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Framework 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 (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, which are owned by a single corporation and are fished from a single vessel.

This stock assessment framework updates that of Pezzack et al. 2015 by exploring the impact of stock boundaries on indicator trends as well as expanding the suite of indicators used to describe the ecosystem and Lobster stock and exploring options for defining stock status and reference points.

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 provides 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, the Atlantic multidecadal oscillation (AMO) were provided to describe some of the external factors which 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.

The LFA 41 stock has never been assessed with a quantitative stock assessment model. Here, a biomass-dynamic model fit through Bayesian state-space methods was attempted for this stock. The carrying capacity parameter was not well defined and was influenced by the median of the prior distribution. The inability to define parameters was partially due to the lack of contrast in the data from the constant TAC despite increased survey biomasses. It was concluded that this quantitative model was currently inappropriate to provide estimates of stock status and reference points, but should be explored in future.

Data driven primary indicators and methods to develop upper stock and limit reference indicators (USI and LRI, respectively) were described. Several options for reference indicators were explored for each of the four surveys covering LFA 41, with the recommendation of a USI being based on survey biomasses from the high productivity period and a LRI defined similar to $B_{recover}$. Although each of the surveys had very similar trends in commercial biomass, with recent years being the highest on record, the recommendation was to continue using all four surveys and evaluate the overall stock status based on the status of 3 of the 4 survey trends. Specifically, 3 of 4 survey trends would need to be below their respective USI's in order for the stock to be considered in the cautious zone. Similarly, 3 of 4 survey trends would need to be below their respective LRI's in order for the stock to be considered in the critical zone

Methods to describe removal references were described; however, due to the stable TAC and currently increasing biomass, the impact of harvesting on stock status was not readily determined. The recommendation was to not provide a removal reference based on the information currently available.

A reproductive potential primary indicator was developed along with boundaries relating to stock productivity. Reproductive potential has long been considered an important component of Lobster stock productivity that is in need of protection, and although this may be more important for inshore Lobster fisheries that are largely recruitment fisheries, the LFA 41 Lobster stock is predominated by large female Lobsters. Removal references and stock status zones were not defined for the reproductive potential indicator; however, it was recommended to be tracked independent of the other indicators as changes may be indicative of the state of future stock productivity.

Analysis of bycatch data and research recommendations were also included in this framework document.

Évaluation cadre du homard du large d'Amérique (*Homarus americanus*) dans la zone de pêche du homard (ZPH) 41

RÉSUMÉ

La pêche hauturière du homard se pratique dans la zone de pêche du homard (ZPH) 41 depuis le début des années 1970 et est actuellement la seule zone canadienne où le total autorisé des captures (TAC) est en vigueur. Le TAC a été établi à 720 t depuis le milieu des années 1980 et n'a subi aucune modification, malgré les augmentations de la biomasse d'après les relevés. Nous comptons actuellement huit permis de pêche détenus par une seule société qui pêche à partir d'un seul bateau.

Cette mise à jour du cadre d'évaluation des stocks effectuée par Pezzack et al. 2015 a pour objectif d'examiner l'incidence des limites des stocks sur les tendances remarquées, de multiplier le nombre d'indicateurs utilisés pour décrire l'écosystème et l'état du stock de homard et d'explorer de nouvelles options pour définir l'état du stock et les points de référence.

Quatre relevés plurispécifiques au chalut effectués par deux organismes, Pêches et Océans Canada (MPO) et National Marine Fisheries Service (NMFS), ont eu lieu dans la ZPH 41 et les zones adjacentes. Chacun de ces relevés fournit des indices sur la biomasse et l'abondance, la fréquence de taille, le sex-ratio, la répartition et les variables environnementales. Six sorties observées en mer sont effectuées chaque année, ce qui fournit de plus amples renseignements sur les prises accessoires et davantage de données sur la taille et le sexe des homards.

Des séries chronologiques d'un ensemble d'indicateurs standards, y compris l'abondance totale, la taille médiane et maximale, le sex-ratio des spécimens matures et immatures, l'inégalité de distribution, la zone occupée, l'abondance des femelles de grande taille et l'abondance des recrues, ont été utilisées pour décrire les changements dans le stock de homard dans la ZPH 41 au fil du temps. De plus, les indices de l'écosystème, notamment la prédation, la température de l'eau de fond, l'oscillation multidécennale de l'Atlantique (OMA), ont été fournis pour décrire certains des facteurs externes qui pourraient avoir une incidence sur la productivité du homard. Tous les indicateurs ont été combinés et classés par une analyse modifiée des principales composantes pour afficher la cohérence des tendances des indicateurs au fil du temps. Dans l'ensemble, les tendances indiquent une diminution de la taille médiane et maximale des stocks de homards ainsi que la diminution de la pression exercée par les prédateurs au fil du temps, mais la hausse de l'abondance, de la répartition, de la température de l'eau du fond et de l'OMA.

Le stock de la ZPH 41 n'a jamais été évalué avec un modèle d'évaluation quantitative des stocks. Un ajustement du modèle dynamique de la biomasse par les méthodes bayésiennes de type état-espace a été tenté pour ce stock. Le paramètre de capacité biotique n'a pas été bien défini et a été a priori influencé par la médiane de la distribution. L'incapacité à définir des paramètres a été partiellement due à l'absence de contraste dans les données du TAC constant malgré l'augmentation de la biomasse de relevé. Nous avons conclu que ce modèle quantitatif est actuellement inapproprié pour fournir des estimations de l'état du stock et des points de référence, mais devrait être étudié à l'avenir.

Les données des indicateurs primaires, les méthodes pour augmenter les stocks et les limites de référence des indicateurs (ISSE et LRI, respectivement) ont été décrites. Plusieurs options pour les indicateurs de référence ont été examinées pour chacun des quatre relevés couvrant la ZPH 41; la recommandation d'une inspection des sites sans employés est fondée sur le relevé de la biomasse à partir de la période de grande productivité et une LRI semblable à $B_{recover}$. Bien que chacun des relevés était très semblable au cours des dernières années en ce qui concerne

la biomasse commerciale, d'ailleurs plus élevée que jamais, il a été recommandé de continuer à utiliser les quatre relevés et évaluer l'état global du stock en fonction de l'état de trois des quatre tendances observées. Plus précisément, trois des quatre tendances observées devraient être sous leur indice d'inspection des sites sans employés pour que le stock soit pris en compte dans la zone de prudence. De même, trois des quatre tendances observées devraient être sous leur indice de limites de référence des indicateurs pour que le stock soit pris en compte dans la zone de prudence.

