal sized lobster of the subsequent year.

- *The most recent assessment has demonstrated that environmental drivers affect recruitment possibly to a greater degree than spawning stock size, therefore only a weak relationship exists.*

(F7): It is recommended that the MA survey be relocated to a region where it is a better prediction of abundance and CPUE in the MA region.

(F8): It is recommended that more reliable effort data is routinely collected from the fishery and that CPUE replace landings in assessing the fishery.

- *Since the previous assessment most states have moved to 100% harvester reporting but the largest landing state still only collects 10% harvester reporting with 100% dealer reporting. This is an issue for the management to address. See response F3 and F9 regarding CPUE.*

(F10): It is recommended that effort be reduced in the fishery to a level equivalent to the 1980s and that a socio-economic study be implemented to determine the economic viability of effort reductions.

- *This is an issue for the management board.*

(F11): It is recommended that a study be undertaken to investigate the longer term future of the fishery. This could be achieved by using the downscaled IPCC climate models.

- *Additional funds are necessary to apply IPCC modeling to the lobster fishery.*

(F12): It is recommended that a decision rule process be considered that involves both government and industry and that incorporates both fishery independent (e.g. YOY) and fishery dependent (e.g. regional CPUEs) indices.

- *This is an issue for the management board.*

(F13): It is recommended that several low recruitment scenarios be determined and included in the projections. Each scenario needs to define what the recruitment value is compared to a base case (e.g. the BH-R).

(F14): Targets and thresholds should be determined for the low (normal) recruitment scenarios.

- *All low ('normal' values or below) recruitment projections result in further deterioration of the SNE stock with no rebuilding. Therefore threshold reference points would not be sustainable and target reference points would most likely never be reached.*

(F15): Further studies are undertaken to attempt to separate F from M.

- *See (F 14) and additional funds are necessary to meet this objective.*

Recommendations from Hall

(H1): It is recommended that these other sources of water temperature data are examined to determine whether they strengthen the evidence of increased temperatures throughout the region occupied by the SNE lobster stock.

- *All available temperature data sets were reviewed and analyzed.*

(H2): It is recommended that the survey, sea sampling and landings data are subjected to appropriate statistical analysis to determine whether the spatial distribution(s) of the stock and/or the fishery have changed in recent years from the spatial distributions that were present in earlier years.

- *The committee examined a series of bubble plots in 5-year intervals that demonstrate the distributional changes of lobster in SNE for the assessment. Maps were generated separately for demographic groups (i.e. eggers, 'large' sizes) to examine specific distributional trends.*

(H3): It is recommended that the University of Maine's length-based model is extended to allow input and use of the other additional time series of indices of abundance or length composition that are available for the SNE lobster stock.

- *The UM model was modified to accommodate up to 16 surveys simultaneously.*

(H4): It is recommended that the University of Maine's length based-model is re-run, using the updated time series of data that are now available, to provide an updated assessment of the state of the SNE lobster stock.

- *This was completed by the assessment.*

(H5): It is recommended that the ASFMC adopts a definition of recruitment failure that is consistent with the criteria used to determine the threshold reference point that is used to assess whether the lobster stock is overfished.

- *This is an issue for the management board.*

(H6): It is recommended that, by fitting appropriately-modified versions of the University of Maine's length-based model, the TC explores alternative hypotheses relating to natural mortality and changing selectivity functions to assess whether these hypotheses provide equally viable alternatives to that which was investigated by the TC and assumes an increase in natural mortality.

- *The basecase and sensitivity analysis runs for the SNE stock include three runs in which different assumptions about natural mortality were considered. These analyses were not extensive but support the basecase model with higher natural mortality rates beginning in 1998 than assumed in the last assessment. Fortunately, different assumptions about natural mortality had modest effects on recent abundance and exploitation estimates or, more importantly, on estimated trends which are used for status determination.*

(H7): It is recommended that the TC determines new reference points for abundance and exploitation that are consistent with the changes in biological processes that are likely to have accompanied the increased temperatures now experienced by the SNE lobster stock.

- *The SNE target was lowered to its long term median value to reflect lowered expectations for any future stock rebuilding.*

(H8): It is recommended that, if and when exploitation of the SNE lobster stock is permitted, male lobster are preferentially exploited and female lobster are protected to the extent that is possible, *e.g.*, through use of a V-notch program or male-only fishery. It is also recommended that, if male lobster are preferentially exploited, monitoring programs are established to detect whether such exploitation produces a significant reduction in the number of females that are mated, or a significant reduction in the fecundity of females of different lengths.

- *This is an issue for the management board.*

(H9): It is recommended that managers impose a five-year moratorium on exploitation of the SNE lobster stock.

- *This is an issue for the management board.*

(H10): It is recommended that fishery-independent research studies and surveys of the SNE lobster stock and fishery should be expanded and/or enhanced, and that the University of Maine's length-based model be extended to use the additional data in future assessments.

- *The UM model was modified to accommodate up to 16 surveys simultaneously.*

Citation

Annis ER, Wilson CJ, Russell R, Yund PO (2013) Evidence for thermally mediated settlement in lobster larvae (*Homarus americanus*). Can J Fish Aquat Sci 70:1641–1649

Howell, Penelope, Jacqueline Benway, Colleen Giannini, Kim Mckown, Robyn Burgess and Jed Hayden. 2005. Long-term population trends in American lobster (*Homarus americanus*) and their relation to temperature in Long Island Sound. Journ. Shellfish Research. Vol. 24 No. 3 849-857.