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2017 Assessment of the Offshore American Lobster (*Homarus americanus*) in Lobster Fishing Area (LFA) 41

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The Lobster Fishing Area 41 (LFA 41) offshore Lobster fishery has been active since the early 1970s and is currently the only Total Allowable Catch (TAC)-based Lobster fishery in Canada. The TAC has been set to 720 t since the mid-1980s without change, despite increases in survey biomasses. The fishery currently has 8 licenses that are owned by a single corporation and are fished from a single vessel.

This stock assessment follows the Framework Assessment of 2017 (Cook et al. 2017), applying the methods and agreed upon primary and contextual indicators from that work.

Four multispecies trawl surveys conducted by two agencies, Fisheries and Oceans Canada (DFO) and the National Marine Fisheries Service (NMFS), occur within LFA 41 and adjacent areas. Each of these surveys provides indices of biomass and abundance, size frequency, sex ratio, distribution and environmental variables. Six at-sea observed trips are conducted each year, which provide further information on by-catch profiles, and Lobster size and sex information.

Time series of a suite of standard indicators including total abundance, median and maximum size, mature and immature sex ratio, patchiness of distribution, area occupied, abundance of large females and recruit abundance were used to describe the changes in the LFA 41 Lobster stock over time. Additionally, ecosystem indices including predation, bottom water temperature, and the Atlantic Multidecadal Oscillation (AMO) were provided to describe some of the external factors that may impact Lobster productivity. All indicators were combined and ranked through a modified principle components analysis to display the coherence in indicator trends over time. Overall, patterns suggest decreasing median and maximum size of the Lobster stock over time, as well as decreasing predation pressure and increasing abundance, distribution, bottom temperature, and AMO.

Data-driven primary indicators were assessed against the proposed reference points from Cook et al. (2017) with overall stock status being in the Healthy Zone as all four surveys are above their respective Upper Stock Indicators (USIs). The LFA 41 Lobster stock has been in the Healthy Zone since 2002, and it has not been in the Cautious Zone since the time series began in 1981.

The reproductive-potential primary indicator, which has long been considered an important component of Lobster stock productivity, remains above the upper bound. This integrative measure incorporates the size distribution of the female Lobster, as well as the abundance-at-length to estimate total egg production. Although median and maximum size are decreasing, which would result in a decrease in mean individual fecundity, the increase in abundance more than offsets this reduction, resulting in the high levels of reproductive potential.

The levels of bycatch in the LFA 41 Lobster fishery have been declining in recent years and currently represent 1.4% of total landings, based on 17% observer coverage. The most frequently captured non-target species include Jonah Crab, Cusk, Atlantic Cod, Red and White Hake, and Atlantic Sea Raven. The non-retained Lobster, which includes berried, v-notched, culls (missing one or two claws), and undersized Lobsters, represent 23% of total landings. In 2016, soft-shelled and cull Lobster account for 28% and 43% respectively, which increased from 2% and 26% in 2015.

INTRODUCTION

BACKGROUND

The offshore fishery for American Lobster (*Homarus americanus)* in Lobster Fishing Area 41 (LFA 41) was established in 1971, although fishing had occurred prior to this time (Pezzack and Duggan 1983). The LFA 41 fishing area is delimited by the inshore/offshore 50 nautical mile line (92 km) off of Nova Scotia, and extends from Georges Bank to the Laurentian Channel off of Cape Breton (Figure 1). Traditionally, commercial fishing occurs on five major grounds: Georges Bank, Georges Basin, Crowell Basin, Southeast Browns Bank, and Southwest Browns Bank, all within the Northwest Fishing Organization (NAFO) Divisions 4X and 5Ze (Figure 2).

In 1976, concerns from the inshore Lobster fleet that Lobster migration may be impacted by offshore Lobster fishing prompted Fisheries and Oceans Canada (DFO) to implement some restrictions to better manage LFA 41 (DFO 2016a). As a result, a Total Allowable Catch (TAC) was set to 408 t for the 4X portion of LFA 41, which included the area closest to the southwest nova inshore fleet (LFA 34).

LFA 41 is the only Lobster fishery in Canada managed with a TAC, and has a total of 8 licenses. In 1979, an area was closed to Lobster fishing on Browns Bank, known as LFA 40. This closure was to protect Lobster broodstock, and it continues to remain in effect today. An official boundary between Canada and the United States (US) was established by the International Court of Justice in 1984 known as the “Hague Line” in the Gulf of Maine. This ruling displaced the American offshore Lobster effort from areas now defined as Canadian waters, principally in Crowell Basin and Georges Basin (DFO 2016a).

The Offshore Lobster Advisory Committee (OLAC) was formed in 1985, which served as a collaborative conservation strategy involving DFO and the offshore Lobster fleet. This decision body identified and adopted effort control measures that benefited both the biological and economical sustainability of the offshore fishery. Among these, the TAC was increased to 720 t to include both the 4X portion of LFA 41, as well as 5Ze (Georges Bank, DFO 2016a). Landings increased accordingly with the removal of American effort from Canadian fishing grounds and an introduction of the 720 t TAC (Table 1).

There have been no changes in the number of licenses in this fishery. The 8 licenses are active and currently owned by one company: Clearwater Seafoods Limited Partnership. There has been a steady reduction of the number of vessels within LFA 41 in order to increase economic efficiencies and maintain conservation goals (DFO 2016a). The status of LFA 41 offshore Lobster was last assessed in 2015 (Pezzack et al. 2015).

Current management measures in LFA 41 include:

- **Fishing Season:** Year-round quota year (January 1st to December 31st)
- **Minimum Legal Size:** 82.5 mm Carapce Length (CL)
- **Landing of berried and or v-notched females:** Prohibited
- **Trap Limit:** None
- **Number of licenses:** 8
- **Lobster TAC:** 720 t

Species Biology

The American Lobster (*Homarus americanus*) is a crustacean species that has been commercially fished since the early 1800s. This decapod has a complex life cycle characterized by several phases from eggs, larvae, juvenile, and adults, and relies on molting its exoskeleton for an increase in size. Typically, the mature females mate after molting in late summer, and they extrude eggs the following summer. These eggs are attached to the underside of the tail to form a clutch. These are then carried for another 10–12 months and hatch in July or August. The eggs hatch into a pre-larvae or prezoea, and through a series of molts become motile larvae. These larvae spend 30–60 days feeding and molting in the upper water column before the post-larvae settle to the bottom seeking shelter. For their first few years of life, juvenile Lobsters remain in or near their shelter to avoid predation, spending more time outside of the shelter as they grow (Lavalli and Lawton 1996). Nova Scotia Lobsters can take up to 8–10 years to reach a minimum commercial size of 82.5 mm Carapace Length (CL). Molting frequency begins to decrease from 1 molt per year at about 0.45 kg to molting every 2 or 3 years for Lobsters above 1.4 kg (Aiken and Waddy 1980).

Lobsters mature at varying sizes depending upon local conditions (Aiken and Waddy 1980, Campbell and Robinson 1983, Comeau and Savoie 2002) with climatological factors such as temperature influencing the size at maturity. Generally, regions characterized by warmer summer temperatures have smaller sizes at maturity than regions with cooler summer temperatures such as the Bay of Fundy (Le Bris et al. 2017). Estimates of the size (carapace length) at 50% maturity (SoM) in the offshore areas varies regionally from 82 mm CL on the slope off New England and 92 mm CL for Georges Bank and Gulf of Maine (Little and Watson 2005), to approximately 97 mm CL for Northeast Georges and Browns Bank (Pezzack and Duggan 1989). In LFA 41, the SoM has recently been estimated to be 92 mm CL (J. Gaudette and A.M. Cook unpublished data). Decreases in size at maturity have been documented for many stocks and may be related to warming waters (Le Bris et al. 2017) and/or fisheries induced evolution as observed in other LFAs where minimum legal sizes are smaller than the SoM.

In LFA 41, although the minimum legal size is below the SoM, the median size at capture is above this threshold (Pezzack et al. 2015), indicating a high proportion of the females caught have had the opportunity to breed. This is in contrast to some of the inshore fisheries where the median size in the catch is below SoM and a small proportion of females have had the opportunity to breed (Gaudette et al. 2014). Between initial maturity and approximately 120 mm, female Lobsters produce eggs every second year with a molt in intervening years. Based on laboratory studies using ambient inshore Bay of Fundy water temperatures, female Lobsters are able to spawn twice without an intervening molt (consecutive spawning) at a size greater than 120 mm CL (Waddy and Aiken 1986, Waddy and Aiken 1990), though this size may vary in nature (Comeau and Savoie 2002). Consecutive spawning may occur in two forms: successive-year (spawning in two successive summers, a molt in the first and fourth years) and alternate-year (spawning in alternate summers). In both types, females often are able to fertilize the two successive broods with the sperm from a single insemination. Intermolt mating has also been observed in laboratory conditions (Waddy and Aiken 1990). This consecutive spawning strategy enables large Lobsters to spawn more frequently over the long term than their smaller counterparts. This, combined with the exponential relationship between body size and numbers of eggs produced (Campbell and Robinson 1983, Estrella and Cadrin 1995), means that very large Lobsters have a much greater relative fecundity and are thus an important component to conservation. In the Gulf of Maine, the management plan and past assessments have looked at maintaining the high reproductive potential in this area by preserving its size structure dominated by mature animals, which has been a key component of stock assessments (Pezzack and Duggan 1987, Pezzack and Duggan 1995).

Distribution and Stock Structure

American Lobster is distributed in coastal waters from Maryland, USA, to southern Labrador in Canada, with the most concentrated fisheries located in the waters between the Gulf of Maine and Gulf of St. Lawrence. In addition to the coastal habitat used by American Lobster, there are offshore areas in the Gulf of Maine and along the outer edge of the Scotian Shelf, from North Carolina to Sable Island, that contain commercial concentrations (Pezzack et al. 2015). It is presumed the presence of Lobsters in the offshore areas is due to the presence of year-round, warm, slope water that maintains suitable temperatures in the slope and deep basins in the Gulf of Maine and western Scotian Shelf. This warm, deep water is not a prevailing oceanographic feature on the eastern Scotian Shelf, the outer Gulf of St Lawrence, or off Newfoundland, where Lobsters do not typically occur in commercial densities in the offshore.

The currently defined Lobster Fishing Areas (LFAs) do not represent biological units but, rather, are based on historical boundaries. There is high potential for the exchange of Lobster between areas in all life stages, and studies have shown relative strong larval connections between some LFAs (Quinn 2014). It is generally accepted that Lobster concentrations are highest in coastal regions with lower concentrations associated with the offshore area. However, there appears to be an increasing concentration of Lobster in the mid-shore and offshore regions of LFAs 33 and 34.

Historic tagging studies suggest mature Lobster display seasonal movements into deep water (200–400 m) during the winter and move to Browns Bank and Georges Bank in the summer (Cooper and Uzmann 1971, Uzmann et al. 1977, Pezzack and Duggan 1986). Whether these findings are indicative of the present day stock structure is unknown as population sizes are currently much higher and density dependence has been shown to influence movement patterns and migration rates in other species (e.g. Rosenberg et al. 1997)

The stock structure of Lobster within the Gulf of Maine has not been fully described. The current hypothesis is that the Gulf of Maine Lobster is a stock complex comprised of several sub-populations that are linked through larval drift and adult migration patterns. Larval exchange likely occurs throughout the area as biophysical circulation modeling studies indicate that larvae can be transported over large distances (Xue et al. 2008, Incze et al. 2010, Quinn 2014). That said, self–seeding was identified as important source of juvenile Lobsters in most LFAs, including LFA 41 (Quinn 2014).

Predators

The predators of Lobsters include cunners, sculpins, skates, Cod, Spiny Dogfish, sea ravens, wolffish, Haddock, hake and crabs (Lavalli and Lawton 1996, Palma et al. 1998, Nelson et al. 2003, Hanson and Lanteigne 2000, Boudreau and Worm 2010, Steneck et al. 2011). Systematic sampling of groundfish food habits during the DFO Research Vessel (RV) survey on the Scotian Shelf has suggested that predation rates on Lobster is relatively low (36 stomachs containing Lobster of the 160,580 stomachs examined between the 1960s and 2009 – data sources reviewed by Cook and Bundy 2010). This likely does not reflect the predation pressure on Lobster larvae and juveniles and is more likely due to the timing and location of sampling.

Stock Assessment History and Framework

The LFA 41 Lobster stock has a long history of assessments, which were reviewed in the most recent framework (Cook et al. 2017). The framework dealt with several of the concerns raised during the stock assessment updates, specifically, options for reference points consistent with DFO's precautionary approach policy were identified, the sensitivity of the indicators to the choice of survey strata were explored, and a new option for assessing reproductive potential was presented. Additionally, data driven stock assessment methods were applied to the LFA 41 Lobster stock dynamics and graphical displays of multiple indicators were explored. This assessment will apply the methods described in Cook et al. 2017 to provide stock status advice for LFA 41 using data to the end of 2016.

DATA SOURCES

FISHERY

Logbook Information

Lobster catch, effort, and location information is available for the LFA 41 Lobster fishery since 1972 and became fully dockside monitored in 1996. Offshore logbooks provided information on date, location, depth fished, effort, soak days, and estimated catch. Logbooks were historically reported on a daily basis, but are currently reported on a string by string basis. At landing, the total catch is weighed and verified by a dockside monitor and recorded in the weigh out section of the logbook. Estimated logbook catches (*E)* by day or string, *i*, were adjusted to reflect the total catch (*D*) as:

$$C_i = \left(\frac{D}{\sum_{i=1}^{n} E_i}\right) E_i$$

These adjusted C_i, were used for subsequent analyses of fishery performance.

The fishing season within LFA 41 was based on a calendar year cycle up to 1985. From 1985 to 2005, the season was October 16 to October 15. In 2006, seven of eight license holders returned to the calendar year fishing cycle (Table 1). The remaining license switched to the calendar cycle in 2007. In both transition periods (1985/1986) and (2004/2005), the offset in fishing year resulted in a 14 month season as the fishery end date moved from October to December. TAC was adjusted to reflect these changes. Landings and TAC are presented on an annual basis since 2006 onward to reflect the majority of the fishery.

Historically, analyses of log data assigned catches and effort to five areas. These areas were:

1. Crowell Basin,
2. Southwest (SW) Browns,
3. Georges Basin,
4. Southeast (SE) Browns, and
5. Georges Bank (Figure 2).

The five areas represent the traditional Lobster grounds used in past assessments (e.g., Pezzack and Duggan 1985, Pezzack et al. 2009). These fishing areas will still be used to describe the size composition data from at-sea samples, but results from area specific fishery performance metrics cannot be displayed. To do so without the consent of the license holder would violate the *Privacy Act*.

At-Sea Observations and Bycatch

At-sea samples were performed to collect information from the catch during normal commercial fishing operation. The data collected included: carapace size, sex, egg presence, and stage; shell hardness; occurrence of culls and v-notches; and the number of traps, location, and depth. At-sea sampling provides detailed information on the size-structure of animals in the traps (including sublegal, berried, and soft-shelled Lobster).

Frequency and distribution of sampling has varied over the history of the fishery (details in Pezzack et al. 2015). Increased effort to obtain one sample per area per quarter was initiated in 1997. This sampling plan was often not completed due to vessels not fishing the areas during the specified time periods. Changes in the plan and its implementation have been made over time to better reach these goals.

Prior to 2000, sampling was done by DFO or Javitech (a company that provided at-sea observer coverage), and other private contractors. Since 2000, Javitech has conducted all of the at-sea sampling in LFA 41.

The sampling protocol was reviewed in 2010 and adjustments made to provide more consistent coverage. The implemented sampling plan proposed at-sea observed trips for the first commercial fishing trip of the month in March, May–July, November and December, resulting in 6 sampled trips per year. These scheduled deployments were deemed adequate to describe the size distribution of the Lobster captured during fishing operations (Pezzack et al. 2015).

A second component of the at-sea observations was non-retained bycatch (herein bycatch) sampling from which estimated weights and species composition of all bycatch were recorded. In 2008, a *Species at Risk Act* (SARA) initiative collected bycatch data from Lobster fishing activities in LFA 41. The influence of the aforementioned sampling scheme relative to a random deployment of at-sea sampling is not known, but it likely impacts the representativeness of the bycatch catch samples in relation to the fishery (Benoit and Allard 2009).

From this information the total weight of bycatch was estimated. A ratio estimator was used to estimate bycatch (Gavaris et al. 2010). This method prorates the observer estimates of bycatch (*O*) across trips (j = 1, 2,…n) for species *i* to the total catch (L_t ; obtained from log book information) using the observed Lobster landings within the trip (L_j) as:

$$I_i = L_t \left(\frac{\sum_{j=1}^{n} O_{ji}}{\sum_{j=1}^{n} L_j} \right)$$

This ratio estimator makes the assumption that bycatch will increase in proportion to the Lobster landings. A more appropriate estimator would use effort to prorate the bycatch, as bycatch rates are likely not be proportional to the Lobster catch rates. Unfortunately, effort proration could not be used as this information has not been consistently recorded. As a research recommendation, however, improvements in data collection should allow for effort proration in future frameworks.

During a trip, a vessel can cover a large area, with variable depths and with location varying between trips in response to Lobster movements and catch rates. Due to sampling and fishing logistics, the number, timing, and location of samples varied year-to-year. Although species assemblages likely vary within LFA 41 (Mahon and Smith 1989), the small sample sizes preclude bycatch analysis on spatial scales smaller than the overall LFA 41. The discard estimates and bycatch profiles from the entire stock area was provided at 3-year intervals.

FISHERY INDEPENDENT

DFO Maritimes Summer Research Vessel Trawl Survey

The DFO Maritimes Region Summer Trawl Survey (herein RV survey) covers the offshore portions on the Scotian Shelf (Figure 3). This survey has been conducted annually since 1970 and has used the same depth stratified survey design for its duration. Set allocation is approximately proportional to stratum area. The survey was originally designed to provide abundance trends for groundfish at depths from about 50 m to 400 m, but it also provided total numbers of Lobsters captured throughout its duration. Beginning in 1999 during the summer survey, all Lobsters were measured to the nearest millimeter (carapace length) and were sexed. In 1993–1995, only total weight of Lobster by set was recorded during the survey. In those years, total number per tow was estimated using the (mean total weight) / (mean total number) for the five years prior to and following the missing years.

Vessel and gear changes have occurred during the time series of the RV survey. There were vessel changes in 1981 and again in 1982 from the RVs *A.T. Cameron* to the *Lady Hammond* and then to the Canadian Coast Guard Ship (CCGS) *Alfred Needler,* which has performed the survey every year since, with exceptions in 1991 when a portion of the survey was conducted by the *Lady Hammond*, in 2004 and 2007 when the CCGS *Teleost* performed the survey, and in 2008 when the survey was conducted by the CCGS *Wilfred Templeman*. Accompanying the vessel change in 1981, the bottom trawl was changed from a Yankee 36 to a Western IIA (for trawl specifications see Carrothers 1988). Although conversion factors were developed for some species (Fanning et al. 1985), American Lobster were not included in the analysis. The small sample sizes of Lobster captured during these surveys suggest comparative analysis would have lacked the statistical power to detect significant changes. In the analysis presented in this paper, a correction factor was applied to account for the differences in nominal wing spread between the Yankee 36 of 10.7 m and Western IIA of 12.5 m, to make all swept area calculations based on Western IIA trawled units. Survey tows were conducted at 3.5 knots for 30 minutes, yielding a swept distance of 1.75 nm. Catch rates for tows that deviated from 1.75 nautical miles (nm) were standardized.

Regional size differences in the trawl survey do not solely represent size selectivity of the trawl, as the size distribution of Lobster within LFA 41 are less variable and generally consist of larger Lobster than are observed elsewhere in the survey (Figure 4).

The distribution of Lobster catches and relative abundance of the catch by time period is shown in Figure 5. The strata considered in the LFA 41 stock were 472, 473, 477, 478, 480–485. The total strata area pruned to the LFA 41 boundaries from this survey represents 44.5% of the total area of LFA 41.

DFO Maritimes George Bank Survey

The DFO Maritimes Region Georges Bank Trawl Survey (herein GB survey) covers the offshore portions on the Scotian Shelf (Figure 6). This survey has been conducted annually since 1987 and has used the same survey design its duration. The survey was designed to provide abundance trends for groundfish on both the American and Canadian sides of Georges Bank. Total number and total weight of Lobsters per tow were estimated throughout the time series. Beginning in 2007, Lobsters were measured to the nearest millimeter (carapace length) and were sexed. In 1993–1995, only total weight of Lobster by set was recorded during the survey. In those years, total number per tow was estimated using the (mean total weight) / (mean total number) for the five years prior to and following the missing years.

Since the initiation of the GB survey, the CCGS *Alfred Needler* using the Western IIA bottom trawl was the research platform. Exceptions occurred in 1993, 2004, 2007 and 2008 when the survey was completed by either the CCGS *Wilfred Templeman* (the sister ship to the CCGS *Alfred Needler*) or the CCGS *Teleost,* both using the Western IIA. No vessel conversion factors were applied. Survey tows were conducted at 3.5 knots for 30 minutes, yielding a swept distance of 1.75 nm. Catch rates for tows that deviated from 1.75 nm were standardized.

The distribution of Lobster catches and relative abundance of the catch by time period are shown in Figure 7. Only 5Z1 and 5Z2 were included in analyses as the entirety of these strata are contained within LFA 41. The total strata area within LFA 41 from this survey represents 22.2% of the total area of LFA 41.

NEFSC Bottom Trawl Surveys

The Northeast Fisheries Science Center (NEFSC) bottom trawl surveys are conducted in spring (March–May) and autumn (September–November). These surveys were initiated in the late 1960s; however, only data from 1969 onward were used (B. Shank pers. Comm. NEFSC).

Both NEFSC surveys use the same depth stratified random sampling design and study area, which extends from the Scotian Shelf to Cape Hatteras including the Gulf of Maine and Georges Bank (Figure 9). Most strata are further subdivided into sampling units to achieve a more even sampling distribution across the area covered by the survey. Station allocation is proportional to stratum area. Lobster size (CL) and sex were determined throughout the survey time series.

Surveys between 1969 and 2008 were conducted using the RV *Albatross IV*, a 57 m long stern trawler; however, between 1973 and 1994 some surveys were made on the 47 m stern trawler RV *Delaware*. On most spring and autumn surveys, a Yankee 36 otter trawl was used. Survey tows were conducted at 3.5 knots for 30 minutes, yielding a swept distance of 1.75 nm. Catch rates for tows that deviated from 1.75 nm were standardized.

From 2009 to present, the RV *Bigelow* became the survey vessel for both spring and autumn surveys. Accompanying this change in vessel, a new trawl and fishing protocols were adopted. The new trawl is a four-seam bottom trawl, which is towed at a speed of 3 knots for 20 minutes yielding an average towed distance of 1 nm. Extensive vessel and trawl comparisons were made as the changes in catch was substantial. The Lobster size-based vessel calibration coefficients were applied to catches of Lobster greater than 50 mm (Jacobson and Miller 2012), yielding all catch rates as Bigelow equivalents.

The strata considered as part of the LFA 41 stock included 1160, 1170, 1180, 1190, 1200, 1210, 1220, 1290, 1300, 1340, and 1360. Strata 1310 was originally included in NEFSC surveys; however, it has not been regularly sampled in the last 10 years and has therefore been excluded (Figure 8).

The distribution of Lobster catches and relative abundance of the catch by time period is shown in Figure 9 and 10. The total strata area within LFA 41 from this survey represents 59.4% of the total area of LFA 41.

GENERAL ANALYSES

SURVEY PRUNING

Both the RV survey and NEFSC surveys have survey strata boundaries that do not conform to stock boundaries of LFA 41 (Figures 3 and 8). As such, the survey strata were pruned to match the stock boundaries of LFA 41. Under this estimation method, for each survey *i* all 'base' strata,

h_i, were intersected with stock boundaries of LFA 41 to define a new set of strata, h_i'. Only survey stations j that were contained within h_i' were retained. Strata weighting was adjusted to reflect the new polygons representing the pruned areas. Survey trends resulting from this method will be referred to as the RV41, NSpr41 and NAut41 representing RV survey, NEFSC Spring survey and NEFSC Autumn survey respectively.

The strata boundaries for the Georges Bank DFO survey were divided along the Canadian – US boundary, with all sets in strata 5Z1 and 5Z2 being contained within LFA 41, allowing for estimation of survey trends within LFA 41 as a simple subset of appropriate strata.

SURVEY ANALYSES AND INDICATORS

For each survey, type and pruning method indices were estimated, accounting for the strata-weighting scheme following the traditional methods of Cochrane (1977), with confidence intervals estimated through bootstrapping with replacement (Smith 1997). As part of the stratified analyses, annual samples sizes used for estimating the specific indicator (i.e., total numbers of observed Lobsters) were provided for each indicator.

RUNNING MEDIANS

For each abundance or biomass index, smoothed trends were shown using a running median. A running median was chosen over the more commonly used running mean as it is more resistant to influential data points. At the ends of the time series, x_1 and x_n , where the values at x_{1-1} and x_{n+1} do not exist, the smoothed values, z, are estimated by z_1 = median (x_1, z_2, $3z_2 - 2z_3$) and z_n = median (x_n, z_{n-1}, $3z_{n-1} - 2z_{n-2}$) (Tukey 1977).

RESULTS

LANDINGS

The total allowable catch for offshore Lobsters in LFA 41 has been set to 720 t since the 1986-1987 season (Table 1). The landings have approximated the TAC throughout this time period, with slight over- or under-runs in some years. In recent years, a three-year quota management cycle has been adopted whereby the quota over the time period is equal to the sum of the three-year annual quota, with the flexibility to remove up to 15% of the next year's quota in either of the first two years (for more details refer to the Integrated Fisheries Management Plan). Harvesting decisions from the licence holders, rather than resource limitation, resulted in landings lower than the TAC in recent years.

BYCATCH

Since 2012, at-sea coverage on a per-trip basis has been between 12% and 17% (Table 2). The number of samples per year has been variable over time; however, there has been an increase in the percentage of trips covered since 2012.

Since 2012, the bycatch species that occurred most frequently in the LFA 41 Lobster fishery were Jonah Crab, Cusk, Cod, Red and White Hake, and Sea Raven (Table 3 and 4). Survival of the non-retained crustaceans has not been reported for Lobster trap fisheries; however, return rates from Lobster tagging studies and knowledge of species biology suggest that it is high for most invertebrates. Work in various crab fisheries indicate high survival if air exposure and handling is minimized (Grant 2003, Tallack 2007). On the LFA 41 vessels, traps are processed immediately upon recovery thereby minimizing air exposure. Higher mortality would be expected for soft-shell Lobsters through handling stress and, as such, the fishery actively avoids fishing times or areas when these sensitive stages are present. Fish species with a swim bladder likely have a lower survival rate, particularly when captured at depth.

The overall estimated non-Lobster bycatch has declined since 2006 from 127.6 t to 10.9 t in 2016, which represented 1.4% of the total Lobster landings (Table 5). The gradual decrease in number of vessels throughout the years, and an increased focus on areas of highest Lobster Catch Per Unit Effort (CPUE), contributed to the reduction in bycatch. Cod represented the largest estimated bycatch in 2016 at 5.8 t. Table 4 shows the estimated bycatch of the species observed in the LFA 41 Lobster fishery from 2006 to 2016.

With regards to non-retained Lobster catch, observer data catch summaries indicated 23% of the Lobster caught in 2016 were returned to the water. If it is assumed that all undersized (<82 mm CL), jumbo (≥140mm CL), berried, v-notched, cull (one or zero claws), or soft Lobsters are returned to the water, the size frequencies from observed trips indicated that 26% of the Lobster caught are returned to the water. The non-retained Lobsters are mostly berried, jumbo, or cull Lobsters (Table 7). Shifts in the proportion of the sublegal, jumbo, and berried females may be related to changes in the areas, times fished, and sampling sizes. Similar decreases in the large Lobsters have been seen in the trawl surveys suggesting changes in the size composition of the stock. All measures that return Lobsters to the water contribute to maintaining the high reproductive potential in this stock.

The at-sea observer data were aggregated by three-year time blocks to smooth the bycatch rates (Figure 11). Of the top three bycatch species, Cusk and Atlantic Cod catch rates have declined consistently over the time periods while White Hake increased during the 2006 to 2014 periods but declined for the 2015–2017 period.

INDICATORS

In the following section, each indicator will be presented separately with the justification for inclusion, the data and analyses used in estimating the indicator, as well as the trends for each of the surveys.

Some indicators used here are directly linked to stock health and status (e.g., abundance), whereas others describe the population characteristics (e.g., sex ratio) or ecosystem considerations (e.g., predator abundance, temperature). These indicators provide a snapshot of the offshore Lobster stock and ecosystem and, although linkages to productivity may not be obvious, documenting the changes in the stock’s characteristics and external factors over time may improve understanding of overall stock health and impact the advice provided to resource managers.