Les méthodes utilisées pour décrire les taux d'exploitation de référence ont été décrites, cependant, en raison de la stabilité du TAC et la hausse actuelle de la biomasse, l'incidence de la pêche sur l'état du stock n'était pas facile à déterminer. La recommandation était de ne pas fournir un taux d'exploitation de référence en fonction des renseignements disponibles à l'heure actuelle.

Un indicateur principal, le potentiel de reproduction, a été élaboré parallèlement à des limites relatives à la productivité du stock. Le potentiel de reproduction a longtemps été considéré comme une composante importante de la productivité du stock de homards qui a besoin de protection. Bien que cela pourrait être plus important pour les pêches côtières au homard qui sont principalement des pêches par quotas, le stock de homard dans la ZPH 41 est prédominé par des homards femelles de grande taille. Le niveau d'exploitation de référence et l'état du stock des zones n'ont pas été définis pour l'indicateur de potentiel de reproduction; toutefois, il a été recommandé de faire un suivi indépendant des autres indicateurs, puisque d'autres changements peuvent indiquer l'état de la productivité future des stocks.

L'analyse des données sur les prises accessoires et les recommandations de recherche ont également été incluses dans ce document-cadre.

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 the 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 it has a total of 8 licenses. In 1979, an area known as LFA 40 was closed to Lobster fishing on Browns Bank. This closure was to protect Lobster broodstock, and continues to remain in effect today. An official boundary between Canada and the USA 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 and 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 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 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 it relies on moulting its exoskeleton for an increase in size. Typically, the mature females mate after moulting 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 moults, become motile larvae. These spend 30-60 days feeding and moulting 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). At this size, 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 moult 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. 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 costal 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 maintain 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.

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 summer (Cooper and Uzmann 1980, 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

The LFA 41 Lobster stock has a long history of assessments, with among the earliest being presented by Pezzack and Duggan (1983). The focus of early assessments was on fishery performance, spatial extent of the fishery and median size of the catch. It was recognized early on that commercial catch rates likely do not reflect abundance trends in the stocks due to the limited number of licences, changes in trap design (in the mid-1970s changed from top to side entry Pezzack and Duggan 1995) and the wide spatial extent (Pezzack and Duggan 1983; 1985). Moreover, the changes in vessel size (1985; Pezzack and Duggan 1987) and more recently the reduction in the number of active vessels in this fishery to one, decreases the value of commercial catch rates as an indicator of stock status.

Size frequencies of commercial catches have been regularly collected since the early 1980s with sporadic collections prior to that time (Pezzack and Duggan 1987). Regional differences in the median size of landed Lobster within LFA 41 have been evident since the start of the fishery (Pezzack et al. 2015). During the early phase of the stock assessments, there was no evidence of decreases in median size of the Lobsters, supporting the idea that fishery removals did not destabilize the stock (Pezzack and Duggan 1985). It has always been suggested that the LFA 41 fishery is not a recruitment fishery as is the case in the inshore due to the persistence of a larger size distribution and overall larger Lobster constituting the catch in the offshore.

Fishery independent bottom trawl data on Lobster was incorporated in the 1995 LFA 41 Lobster assessment (Pezzack and Duggan 1995). Specifically, the body size and catch rate trends from the National Marine Fisheries Service Northeast Fisheries Science Center (NEFSC) spring and autumn bottom trawl survey series were included in the assessment. These trawl surveys collected information on Lobster prior to the start of the fishery (1969) to present. While recognizing these trawl surveys were highly variable, the increasing or stable trends in survey catch rates at that time suggested the Lobster population was growing in abundance (Pezzack and Duggan 1995).

Despite the concerns with commercial catch rates in LFA 41, a standardized catch rate analysis was performed in 2000 and 2001 (Claytor et al. 2001). The models explored the seasonal, annual and regional change in commercial catch rates through generalized linear modelling. There were significant correlations between areas and suggested a peak in catch rates through the mid-1990s that decreased through 2000-2001 (Claytor et al. 2001).

These catch rate models were presented again at the 2009 assessment, along with a suite of indicators from fishery, at-sea samples and research vessel surveys (Pezzack et al. 2009). Both the DFO Summer RV survey, DFO Georges Bank Survey and the NEFSC surveys were included in the analysis, as well as catch rate trends and size structure information. Furthermore, a comparison of ecosystem considerations including fishery footprint, spatial distribution of landings and survey indices, environmental conditions and predator prey dynamics were also included. Survey indices were compared using a process similar to a traffic light approach to indicate increases, decreases or no change in indicators.

Pezzack et al. (2015) continued to build on the 2009 document and developed a suite of primary and secondary indicators with upper and lower bounds to assess the LFA 41 Lobster stock. The primary indicators identified were grouped into abundance, exploitation and reproductive potential indicators. The abundance indicators included the stratified mean abundance of Lobster in the DFO Summer RV survey and DFO Georges Bank Survey. The exploitation rate indicators were the stratified mean catch rate of large females (>140 mm) in the DFO Summer RV survey and the NEFSC autumn survey. Reproductive potential indicators were defined as the median size of Lobsters from the DFO Summer RV survey and the NEFSC autumn survey, as well as from sea samples collected during fishing activities within specific areas and seasons.

Secondary indicators were grouped as abundance, population structure and recruitment indicators. The secondary abundance indicator was based on the proportion of sets containing

Lobster from the DFO Summer RV and DFO Georges Bank surveys. Population structure indicators were the time series of sex ratios from the DFO Summer RV survey and the NEFSC autumn survey. The recruitment index was described by the DFO Summer RV survey and the NEFSC autumn survey as the stratified mean number per tow of Lobsters <82.5 mm.

Boundaries for indicators were based on trends from historical data and biological parameters with full details being described in Pezzack et al. (2015). These stock status indicators as well as a number of ecosystem indicators were included in a traffic light approach (Caddy 2002) to show the stock status in a holistic context. Some of the spatial analyses and catch rate analyses conducted in the 2009 and previous assessments were no longer relevant in 2015 as the fishery was being exploited by one vessel under the operation of a single corporation.