Total Abundance

Justification

Annual trends in total abundance of the Lobster captured in the trawl survey series is a useful metric of the overall population abundance trends over time as we can assume similar catchability coefficients of the gear over time. In the case of the NEFSC surveys where substantial gear changes were made, length-based catchability conversion factors were applied to make this a continuous time series. This indicator represents the longest time series of data available from the survey trends, and sample sizes are not sacrificed through sex and size portioning.

Data Inclusion and Analyses

For each of the DFO surveys (RV41 and GB), all Lobster captured in tows were considered in this analysis. Total abundance from the NEFSC surveys (NSpr41, NAut41) was limited to all individuals ≥50 mm due to concerns over the reliability of conversion coefficients for Lobsters <50 mm (Jacobson and Miller 2012).

Stratified total abundance estimates were computed following traditional procedures outlined by Cochrane (1977) with confidence intervals estimated by bootstrapping with replacement (Smith 1997).

Results

Both the RV41 and NSpr41 surveys showed low and variable mean number of Lobsters·tow^{-1} from the start of the survey time series until approximately 2000-2001 (Figure 12). The catch rates in each of these surveys then increased to a new stable level until 2009–2010 when abundances increased again to the highest levels observed (Figure 12). The current level of 10.5 Lobsters·tow^{-1} in RV41 and 9.3 Lobsters·tow^{-1} in NSpr41 were the highest and second highest catch rates on record, respectively. Compared to the RV41 and NSpr41 surveys, the NAut41 showed the same low and variable level of catch rate until 2000, but did not show the same increase to a stable level in the mid-2000s. Instead, a slow increase was observed until 2009 when, similar to the other surveys, the highest catch rates were observed within the last several years. The current catch rates in NAut41 were the second highest on record at 8.9 Lobsters·tow^{-1}. The GB survey mean Lobsters·tow^{-1} were again low and variable until 2003, decreased though the late 2000s, but are currently at among the highest catch rates on record at a rate of 4.7 Lobsters·tow^{-1} (Figure 12).

The coherence between surveys provides confidence in their trends and suggests that Lobster abundance is currently near the highest on record in LFA 41.

Design Weighted Area Occupied (DWAO)

Justification

Changes in the distribution of a stock typically correspond to changes in abundance (Fisher and Frank 2004). Changes in distribution through the total area occupied were considered important to document, as they provide information on the breadth of the habitat usage for the stock as well as their susceptibility to localized depletion, through anthropogenic or ecological events (Hanselman et al. 2007).

Data Inclusion and Analyses

The total abundance of Lobster captured in each survey set was used to define the changes in distribution. No size or sex filtering of data was performed. Annual estimates of spatial distribution for Lobster from each survey were determined using survey Design Weight Area Occupied (DWAO):

$$DWAO = \sum_{i=1}^{n} a_i I \text{ where } I = \begin{cases} 1 \text{ if } y_i > 0 \\ 0 \text{ otherwise} \end{cases}$$

where n was the number of tows within the survey year, y_i is the number of Lobster caught in tow i, and a_i is the area of the stratum fished for tow i divided by the number of sets fished in that stratum (Smedbol et al., 2002). DWAO was expressed as km^2 for each survey.

It is important to note that, due to the differences in total area of each survey, the estimates of DWAO will only be comparable within a survey.

Results

The area occupied by American Lobster increased in recent years for all surveys, with current estimates of DWAO being among the highest on record (Figure 13). Specifically, DWAO increased for RV41, NSpr41 and NAut41 between the period of 2000 and 2015, with four-fold increases to over 8000 km^2 for the NEFSC surveys and over 4000 km^2 in the RV41 survey. The GB survey had a similar increase in recent years; however, the increase in area occupied in this survey began in the mid-1990s and was approximately a five-fold increase in area occupied. The wide distribution of the stock related to the increased abundance in recent years and suggested the Lobsters were found in more habitats than previously recorded. The increased distribution suggests an increase resilience of the stock as localized events should have less of an impact on the overall stock status.

Patchiness of Distribution from Survey Data

Justification

Patchiness was a spatial indicator that provides information on the overall distribution of the population. Patchiness was estimated through the use of the Gini Index, which has been used as an index of dispersion for catch rates (Myers and Cadigan 1995). Specifically, the Gini Index quantifies the areal difference between Lorenz curves of the sorted cumulative proportion of total area to the cumulative proportion of total catch relative to the identity function (0,0) → (1,1). If Lobsters were identically distributed across all strata, the Lorenz curve would be the identity function. Typically, densities are not uniform across space and the Lorenz curve has a characteristic convex relationship as some strata provide greater proportions of the cumulative density. The Gini Index quantifies the difference between the Lorenz curve and the identify function and represents a measure of inequality or patchiness (Gini 1909). High levels of the Gini Index can occur at any abundance, but are more likely to occur at low abundance, when small pockets of relative high abundance may persist. Regardless, the Gini Index provides a measure of patchiness from data provided.

Data Inclusion and Analyses

Total abundance of Lobster per tow across the entire time series for each survey were used to develop Lorenz curves and estimate the Gini Indices. Estimating the Gini Index per year and survey involved estimating the within strata (h) total abundance of Lobster (x_h) as:

$$x_h = \frac{\sum_{i=1}^{n} x_{hi}}{n} \times A_h$$

Where n represented the total number of sets within a stratum, x_{hi} was the observed abundance within each tow (corrected to towed distance) and A_h was the stratum area. The x_h were then ordered such that $x_1 \leq x_2 \leq x_3 \leq \ldots \leq x_N$., with N representing the total number of strata within the survey. The corresponding A_h were ordered based on the indices of the ordered x_h. The Lorenz curve was the line joining the cumulative sum of the ordered area ($p_a = \frac{\sum_{h=1}^{N} A_h}{\sum A_h}$) on the x-axis and the cumulative proportion of total abundance ($p_x = \frac{\sum_{h=1}^{N} x_h}{\sum x_h}$) on the y-axis (Myers and Cadigan 1995). The Gini Index was defined as twice the area between the identity function and the Lorenz curve, with higher values representing patchy distributions.

Results

In recent years (>2000), decreases in the patchiness of Lobster in each of the RV41, NSpr41 and NAut41 surveys were evident (Figure 14). There was no trend evident in the GB survey, which suggests that despite increases in area occupied and abundance, patches of increased densities remain. From the GB survey, these high density areas are evident along the outer strata (Figure 7). The decrease in patchiness in RV41 and NAut41 were much more pronounced than in the NSpr41. Due to the timing of the surveys in late winter / early spring for the GB and the NSpr41 surveys, this provides support to the supposition of Cooper and Uzmann (1980), who suggest that Lobsters are more concentrated during the winter and spring months compared to the summer and autumn seasons.

The overall decreased patchiness across the majority of the surveys follows the pattern observed in the DWAO with the increased area occupied. Combining the two pieces of information suggest that the Lobsters are found in a greater number of habitats and are also move evenly distributed across these habitats, which is a positive sign for stock health.

Size – Median and Maximum

Justification

Broad size distribution provides an indication of the stability of populations. In populations that are heavily fished, size distributions skew toward smaller individuals as the increased total mortality (natural + fishing) decreases the probability of reaching old ages and/or large body sizes. Size distributions skewed toward small (or large) individuals may occur for a variety of reasons, including the loss of large individuals or an increase in the abundance of small individuals. Using size frequency distributions from the surveys and at-sea samples collected during fishing operations, the changes in the median and maximum were documented. The maximum of the size distribution was used to track changes in the large animals to provide context to the estimates of the median. Data collected at-sea was separated by fishing area within LFA 41 but not by fishing season, as differences in the size distribution was predominantly affected by area.

Data Inclusion and Analyses

Population weighted median size as well as first and third quartiles were estimated from the RV survey abundance at length information combining all sexes and stages were estimated. Similar to other size and sex based indicators, the DFO Summer RV survey was reduced to 1999–2016 and the DFO Georges Bank survey was reduced to 2007–2016, as detailed Lobster information was not collected prior to these date ranges. The full time series of NEFSC surveys was included in analyses.

The length frequencies of the at-sea samples were available for trips from 1977–present. Earlier reports (e.g., Pezzack and Duggan 1983) provided size information prior to 1977, as there were no changes in size distributions during this early period the early data set was excluded. Results were only presented for areas where at-sea samples were obtained in most years.

The maximum length indicator was estimated as the 95th quantile of the population weighted (survey data) or raw (at-sea sampled) length frequency distributions. This metric was chosen over the absolute maximum length as it is less sensitive to sample sizes.

Size frequency distributions for both the survey and at-sea samples are provided in Appendix 1.

Results

Analyses of at-sea samples showed moderate decreases in the median size of Lobsters from the historic levels between 1970–1989 to the recent years (2010–2015) as Georges Bank went from 125 mm to 115 mm; Georges Basin went from 119 mm to 107 mm; Southeast Browns went from 125 mm to 116 mm; and Southwest Browns went from 109 mm to 102 mm (Figure 15). Similarly, the time series of maximum sizes decreased across the at-sea samples across the same time periods as Georges Bank went from 160 mm to 145 mm; Georges Basin went from 147 mm to 133 mm; Southeast Browns went from 154 mm to 140 mm; and Southwest Browns went from 138 mm to 125 mm (Figure 16).

Similarly, RV41 and NAut41 showed decreases in median and maximum sizes, although not to the same extent as was observed in the at-sea sampled data (Figure 17 and 18).

Decreases in the size distribution of populations are often observed with increasing abundance (Ebenman et al. 1995). The current decreasing size has implications for reproductive potential of the stock as large females produce exponentially more eggs and spawn more frequently (Koopman et al. 2015, Aiken and Waddy 1980). The median size of the fishery and survey captured Lobsters remain above the size at 50% maturity.

The impact of the LFA 41 fishery on changes in size distribution is not currently known; however, its impact is suspected to be minimal given the low fishing pressure in recent years when the changes to size distribution are most prevalent. Environmental and ecological drivers may also impact size distributions of animals through increased natural mortality (Myers and Cadigan 1993).

Predator Index

Justification

Predator release has been suggested to be one contributing factor to the recent increase in Lobster abundance as the decrease in Atlantic Cod and other groundfish populations occurred during similar time periods (e.g., Boudreau and Worm 2010). Other reports refute this hypothesis, suggesting that although the decrease in predation likely contributed to the increase in Lobster stocks it was not the primary contributor (Hansen 2009). Nonetheless, reporting on trends in groundfish biomass and abundance provides information on potential changes in predation pressure and ecological interactions.

Reported predators of Lobsters include Cunners, Sculpins, skates, Cod, Spiny Dogfish, Atlantic Sea Raven, Wolfish, Haddock, Hake, Plaice, Wolffish and Crabs (Lavalli and Lawton 1996, Palma et al. 1998, Nelson et al. 2003, Hanson and Lanteigne 2000, Boudreau and Worm 2010, Steneck et al. 2011, Cook and Bundy 2010). The food habits database collected across the Scotian Shelf has few records of American Lobster found in stomach contents of any species. Specifically, of the 160,500 stomachs covering 68 finfish species, only 36 instances of stomach contents with Lobster have been reported. It is important to consider, however, that the spatial extent of small Lobster, which are most susceptible to predation, is generally considered more inshore than the spatial coverage provided by the trawl survey.

Providing an index of abundance for the predators of Lobster from the RV survey represents a relative index of the predators in the area, although not specific to the small Lobster habitat, and yields info on the area as distributions of species expand with increasing abundance; therefore, the RV survey should reflect the overall pattern of abundance for the region.

Data Inclusion and Analyses

Abundance and biomass of predator species was estimated from the DFO RV survey using data on the western Scotian Shelf and Bay of Fundy (strata 474 to 484). The broader region was chosen as significant population connectivity and migration patterns within groundfish stocks may impact the LFA 41 Lobster population. The specific species included as Lobster predators in analyses were Atlantic Cod, Haddock, White Hake, Red Hake, American Plaice, Atlantic Wolffish, Barndoor Skate, Thorny Skake, Little Skate, Winter Skate, Longhorn Sculpin and Spiny Dogfish. Some of the other predator species (e.g., Cunner) do not regularly appear in offshore trawl surveys and were therefore not included in analyses.

Stratified abundance and biomass estimates were computed following traditional procedures outlined by Cochrane (1977) with confidence intervals estimated by bootstrapping with replacement (Smith 1997).

Results

The trends in combined predator species from the RV survey show a decreasing trend in biomass since 1970, but at a much lower rate of decrease than is typically shown for individual species (Figure 19, DFO 2016b). The change in predator biomass is not completely reflected in predator abundance as current levels are among the highest on record (Figure 19). Taken together, these results suggest a decrease in the mean body size of the Lobster predators captured in the trawl survey. The relative importance of predation in LFA 41 is unknown, but it is likely low due to the size structure of the offshore Lobster (Figure 4). Predation has, however, been identified as an important component of population regulation in other regions (Boudreau and Worm 2010) and, due to the likely high levels of connectivity between stocks, should be tracked.

Bottom Temperature

Justification

Lobster behavior and phenology are influenced by water temperatures (Campbell and Stasko 1986). Processes such as molting, growth, gonadal development, and egg development have all been shown to be impacted by seasonal and interannual temperature changes (Mills et al. 2013). The impact of broad-scale and long-lasting temperature changes has not been fully evaluated; however, it is suspected that Lobster production may be affected by variable and changing climates. Rather than reporting temperature outputs from models that have their own assumptions, the trends in bottom temperature obtained during the same surveys where Lobster are being sampled were presented here.

Data Inclusion and Analyses

Bottom temperature was measured during trawl sets for all surveys. As these surveys employ a stratified random design, bottom temperature trends will be estimated incorporating this design as outlined in Cochrane (1977) with confidence intervals estimated by bootstrapping with replacement (Smith 1997).

Results

Each of the surveys showed significant interannual variability in mean temperature over the time series of the surveys (Figure 20). In the last 4–6 years, all surveys have reported temperatures among the highest in the time series with less interannual variability. The overall median temperatures from the NEFSC fall survey and the GB winter surveys are higher than the RV survey and the NEFSC spring surveys (Figure 20). The implications of the consistently warm temperatures over the last 4–6 years are currently unknown, however, monitoring of population processes and temperature trends will continue. With warming temperatures, changes in molt timing, egg incubation and release and growth may all be affected, which could result in longer term population changes.

Species Distribution Modelling

Justification

Integrating the temporal trends in species occurrence data with environmental data allows for the identification of trends in the amount of suitable habitat. This type of analysis has been previously performed in stock assessments using several approaches, including generalized additive models (Choi and Zisserson 2012), kriging with external drift (Petitgas 2001), and species distribution modelling (Elith and Leathwick 2009). In the former two, space is typically a component of the model, and environmental gradients are examined over spatial variables. The latter approach relies on the environmental characteristics of the presence and absence data to describe the probability of species occurrence (or abundance); this method is useful to predict species distributions over space where sampling is imperfect.

There are several types of species distribution models that have been applied in ecology, including maximum entropy (maxent), which uses presence only data (Phillips et al. 2006), random forests (Breiman 2001) and Boosted Regression Trees (BRT, Elith et al. 2008), among others. BRT combines statistical decision tree analyses with Machine Learning (ML) to develop robust species distribution models. BRT splits the data into a series of training sets and iteratively develops regression trees to partition the data in order to minimize prediction errors. These trees are then iteratively added to the modelling process to further reduce prediction errors; this process is continued until the learning rate or shrinkage factor does not reduce further with additional trees (Elith et al. 2008).

Methods

The full spatial extents (i.e., not reduced to specific strata) of all four surveys were used to develop BRTs. From each survey set, the presence or absence of Lobster was identified and the predictor variables of continuous time (decimal year), depth, temperature, slope and curvature were used. The presence-absence data was treated as a Bernoulli process, with depth natural log transformed prior to inclusion in the model. The learning rate was set to 0.015 and the bag fraction (or the proportion of information used to inform the selection of variables) was set to 0.5. Results were robust to the setting of these two parameters. The BRT was fitted using the gbm.step function in the dismo package (Hijmans et al. 2016) in R (v. 3.3.1).

The resulting best fit trees were used to develop species distribution maps based on the surfaces of bathymetry, slope and curvature (Figure 21), as well as the annual temperature interpolations (Choi and Zisserson 2012; Figure 22).

The indicator resulting from the species distribution modelling was the proportion of habitat within LFA 41 with a probability ≥0.35 of containing Lobster.

Results

Each predictor variable influenced the output of the BRT analysis (Figure 23). The final BRT set explained 38% of the total deviance. Time, in decimal years, and temperature were the most important factors influencing the regression trees and accounted for 36% and 27% of the total contribution of the predictors. Depth, slope, and curvature also accounted for portions of the total model contribution, however to a much smaller extent.

Time was included in the model as abundance has increased throughout the time series, which was expected to influence the species distribution and habitat usage. Rather than implicitly incorporating the total abundance as a predictor variable, decimal year was used to include both the seasonality of habitat usage (see above) as well as the changes in abundance.

Temperature was the second most influential variable defining Lobster distribution models. Model fits show that there was a lower probability of occurrence at temperatures below 5°C or above 15°C (Figure 24).

Probability of occurrence with depth relationship was a more complicated pattern, as can be seen with the fitted values. Lobsters will seek a broader range of depths depending on seasonality, which has typically been associated with following preferred temperature ranges (Campbell and Stasko 1986).

Although temperature was the only temporally variable factor included in the model, incorporating time, in fractional years, allowed the relationship with other factors to vary both seasonally and interannually. This was an influential component in the BRT model and, with the abundance changes shown within this stock, it was important to include as the changes in the abundance likely resulted in changes in the distribution in relation to environmental variables through density dependent processes (McCall 1990).

The time series of predicted species distributions from the BRTs showed the change in the amount of suitable habitat over time (Figure 25). Reducing these maps to an index of the proportion of suitable habitat (≥0.35) within LFA 41 shows the increase in the amount of Lobster habitat in recent years with >80% of LFA 41 being classified as suitable habitat in 2016, the highest value on record (Figure 26).

Atlantic Multidecadal Oscillation

Justification

The Atlantic Multidecadal Oscillation (AMO) is alternating warm and cold periods of the North Atlantic, which has been recently recognized to have occurred over the last 150 years (Enfield et al. 2001). Over the past 20 years, a warm period of the AMO has led to conspicuous changes in abundance and distribution both plankton and fish populations on both sides of the North Atlantic. Similar patterns were also reported in 1925–1965 using historic observations (Drinkwater et al. 2014). These long-term fluctuations cannot be explained by the North Atlantic Oscillation (NAO), which fluctuates on shorter time scales. The physical basis for the AMO and its impact on ecosystem responses are poorly understood; however, recent reviews have shown relationships between the AMO and numerous ecological responses across many taxa, predominantly within mid-latitudes of the Atlantic (approximately 35°N–60°N; Nye et al. 2013). However, while it was recognized that the simple correlation between climatic processes and biological time series are interesting, the importance of determining causal linkages with ecosystem processes should be emphasized.

Although the influence of the AMO on Lobster production, outside of the presumed changes in temperature and oceanographic circulation patterns, are unknown, it has been suggested to be an important correlate with many regional processes and, as such, was included here.

Data Inclusion and Analyses

The AMO time series data was obtained from the National Oceanographic and Atmospheric Administration.

Results

The cyclicity of the AMO over the past 150 years can be seen as the 30 – 50 shifts in phase from positive to negative anomalies (Figure 27). Currently AMO resides in a positive phase, which has been present since 1999–2001. The initial increase in Lobster abundance from survey trends was apparent during the same time period. The time lag for the impact of a positive AMO to show up as direct increases in Lobster production would be approximately

10 to 13 years (2010–2014) given published growth rates and the size range of the Lobsters characteristic of LFA 41 (Bergeron 2011). Coincidently, this time period matches some of the highest abundances of Lobster from the trawl survey. Further investigation of the impact of the AMO on Lobster production is warranted; however, it is useful to maintain this indicator as a potential correlate of ecosystem structuring.

Commercial Catch Rates

Justification

Despite the caveats of the use of catch rates as a proxy for abundance mentioned in the previous sections on the history of the stock assessment, there remains value in examining the trends in fishery performance relative to the other stock productivity indices.

Data Inclusion and Analyses

Commercial catch rate information was obtained from the logbook data and was described in the section above on data sources.

Results

Catch rates of Lobster during the early 1980s to mid-1990s were interannually variable (Figure 28). In the late 1990s, catch rates decreased to their lowest levels on record, but they have since rebounded and, as of 2015, were the highest on record, with 2016 remaining at near record highs. Although there have been changes in fishing patterns and technological advances to improve efficiency, the recent increase in catch rates mimics the trends seen in survey abundance and biomass.

Fishery Patchiness

Justification

Similar to the commercial catch rates, fishery patchiness is a primarily a measure of fisheries performance, as variability in knowledge of the distribution of the Lobster may impact catch rates similarly to a random survey. With increased knowledge of Lobster distribution, the index of Lobster patchiness from fisheries data would be reduced irrespective of an actual change in the population. Low levels of patchiness maybe the result of limited (or complete) knowledge of the Lobster distribution across the fleet resulting in uniformly low (or high) levels. Similar to the survey patchiness index, Lorenz curves and the Gini Index were used to represent the patchiness of the Lobster distribution from the fishery.

Data Inclusion and Analyses

The annual catch and effort data was discretized to estimate a catch rate within each grid. These catch rates were then ranked and the plot of the cumulative density versus cumulative area or Lorenz curve was produced. If Lobsters were identically distributed across all grids, the Lorenz curve would be the identity function $(0,0) \rightarrow (1,1)$. Typically, densities are not uniform across space and the Lorenz curve has a characteristic convex relationship, with some grids providing a greater proportion of the cumulative density. The Gini Index is defined as twice the area between the identity function and the Lorenz curve, with higher values representing higher densities of Lobster in small areas.

Results

The fishery was characterized by low patchiness during the early 1980s to early 1990s when catch rates were lower and interannually variable, suggesting that, catch rates were similar in all areas of LFA 41 (Figure 29) within a year. As catch rates were decreasing, leading up to 2000, the patchiness was increasing, suggesting there were either localized patches of high densities of Lobster or some vessel operators were obtaining higher catch rates than others. Following the low catch rates, the subsequent increase also yielded a decrease in patchiness up to 2008 when patchiness appears to have declined to a low level, which has been maintained despite the increases in catch rate (Figure 29). Median fishery patchiness has been stable or moderately decreasing at low levels for the past 7 years.

Combining Indicators

Justification

In order to combine the patterns and trends estimated from the various indicators in a display that shows the changes over time, a modified version of the method developed by Brodziak and Link (2002) was implemented. Using this approach boundaries or reference points were not defined, as would be typical of a traffic light approach (Caddy 2002). The contextual indicators described above represent not only the biological processes that influence production but ecosystem and fishery performance indicators.

Methods

The indicators described throughout this section were made directly comparable through statistical standardization (z-scores) after log transformations to normalize the appropriate indicators (e.g., abundance or biomass) were applied. Data points consisting of fewer than 20 individuals measured within the measurement period were considered missing for this analysis. As this data set was characterized by a number of missing values, classical multivariate analyses could not be applied as they typically require the deletion of all such cases. As such, the Pearson correlation coefficients were calculated for all possible pair-wise combinations. A variant of Principal Components Analysis (PCA) involving an eigen analysis was performed on the resultant correlation matrices of the indicators. It was recognized that the missing values can result in an ill-determined matrix; it was assumed that the relationships presented here are a first-order approximation of the ‘true’ correlational structure (Choi et al. 2005).

After eigen analysis, the component scores were ordered by the first eigenvector and color coded within each indicator. This allowed for the visualization of the coherent trends in the indicators over time.

Overall Indicator Results and Patterns

Results from the suite of indicators had the first axis of the principle component scores explaining approximately 32% of the total variance, whereas the second axis explained 9% (Figure 30). Although the amount of variance explained was low by comparison to typical multivariate tests, the broad range of types of indicators used and the temporal coherence of similar indicator types provides justification for this analysis. The component scores that define the differences in the first axis were predominated by the decreasing body size metrics and increasing abundance trends and distribution (Figure 31).

Decreasing body size was observed in at-sea sampling of fishing activities and was not only a decrease in median size, but also a reduction in the maximum carapace length. The body sizes recorded during surveys showed similar decreases, although not to the same extent. The reduction in Gini Index, representing patchiness, was also present in the decreasing trends of indicators; however, a decreasing Gini Index indicates a more evenly distributed stock, which is therefore considered a positive sign for stock status in LFA 41.

There was coherence of the increasing abundance, biomass and distribution of Lobsters with the increasing temperature and AMO such that production and environmental characteristics have been changing at similar time periods. Higher temperatures within a year likely has little impact on an increased trawl survey abundance in the same year other than perhaps to alter distributions as individuals may seek specific thermal regimes (Jury and Watson 2013). Longer term changes in the ecosystem structure and increases in habitat suitability have been likely contributors to the increase in Lobster productivity.

The current LFA 41 stock and ecosystem was characterized by higher survey abundances, warmer bottom temperatures, and the smaller median body size with a lower maximum length and decreased predator biomass compared to historic levels.

STOCK ASSESSMENT AND DEVELOPMENT OF REFERENCE POINTS

The Federal Government of Canada has committed to using the Precautionary Approach (PA) for managing fish stocks as part of the Sustainable Fisheries Framework. As a result, DFO developed a policy document entitled "A fishery decision-making framework incorporating the Precautionary Approach" that explains how the precautionary approach will be applied in practice (DFO 2009). One of the key components of the framework is the definition of reference points and stock status zones. These zones are defined by a Limit Reference Point (LRP), which delineates the critical (red) and cautious (yellow) stock status zones, and an Upper Stock Reference (USR), which is the boundary between the cautious and healthy (green) zones (Figure 32). Within each zone, a Removal Reference (RR) establishes the maximum removal rate.

The LRP defines the boundary below which serious harm is occurring to the stock, and is defined on the basis of biological criteria through Science Review Process (DFO 2009). The USR is the upper stock limit where removals should be progressively reduced in order to reduce the risk of reaching the LRP. The USR is developed by fisheries managers in consultation with the fishery and other interests in consultation with advice and input from Science (DFO 2009). The policy guidance for setting a removal reference suggests using a fishing mortality (*F*) not to exceed the *F* at maximum sustainable yield (F_{MSY}; DFO 2009).

Part of the context for the PA identifies that the management of fisheries should be cautious when scientific knowledge is uncertain, unreliable or inadequate, and, despite uncertainties, reference points should still be developed based on best available information to avoid serious harm to the resource.

Recommendations for USR and LRP were presented during the 2017 stock assessment framework using an indicator approach, as quantitative approaches did not yield robust parameter estimates (Cook et al. 2017). The primary indicators to define stock status were the biomass indices from four fisheries independent trawl surveys. Accompanying each survey index, an Upper Stock Indicator (USI) and a Limit Reference Indicator (LRI) were identified with the former accounting for changes in productivity regime. Upper stock Indicators was defined as 0.4 times the median biomass of the high productivity period. The LRI was defined as the median of the five lowest non-zero biomass in each time series.

The overall stock status will be determined from the combination of all survey indices relative to their respective LRIs and USIs. The definition to change from a healthy stock status to a cautious stock status would require 3 of 4 survey biomasses to fall below the respective USIs. Similarly, to enter the critical zone would require 3 of 4 survey biomasses to fall below respective LRIs.

Options for Removal References were explored during the framework, using relative fishing mortality (*relF*) (Survey Biomass / landings; Cook et al. 2017). However, due to the constant TAC since the mid-1980s coupled with the large increase in biomass, the consensus from the meeting was that there was limited information to define a Removal Reference at present and, as such, no removal reference was accepted for LFA 41.

METHODS

Each of the four survey time series in LFA 41 cover only a portion of the total stock area. Therefore, biomass reference points were estimated using data from each survey and the annual landings within each surveyed area (C_{jt}). In years that fishing location was not recorded on all trips, C_{jt} was estimated by prorating the proportion of landings with positional information found within the survey area (C'_{jt}) to the total landings with positional information (C'_t) prorated to the total landings (with or without positional information; C_t) as:

$$C_{jt} = \frac{C'_{jt}}{C'_t} \times C_t$$

The landings time series was reduced to 1981-present, as there was limited positional information for the landings data prior to 1981.

In order to use the entire time series of survey data from DFO surveys, the estimated proportion of commercial biomass to total biomass for years where data was available (0.876) was applied to all other years. Commercial biomass from the NEFSC surveys was estimated for the entire time series using available information.

Phase plots were produced show the biomass and *relF* trends in relation to the reference points for each survey index. Rather than relying on the raw survey trends, which are inherently variable, the three year running medians of biomass were used for both the biomass index as well as the denominator in the *relF* estimations. The *relF* was undefined for running median biomasses of 0, to overcome this issue; a small positive value was added to the survey biomass. This procedure was only done for graphical purposes and does not influence the outcome of reference point identification.

RESULTS AND DISCUSSION

Stock status for LFA 41 Lobster is currently considered in the Healthy Zone and has been in the Healthy Zone since 2002, as three of four surveys indices have been above their respective USIs (Figure 33). It is important to note that the stock status of LFA 41 has never been considered in the Critical Zone, using the stock status definitions described above (Figures 33 to 35).

The current commercial biomasses are well above the USIs for each index, and the relative fishing mortalities are at or near their lowest on record (Figure 34). Even at the lowest survey biomasses in the mid-1980s, TAC and landings were 720 t annually, which did not impeded the stock’s ability to be maintained nor did it cease the population growth realized in the past 15 years.

The coherence of biomass trends across surveys provides support to their value as stock status indicators as the surveys were performed in different seasons and under the direction of two different national agencies. Although the survey trends are showing the same general patterns, it is valuable to define reference indicators and maintain the separate analyses for each survey as indicators of stock status.

REPRODUCTIVE POTENTIAL BOUNDARIES

Offshore LFA 41 stock has always been recognized to contain a high proportion of large and berried females relative to other Lobster fishing areas (Pezzack et al. 2015). Maintaining the reproductive potential of this stock is important not only to LFA 41 but potentially Lobster production in other areas. Although, commercial biomass was the primary indicator of stock status as it relates to the fishery and removals, having a second primary indicator designed to detect changes in reproductive potential was desired. Reproductive potential, as estimated here, will provide an integrated index combining female abundance at size, fecundity at size and size at maturity, thereby producing an estimate of total eggs produced within the stock area.

Although reproductive potential will be treated as a primary indicator, the stock thresholds will not be defined as the traditional USR and LRP, as this implies changes to harvest strategies are required when stock status changes to allow stock rebuilding. As there are regulatory mechanisms protecting berried and v-notched females, this indicator provides information on changes in the potential egg production in order for proactive measures to be discussed. The thresholds will instead be termed upper (UB) and lower (LB) boundaries.

The UB was defined as 40% of the median of reproductive potential estimated during the high productivity period (approximately 2000–2015), whereas LB was defined as the median of the five lowest non-zero estimates of reproductive potential (Cook et al. 2017).

METHODS

For each survey, reproductive potential was defined as the potential number of eggs produced per year. This indicator required the estimation of stratified mean numbers of females at length. As such, time series of reproductive potential from could only be estimated since 1999 in the RV survey (RV41) and 2007 in the DFO Georges Bank (GB) surveys as detailed biological information was only systematically collected after those dates. The full time series of NEFSC surveys was used in the estimation of reproductive potential.

Reproductive potential, expressed as an index of egg production, for each survey and year (*t*) was estimated on a length basis (*L*) using the annual stratified mean numbers of female at length N_{Lt} incorporating fecundity and maturity at length relationships as:

$$R_t = \sum_{L=1}^{L_{max}} N_{Lt} \times M_L \times F_L$$

Where,

$$F_L = \gamma L^{\omega}$$

$$M_L = \frac{1}{1 + e^{-(\alpha + \beta \times L)}}$$

The parameters γ and ω for fecundity at length (F_L) were 0.003135 and 3.354 respectively obtained from Campbell and Robinson (1983). The maturity at length (M_L) parameters α and β were set to -22.55 and 0.2455, respectively (unpublished data Gaudette and Cook 2016). Sized-based spawning frequencies were also included in the analysis, such that females ≥120mm spawned in 2 of 3 years whereas mature females <120 mm spawned every second year (Aiken and Waddy 1980).

Stratified mean abundance per tow was calculated following traditional procedures outlined by Cochrane (1977). Confidence bounds were not presented for this indicator as the errors associated with fecundity at length and maturity at length relationships were not available and could, therefore, not be propagated along with the errors in abundance.

RESULTS AND DISCUSSION

Reproductive potential remains in a state well above the long-term average and all survey indices were above their respective UBs (where defined) with estimates of reproductive potential being at or near the highest values on record (Figure 36). One exception was the NSpr41, where reproductive potential has decreased from an extreme high in 2014, but the current estimate remains within the top five estimates recorded.

The increase in overall abundance was the main driver of the increase in reproductive output. The decrease in median size of the Lobsters observed in the at-sea samples and survey likely decreased the rate of increase of reproductive output; however, it was not a large enough decline to negate the effect of the increase in abundance.

Similar to the commercial biomass indicator, survey trends are showing the same general patterns in reproductive potential; however, it remains valuable to define reference points for each survey (where appropriate) and monitor the time series trends as indicators of stock status. This redundancy improved the robustness of the analysis as changes in reproductive potential from a single survey may not reflect overall stock productivity but may be due to other unobserved factors. These reproductive potential zones are not meant to provide advice on removal references but provide the detailed information on the state of the spawning stock and report on changes.

QUALITATIVE RISK ANALYSIS OF HARVEST OPTIONS

The TAC has been set to 720 t since the mid-1980s despite recent large increases in survey biomass indices. An index of exploitation, *relF*, has by consequence of the increase in biomass decreased to low levels in recent years. Given the resilience of the LFA 41 stock to landings at 720 t, there may be considerable scope for harvest options. During the framework assessment Cook et al. (2017), proposed removal references were not adopted due to the uncertainty associated with the productivity regime shift in LFA 41 and the relevance of historic *relF* on the current stock. Specifically, during the 1980s, the LFA 41 stock was maintained at *relF* levels more than 10 fold higher than the current estimates (Figure 34), and biomass were able to grow to current levels. The stock at lower productivity was considered to have high resilience. Under the new higher productivity regime, the resilience to increased fishing pressure is not known. Fishing at the current TAC poses minimal risk of the stock falling into the Cautious Zone in the short term. Increases in TAC should be done in a step-wise fashion to annually assess the impacts of higher removals on stock.

CONCLUSIONS

Primary indicators of stock status for the LFA 41 Lobster stock indicate that the stock is currently in the Healthy Zone, with all four survey indices well above their respective USIs. Additionally, the second primary indicator, reproductive potential, was well above the upper bounds for the surveys where bounds were defined. The long term low TAC of 720 t poses minimal risk to the stock status falling into the Cautious Zone, as the stock has proven resilient to this level of removals across a broad range of biomasses. There may be scope for flexibility in setting a TAC given the current high biomasses; however, increases should be done in a stepwise fashion to assess the impacts of higher removals.

The suite of contextual indicators suggested coherent trends over time with both the median size and maximum size of Lobsters from at-sea observations decreasing over time. Conversely, the abundance, biomass and distribution of Lobsters in all four surveys within LFA 41 have been increasing in recent years and are currently at levels among the highest on record.

Accompanying the increase in abundance, bottom temperature has been approaching the highest levels recorded in recent years with large scale environmental forcing factors (AMO) being in a positive state.

Overall, the LFA 41 stock status is considered in the Healthy Zone from all primary and contextual indicators.

STOCK ASSESSMENT SCHEDULE AND TRIGGERS

Stock assessment updates, following the document provided, will be conducted on an annual basis in the autumn of 2018, 2019, 2020, and 2021. The next stock assessment framework will be tentatively scheduled for the 2021/2022 fiscal year.

An earlier stock assessment or framework would be triggered if the stock status approached the Cautious Zone for 2 of the 4 survey indices, or if any unforeseen change in stock characteristics became a cause for concern.

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TABLES

Table 1. Lobster Fishing Area (LFA) 41 Lobster landings in tons (t), the Total Allowable Catch (TAC) and the number of active vessels from 1981 to 2016 by fishing season. Fishing season is defined as the period for catching the TAC, which has varied over time (January 1st to December 31st for 1981–1985; August 1, 1985, to October 15th, 1986; October 16th to October 15th for 1986-87 to 2003-04; October 16, 2004, to December 31, 2005; Janyar 1st to December 31st for 2006 to present). The TAC from 1976 to 1985 of 408 t is applied to NAFO Division 4X only. The 1985–present TAC of 720 t is applied to the entire fishery.

Season	Total Landings	TAC	Vessels
1981	572	408 (4X)	8
1982	469	408 (4X)	8
1983	478	408 (4X)	8
1984	440	408 (4X)	7
1985	467	408 (4X)	7
1985–86	851	870[1]	8
1986–87	718	720	8
1987–88	578	720	7
1988–89	403	720	6
1989–90	532	720	6
1990–91	714	720	5
1991–92	609	720	5
1992–93	544	720	5
1993–94	701	720	7
1994–95	721	720	6
1995–96	725	720	7
1996–97	673	720	7
1997–98	620	720	8
1998–99	590	720	8
1999–00	731	720	9
2000–01	718	720	8
2001–02	726	720	9
2002–03	718	720	8
2003–04	717	720	8
2004–05	1,010	1008[2]	7
2006	780	720	6
2007	691	720	4
2008	692	720	4
2009	541	720	2
2010	869	720	2
2011	752	720	1
2012	654	720	1
2013	746	720	1
2014	723	720	1
2015	680	720	1
2016	789	720	1

[1] Pezzack and Duggan 1987.

[2] Includes the additional months switching from and October 16th to October 15th season to a calendar year.

Table 2. Annual observer trips with recorded bycatch and percent of total trips observed within LFA 41.

Year	Number of Trips	% Coverage by Trips
2002	5	2.4
2003	7	3.9
2004	3	1.8
2005	9	4.8
2006	8	5.6
2007	5	4.1
2008	4	3.3
2009	4	5.1
2010	3	3.9
2011	3	5.9
2012	5	16
2013	6	17
2014	6	17
2015	4	12
2016	6	17

Table 3. Annual observed bycatch composition for LFA 41 in kilograms (kg).

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
American Lobster	22,426	10,510	5,114	4,032	9,302	8,405	5,978	11,317	14,824	5,757	20,172
Jonah Crab	6,918	3,063	336	5,055	3,399	1,190	816	3,220	1,070	124	246
Cusk	1,211	1,517	1,253	653	715	315	1,030	1,473	868	526	67
Cod (Atlantic)	96	758	338	407	490	73	219	974	462	109	505
White Hake	72	102	15	81	388	80	509	829	837	347	53
Atlantic Rock Crab	0	0	1,509	0	0	0	10	0	1	41	0
Squirrel or Red Hake	56	133	0	0	31	0	17	408	136	36	0
Sea Raven	5	2	0	7	9	4	56	251	31	39	2
Haddock	2	31	19	96	165	4	13	28	6	12	19
Redfish Unseparated	44	33	6	6	10	5	14	55	26	12	5
Hake (NS)	80	0	0	0	0	0	0	0	0	108	0
Brachiuran Crabs	0	0	19	0	0	0	0	140	0	0	0
Rosefish (Black Belly)	9	37	0	0	18	0	1	25	3	40	0
Groundfish (NS)	0	0	0	0	0	0	0	0	0	78	0
Pollock	0	0	18	0	2	0	3	25	0	5	0
Asteroidea S.C.	4	7	26	2	0	2	0	0	0	1	0
Striped Atlantic Wolffish	5	0	0	0	4	0	0	26	1	3	0
Spiny Dogfish	0	11	0	0	0	0	0	12	1	0	0
Sea Scallop	0	0	0	0	0	0	0	18	0	0	1
Finfishes (NS)	12	0	0	0	0	0	0	0	0	0	0
Off-Shore Hake	0	0	0	0	0	11	0	0	0	0	0
Sea Robins	0	0	0	0	9	0	0	0	0	0	0
American Eel	0	0	0	0	0	0	0	8	0	0	0
Whelks	0	0	0	0	0	0	0	8	0	0	0
Monkfish, Goosefish, Angler	2	0	0	0	0	0	0	2	0	2	2
Sculpins	0	6	0	0	0	0	0	0	0	0	0
Longhorn Sculpin	1	0	0	3	2	0	2	0	0	1	2
Jellyfishes	0	3	0	0	0	0	0	0	0	0	0
Winter Skate	0	0	0	0	0	0	0	1	0	1	0
American Plaice	0	0	0	0	0	0	0	1	0	0	0
Mussels (NS)	0	0	0	1	0	0	0	0	0	0	0
Red Deepsea Crab	1	0	0	0	0	0	0	0	0	0	0
Smooth Skate	0	0	0	0	0	0	0	0	1	0	0
Spiny Crab	0	0	0	0	0	0	1	0	0	0	0
Mollusca P.	0	0	0	0	0	0	0	0	0	0	0
Northern Wolffish	0	0	0	0	0	0	0	0	0	0	3
Sea Lamprey	0	0	0	0	0	0	0	0	0	0	0
Seaweed, (Algae), Kelp	0	0	0	0	0	0	0	0	0	0	2

Table 4. Annual total estimated catch composition for LFA 41 in kilograms (kg).

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
American Lobster	335,821	259,472	141,767	89,493	269,471	208,465	76,350	113,007	162,839	78,923	232,903
Jonah Crab	103,594	75,620	9,314	112,199	98,466	29,515	10,422	32,153	11,754	1,700	2,840
Cusk	18,134	37,452	34,735	14,494	20,713	7,813	13,155	14,709	9,535	7,211	774
Cod (Atlantic)	1,438	18,714	9,370	9,034	14,195	1,811	2,797	9,726	5,075	1,494	5,831
White Hake	1,078	2,518	416	1,798	11,240	1,984	6,501	8,278	9,194	4,757	612
Atlantic Rock Crab	0	0	41,831	0	0	0	128	0	11	562	0
Squirrel or Red Hake	839	3,284	0	0	898	0	217	4,074	1,494	494	0
Sea Raven	75	49	0	155	261	99	715	2,506	341	535	23
Haddock	30	765	527	2,131	4,780	99	166	280	66	165	219
Redfish Unseparated	659	815	166	133	290	124	179	549	286	165	58
Hake (NS)	1,198	0	0	0	0	0	0	0	0	1,481	0
Brachiuran Crabs	0	0	527	0	0	0	0	1,398	0	0	0
Rosefish (Black Belly)	135	913	0	0	521	0	13	250	33	548	0
Groundfish (NS)	0	0	0	0	0	0	0	0	0	1,069	0
Pollock	0	0	499	0	58	0	38	250	0	69	0
Asteroidea S.C.	60	173	721	44	0	50	0	0	0	14	0
Striped Atlantic Wolffish	75	0	0	0	116	0	0	260	11	41	0
Spiny Dogfish	0	272	0	0	0	0	0	120	11	0	0
Sea Scallop	0	0	0	0	0	0	0	180	0	0	12
Finfishes (NS)	180	0	0	0	0	0	0	0	0	0	0
Off-Shore Hake	0	0	0	0	0	273	0	0	0	0	0
Sea Robins	0	0	0	0	261	0	0	0	0	0	0
American Eel	0	0	0	0	0	0	0	80	0	0	0
Whelks	0	0	0	0	0	0	0	80	0	0	0
Monkfish	30	0	0	0	0	0	0	20	0	27	23
Sculpins	0	148	0	0	0	0	0	0	0	0	0
Longhorn Sculpin	15	0	0	67	58	0	26	0	0	14	23
Jellyfishes	0	74	0	0	0	0	0	0	0	0	0
Winter Skate	0	0	0	0	0	0	0	10	0	14	0
American Plaice	0	0	0	0	0	0	0	10	0	0	0
Mussels (NS)	0	0	0	22	0	0	0	0	0	0	0
Red Deepsea Crab	15	0	0	0	0	0	0	0	0	0	0
Smooth Skate	0	0	0	0	0	0	0	0	11	0	0
Spiny Crab	0	0	0	0	0	0	13	0	0	0	0
Mollusca P.	0	0	0	0	0	0	0	0	0	0	0
Northern Wolffish	0	0	0	0	0	0	0	0	0	0	35
Sea Lamprey	0	0	0	0	0	0	0	0	0	0	0
Seaweed, (Algae), Kelp	0	0	0	0	0	0	0	0	0	0	23

Table 5. Total annual observed bycatch and total estimated bycatch for LFA 41 in metric tonnes (t) excluding Lobster catch.

Year	Observed Bycatch (t)	Landings Estimated Bycatch (t)
2006	8.5	127.6
2007	5.7	140.8
2008	3.5	98.1
2009	6.3	140.1
2010	5.2	151.9
2011	1.7	41.8
2012	2.7	34.4
2013	7.5	75.1
2014	3.4	37.8
2015	1.5	20.4
2016	0.9	10.9

Table 6. Percentage of Lobster discards from catch summary vs. Lobster measurements.

	Observer Catch Summary (kgs)			Observer Measured Catch (kgs)		
YEAR	Discarded Catch	Total Catch	% Discard	Discarded Catch	Total Catch	% Discard
2006	22,426	74,531	30%	8,182	20,846	39%
2007	10,510	38,490	27%	3,800	9,713	39%
2008	5,114	30,087	17%	2,050	5,905	35%
2009	4,032	28,389	14%	1,823	5,138	35%
2010	9,302	39,313	24%	2,805	7,114	39%
2011	8,405	38,738	22%	1,862	7,568	25%
2012	5,978	57,173	10%	3,301	12,128	27%
2013	11,317	86,058	13%	6,071	20,040	30%
2014	14,824	80,645	18%	4,125	13,783	30%
2015	5,757	55,326	10%	1,938	8,801	22%
2016	20,172	88,485	23%	3,733	14,622	26%

Table 7. Proportion of returned Lobster catch composition from observed samples by year. Note: Individual Lobsters may be more than one category (i.e. berried and jumbo and v-notched), therefore the proportions do not necessarily sum to 1 in any given year.

Year	Undersize	Berried	Jumbo	V-Notch	Soft Shell	Cull
2006	0.01	0.26	0.55	0.05	0.05	0.28
2007	0.01	0.35	0.50	0.08	0.01	0.28
2008	0.00	0.27	0.63	0.08	0.36	0.30
2009	0.04	0.24	0.41	0.17	0.07	0.23
2010	0.01	0.31	0.41	0.14	0.08	0.26
2011	0.02	0.42	0.27	0.15	0.01	0.28
2012	0.01	0.27	0.35	0.14	0.10	0.34
2013	0.00	0.41	0.33	0.16	0.04	0.25
2014	0.00	0.46	0.30	0.08	0.05	0.28
2015	0.00	0.30	0.35	0.20	0.02	0.26
2016	0.00	0.23	0.19	0.05	0.28	0.43

FIGURES

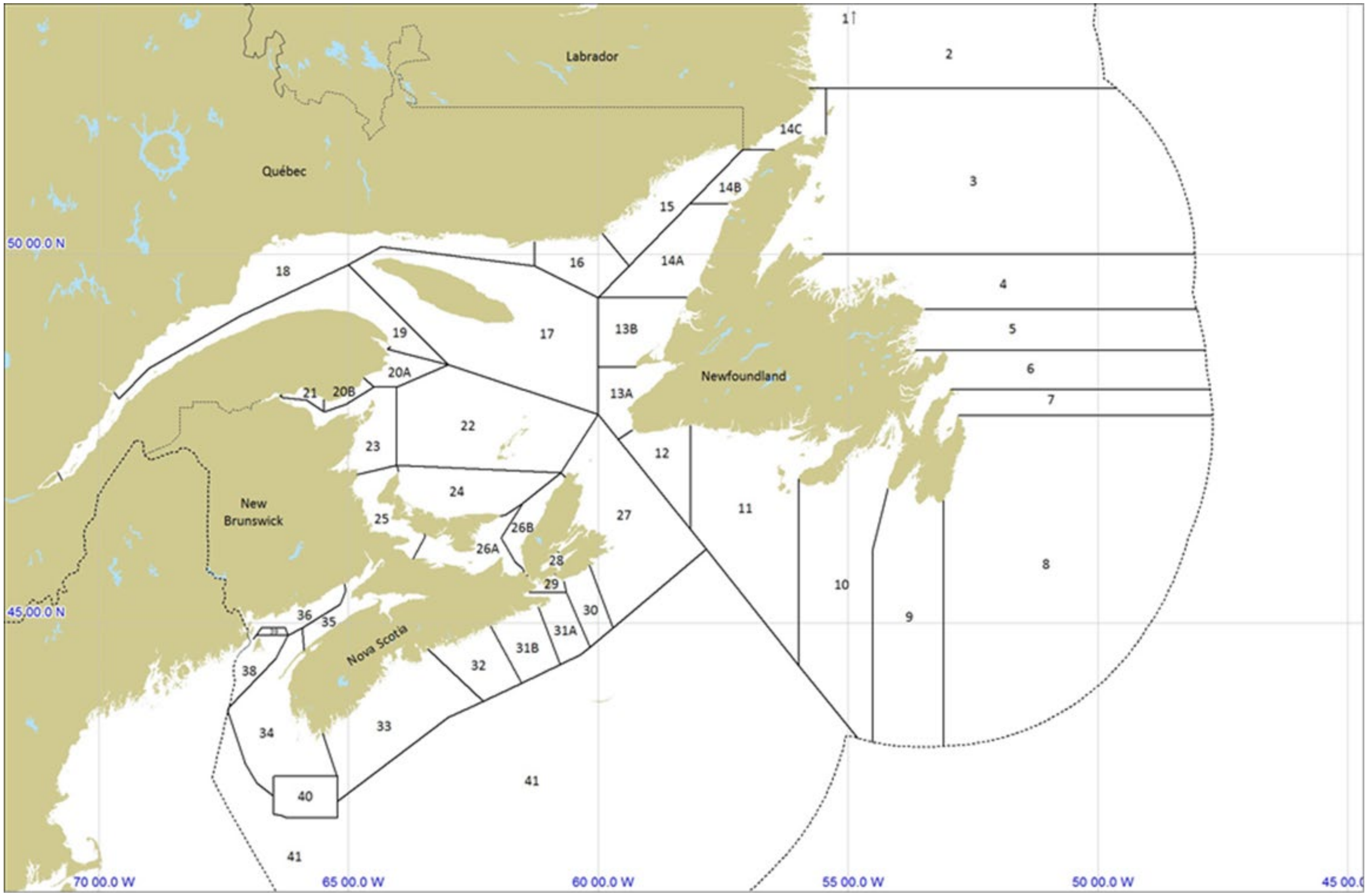

Figure 1. Map of the Lobster Fishing Areas in Atlantic Canada using the boundaries identified in the Atlantic fishery regulations.

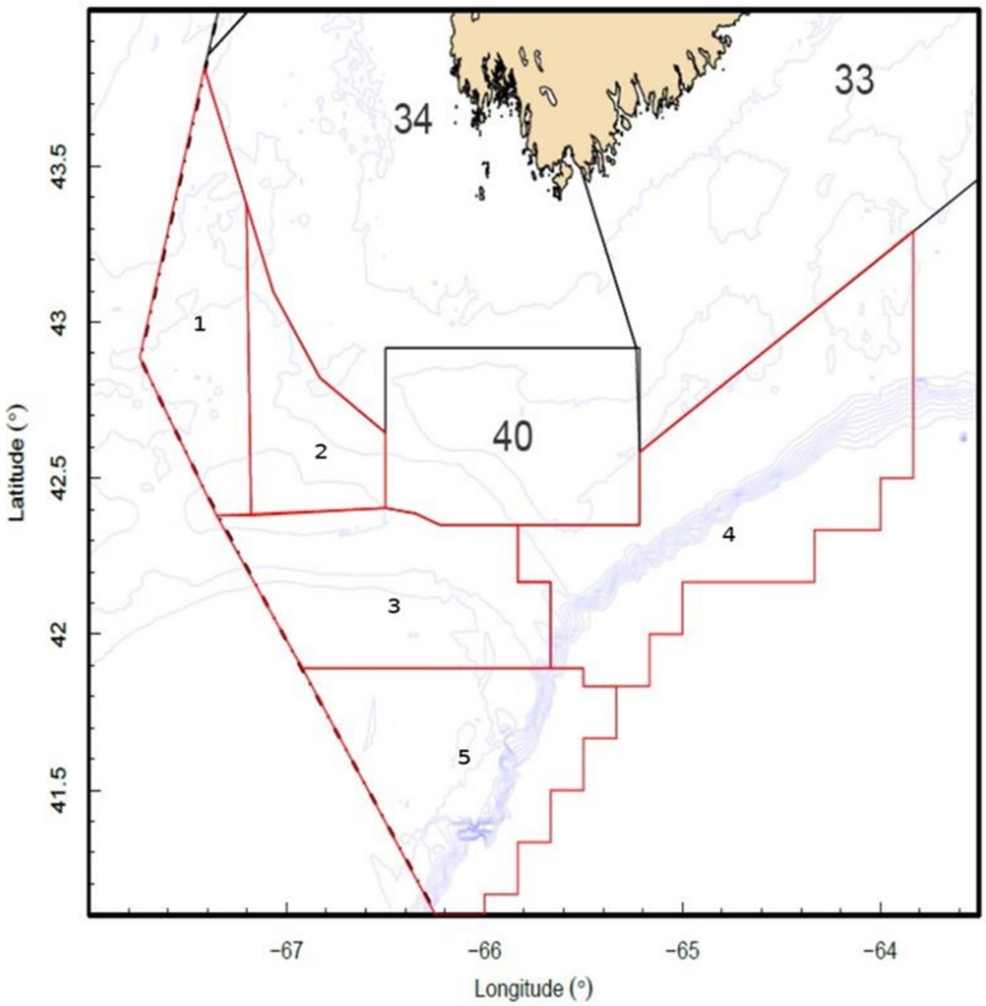

Figure 2. Map showing the offshore zones used in assessments. Zone 1 represents Crowell Basin, Zone 2 SW Browns, Zone 3 Georges Basin, Zone 4 SE Browns and Zone 5 Georges Bank.

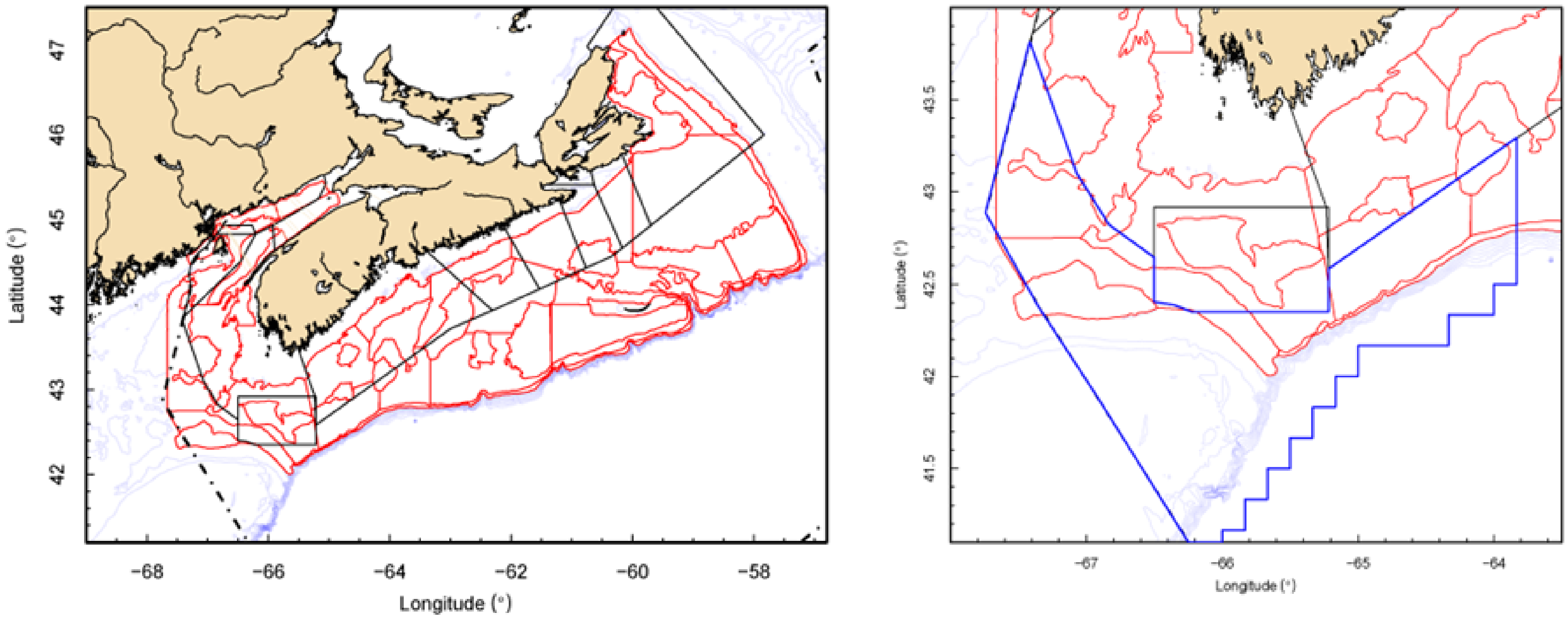

Figure 3. Map of Lobster Fishing Areas (LFAs) in black overlain with the full DFO Summer RV survey strata shown in red (left). Close-up of the fished areas of Lobster Fishing Area 41 (blue line) with the DFO Summer RV survey strata included in survey trends outlined in red (right).