Following the framework of 2013 (published in Pezzack et al 2015), stock status updates were prepared in 2014, 2015 and 2016 based on the indicators presented and briefly described above. During these stock assessment updates, discussion centered on the applicability of the indicators for providing TAC advice as removal references and stock status zones were not identified. The applicability of median length as a proxy for reproductive potential was also a topic of discussion as median length can decrease from either a decrease in the number of large individuals, an increase in recruitment or both. Furthermore, the sensitivity of indicators to the survey strata was questioned as the strata included by Pezzack et al. (2015) contained areas outside the LFA 41 stock boundaries, including the closed LFA 40. These discussions were the impetus for the current LFA 41 stock assessment framework.

It is important to note that the healthy stock status for LFA 41 presented in each of those stock status updates was never debated. Moreover, there have been no concerns raised over the harvest strategies and apparent exploitation rates of the offshore fishery on the Lobster stock. The long history of constant TAC (720 t) was sustainable during periods of lower stock abundance than is currently present (see below).

In the current stock assessment framework, several of the concerns raised during the stock assessment updates will be addressed. Specifically, options for reference points consistent with DFO’s precautionary approach policy (see below) will be identified, the sensitivity of the indicators to the choice of survey strata will be explored and a new option for assessing reproductive potential will be presented. Additionally, simple stock assessment modelling methods will be applied to the LFA 41 Lobster stock dynamics and graphical displays of multiple indicators will be explored. Further work will explore the impact of grouping years of bycatch data on trends in catch rates.

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 1985-2005 the season was October 16th to October 15th. 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 5 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 to adequately 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 are 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 can be 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 and include several areas, 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. In some years, areas were not fished or fished but not sampled. LFA 41 observer coverage from 2002 to present are less than 10 observer trips annually and usually consist of more than one subarea (Table 2). 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 interannual sensitivity of the discard estimates from the entire stock area was explored by combining years at 1, 3 and 5 year groupings to provide the overall snapshot of the bycatch profile.

FISHERY INDEPENDENT

DFO Summer RV Survey

The DFO Summer 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. This survey was originally designed to provide abundance trends for groundfish at depths from about 50 m to 400 m, but it provided total numbers of Lobsters captured throughout its duration. Beginning in 1999 during DFO Summer RV 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 this survey. There were vessel changes in 1981 and again in 1982 from the *Research Vessel (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 *RV 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 experiments 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 (nautical miles). Catch rates for tows that deviated from 1.75 nm were standardized.

Regional size differences in the trawl survey do not 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 this 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 and adjacent areas 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 Georges Bank Survey

The DFO Georges Bank 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 this 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 this 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 Surveys

The NEFSC 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 will be 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.

NEFSC 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 of these 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-present, the *RV Bigelow* became the survey vessel for both spring and autumn NEFSC 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 and adjacent areas included 1160, 1170, 1180, 1190, 1200, 1210, 1220, 1290, 1300, 1340, 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 Figures 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 DFO Summer RV Survey and NEFSC surveys have survey strata boundaries that do not conform to stock boundaries of LFA 41 (Figures 3 and 8) and, thus, survey indices were examined in several ways. First, survey indices were estimated using the survey strata included in and straddling the LFA 41 stock boundaries (strata defined above). Survey trends resulting from this method will be referred to as the RVbase, NSprbase and NAutbase representing DFO Summer RV survey, NEFSC Spring survey and NEFSC Autumn survey, respectively.

The second method involved pruning survey strata to match the stock boundaries of LFA 41. Under this estimation method, for each survey 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 DFO Summer RV survey, NEFSC Spring survey and NEFSC Autumn survey, respectively.

Additionally survey areas adjacent to, but outside of, LFA 41 were examined. For this, the base surveys were again pruned to use only those strata adjacent to and straddling the LFA 41 boundaries; however, under this method the areas *within* LFA 41 stock boundaries were excluded from the ‘base’ strata, leading to a new strata set h_i''. Again, only survey stations contained within h_i'' were retained. Strata weighting was adjusted to reflect the new polygons representing the new polygon areas. Survey trends resulting from this method will be referred to as the RVAdj, NSprAdj and NAutAdj representing DFO Summer RV survey, NEFSC Spring survey and NEFSC Autumn survey, respectively.

The strata boundaries for the DFO Georges Bank survey were divided along the Canadian – USA 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 EFFICIENCIES

The appropriateness of survey strata for defining Lobster abundance trends has routinely been raised (e.g. Pezzack et al. 2015). An analysis was conducted to determine the effectiveness of the stratification scheme for the base, pruned and adjacent surveys. The GB survey was not analyzed as only two strata were included in analyses.

Generally, stratified random surveys (STRS) are designed such that the variances between strata are greater than those within strata. This strategy should increase survey efficiency over a simple random survey (SRS) as part of the variance should be accounted for by appropriate choice of strata characteristics. If strata are chosen that do not characterize the species distribution, there will be minimal improvement in variance when compared to a SRS. Each survey design's efficiency was determined using the methods of Smith and Gavaris (1993). Briefly, this method assesses the change in estimated variance if survey data were analyzed as a STRS compared to that estimated if the survey were analyzed as a SRS. The estimator of the difference between variances can be further partitioned into the gains based on stratification scheme and those based on the allocation scheme. The efficiency gains from the strata scheme can be positive, negative or zero, depending on whether the stratification improves variances estimates or offers no improvement, respectively. Similarly, the efficiency from the allocation scheme can be negative or positive if the allocation scheme is essentially arbitrary, or if it approaches optimal allocation, respectively. All survey efficiency analyses were conducted using abundance data. Analyses were limited to 1999 to 2015 to ensure catch rates were sufficiently high for developing reasonable variance estimates on which to perform these analyses.

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 Cochran (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}, $3_{zn-1} – 2_{zn-2}$) (Tukey 1977).

RESULTS

BYCATCH

Since 2012, at-sea coverage on a per-trip basis was approximately 15%, whereas the coverage of at-sea sampling by weight was approximately 3.8% (Table 3; Figures 11 and 12). The number of samples per year has been variable over time, although there was an increase in the weight of Lobsters sampled for the same number of trips in 2008 and 2009 compared to 2015. The monthly distribution of the at-sea sampling coverage by weight and trip closely match the within year distribution of fishing effort in most years (Figures 11 and 12) and, thus, was assumed to sufficiently characterizes the size distribution of Lobsters in the landings.

Using the at-sea samples to characterize the bycatch requires the assumption that the observed trips are representative of a typical fishing trip. Given the predetermined schedule for at-sea sampling, there is potential for biases in the at-sea sampling as have been identified in other fisheries (Benoit and Allard 2009). That said, estimates of bycatch were provided assuming sampling was representative of the commercial fishing practices.