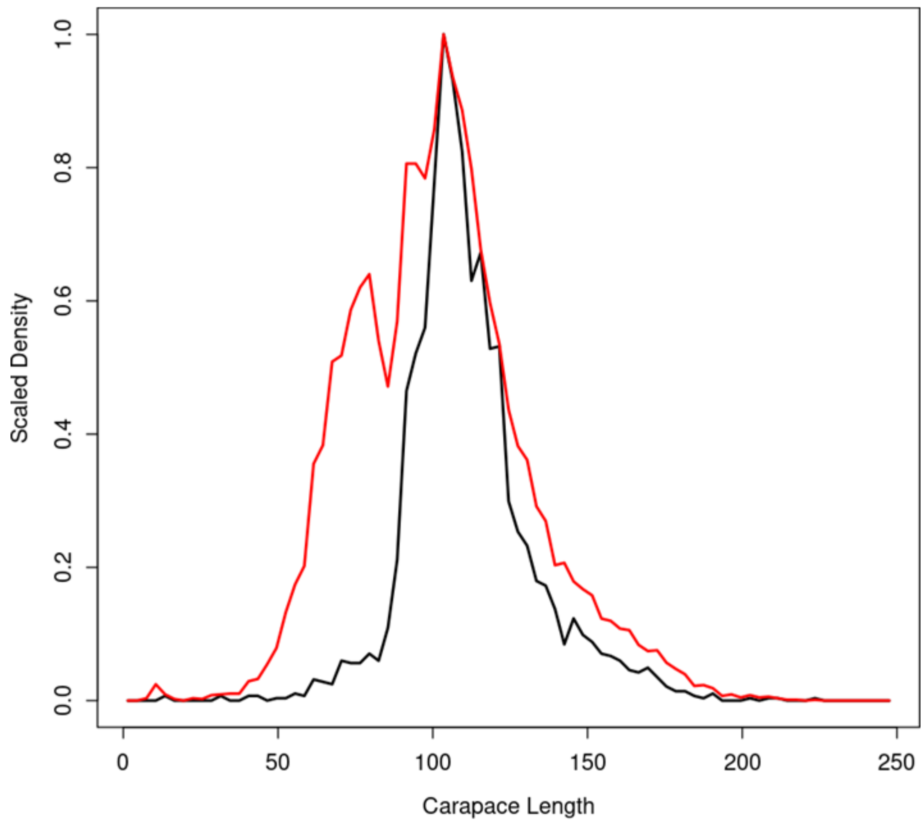

Figure 4. Comparison of sampled length frequencies from the DFO summer RV survey for the entire surveyed area (red) and the Lobsters sampled within LFA14 (black). Densities were scaled to the maximum density within each data set.

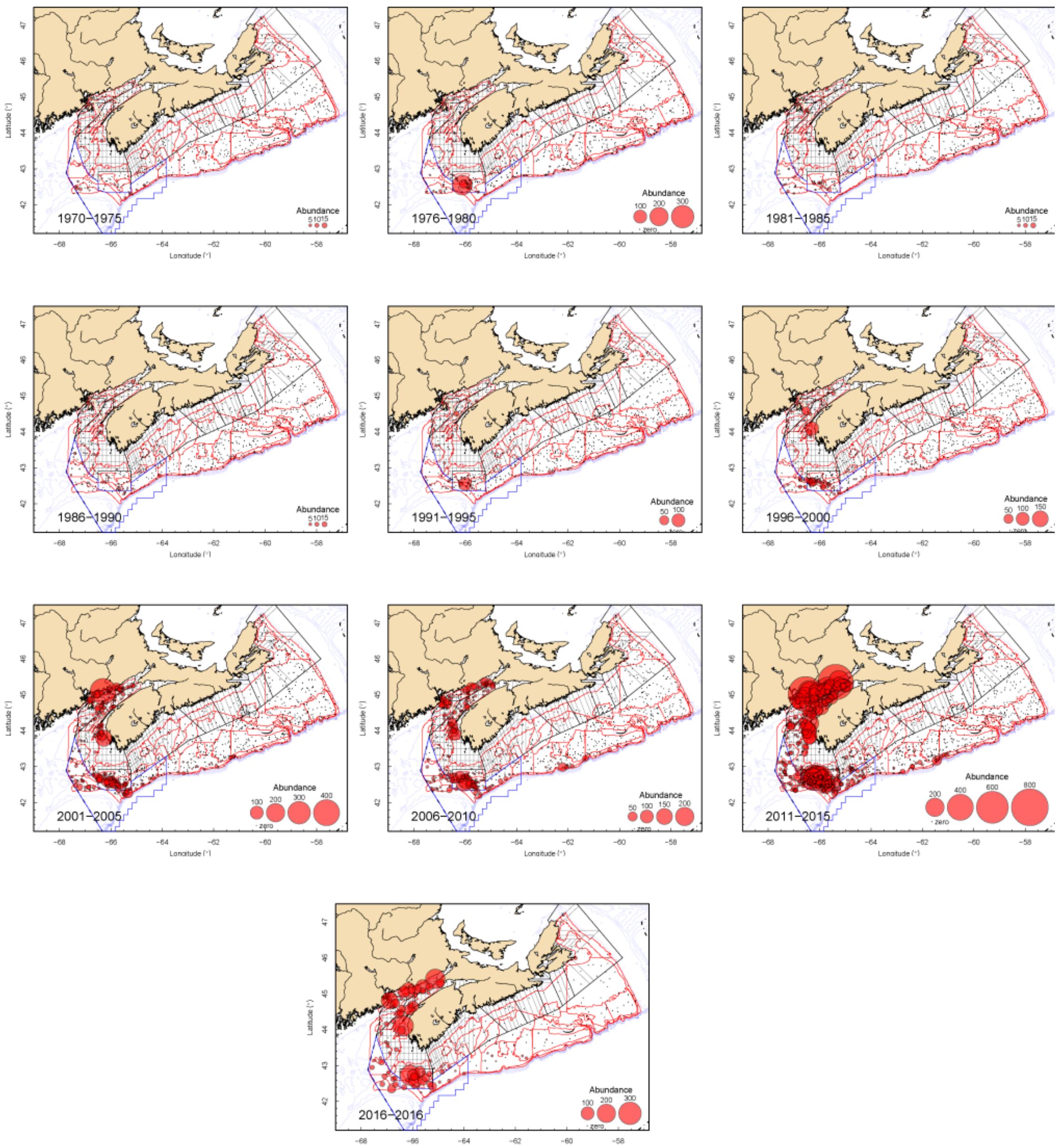

Figure 5. Map of the abundance of Lobster captured during DFO's Summer RV survey of the Scotian Shelf. Strata boundaries are outlined in red and LFA 41 stock boundaries are outlined in blue. Size of the symbols are scaled to the number of Lobster observed within each tow. Black points represent tow locations with no Lobsters.

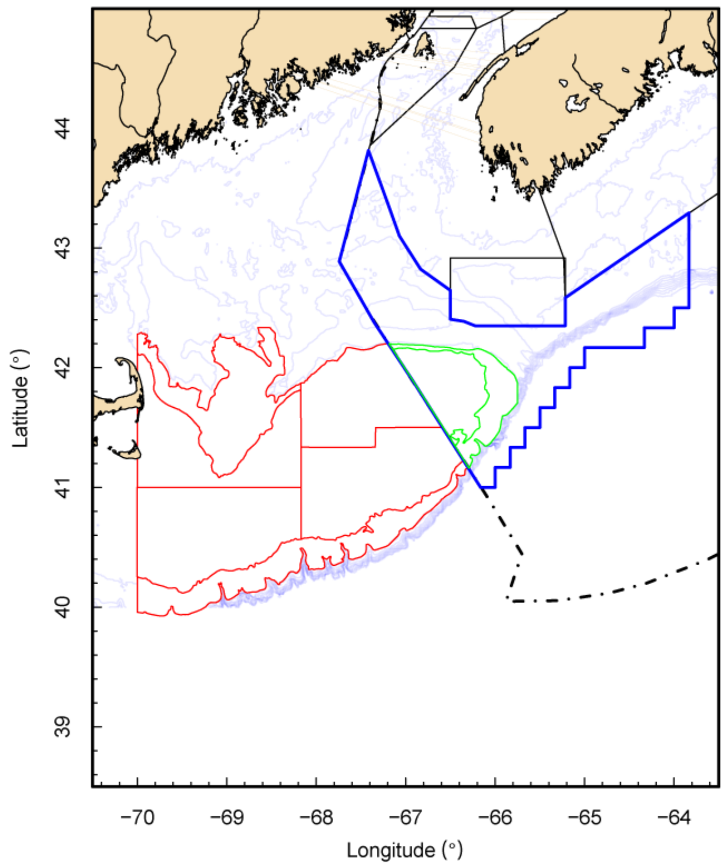

Figure 6. The DFO Georges Bank Spring strata from the depth stratified survey are shown in red and green. The strata outlined in green are those used in survey trends from the Georges Bank Survey. Lobster Fishing Area 41 (blue line) is outlined in blue.

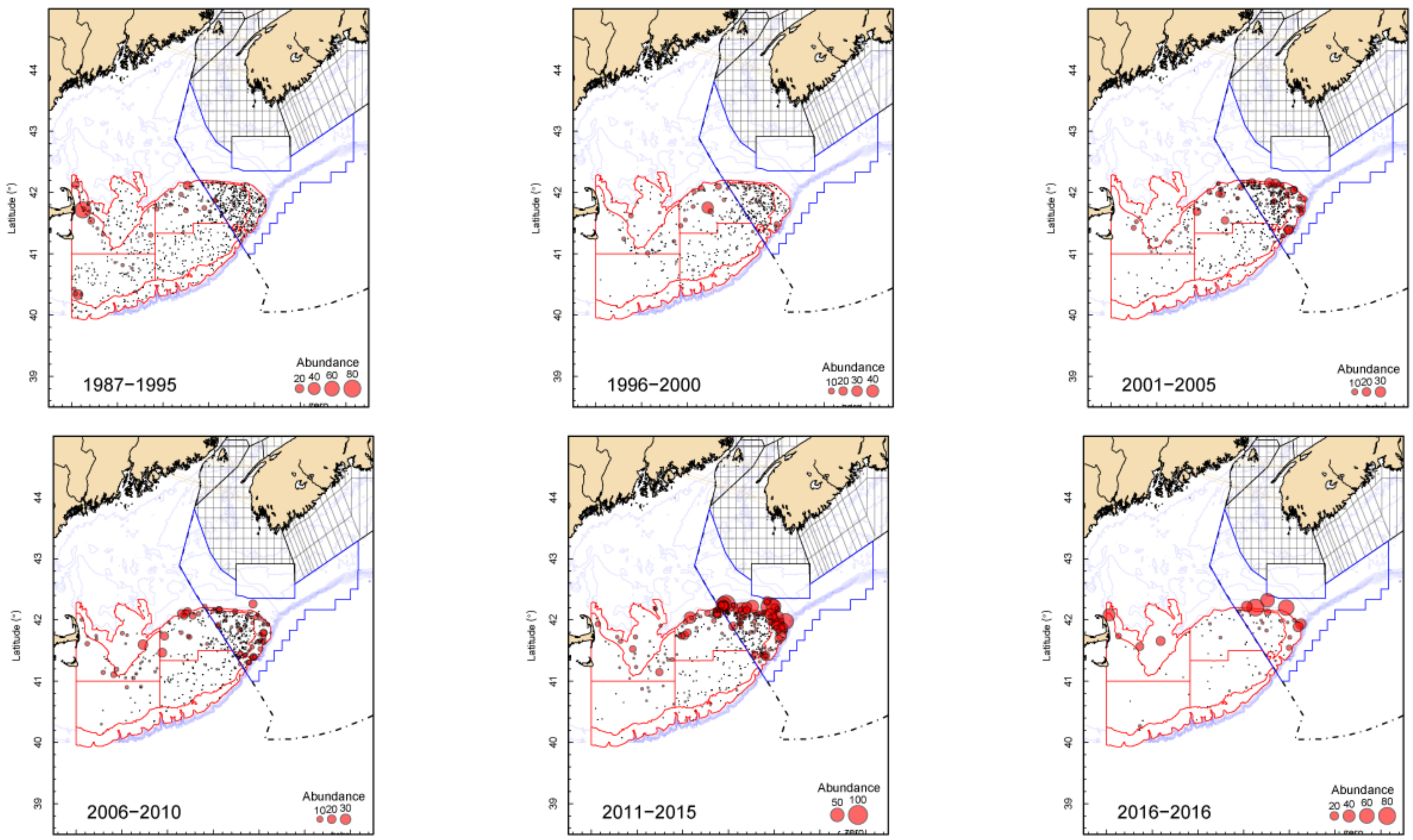

Figure 7. Map of the abundance of Lobster captured during DFO's Georges Bank Survey. Strata boundaries are outlined in red and LFA 41 stock boundaries are outlined in blue. Size of the symbols are scaled to the number of Lobster observed within each tow. Black points represent tow locations with no Lobsters.

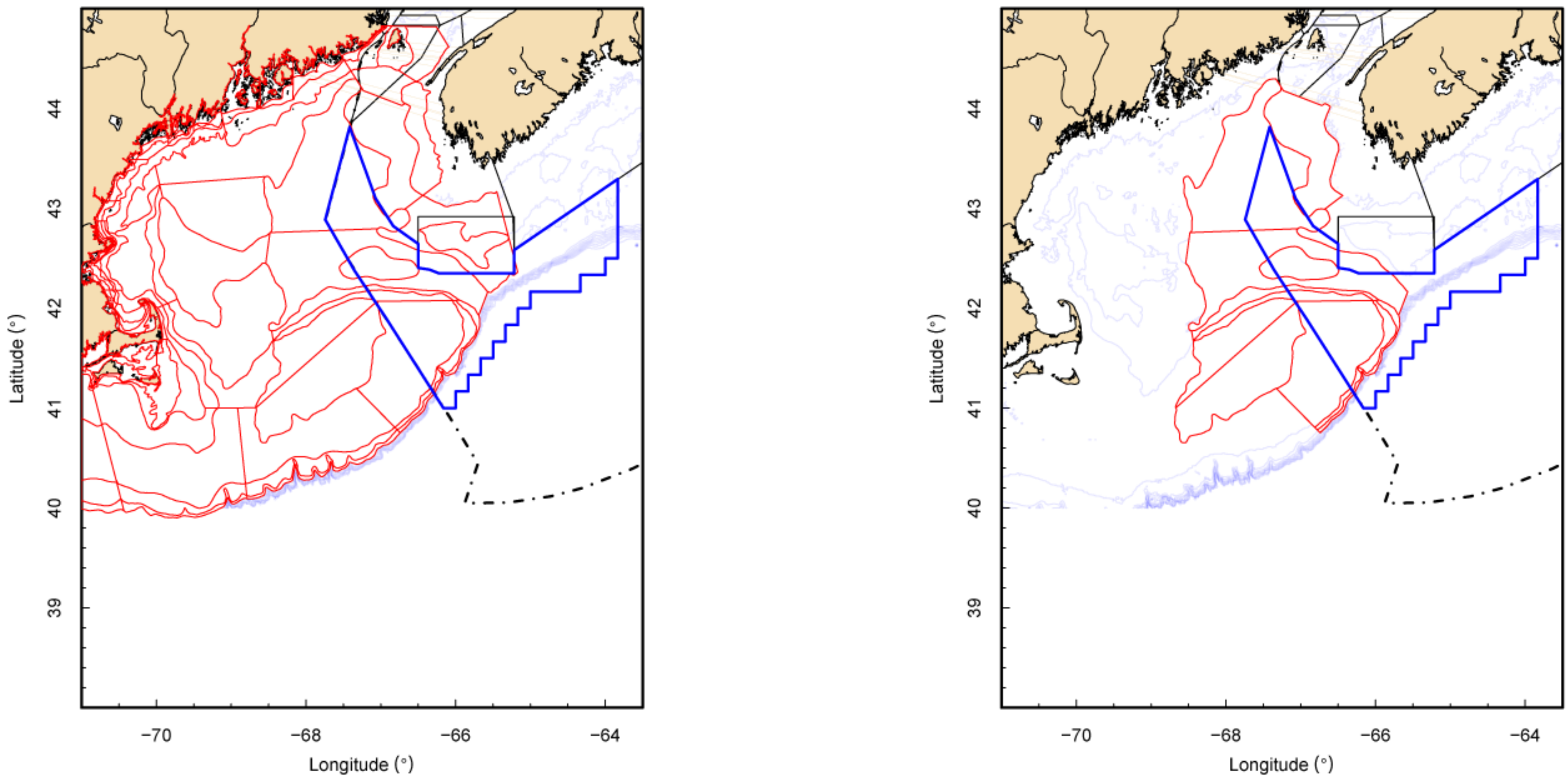

Figure 8. The NEFSC spring and autumn strata from the depth stratified survey shown in red (left). Lobster Fishing Area 41 (blue line) with the NEFSC spring and autumn strata (shown in red) used for the analysis of survey trends (right).

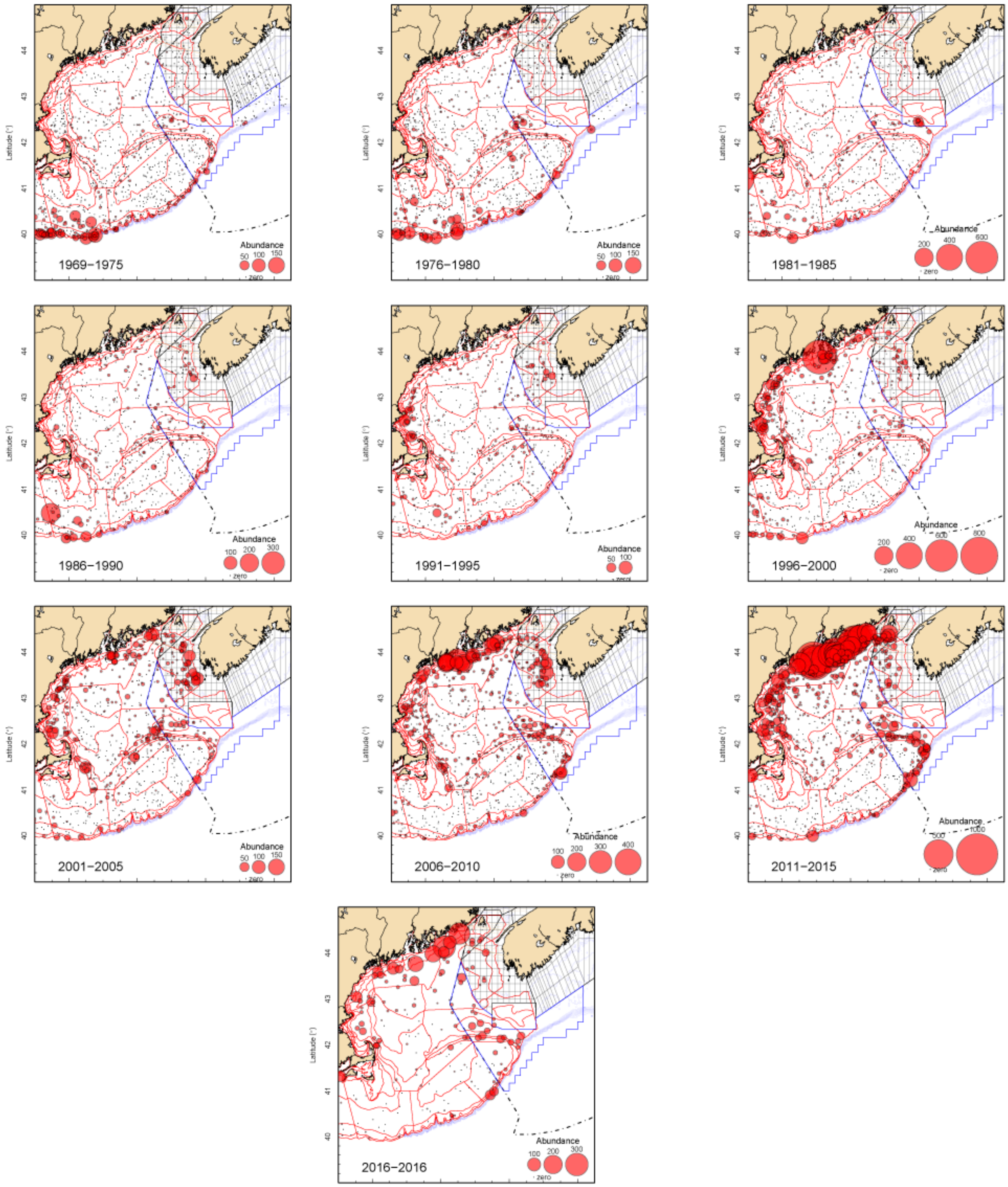

Figure 9. Map of the abundance of Lobster captured during NEFSC's Spring Survey of the Gulf of Maine, Georges Bank and Scotian Shelf. Strata boundaries are outlined in red and LFA 41 stock boundaries are outlined in blue. Size of the symbols are scaled to the number of Lobster observed within each tow. Black points represent tow locations with no Lobsters.

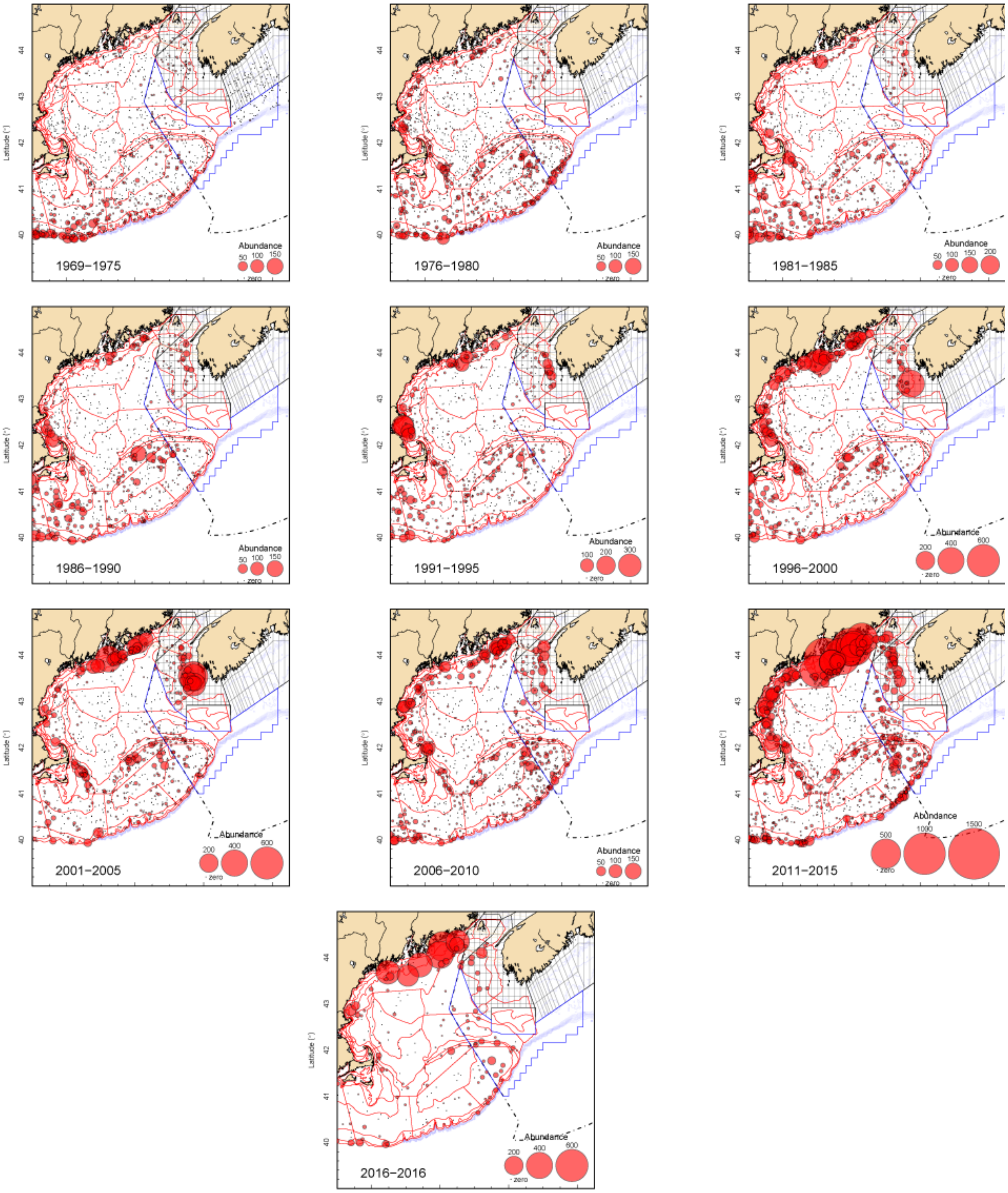

Figure 10. Map of the abundance of Lobster captured during NEFSC's Fall Survey of the Gulf of Maine, Georges Bank and Scotian Shelf. Strata boundaries are outlined in red and LFA 41 stock boundaries are outlined in blue. Size of the symbols are scaled to the number of Lobster observed within each tow. Black points represent tow locations with no Lobsters.

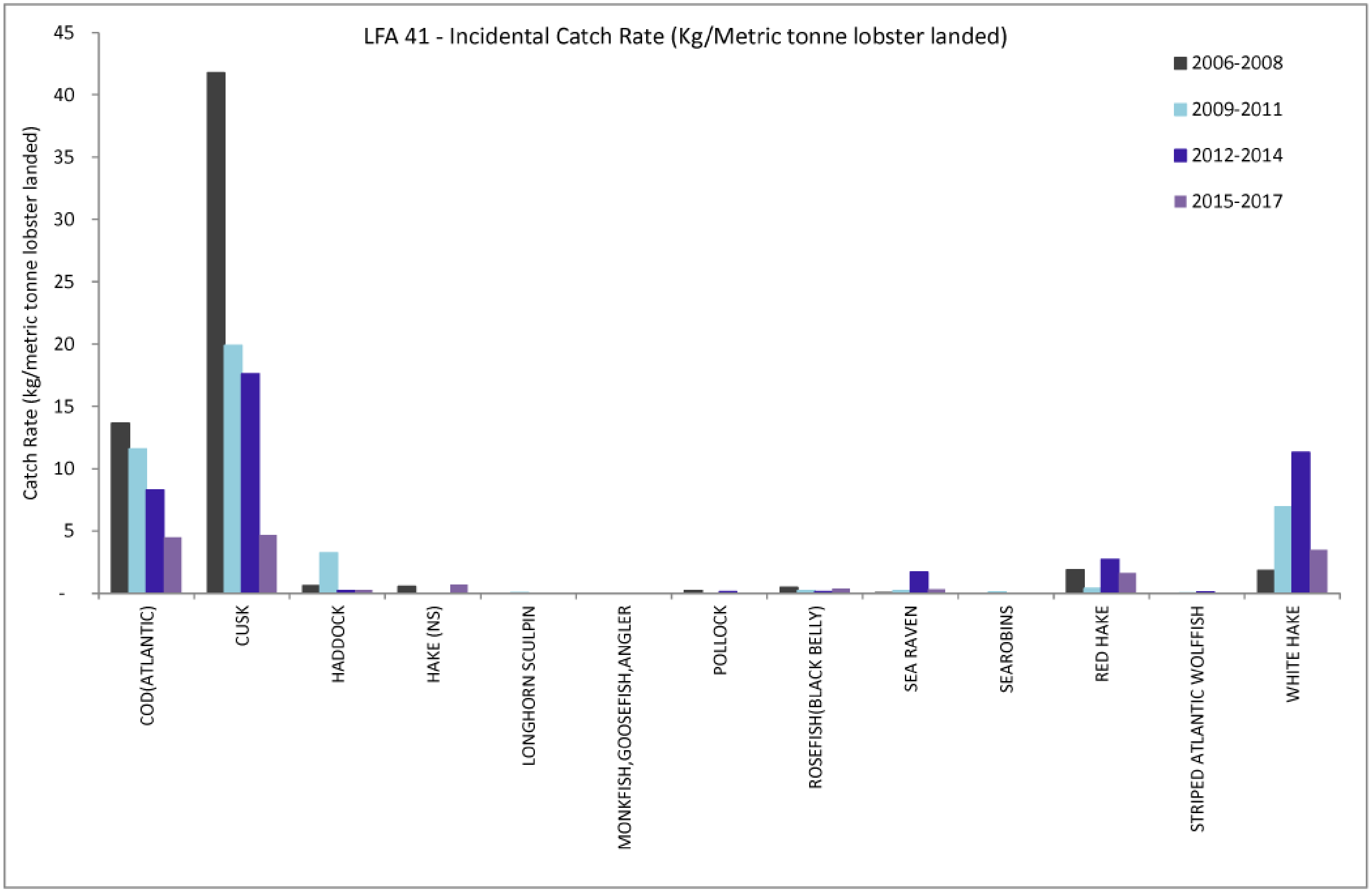

Figure 11. Estimated incidental catch rate (kg/t of Lobsters) of fish species from the at-sea sampled data of the LFA 41 Lobster fishery between 2006 to 2015 in 3 year time blocks.