Bycatch species that occur most frequently in the LFA 41 Lobster fishery include Jonah Crab, Cusk, Atlantic Cod, Red and White Hake, and Haddock (Tables 4 and 5). 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 bycatch has declined since 2006 from 126 t to 19 t in 2015, which represented 3% of the total Lobster landings (Table 6). 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. The bycatch of all species declined with the exception of combined hake (White, Red and unspecified –NS), Rosefish and Haddock (which showed minor changes, Table 5). Cusk represented the largest estimated bycatch in 2015 at 6.7 t. Atlantic Wolffish or Monkfish were observed in the recent years. Table 6 shows estimated bycatch of the species or species groups observed in the LFA 41 Lobster fishery 2006 to 2015.

With regard to non-retained Lobster catch, approximately 18.5% of the Lobsters caught are returned to the sea. In 2015, sublegal sizes account for 2% of the returns, Lobsters greater than 6 lbs, 7%, and berried females, 32% (Table 7). The non-retained Lobsters in LFA 41 are predominantly berried females or 'jumbo' Lobsters. 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, which suggests changes in the size composition of the stock (see section on size indicators below). In 2015, the sample size from at-sea samples was 30% less than what has been collected in the last 3 years. All measures that return Lobsters to the water contribute to maintaining the high reproductive potential in this stock.

Aggregating the at-sea observer data at three and five year time blocks resulted in a smoothing of the bycatch rates (Figure 13). The top three bycatch species, Cusk, Atlantic Cod and White Hake, retained their high ranks regardless of the grouping; however, the five year grouping of bycatch rates may not provide an accurate reflection of the fisheries impact on bycatch species. For example, annual estimates of Cusk bycatch, showed a peak in 2007 and 2008, which are represented in the 2006-2008 time block in the three year aggregation and the 2006-2010 time block in the five year aggregation (Figure 13). The five year aggregation suggests that Cusk bycatch remained high for a longer period than the data supports. A three year aggregation provided a reasonable trade-off between increasing sample sizes to reduce the interannual variability and maintaining a short enough time block to allow for description of the short-term changes in bycatch profiles.

Future work should be directed toward determining if biases exist in bycatch rates resulting from the predetermined sampling schedule used in the LFA 41 fishery. The sampling schedule was originally designed to provide information on the Lobster stock characteristics including carapace length profiles and information on the non-retained Lobsters. In order to determine if biases exist in bycatch data, a random deployment of at-sea sampling could be performed along with the existing scheduled deployments. By comparing several years of data from these two types of deployment, differences in bycatch profiles could be examined, which would improve confidence in the currently presented data.

OVERALL SURVEY RESULTS

Survey Efficiency

The fisheries independent trawl data sources used here all employ stratified random surveys, which provide unbiased information on the stock status of the Lobster in the area that are available to trawls. Although the original surveys were not originally designed to reduce the variance of Lobster catch as they were considered groundfish surveys, with stratification schemes defined by region and depth zones, the results of the survey efficiency analysis suggests that significant proportion of the total variation was explained by the stratification scheme (Figures 14-16). Specifically, the average reduction in variance accounted for by the stratification scheme was 19% for the NSprbase, 14% for the NAutbase and 18% for the RVbase survey. Similarly the pruned survey stratification schemes reduced the total variance of abundance by similar levels across all surveys (Figures 14-16). Allocation efficiencies were more variable but generally resulted in decreased variance for the all stratification schemes of the DFO Summer RV, NEFSC Spring and NEFSC Aut surveys (Figures 14-16).

Sample Sizes

RVbase had an increase in the sampling intensity after 1986 going from annual averages of 26 to 41 to stations (Table 8).The NEFSC surveys had little variability in the number of stations sampled annually with overall averages of 68 for the NAutbase and 65 for the NSprbase (Tables 9 and 10). By comparison the GB survey was more variable in its coverage with between 16 and 62 stations sampled annually (Table 11). The pruned surveys, NSpr41, NAut41 and RV41 contain 33%, 34% and 38% of the annual allocation of sets when compared to the base surveys, respectively (Tables 8-11).

The observed numbers of Lobster within surveys has increased dramatically across all surveys in recent years (Tables 8-11). The percent of total Lobsters observed in the survey stations pruned to LFA 41 compared to the based surveys was variable across surveys. Specifically, over the past five years the mean annual percent of Lobster observed in NSpr41, NAut41 and RV41 were 67%, 40% and 18%, respectively (Tables 8-11).

Survey Pruning

Results of the survey pruning were presented in Appendix A, with some general patterns prevailing. Trends in the abundance and biomass indicators were particularly sensitive to the choice of survey area or pruned area, whereas; the trends in distribution and size based indicators were similar within surveys irrespective of area. From the DFO Summer survey the abundance and biomass indices for RV41 were markedly lower than those compared to RVAdj, indicating more Lobster are located in the areas adjacent to LFA 41 stock bounds. These Lobsters were clearly visible in the bubble plots shown in Figure 5, where a large number of Lobsters can be seen in the adjacent LFA 40. This gives credence to the value of LFA 40 as a conservation area as there are large numbers of Lobsters congregating in the area (at least during the summer months). In both NEFSC spring and autumn surveys, the area pruned to LFA 41 had higher abundance and biomass indices than adjacent areas.

For the remainder of the document, all Lobster specific indices presented represented the surveys pruned to LFA 41 stock boundaries. It was recognized that there is likely connectivity between LFA 41 and adjacent areas as shown through the tagging studies in the 1970s and 1980s (Cooper and Uzmann 1980, Uzmann et al. 1977, Pezzack and Duggan 1986). It is unknown if these movement patterns are temporally stable given the dramatic shifts in stock sizes, productivity and environmental conditions in recent years. Given this uncertainty, it was deemed more precautionary to estimate indices using the information from within the LFA 41 stock boundaries until updated information on connections between stock areas is gathered.

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. For comparison to Pezzack et al. (2015), the indicators presented in that document will be estimated with the up to date information in respective sections.

Some indicators developed 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 Spring and Autumn 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 RV41 and GB all Lobster captured in tows were considered in this analysis. Total abundance from the NSpr41 and 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).

To maintain consistency across framework assessments, in addition to the surveys defined above, strata groups used by Pezzack et al. (2015) were used to compare to the overall abundance trends estimated here. The strata groupings used by Pezzack et al. (2015) for this indicator were DFO Summer RV Strata 477, 478, 480-484 and DFO Georges Bank Survey Strata 5Z1-5Z4.