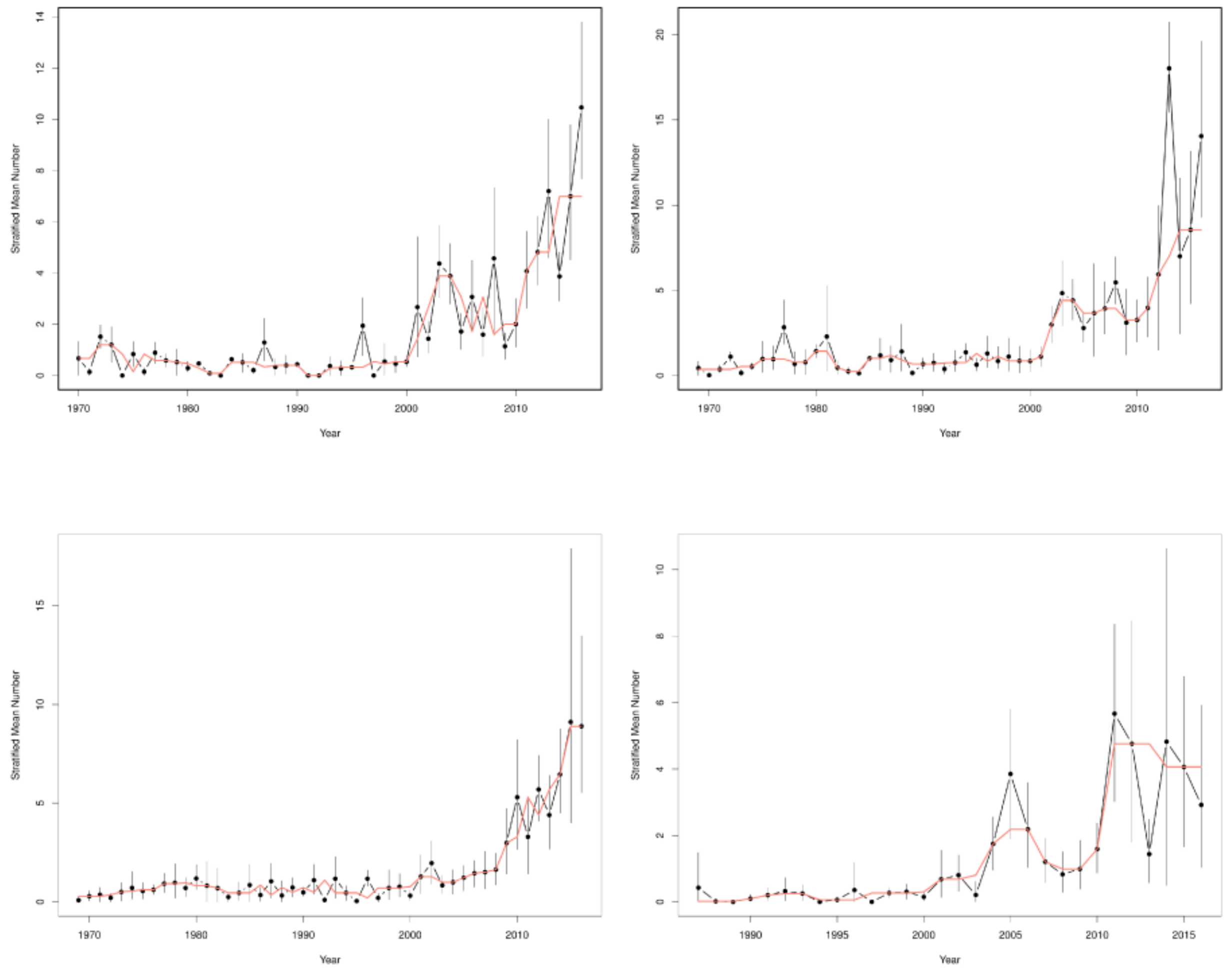

Figure 12. Stratified mean number per tow for the DFO Summer RV Survey (RV 41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Confidence bounds are presented for each point estimate.

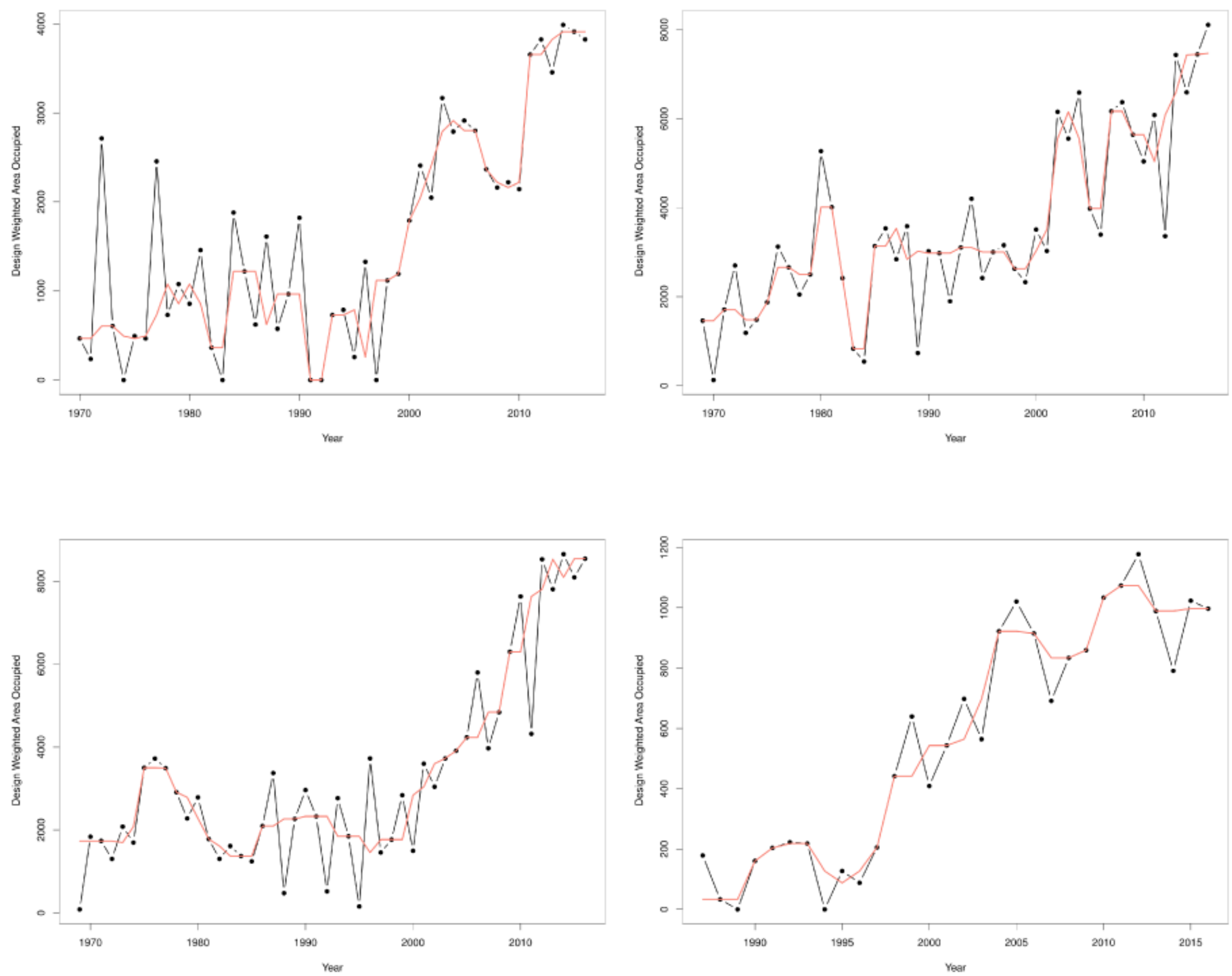

Figure 13. Design weighted area occupied (km2) of American Lobster from DFO Summer RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median.

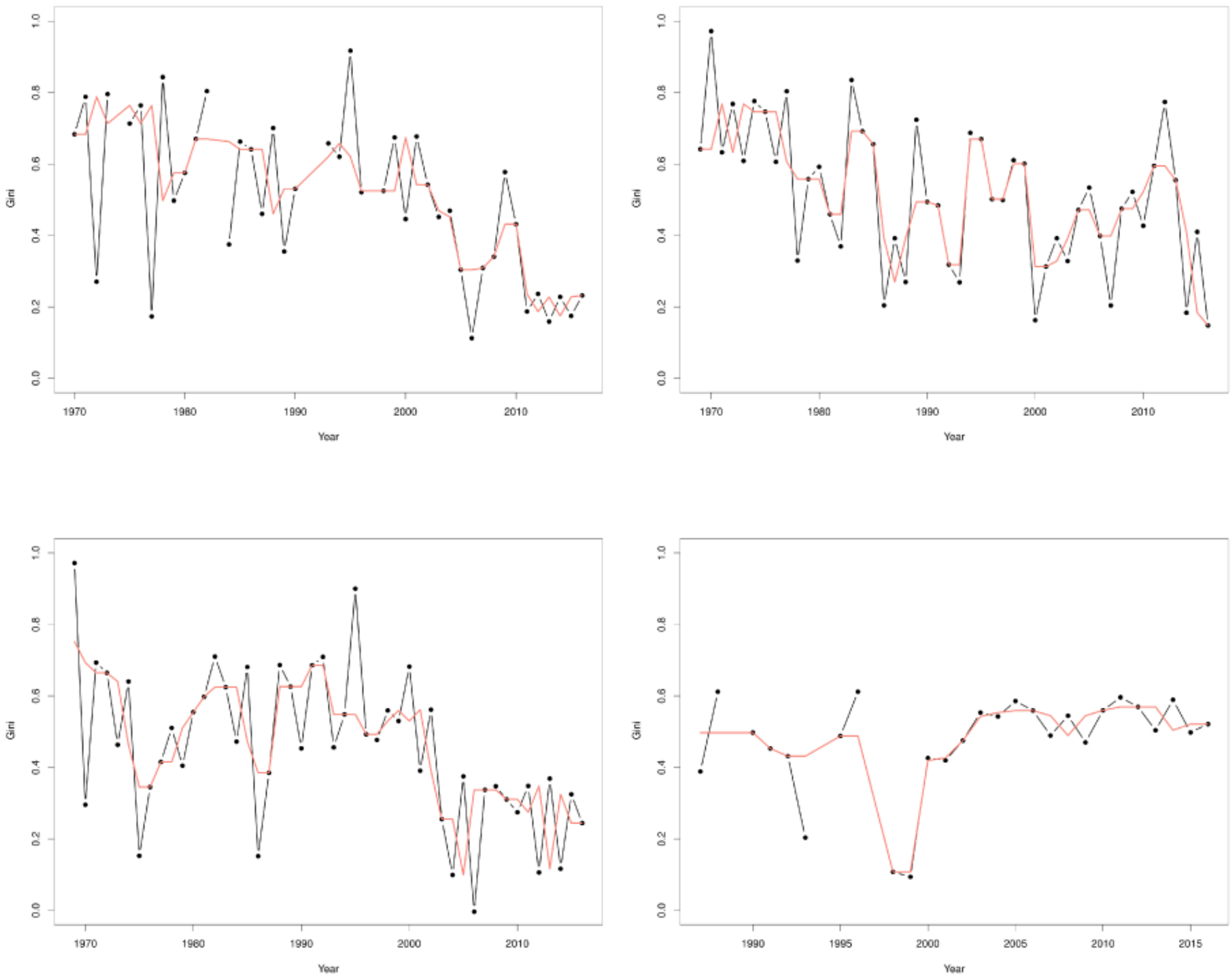

Figure 14. Patchiness as estimated through the Gini index from DFO RV Survey (RV 41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster was captured in the survey strata.

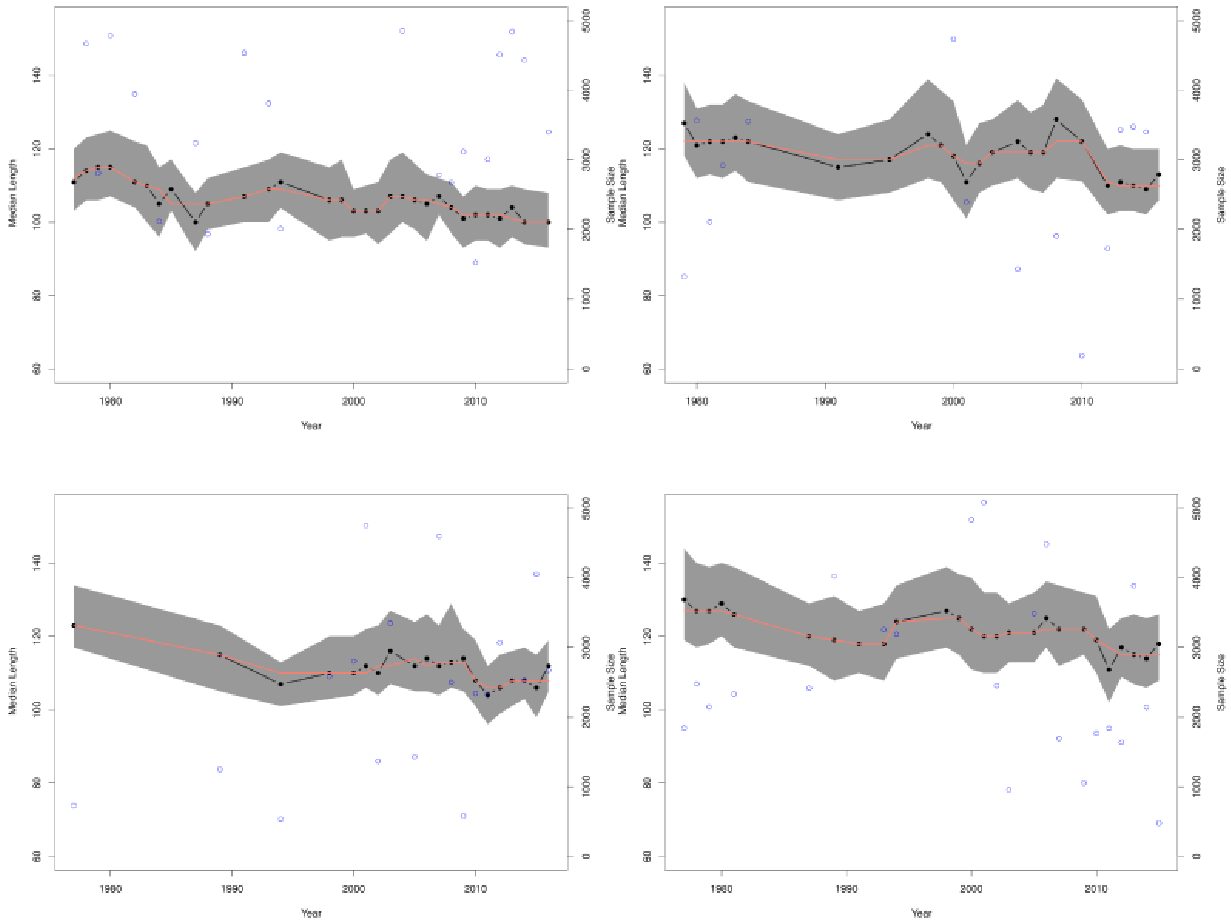

Figure 15. Median length (black line) with observed 25th and 75th quantiles (shaded polygon) from American Lobster observed during at sampling of fishing activities. Upper: Left – Southwest Browns; Right – Southeast Browns; Lower: Left – Georges Basin; Right – Georges Bank Summer. Within each plot red line represents a three year running median, whereas blue circles represent the annual sample sizes.

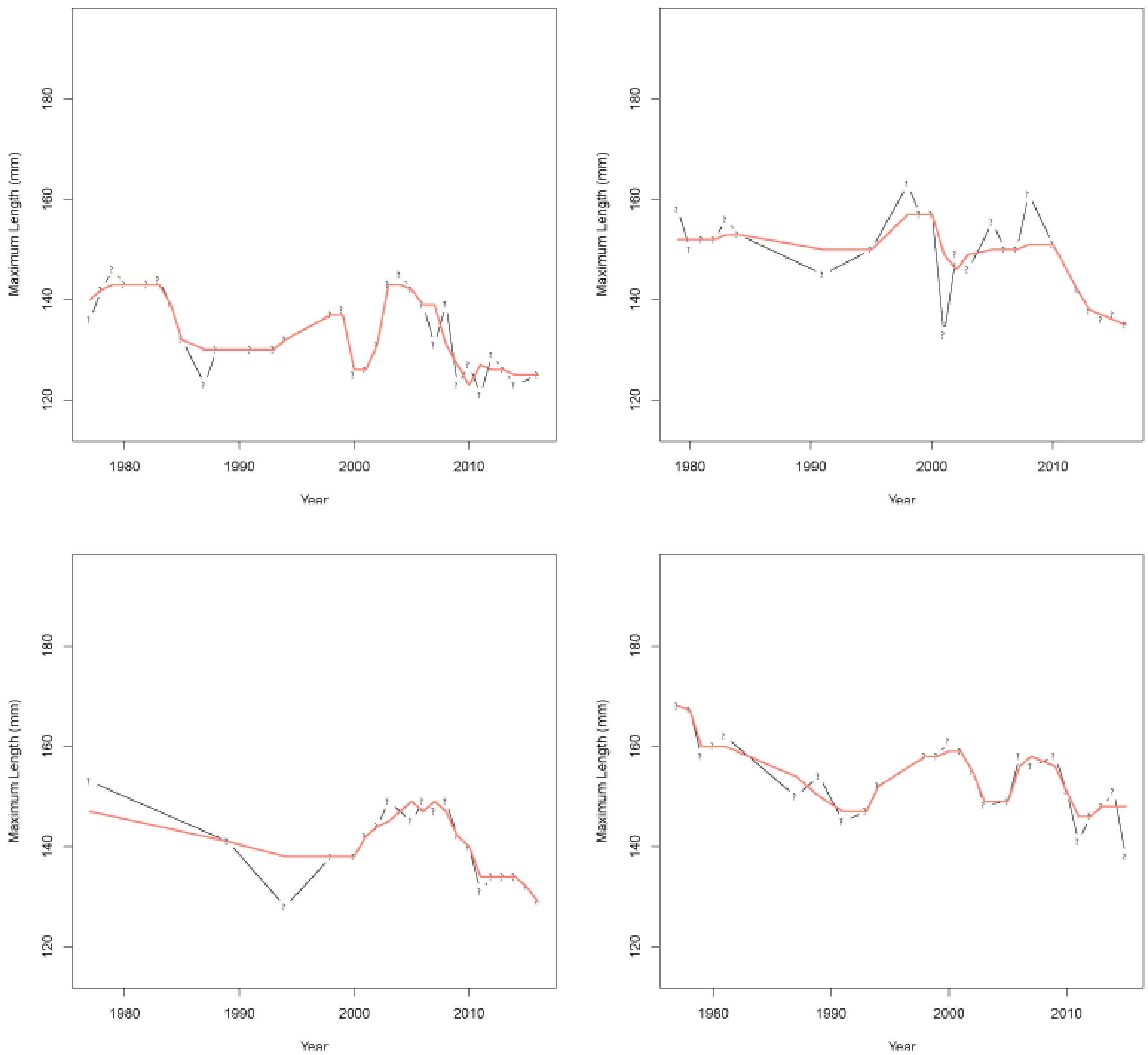

Figure 16. Maximum length (upper 95 quantile) of American Lobster observed during at sampling of fishing activities. Upper: Left – Southwest Browns ; Right – Southeast Browns; Lower: Left – Georges Basin; Right – Georges Bank. Within each plot red line represents a three year running median.

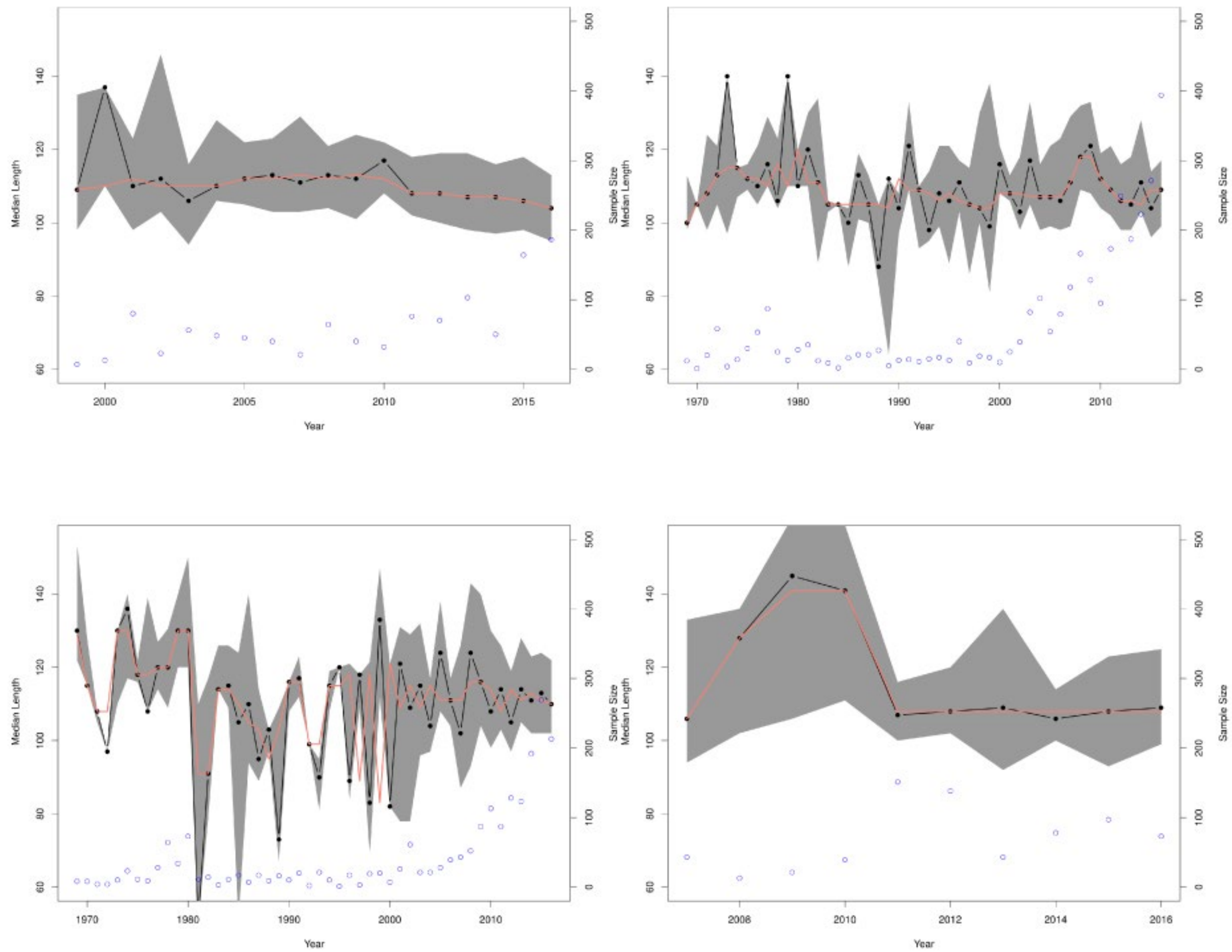

Figure 17. Population weighted median carapace length (solid line and points) with accompanying first and third quartiles (shaded polygon) DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster was captured in the survey strata. Within each plot the blue points represent the annual sample sizes of observed Lobster.

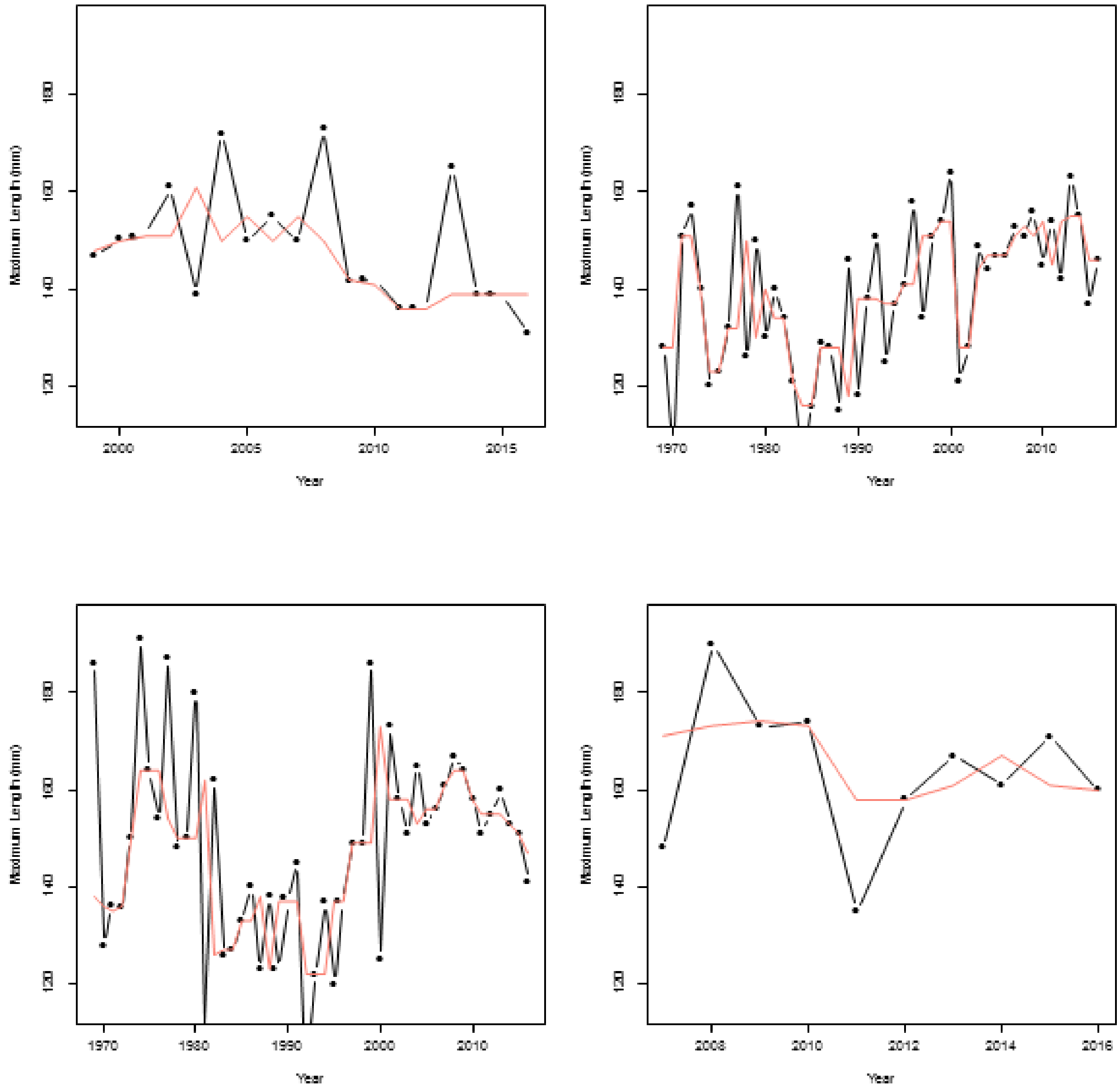

Figure 18. Maximum carapace length (upper 95 quantile) of American Lobster from DFO Summer RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster was captured in the survey strata.

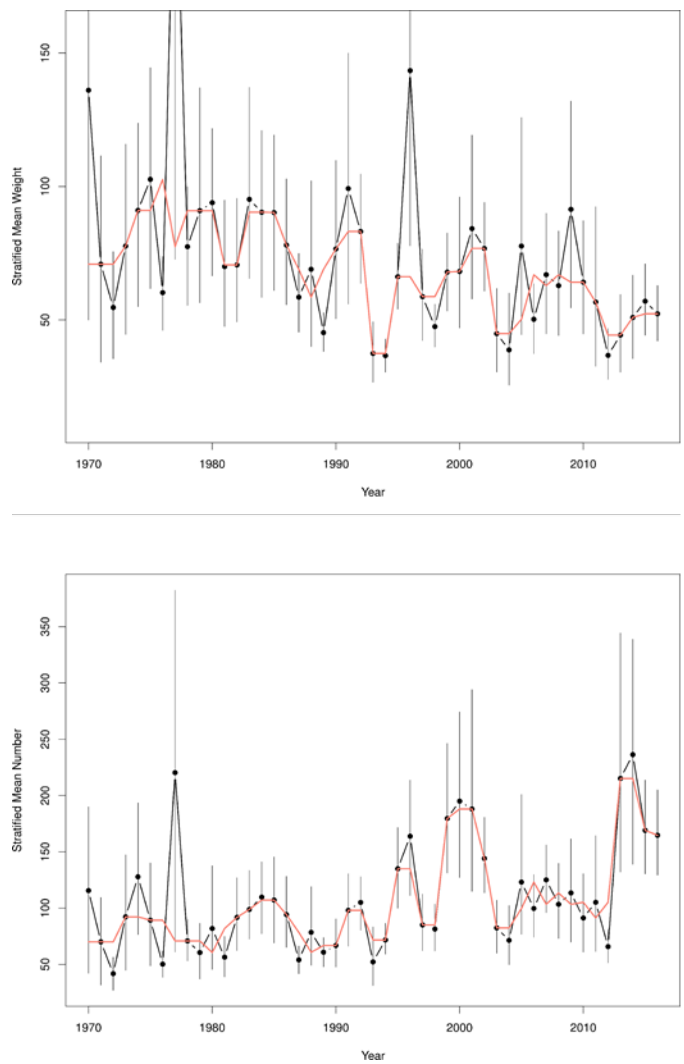

Figure 19. Time series of biomass (lower) and abundance (upper) of predators of American Lobster captured on the western Scotian Shelf during the DF Summer RV survey.