Stratified total abundance estimates were computed following traditional procedures outlined by Cochran (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 17). 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 15). 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 GB survey mean Lobsters·tow-1 was again low and variable until 2003, decreased though the late 2000s, but are currently at among the highest catch rates on record (Figure 17).

The Pezzack et al. (2015) abundance trend indicator from the DFO Summer RV survey shows similar trend, but increases in Lobster abundance are much greater than for the RV41 pruned survey. These differences are due to the Pezzack indicator including the strata for LFA 40, which, as mentioned above, has some of the highest abundances in the survey (Figure 18). The Pezzack et al. (2015) Georges Bank abundance indicator showed similar patterns to the GB survey pruned to LFA 41; however, the catch rates were lower for Pezzack et al. (2015) due to the lower abundance of Lobster on the American side of Georges Bank (5Z3, 5Z4; Figure 19).

All surveys pruned to LFA 41 stock boundaries had similar catch rates of between 5 and 10 Lobsters·tow^{-1} in the recent, high catch rate periods. The coherence between surveys provides confidence in their trends.

Recruit Abundance

Justification

The abundance of Lobsters recruiting into the population provides an indication of the animals entering the fishery in future years. It is an important metric for stock assessment and for forecasting stock productivity as changes in recruitment, may result in changes to commercial stocks. Total sample sizes are reduced for examining recruitment trends as the trawl survey does not capture many recruit sized animals in LFA 41, which was due to the lack of availability rather than the size selectivity of the gear (see example Figure 4).

Data Inclusion and Analyses

In all surveys, recruiting Lobsters were defined as all those <83 mm as the minimum legal size is defined at 82.5 mm. The NEFSC Spring and Autumn surveys were limited to a minimum size of 50 mm due to concerns over the reliability of conversion coefficients for Lobsters <50 mm (Jacobson and Miller 2012). The time series of recruit data was only available since 1999 in the RV41 and 2007 in GB surveys as detailed biological information, including sex and size was only systematically recorded after those dates.

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

Results

Sample sizes were low for all of the surveys with a total range between 0 and 25 recruiting sized Lobsters observed per survey per year. These small sample sizes reduce the amount of information contained in this indicator of stock status. That said, in NSpr41 survey there was some evidence of an increase in the recruitment signal in the early to mid-2000s, which has subsequently decreased to near the long term average. Only weak signals were evident in each of the other recruitment indices from other surveys (Figure 20).

Large Female Abundance

Justification

Large female abundance was used as an indicator in Pezzack et al. (2015) as a proxy for reproductive potential and exploitation rate. For reproductive potential, large females produce significantly more eggs (Koopman et al. 2015), spawn more frequently (Aiken and Waddy 1980), which, therefore, contribute greater proportion to the overall population productivity. In terms of the abundance of large females as an indicator of exploitation rate, it is generally assumed under low fishing pressure, there will be significantly greater proportion of large (and by assumption old) Lobsters in the population. Under increased exploitation rates, fewer of these Lobsters will reach the largest components of the population resulting in truncation of the size distribution and decrease in abundance of the largest animals (Pezzack et al. 2015).

Data Inclusion and Analyses

Across all surveys, large females were defined as those ≥140 mm. A time series of data was only available since 1999 in the RV41 and 2007 in GB surveys as detailed biological information, including sex and size was only systematically recorded after those dates. The full time series of NEFSC Spring and Autumn surveys were available for this analysis.

In addition to the stratified surveys defined above, this indicator was also estimated using the surveys and strata groupings presented in Pezzack et al. (2015), for the DFO Summer RV survey include strata 480-481 and DFO Georges Bank survey including strata 5Z1-5Z4.

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

Results

Sample sizes for the large female indicator limited the amount of information in this indicator. The sample sizes ranged from 0-11 for the RV41 survey, 0-26 for the NSpr41, 0-31 for the NAut1 survey and 1-7 large females from the GB survey (Figure 21). That said, there was evidence of a marginal increase in abundance of large females in the NSpr41 and NAut41 surveys since the mid- to late 2000s. Sample sizes from Pezzack et al. (2015) index using DFO Summer RV survey were higher than those observed in RV41, as the strata boundaries included the LFA 40, which has higher overall abundance as well as increased prevalence of large females (Figure 22). This result supports the supposition that LFA 40 represents an important area for large reproductive females (Pezzack and Duggan 1983). The Pezzack et al. 2015 indicator for Georges Bank was low and variable throughout the time series (Figure 23).

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). The proportion of sets occupied by Lobster was provided as an indicator by Pezzack et al. (2015); however, this analysis did not include the stratification scheme into its estimation, and was, therefore, not presented here.

Data Inclusion and Analyses

The total abundance of Lobster was used to define the changes in distribution. No filtering of data based on sex or size was performed. Annual estimates of spatial distribution for Lobster from each survey were determined using survey design weight area occupied (DWAO):

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

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). The 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 24). Specifically, DWAO increased for RV41, NSpr41 and NAut41 between the period of 2000 and 2015, with the greatest increases being seen in both the RV41 and the NAut41 surveys. The GB survey had a similar increase in recent years; however, the increase in area occupied in this survey began in the mid-1990s. The wide distribution of the stock relates to the increased abundance in recent years and suggests the Lobsters are found in more habitats than previously recorded.

Patchiness of Distribution from Survey Data

Justification

Patchiness was another 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 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 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 $x_1 \le x_2 \le x_3 \le \ldots \le x_{N.}$, 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 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 25). There was no trend evident in the GB survey, which suggests that despite increases in area occupied and abundance, patches of increased densities remain. 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, as surveyed by RV41 and NAut41, respectively.

Sex Ratio (Mature and Immature)

The natural sex ratio of immature Lobsters is unknown but presumed to be 1:1 as there is no evidence of differential mortality in immature Lobsters. Mature sex ratios, are presumed to be skewed toward females as they are protected from fishing mortality when egg bearing, or v-notched. The implications of a highly skewed sex ratio are not known, however, as males are able to mate with a large number of females each year and females are able to carry sperm to fertilize eggs for more than 1 year prior to releasing eggs (Aiken and Waddy 1980), indicating a female skewed population may not be detrimental to the population’s health.

Data Inclusion and Analyses

Sex ratios were determined using the stratified abundance data from the trawl surveys. Similar to other size and sex-based indicators, the RV41 survey was reduced to 1999-2015 and the GB survey was reduced to 2007-2015 as detailed Lobster information was not collected prior to these date ranges. The full time series of NSpr41 and NAut41 was included in analyses.

Sex ratios (S_t) were estimated as proportion female as:

$$S_t = \frac{\bar{y}_{ft}}{\bar{y}_t}$$

Where $\bar{y}_{ft}$ was the stratified mean abundance of females at time *t* and $\bar{y}_t$ was the stratified mean abundance for all Lobsters within the size class. This indicator was estimate for mature ≥92 mm and immature <92 mm Lobsters separately.

Results

The sex ratio of Lobster in LFA 41 was highly skewed toward females for the mature component with proportions of females being in the range of 0.6 to 0.8 (Figure 26). During the lower abundance years of 1969-2000 in NSpr41 and NAut41 sex ratios were highly variable, but with median proportion females of 0.69 and 0.72, respectively. In recent years with increasing sample sizes the mature sex ratios were 0.86 and 0.83 female for the NSpr41 and NAut41, respectively. The shortened time series for both the RV41 and GB offer little information on the changes over time, but both support the highly female sex ratio shown in other surveys (Figure 26).

Immature sex ratios were highly variable due to the low sample sizes for all surveys (Figure 27). However, in recent years with increased sample sizes, the sex ratio of immature Lobsters appears similar to the mature component, skewed toward females.

The high proportion of females found in LFA 41 suggests either differential morality on the sexes or sex specific migration patterns. Movement and migration patterns in offshore Lobster were examined in several studies through the 1970s and1980s (Pezzack and Duggan 1986) with general results suggesting movement across offshore banks. Recent work by Jury and Watson (2013) suggested sex specific temperature preferences in some Lobster populations, which may be the case in the offshore Lobster stock with a higher proportion of females seeking the offshore thermal regime.

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 / 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. The survey median size indicator was similar to that presented by Pezzack et al. (2015). Data collected at-sea was separated by fishing area within LFA 41 as was done in Pezzack et al. (2015) 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 surveys abundance at length information combining all sexes and stages. Similar to other size and sex based indicators, the RV41 was reduced to 1999-2015 and the GB survey was reduced to 2007-2015 as detailed Lobster information was not collected prior to these date ranges. The full time series of NSpr41 and NAut41 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 95^{th} 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 B.

Results

Most of the surveys and at-sea samples taken in the last several years show modest decreases in the median size of Lobsters (Figures 28-31). Decreases in median carapace length in RV41 since 2010 were also seen in the GB survey during the same time period. Median length from the NEFSC surveys were highly variable during the early years of the survey due to low sample sizes; however, in recent years with the increasing abundance of Lobsters present in the survey, sizes are stable or decreasing. The size decrease in the RV41 survey data appears to be largely due to the decrease in maximum size as marked decreases are evident from the early 2000s to present (Figures 29 and 31). In the NSpr41 and NAut41 surveys, periodic changes in maximum length have been evident throughout the time series, with large Lobsters being present in the surveys during the 1970s, decrease in maximum size through the 1980s and early 1990s, with stable to decreasing maximum length in recent years (Figure 29).

Similarly at-sea samples have shown decreases over time for most of the time series with current Lobster median sizes being smaller than those observed in the late 1970s across areas (Figure 30). Similar to the survey data, maximum size has decreased in recent years for each of the areas where at-sea samples were taken (Figure 31). Each of the regions has characteristic maximum body sizes that define the area. Specifically, southwestern Browns Bank Lobsters have smaller maximum body size compared to southeastern Browns Bank and Georges Bank (Figure 31).

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 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, Atlantic Cod, Spiny Dogfish, sea ravens, wolffish, Haddock, hake, plaice, 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, 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 broader DFO Summer RV survey, represents a relative index of the predators in the area. Although it is recognized that it is not specific to the Lobster habitat utilized by juvenile lobster, this indicator yields information on the area as distributions of species expand with increasing abundance, therefore the 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 Summer 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 Cochran (1977) with confidence intervals estimated by bootstrapping with replacement (Smith 1997).

Results

The trends in combined predator species from the DFO Summer 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 32; DFO 2016b). The change in predator biomass is not completely reflected in predator abundance as current levels are among the highest on record (Figure 32). Taken together, these results suggest a decrease in the mean body size of the Lobster predators captured in the trawl survey. This indicator would be improved by the inclusion of a weighting scheme whereby the consumption estimates of Lobster by individual predator species would inform the relative predation pressures, which would provide a more representative index.

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 have 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 a model that has its 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 Cochran (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 33). In the last 4-6 years, all surveys have had temperatures among the highest in the time series with less interannual variability. The overall median temperatures from the NEFSC fall survey and the GB surveys are higher than the DFO Summer RV survey and the NEFSC spring survey (Figure 33). The implications of the consistently warm temperatures over the last 4-6 years are unknown and should be monitored. 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.

Habitat Associations

Justification

Identifying the habitat associations of a species can help predict changes in fish distributions as a response to changes in oceanographic conditions. As changes in the Scotian Shelf and surrounding environment have been documented (e.g. Morse et al. 2017), it is important to understand how Lobster distribution may have changed to reflect these patterns. In a stratified random survey, the strata are characterized by possessing specific suite of characteristics. In the case of the DFO Summer RV, DFO Georges Band and NEFSC Spring and Autumn surveys, depth and area were the primary characteristics defining strata boundaries.

Data Inclusion and Analyses

Using the DFO Summer RV, NEFSC Spring and Autumn as well as Georges Bank survey data, the relationship between Lobster catches and the habitat variables salinity, temperature and depth was described using the methods of Perry and Smith (1994). Briefly, cumulative distribution functions (cdf) were used to describe species associations with temperature, salinity and depth as the cdf for each sampled habitat variable (*x*) across sets (*i*) in a stratum (*h*) incorporating the survey design was defined as:

$$f(t) = \sum_h \sum_i \frac{W_h}{n_h} I(x_{hi}) \qquad I(x_{hi}) = \begin{cases} 1, & \text{if } x_{hi} \le t; \\ 0, & \text{otherwise.} \end{cases}$$

where W_h was the proportion of the survey area in stratum *h*, n_h was the number of sets performed within the stratum and *t* was an index ranging between the minimum and maximum levels of the observed habitat variable. Similarly, the cdf for catch of a particular species within a set (y_{hi}) with specific habitat conditions is:

$$g(t) = \sum_h \sum_i \frac{W_h}{n_h} \frac{y_{hi}}{\bar{y}_{st}} I(x_{hi}) \qquad I(x_{hi}) = \begin{cases} 1, & \text{if } x_{hi} \le t; \\ 0, & \text{otherwise.} \end{cases}$$

By scaling the catch to the stratified mean ($\bar{y}_{st}$) yields $\Sigma g(t) = 1$ across all values of t. Large values of $y_{hi}/\bar{y}_{st}$ that are consistently associated with a particular habitat condition suggest strong associations. Randomization tests were used to test the significance of habitat associations. The test statistic, *L*, was the maximum absolute difference between the *f(t)* and *g(t)* curves. Statistical significance of *L* was determined by its comparison with the distribution of values from 2999 random perturbations of the data (3000 repetitions, including *L*; Perry and Smith 1994). Additionally, the median sampled habitat, the median habitat for species occurrence and the 95% bounds of sampled habitat were identified.