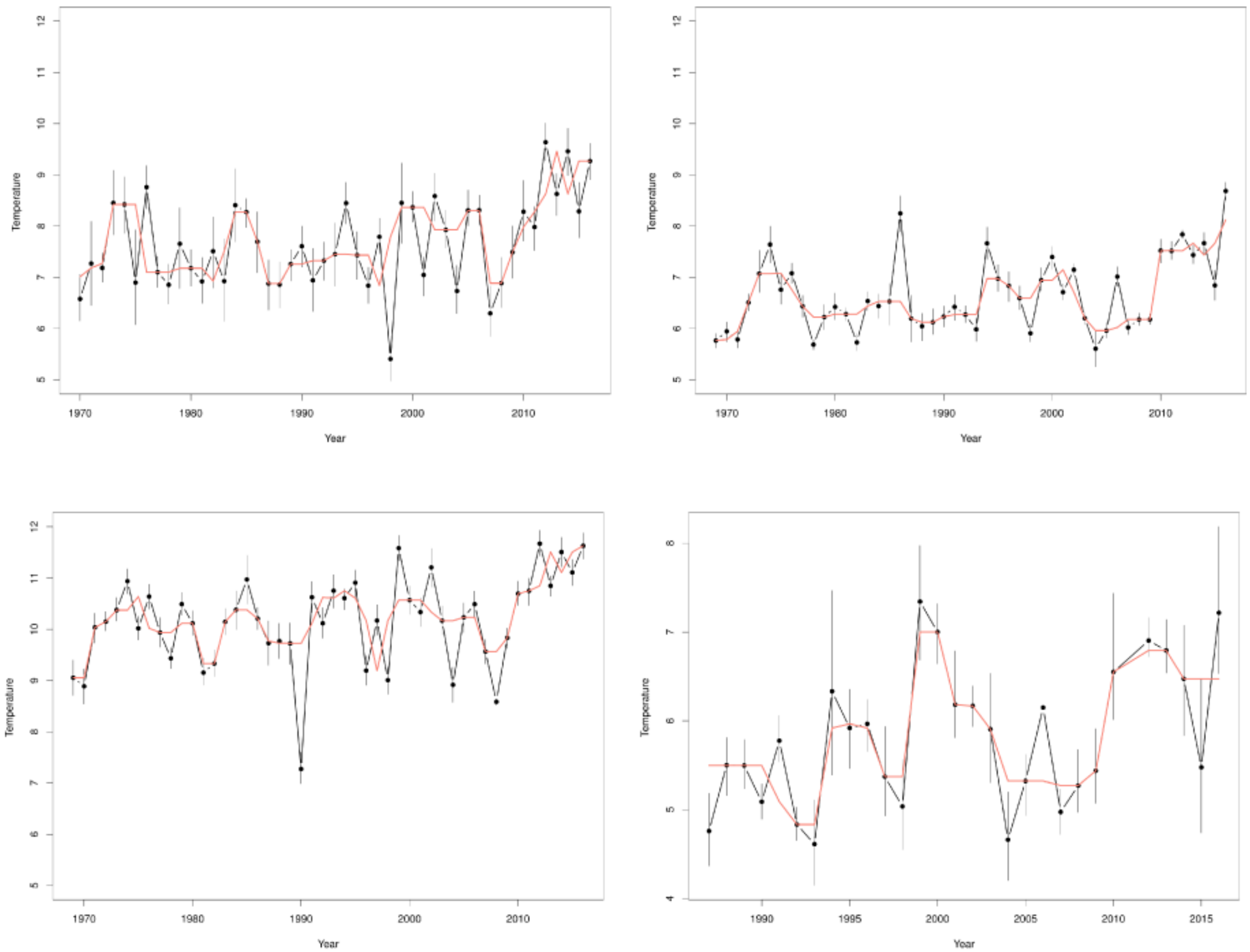

Figure 20. Stratified mean temperatures from DFO RV summer (upper-left), NEFSC spring (upper-right), NEFSC fall (lower-left) and Georges Bank (lower-right), surveys with base strata for LFA 41. Within each plot red line represents running median and error bars are the 95% bootstrapped confidence intervals.

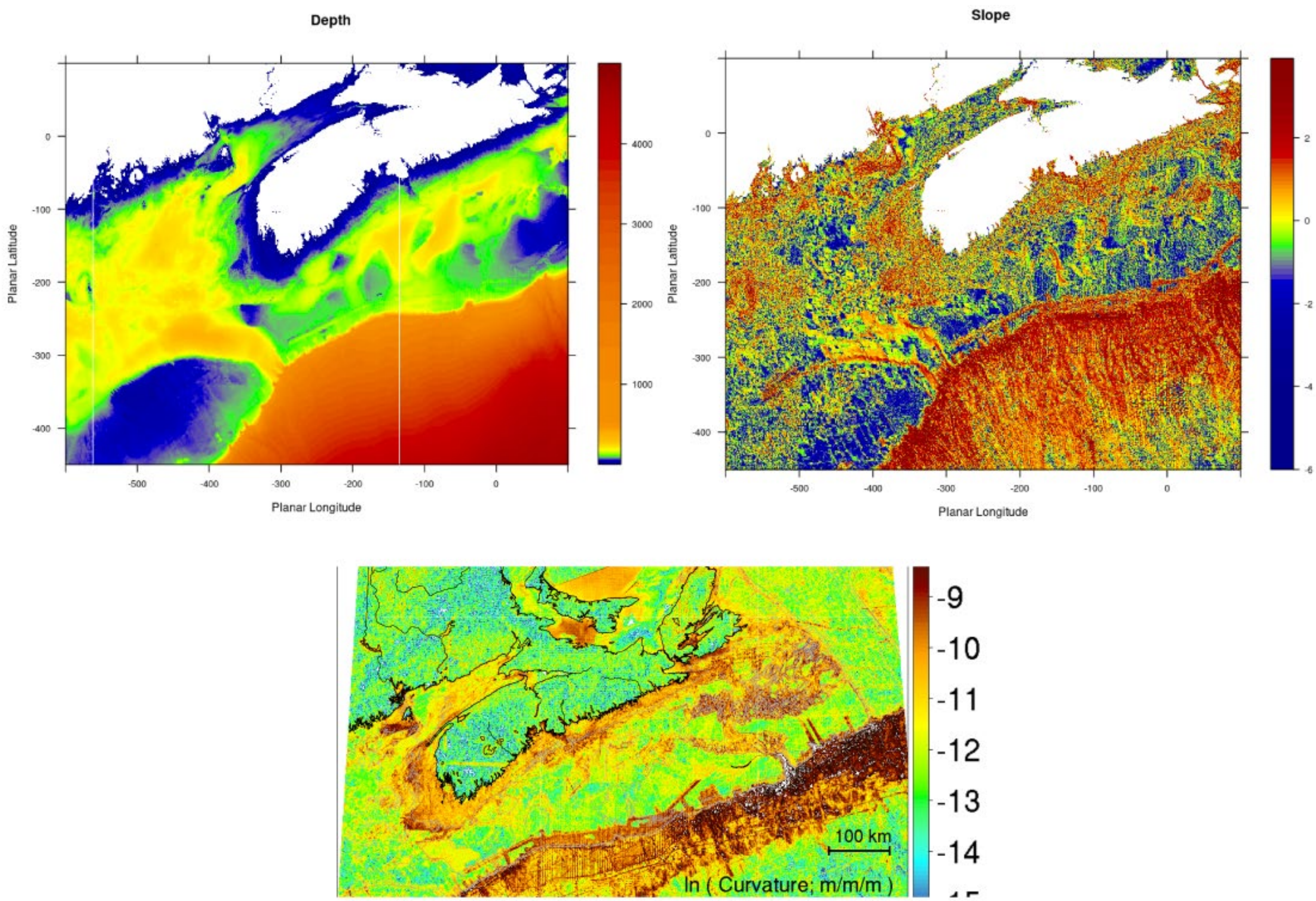

Figure 21. Interpolated surfaces for bathymetry, slope (log-scale) and curvature (log-scale) for the Scotian Shelf, Gulf of Maine and Georges Bank used as the projection layers for species distribution modeling. Planar coordinates are used for mapping with Zone 20 specified.

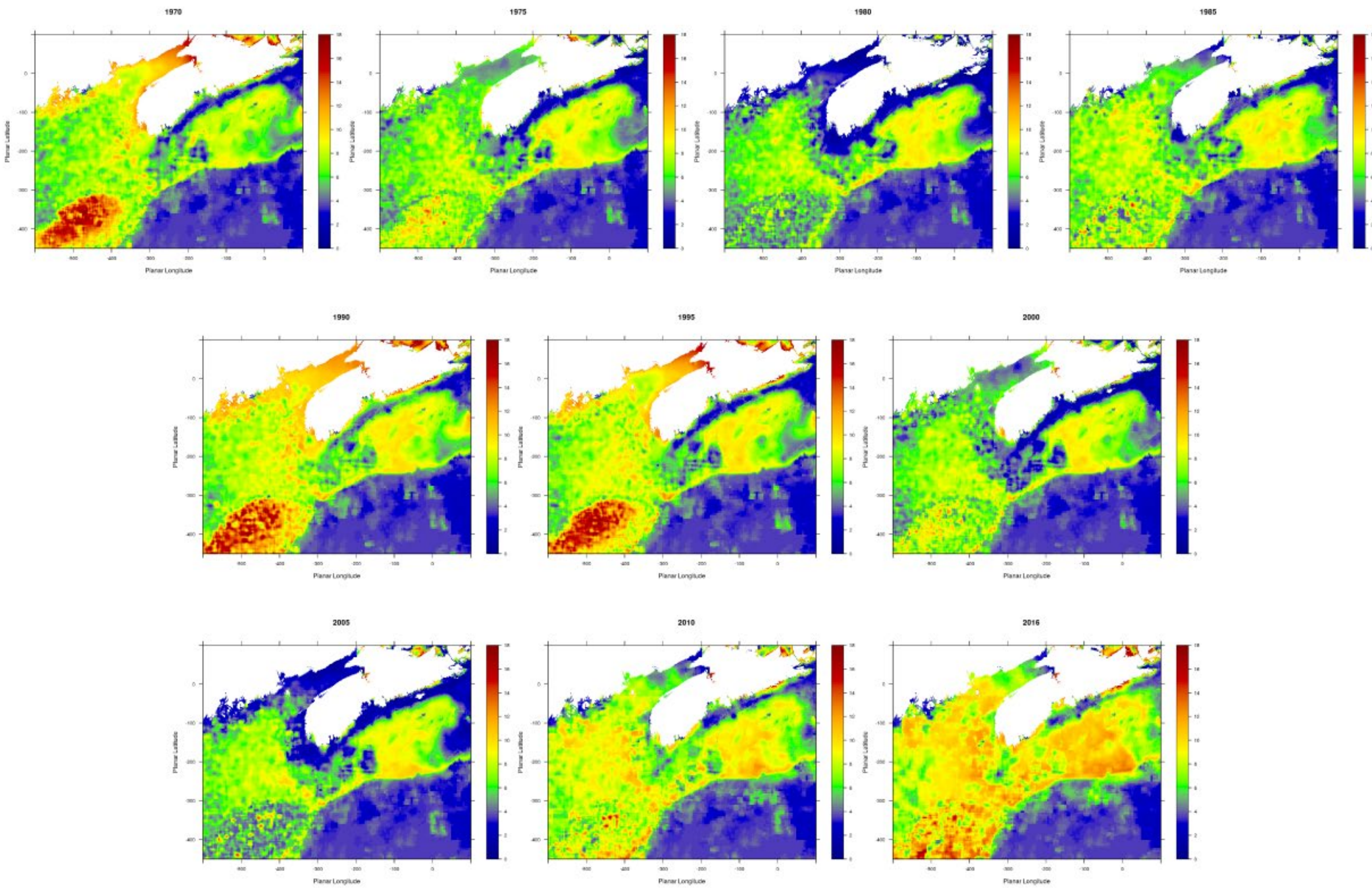

Figure 22. Interpolated temperature surfaces by year for the Scotian Shelf, Gulf of Maine and Georges Bank used as the projection layers for species distribution modeling. Planar coordinates are used for mapping with Zone 20 specified.

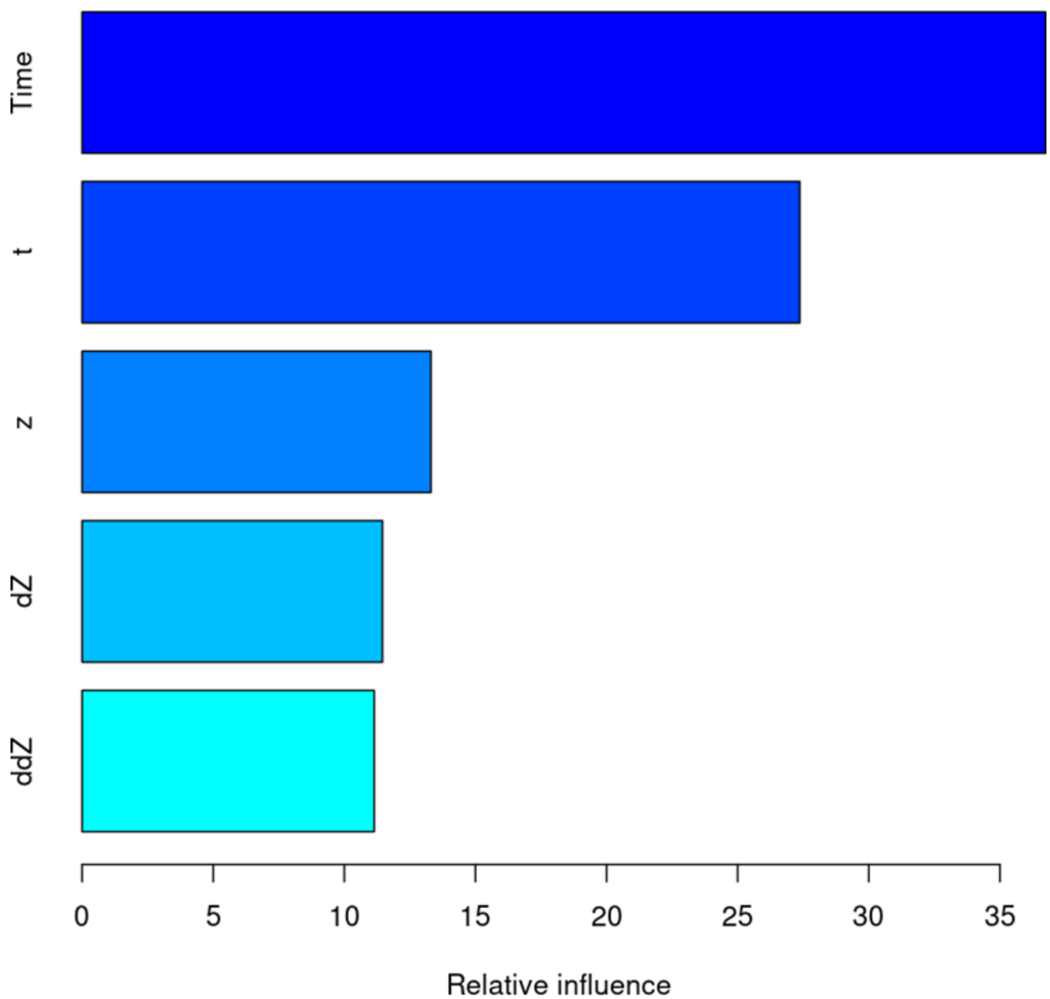

Figure 23. The relative influence of predictor variables Time (decimal year), temperature (t), depth (z), slope (dZ) and curvature (ddZ) from the boosted regression trees on the species distribution model.

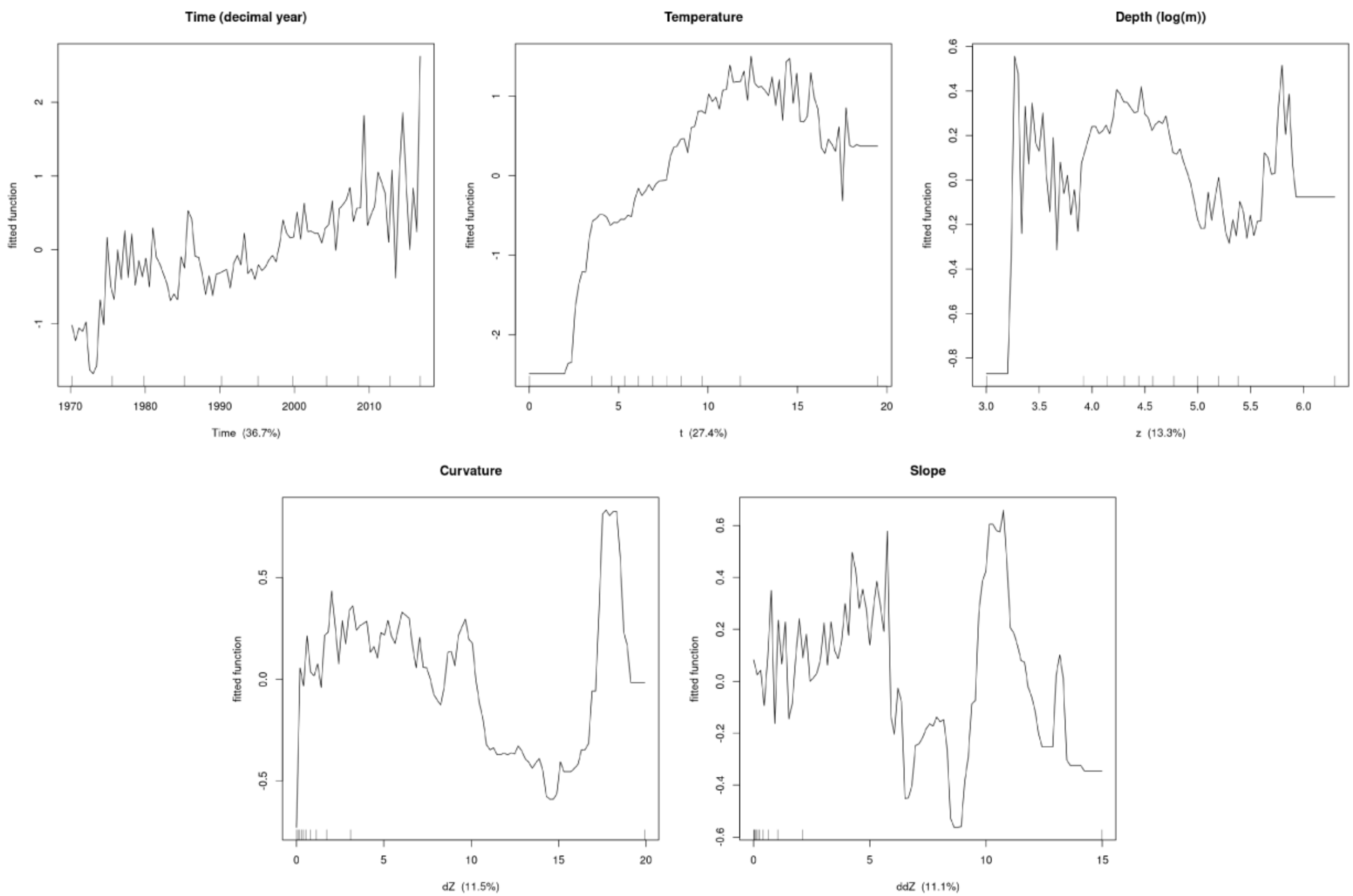

Figure 24. Fitted functions from the boosted regression tree models of Lobster species distribution based on the variables of Time (decimal years), bottom temperature, depth, curvature and slope.

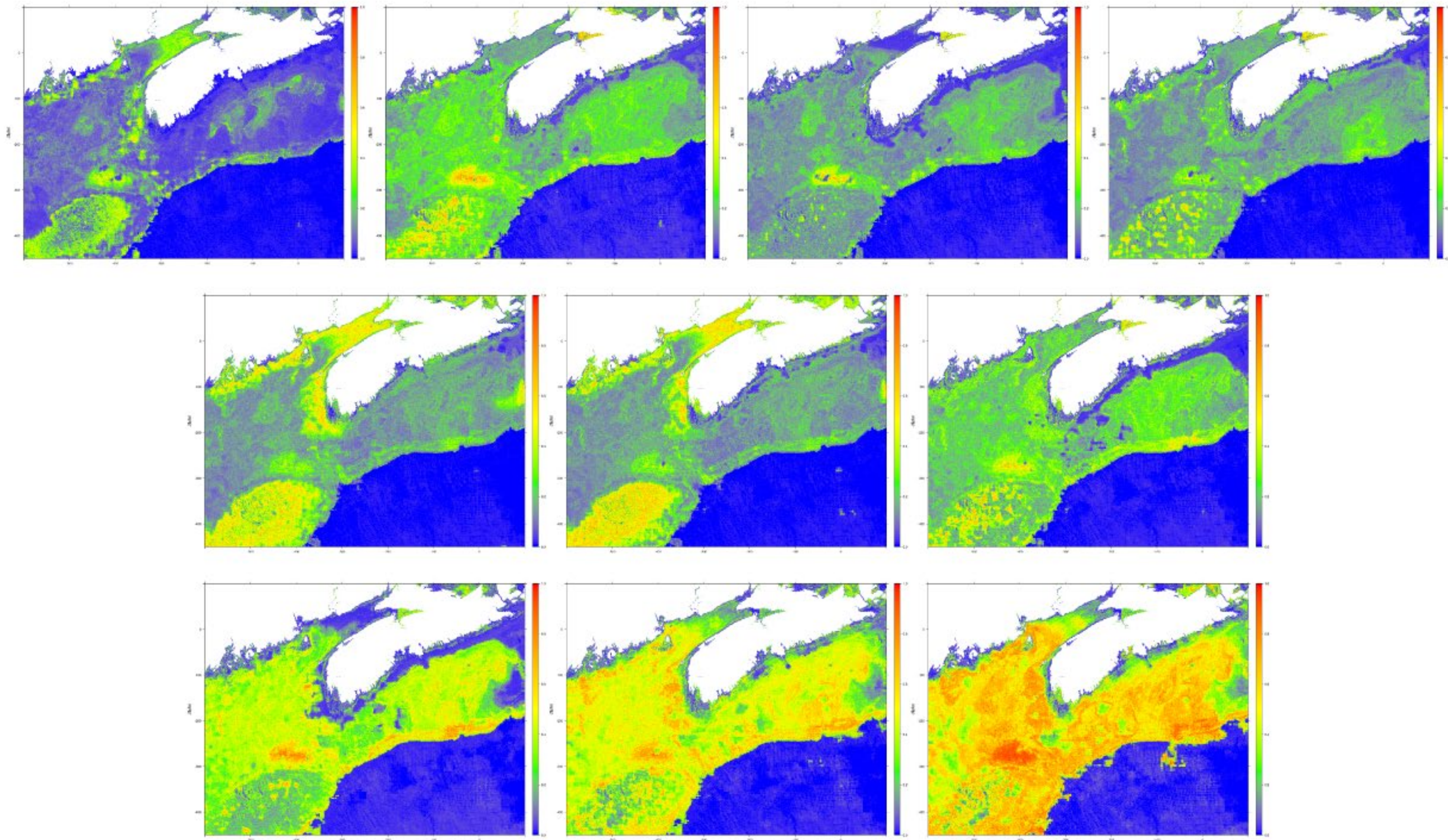

Figure 25. Predicted annual species distribution surfaces for American Lobster from the boosted regression tree model results. From left to right: top row – 1970, 1975, 1980, 1985; middle row – 1990, 1995, 2000; bottom row – 2005, 2010, 2016.

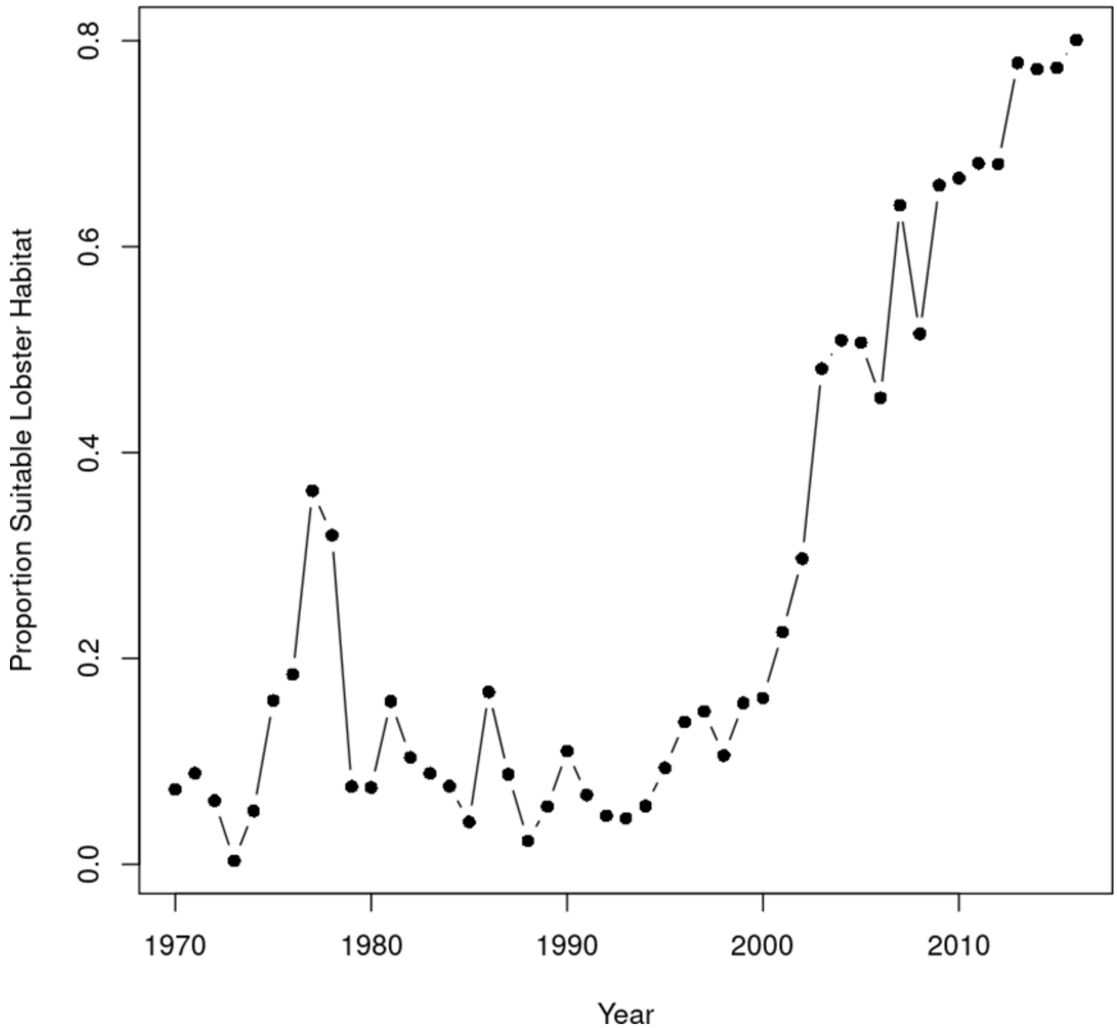

Figure 26. The proportion of total area within LFA 41 representing ≥0.35 probability of being suitable Lobster habitat from the boosted regression tree results.

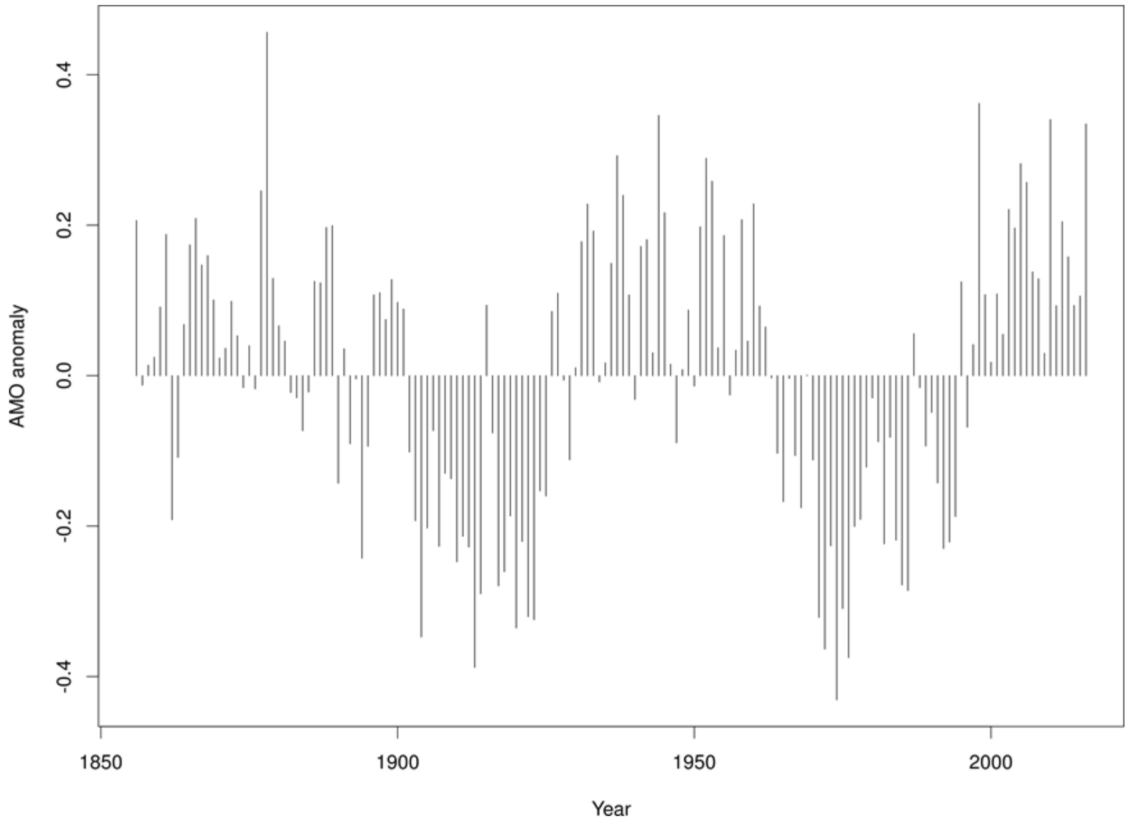

Figure 27. Annual mean anomalies of the Atlantic multidecadal osscillation (AMO). [Data obtained from NOAA](#).

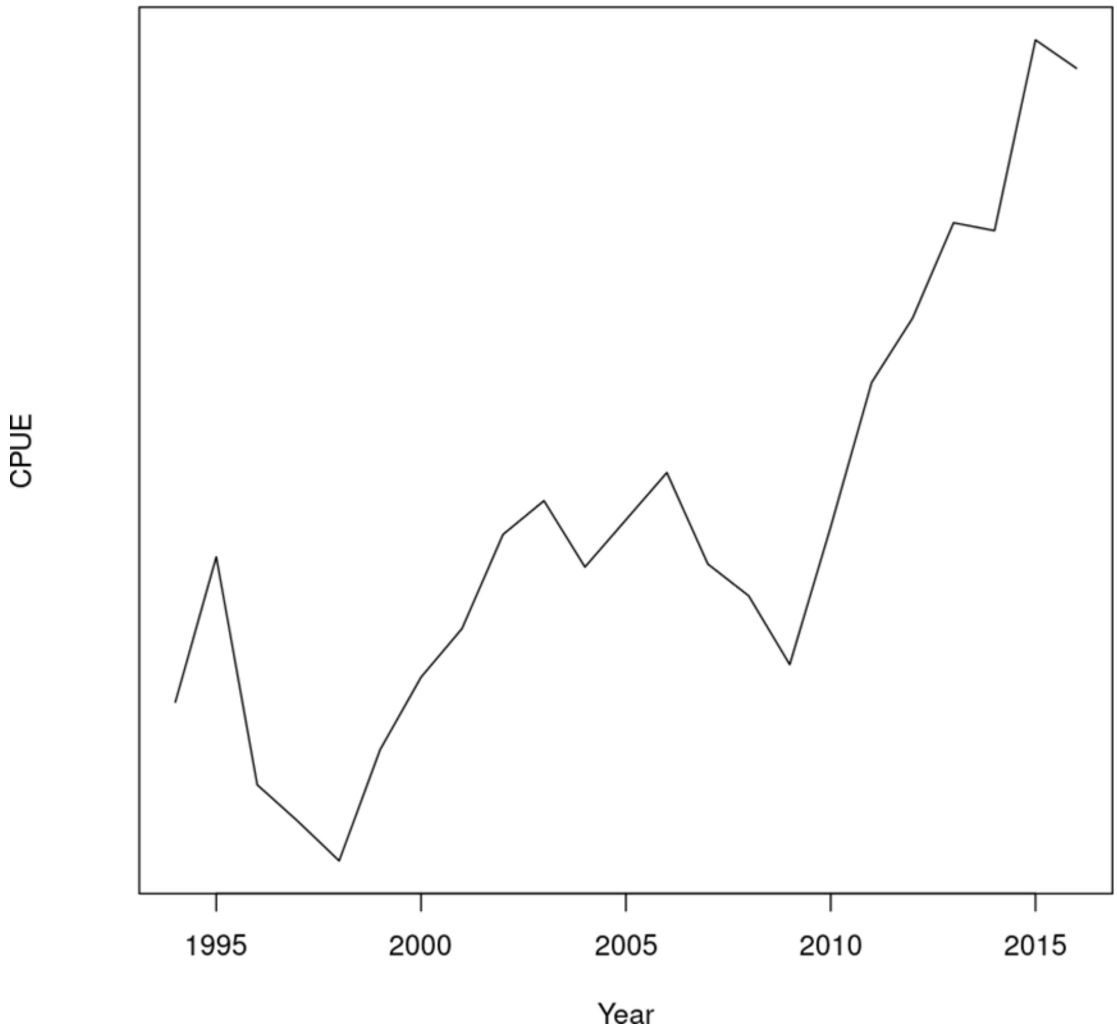

Figure 28. Catch per unit effort for Lobster in the LFA 41 fishery. The Y-axis labels were removed due to Privacy Act concerns of the commercial catch rate levels.

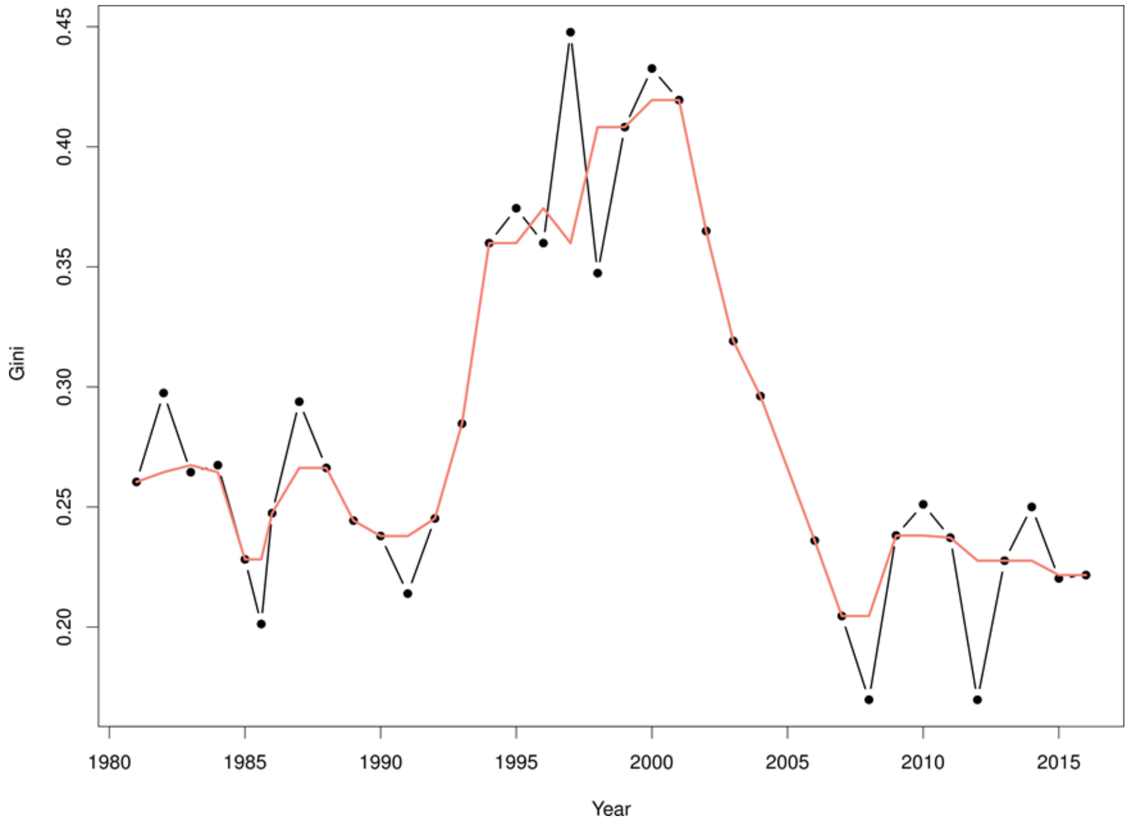

Figure 29. Time series of spatial evenness of fishery catch rates (kg\TH) estimated through the Gini Index for LFA 41. The Red line represents the three year running median. Annual catch rates were estimated by grouping fishing trips into 0.05 deg².

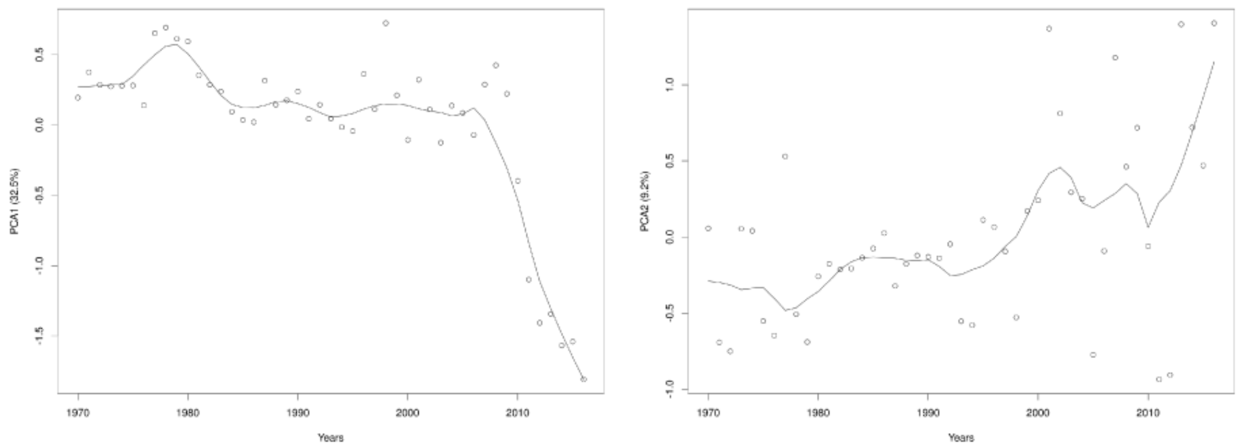

Figure 30. First and second axes of variation of the component scores from the ordination of the subset of biological and ecosystem indicators associated with the offshore LFA 41 Lobster. Within each plot, the line represents a loess smoother through the component scores.

Figure 31. Time series of sorted ordination of the anomalies from the subset of biological and ecosystem indicators associated with LFA 41. Green indicates levels above the mean, whereas red indicates levels below the mean. White blocks indicate <20 observations were available for that indicator and time period.

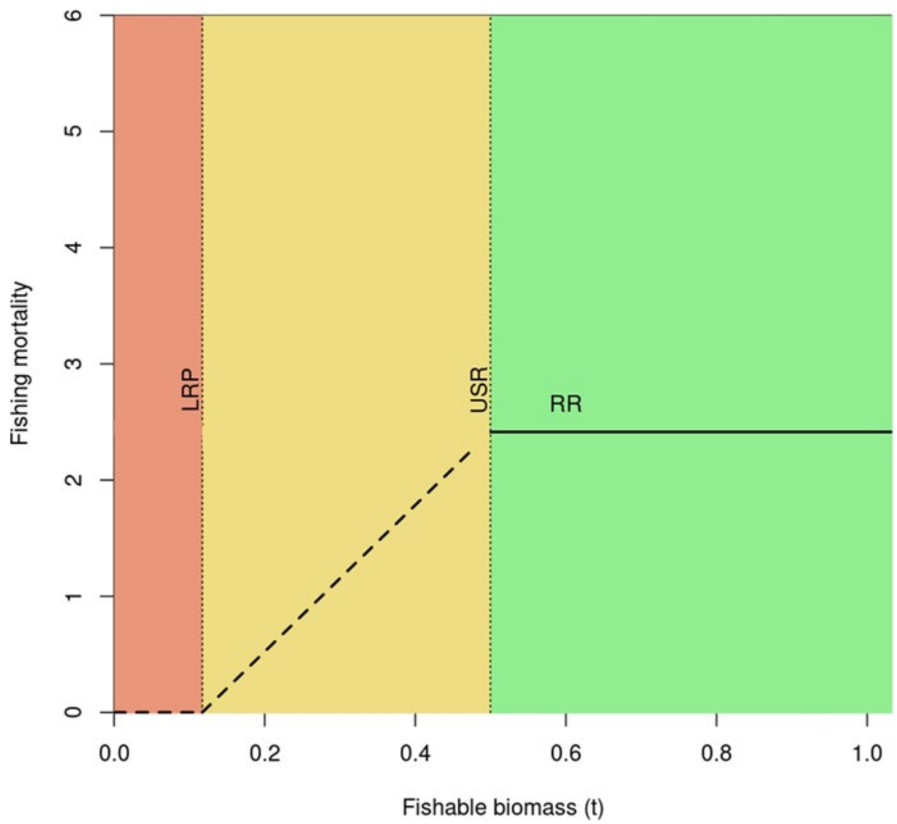

Figure 32. Example precautionary approach phase plot delimiting the Healthy Zone (green) above Upper Stock Reference (USR) the Cautious Zone (yellow), between the USR and the Limit Reference Point (LRP) and Critical Zone (red), below the LRP. The Removal Reference (RR) is shown as a solid black line in all three zones, however in practice the RR should be reduced in the Cautious Zone (black dashed) to allow stock rebuilding and set to 0 in the Critical Zone.

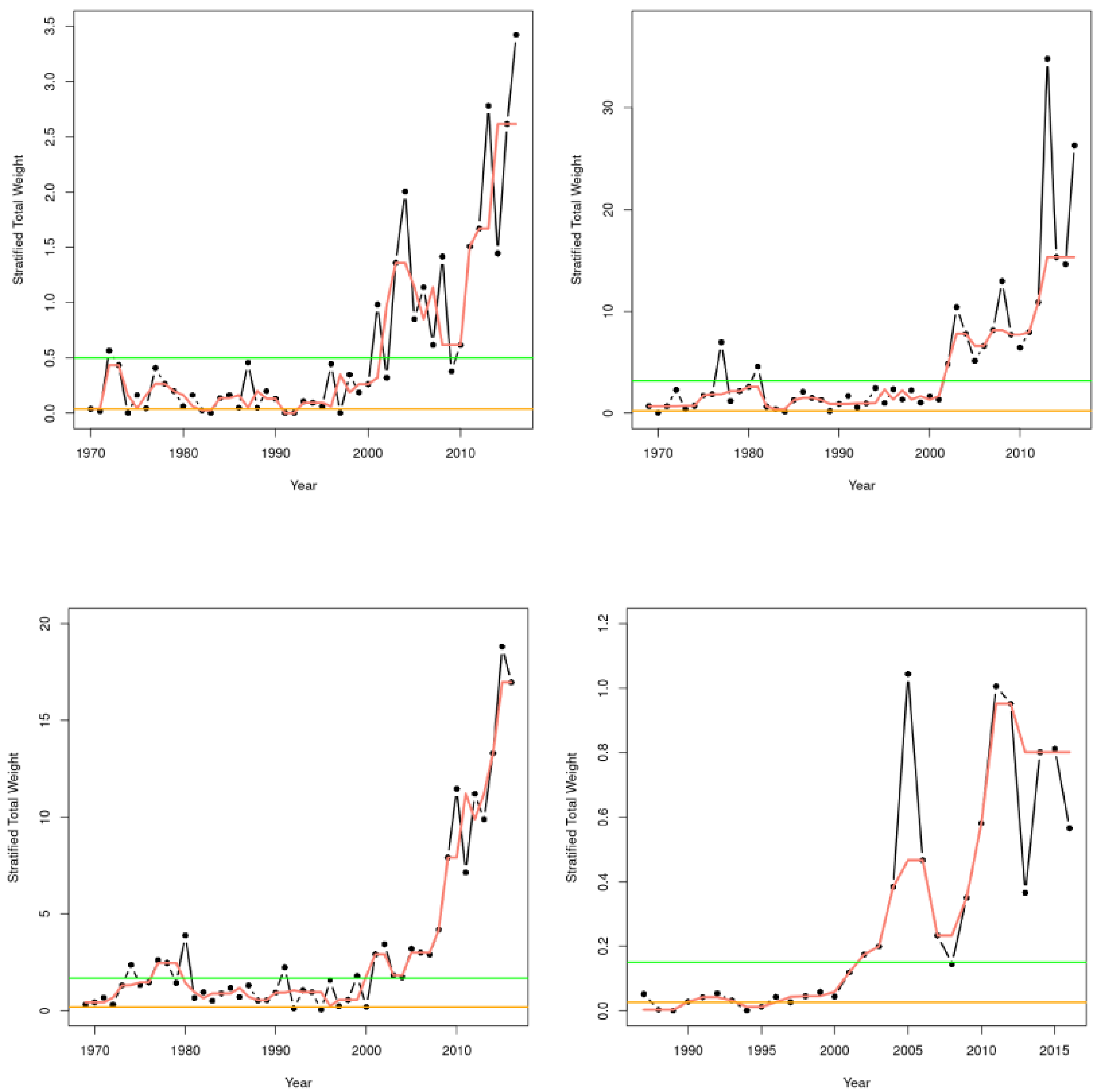

Figure 33. Commercial biomass time series along with the running median (red line) the median of the five lowest non zero biomasses (LRI ; orange) and 40% of the median of the higher productivity period (2000–2015;USI, green). Top row: left – RV41, right – NSpr41. Bottom row: left – NAut41, right – GB.

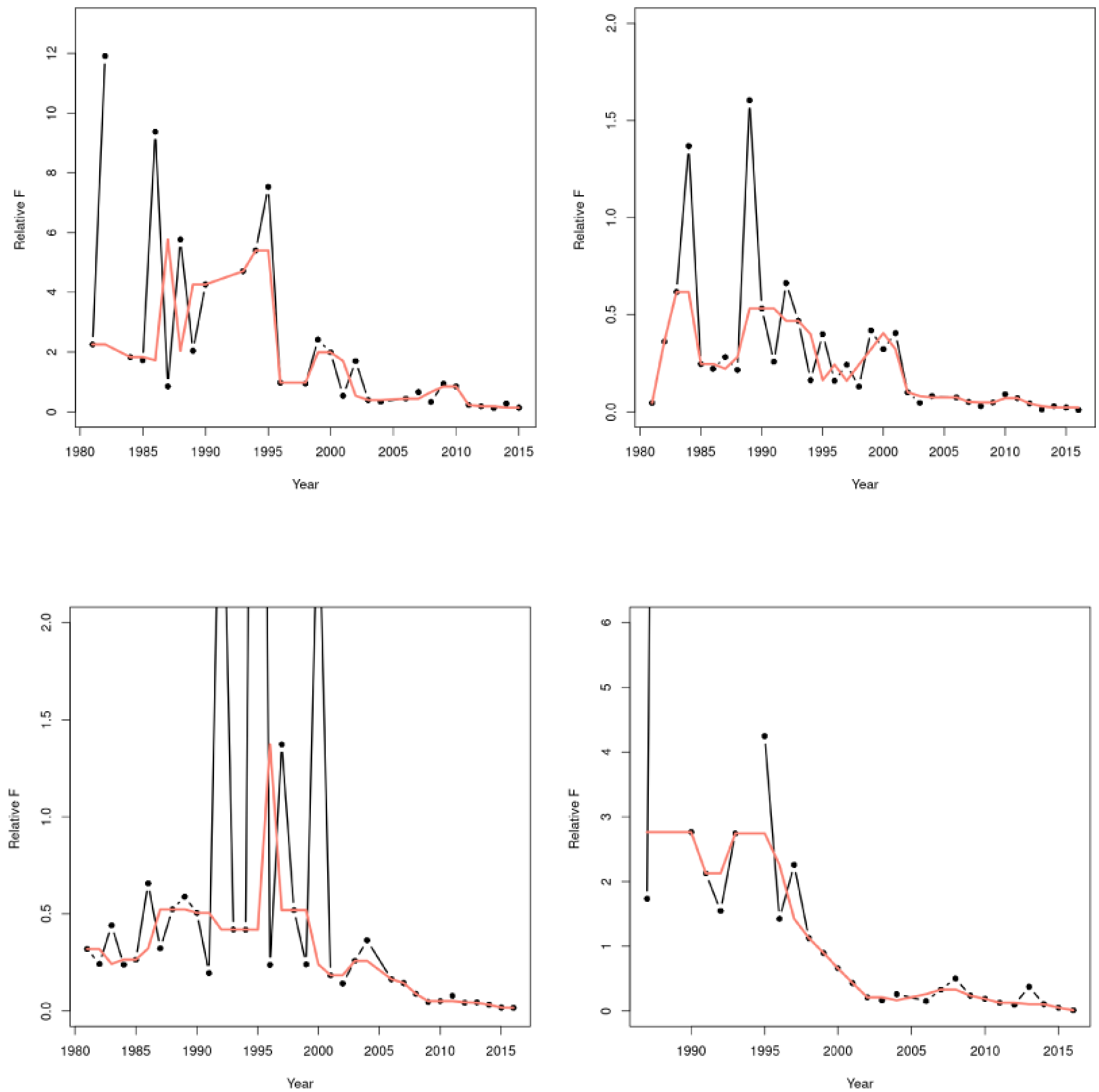

Figure 34. Relative fishing mortality (relF) along with the running median (red line) for each survey. Top row: left – RV41, right – NSpr41. Bottom row: left – NAut41, right – GB.

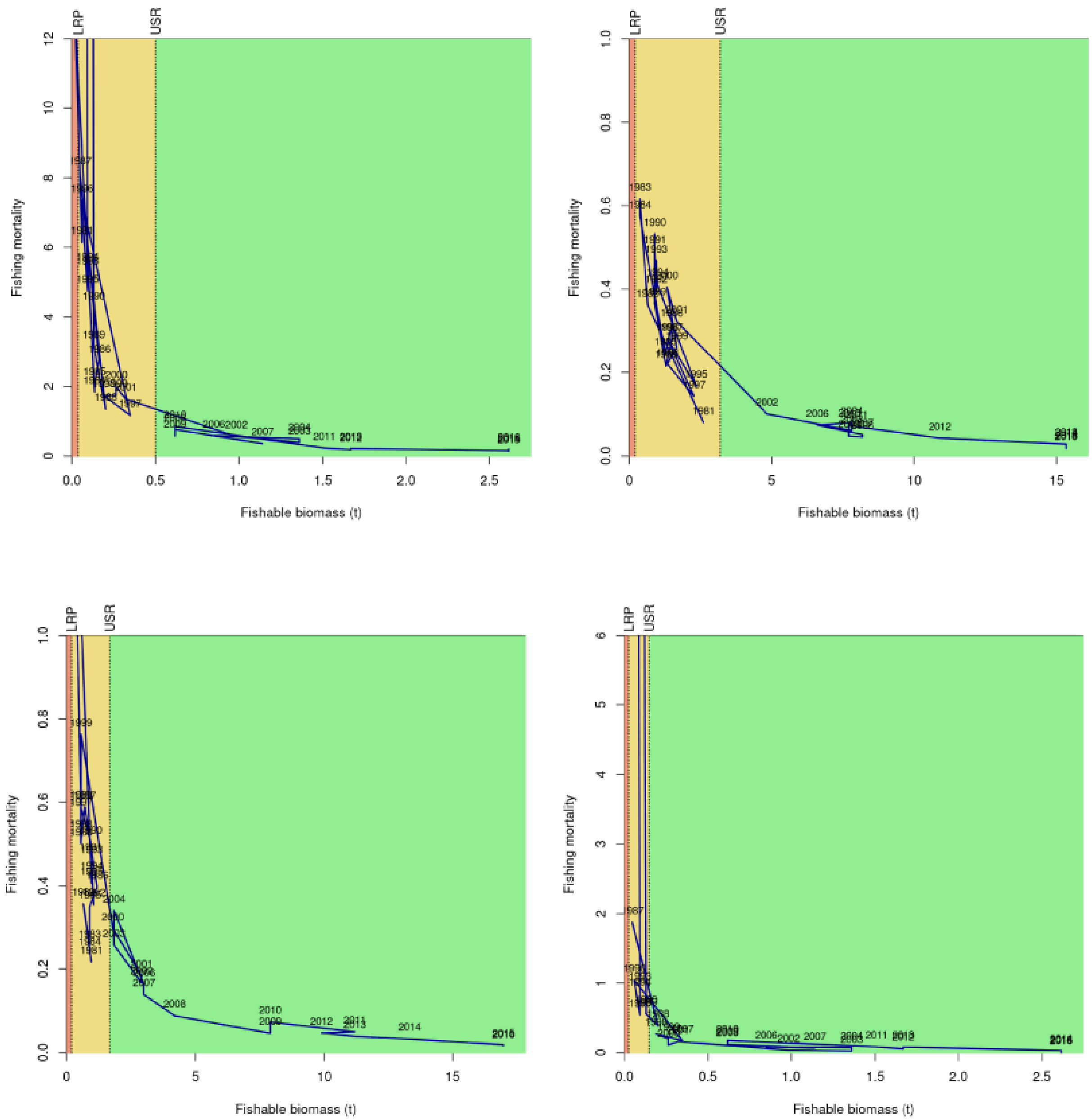

Figure 35. Phase plots showing the relationship between the running median of commercial biomasses and relative F for each survey. Top row: left – RV41, right – NSpr41. Bottom row: left – NAut41, right – GB. In all plots USI was defined using 40% of the median of commercial biomass the higher productivity periods and LRI was defined as the median of the 5 lowest non zero biomasses.

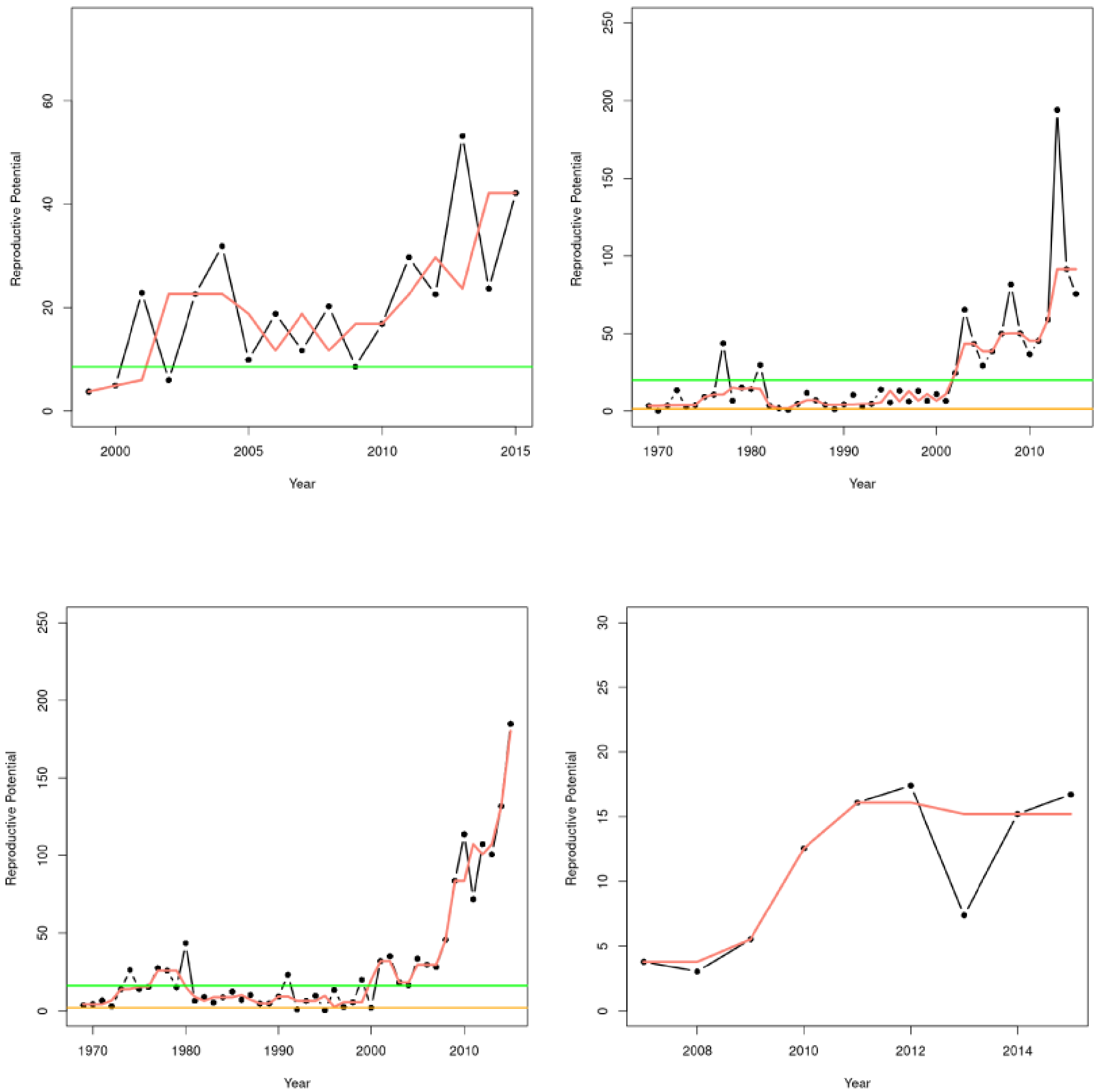

Figure 36. Reproductive potential in millions of eggs estimated from the four surveys covering LFA 41. Top row: left – RV41, right – NSpr41. Bottom row: left – NAut41, right – GB. Within panels reproductive potential time series along with the running median (red line). Where appropriate, the median of the five lowest non zero biomasses (lower boundary; orange) and 40% of the median of the higher productivity period (upper boundary; green) are shown (see text for details).