Results

Recent changes in the environmental conditions on Georges Bank and the Scotian Shelf have not resulted in marked changes in the habitat associations for Lobster within LFA 41. However, based on habitat associations from the various surveys, the seasonal habitat usage by Lobster within LFA 41 can be described. In the summer months, the RV41 survey suggests that Lobsters are found in generally found in a broader range of habitats with median catch rates following both median sampled habitats for both depth and temperature (blue and red lines Figure 34). In the autumn, NAut41 survey provides indications that Lobsters are found in shallower depths and in warmer waters than the median sampled (Figure 35). Similar to the autumn, the GB survey suggested Lobsters are found in warmer waters than the median sampled and in similar depths to the autumn (Figure 36). The figure for the GB depth associations shows that the median catch weighted depth was deeper than the median sampled; however, the survey coverage from the autumn and winter surveys differ such that shallower depths are sampled more heavily in the GB survey. The NSpr41 survey suggests Lobsters are typically found deeper than the median sampled and in waters with a similar temperature to the median sampled. Movement patterns of tagged Lobsters in the Bay of Fundy by Campbell and Statsko (1986) suggested Lobsters were found in deeper waters during the winter than summer, which differs from results presented here. These differences in depth preference are likely due to the differences in seasonal temperature profiles in the Bay of Fundy compared to the offshore banks where temperatures are more stable and warmer for much of the year.

Maintaining the time series of habitat associations in the future under predications of increased climate variability may provide information on any behavioral changes prior to detecting changes in stock production.

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 et al. 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 (RF, Breiman 2001) and boosted regression trees (BRT; Elith et al. 2008), among others. The BRT combines statistical decision tree analyses with machine learning (ML) to develop robust species distribution models. The 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 0.01 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 38) as well as the annual temperature interpolations (Choi and Zisserson 2912; Figure 39).

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 40). The final BRT set explained 32% of the total deviance. Time, in decimal years, and temperature were the most important factors influencing the regression trees and accounted for 36 and 29% 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 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 very low probability of occurrence at temperatures below 5°C. Probability of occurrence also dropped for temperatures above 15°C (Figure 41).

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 BRT’s show the change in the amount of suitable habitat over time (Figure 42). 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 (Figure 43).

These and similar types of species distribution models should be further explored in future frameworks for development of spatial abundance estimates that can be used to develop indices of abundance for stock assessment purposes (Pettigas 2001, Choi and Zisserson 2012).

Atlantic Multidecadal Ossicillation (AMO)

Justification

The Atlantic multidecadal oscillation 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, it was recognized that the simple correlation between climatic processes and biological time series are interesting, and 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

AMO time series data was obtained from the National Oceanographic and Atmospheric Administration at the following website:
http://www.esrl.noaa.gov/psd/data/correlation//amon.us.long.data

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 44). 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 10-13 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.

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 45). In the late 1990s, catch rates decreased to their lowest levels on record but have since rebounded and, as of 2015, were the highest on record. 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 would be reduced irrespective of an actual change in the population. Low levels of patchiness may be 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)→(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 within a year, catch rates were similar in all areas of LFA 41 (Figure 46). 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 46).

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. Previous assessments for Lobster used a traffic light approach advocated by Caddy (2002), where each indicator required the definition of stock boundaries or reference points. For contextual indicators that are provided to describe not only the biological processes that influence production but ecosystem and fishery performance indicators, specific reference levels are not required and may often be misleading.

The combining of indicators was performed using the complete set of indicators as well as a subset of indicators representing those, based on expert opinion, that best characterize the offshore Lobster stock and ecosystem while maintaining a minimum 10 years of data.

Methods

The indicators described throughout this section were made directly comparable through statistical standardization (z-scores) after log transformations to normalize the appropriate indicators (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 full suite of indicators have the first axis of the principle component scores explained approximately 22% of the total variance, whereas the second axis explained 10% of the total (Figure 47). By comparison, the component scores from the first and second axis for the reduced set described approximately 29 and 11% of the total variation, respectively (Figure 48). The increase in variance explained for the reduced set was due to the exclusion of data limited variables, which tended to be more variable.

Although the amount of variance explained was low by comparison to typical multivariate tests, the differences in the types of indicators used here 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 (Figures 49 and 50). The decreasing body size was observed in both the trawl survey data sets as well as the at-sea sampling, which occurred during fishing activities, and was not only a decrease in median size but also a reduction in the maximum carapace length. The decrease in predator abundance also contributed to variance explained along the first axis, as the overall biomass has declined in recent years. The 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 offshore Lobster.

There was coherence of the increasing abundance and biomass of Lobsters and the increasing temperature and AMO such that both 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).

The contextual information provided in this combined analysis of stock and ecosystem indicators does not, on its own, provide advice to resource managers, but it provides the context surrounding the current status of the ecosystem and Lobster stock characteristics in LFA 41. The higher survey abundances, warmer bottom temperatures, smaller median body size, lower maximum length and decreased predator biomass currently characterize the stock as well as the ecosystem attributes examined. The recommendation was to provide the indicator trends from the subset of indicators, as the variance explained was increased and the reduced number of indicators aids in interpretability.

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”, which 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 51). 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 it is defined on the basis of biological criteria through a 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).

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.

USR and LRP are usually defined in terms of biomass or spawning biomass (SSB), as these are typically the units that best describe the species current productivity. In quantitative fisheries assessments, modeled estimates of biomass or SSB where maximum sustainable yield (B_{MSY} or SSB_{MSY}) is attained can be used to guide the definition of zones. Specifically, under the PA policy, the default USR is defined as 80% of B_{MSY} and the LRP is 40% of B_{MSY}, with the RR not to exceed F_{MSY} when the stock is in the healthy zone (i.e. above the USR). In stocks without quantitative assessments, proxies for MSY reference points and alternatives are acceptable.