APPENDIX

APPENDIX 1. SIZE FREQUENCY DISTRIBUTIONS FOR BOTH THE SURVEY AND AT-SEA SAMPLES

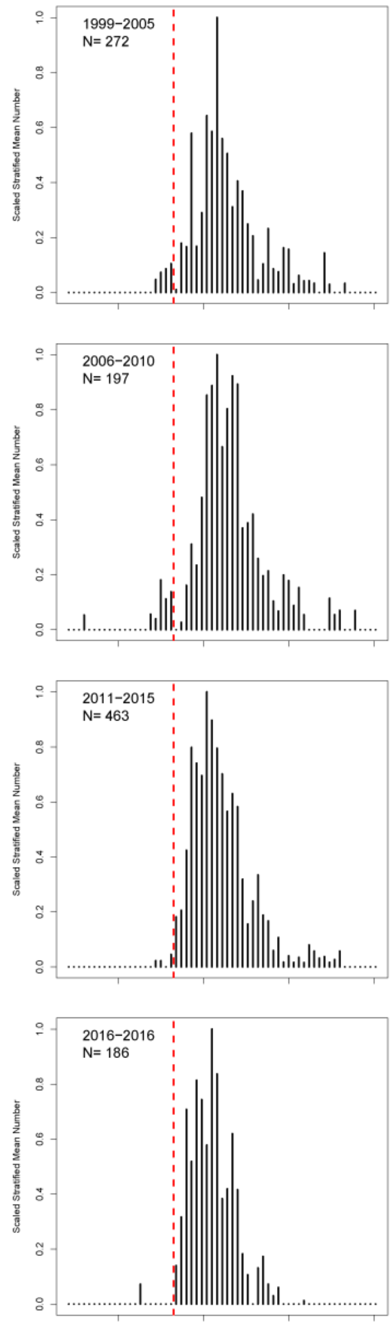

Figure A1. Carapace length frequencies of American Lobster captured during the DFO Summer RV survey with following the restratification strategy to areas within LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates the minimum legal size.

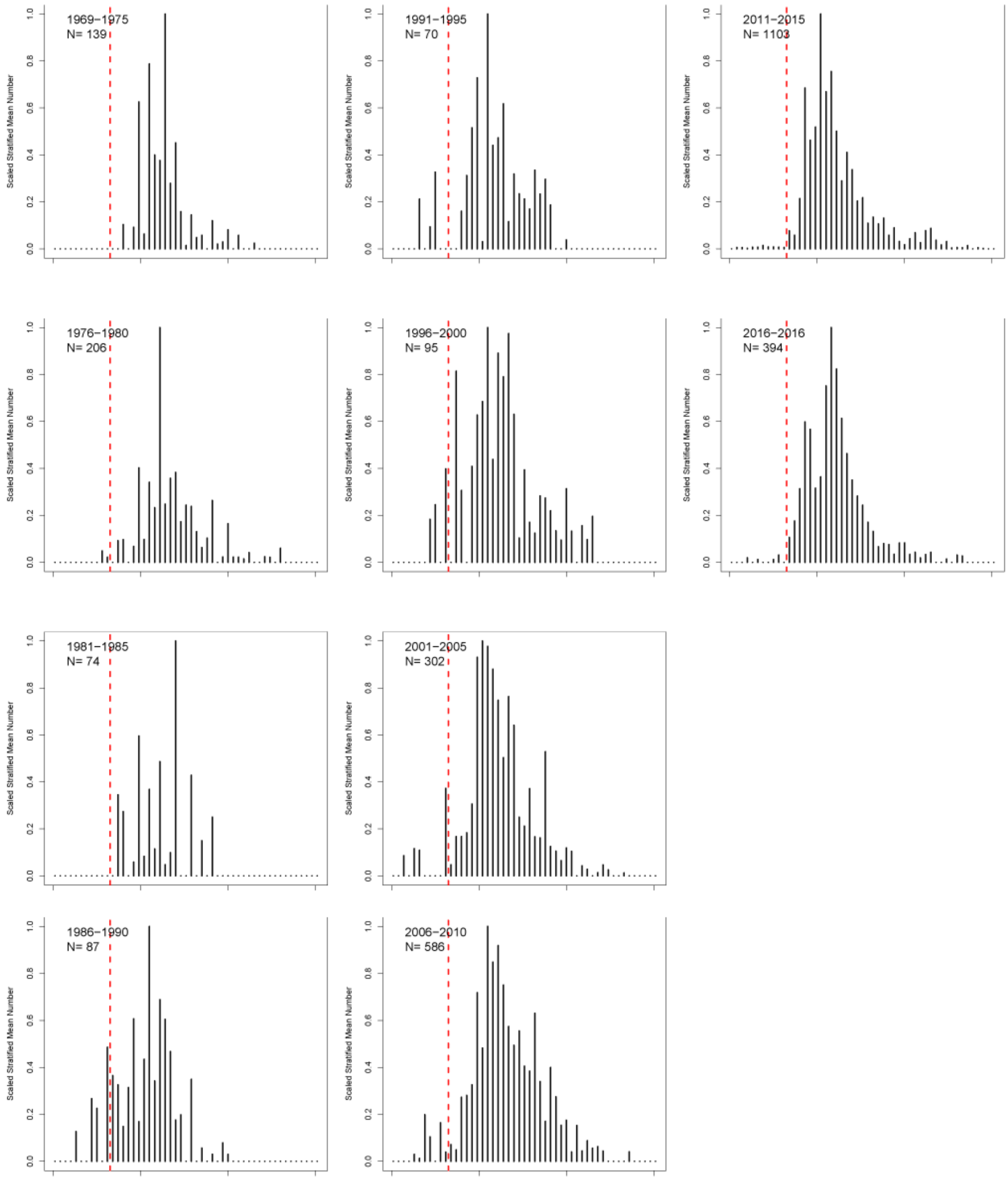

Figure A2. Carapace length frequencies of American Lobster captured during the Spring NEFSC survey with the restratified strata for LFA 41. The bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

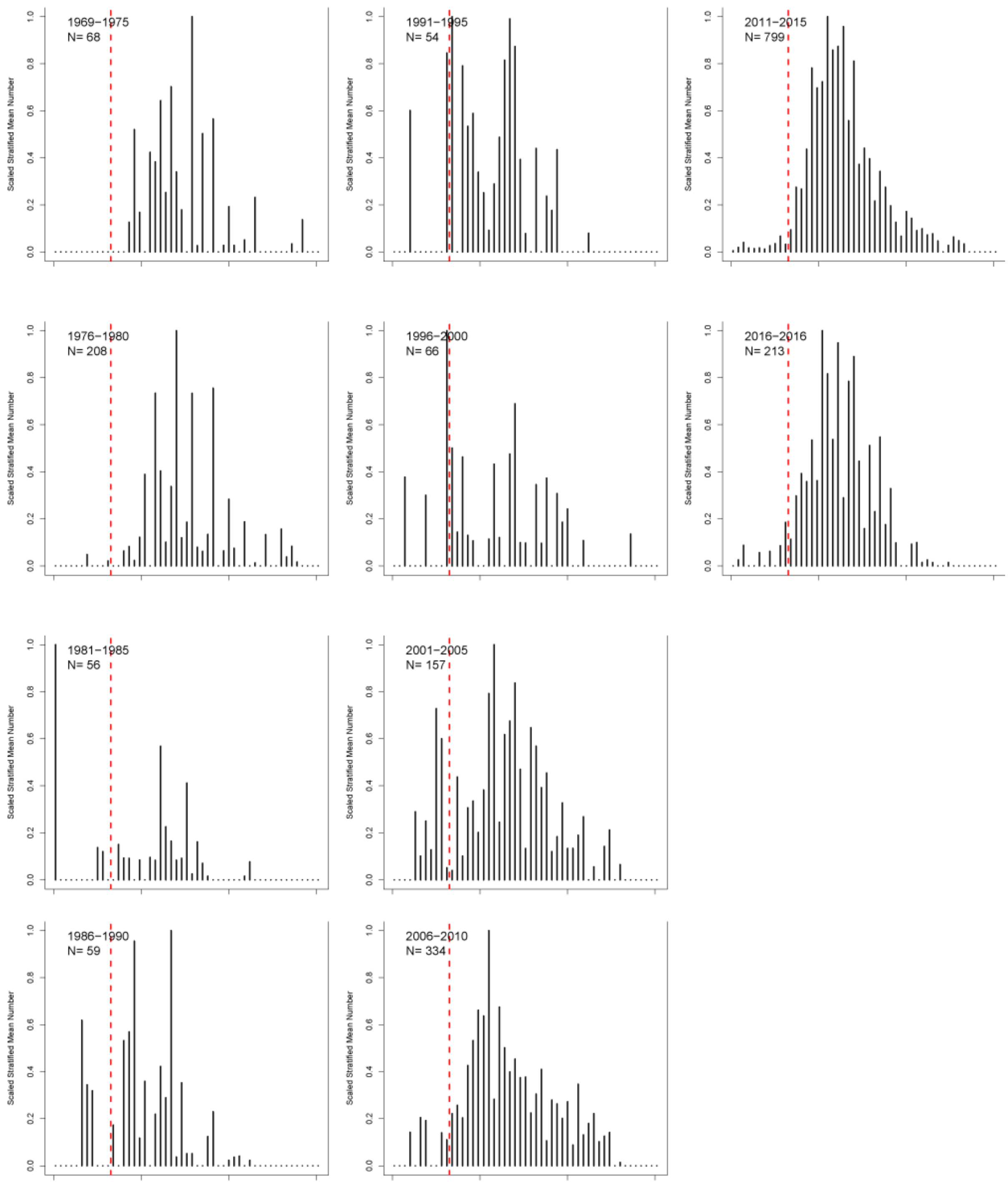

Figure A3. Carapace length frequencies of American Lobster captured during the fall NEFSC survey with the restratified strata for LFA 41. The bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

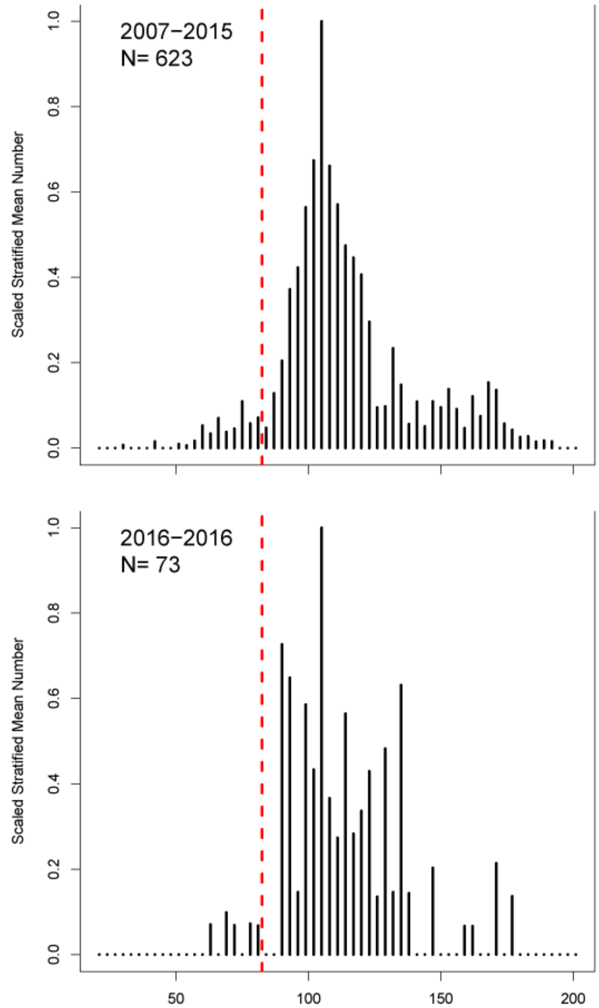

Figure A4. Carapace length frequencies of American Lobster captured during the Georges Bank survey within LFA 41. The bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

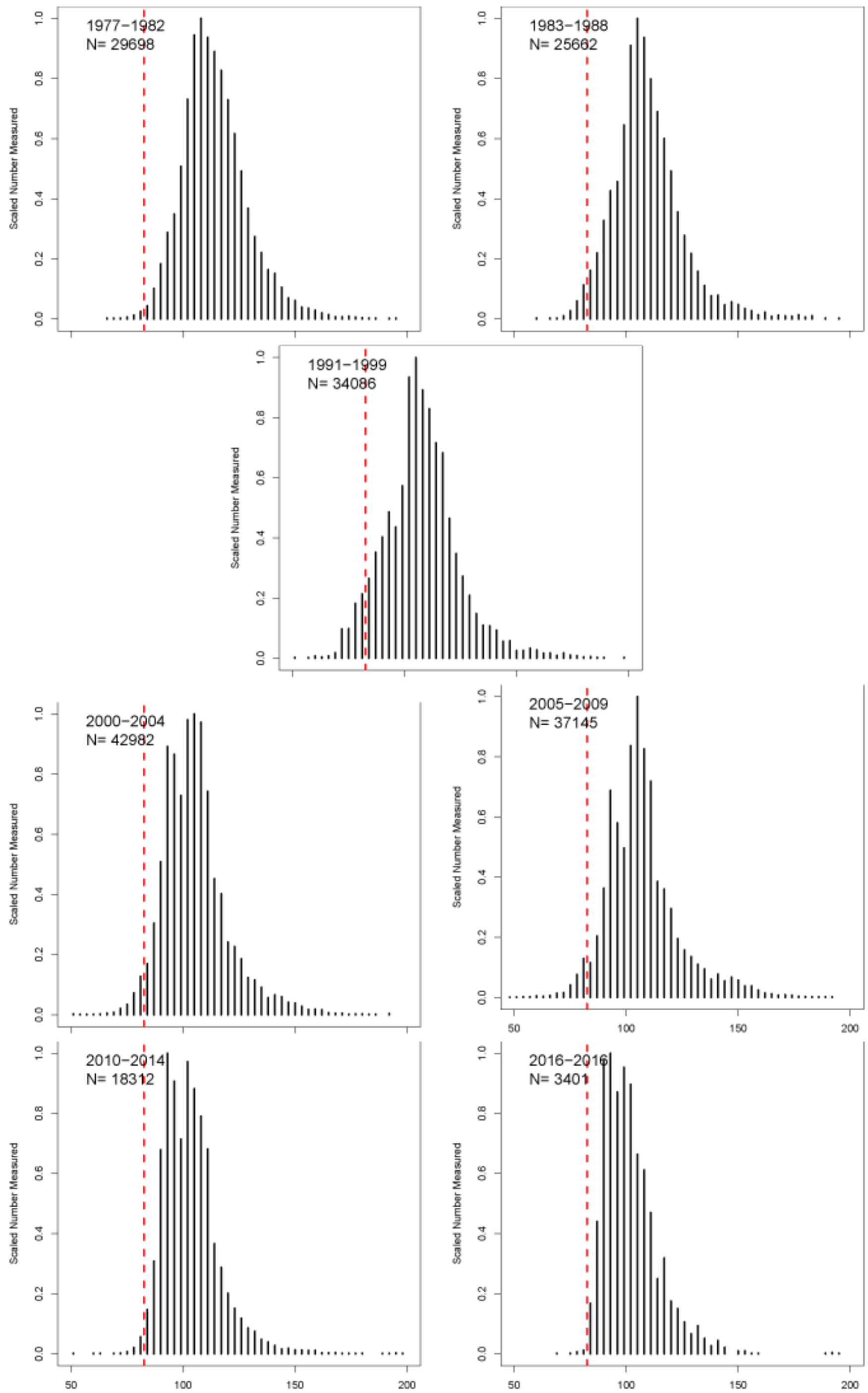

Figure A5. Southwestern Browns Bank carapace length frequency histograms binned into 3 mm groups. Red dashed line represents minimum legal size of 82.5 mm. Total sample sizes are shown in the legend.

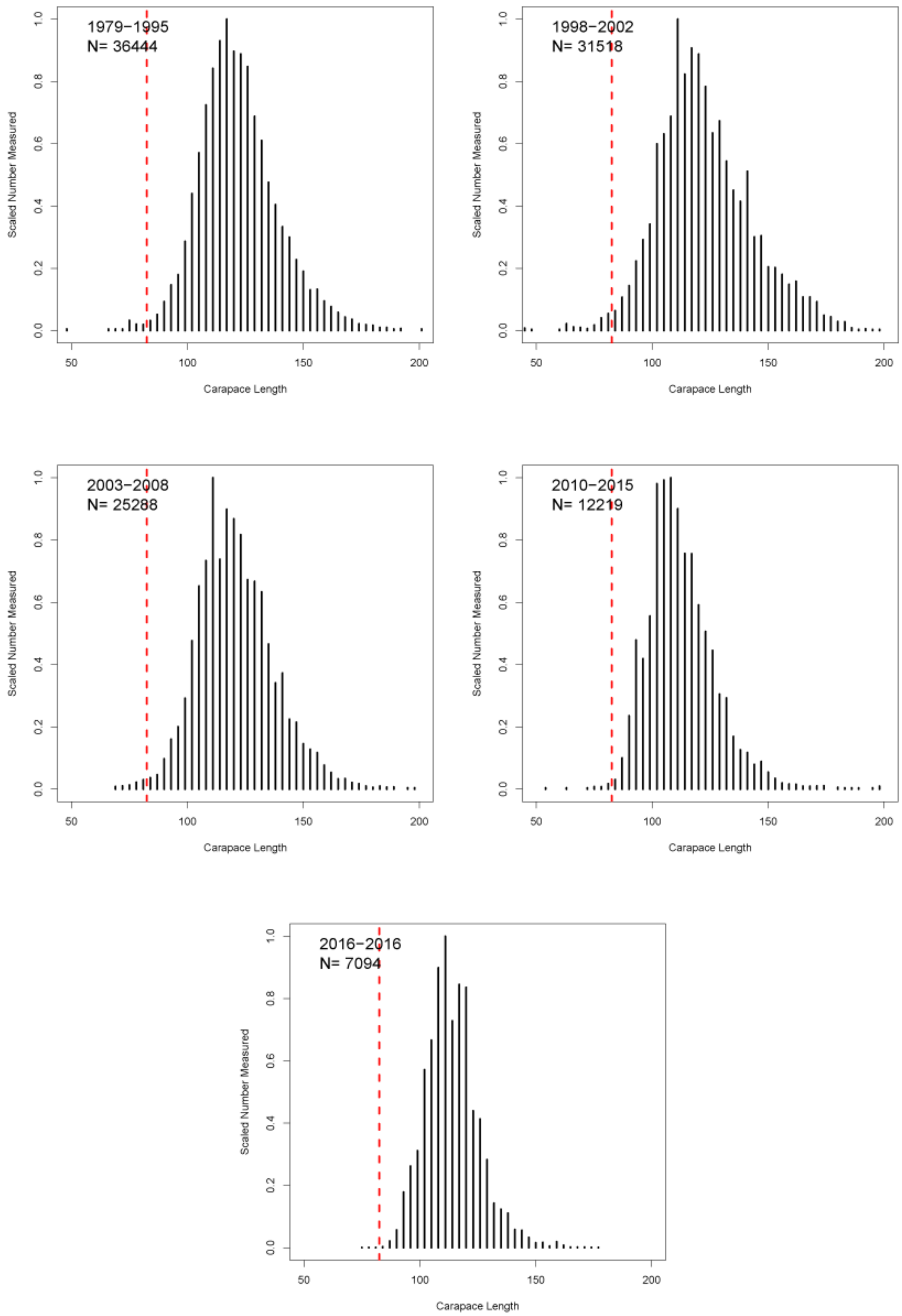

Figure A6. Southeastern Browns Bank carapace length frequency histograms binned into 3 mm groups. Red dashed line represents minimum legal size of 82.5 mm. Total sample sizes are shown in the legend.

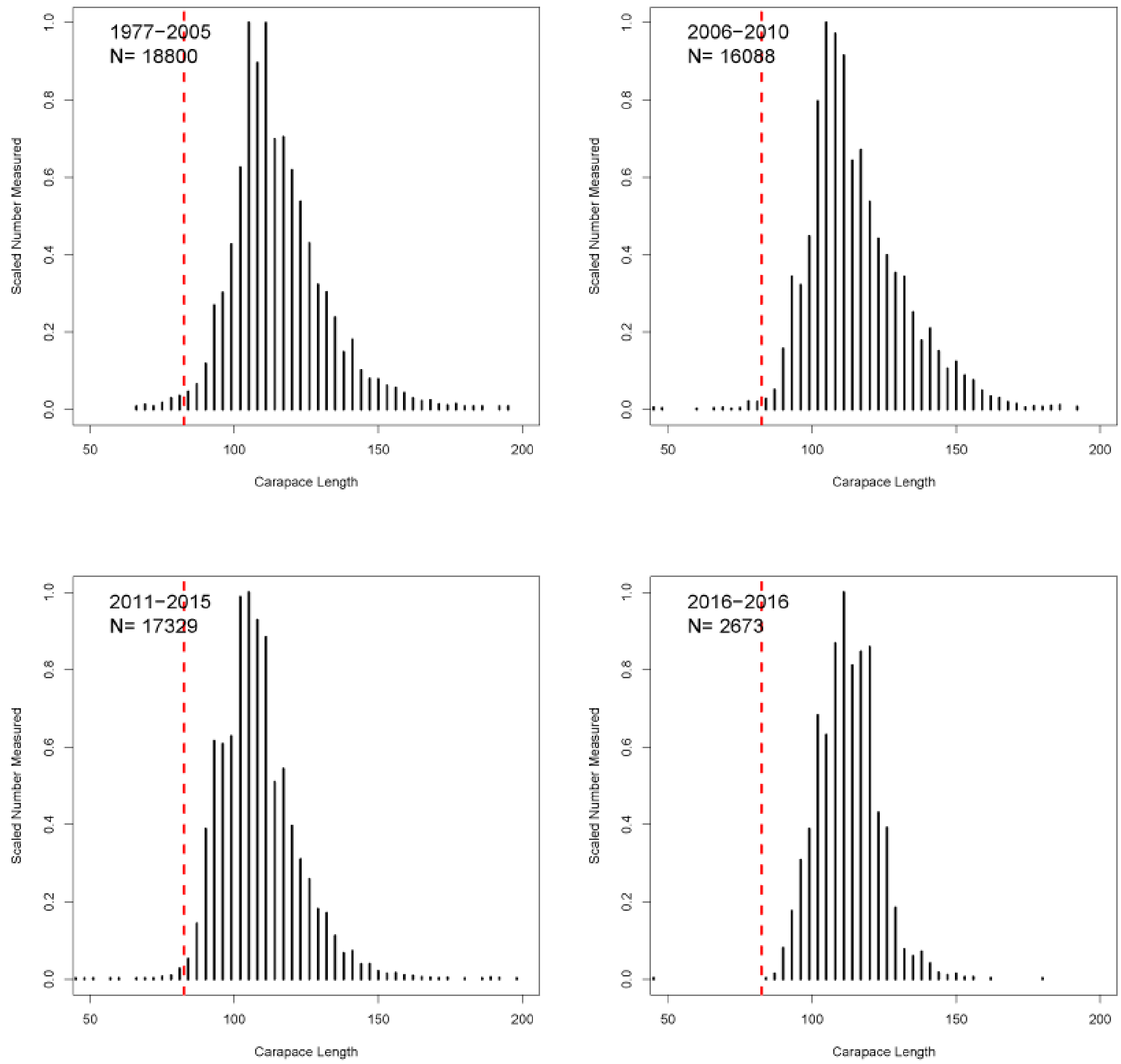

Figure A7. Georges Basin carapace length frequency histograms binned into 3 mm groups. The red dashed line represents minimum legal size of 82.5 mm. Total sample sizes are shown in the legend.

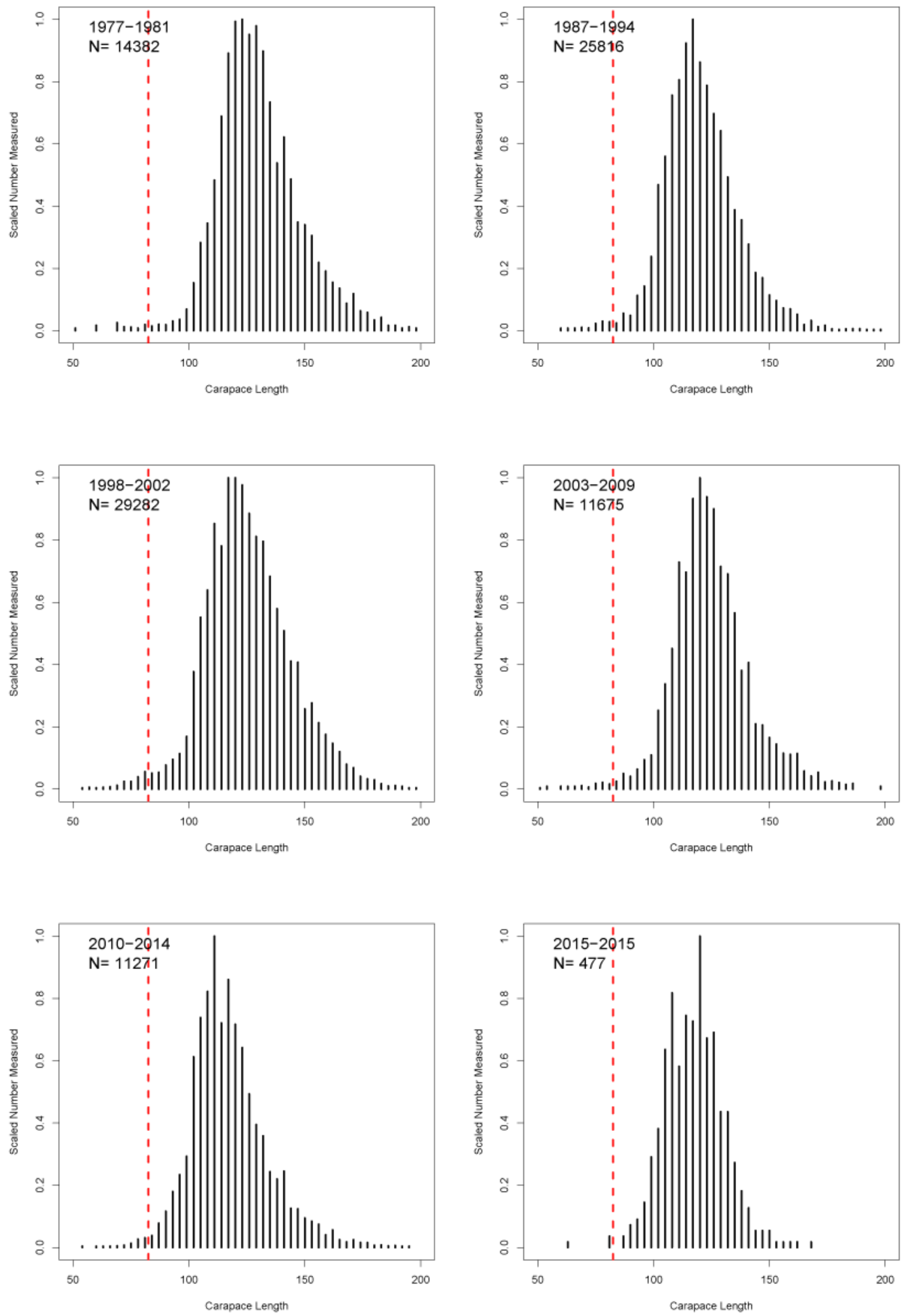

Figure A8. Georges Bank carapace length frequency histograms binned into 3 mm groups. The red dashed line represents minimum legal size of 82.5 mm. Total sample sizes are shown in the legend.