REFERENCE POINT ESTIMATION

Although defining reference points can be accomplished quantitatively through various techniques, the underlying theory is based on defining productivity and virgin biomass. In general, quantitative analyses seek to provide estimates of productivity parameters such as population growth (r) or the steepness of the stock recruitment relationship (h) in combination with virgin biomass (B_0) or carrying capacity (K). These parameters are then used to describe the population's ability to respond to perturbations from fishing or other causes and define the current stock status relative to a virgin state. From there, maximum sustainable yield (MSY), or the level of removals that can be routinely taken from a stock maximum level without long-term depletion, along with the biomass at which MSY can be sustained (B_{MSY}) and the fishing mortality to maintain MSY (F_{MS}Y) are estimated. Typically, reference points rely on the development of a stock recruitment relationship; however, other approaches using yield and spawner per recruit analyses (e.g. Sissenwine and Shepard 1987), or biomass dynamic modelling (Hilborn and Walters 1992) are often explored.

To date there have been no modelled estimates of biomass or MSY reference points developed for the Lobster stock in LFA 41. Due to the current lack of a strong evidence to describe spawner - recruit relationships for Lobster, biomass dynamic modelling was explored.

Biomass Dynamic Modelling

Biomass dynamic modelling is one of the simplest forms of population modelling that has been applied to address fisheries questions and define reference points. This modelling approach is often chosen due to its low data requirements and few, but interpretable, parameters. The time series or recursive form of a biomass dynamic model describes the changes in biomass over time as:

$$B_t = B_{t-1} + f(B_{t-1}) - C_{t-1}$$

Where biomass at time t (B_t) was equal to the biomass in the previous time step (B_{t-1}) plus the surplus production ($f(B_{t-1})$), subtracting off the landings that occurred during the time step (C_{t-1}). Often the surplus production term is described in terms of the population growth rate, r, and the population carrying capacity, K. The simplest form of the surplus production term was described by Schaefer (1954) as:

$$f(B) = rB\left(1 - \frac{B}{K}\right)$$

which is a density dependent relationship, with growth slowing as the population size approaches *K*. In order to apply this model to a stock assessment framework and obtain estimates for the parameters *r* and *K,* an index of stock biomass is required. This model has the implicit assumption that the index of biomass (*I*) is proportional to the total biomass, $B_{t,}$ as:

$$I = qB$$

where *q* is the proportionality constant. Along with the I_t , the only other data requirement was a time series of total landings (C_t). The estimated parameters are *r*, *K* and *q*.

From the fitted model, deterministic estimates of MSY reference points are readily obtained as:

$$MSY = \frac{r \times K}{4}$$

$$F_{MSY} = \frac{r}{2}$$

$$B_{MSY} = \frac{K}{2}$$

Applying deterministic MSY rules to stochastic environments may lead to increased probability of decreasing stock sizes and productivity (Bousquet et al. 2008). The inclusion of process error has previously been shown to decrease the MSY reference points (Cook 2013), making them more precautionary and, depending on the level of process error or non-stationarity in the system, these decreases may be significant (Bousquet et al. 2008, Cadigan 2012).

Although the model is easily fitted and determination of reference points from parameter estimates is relatively straight forward, the uncertainty of parameter estimates and the quality of model results need to be rigorously reviewed prior to implementation of reference points into fisheries management systems.

Methods

In this framework, the biomass dynamic model parameters were estimated using nonlinear Bayesian state space methods (Millar and Meyer 2000). This method was chosen due to the greater numerical stability, ability to propagate credible errors, and its ability to estimate both process errors and observation errors. Process errors (τ^2) are the model uncertainties that describe future states via error propagation such as the errors in B_t from those in B_{t-1}. Observation errors (σ^2) or data errors refer to the uncertainties associated with measurement and observation such as the survey variance. The τ^2 and σ^2 are estimable parameters in the state space modelling approach.

The above equations were modified to incorporate log-normal process errors (τ^2) and observation errors (σ^2) and were reparametrized to (P_t=B_t/K) as:

$$P_t|P_{t-1}, K, r, \sigma^2 = \left(P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{C_{t-1}}{K}\right)e^u$$

$$I_t|P_t, q, \tau^2 = qKP_te^v$$

where *u* and *v* are iid (independent and identically distributed) normal parameters with mean 0 and variance τ^2 and σ^2, respectively (Millar and Meyer 2000). In this notation, X|Y indicates the conditional distribution of X given Y.

In LFA 41, four surveys cover the stock area, RV41, NSpr41, NAut41 and GB. From each survey, the stratified total commercial biomass (males and females >82 mm) were used as indices. In RV41 and GB, the time series of commercial biomasses were only available since 1999 and 2007 rather than from the start of the survey in 1970 and 1987, respectively. To use the entire time series of data for each survey, the estimated proportion of commercial biomass to total biomass for years where data was available was determined to be 0.876. This proportion was applied to all other years.

As each survey occurs at a different time of year and covers a different proportion of the total stock area, proportionality constants, q, and observation errors, σ^2, were estimated for each survey index.

In a Bayesian modelling approach, each parameter requires the specification of a prior distribution. The priors defined as X~DIST(moment1,moment2) used for this analysis were:

$$K \sim LN(12.3, 0.46)$$

$$r \sim N(0.7, 0.279)$$

$$q_{RV} = q_{GB} = q_{NSpr} = q_{NAut} = U(0.01,7)$$

$$\tau^2 = U(0.01,7)$$

$$\sigma_{RV}{}^2 = \sigma_{GB}{}^2 = \sigma_{NSpr}{}^2 = \sigma_{Naut}{}^2 = U(0.01,7)$$

where K was defined based on the observed biomass per survey, r, was defined based on life history information and was kept broad. Uniform prior distributions were chosen for all q's, τ^2 and σ^2. The sensitivity of posterior distributions of K to the prior was explored by increasing its median in a step wise approach and examining the impact on resultant posterior distributions and convergence diagnostics.

The posterior distribution of the parameters conditional upon the data and prior distributions were estimated via MCMC (Gibbs) sampling using the JAGS platform (Plummer 2010). Three Markov chains were followed to ensure convergence; 4,000 simulations in the burn-in phase were sufficient to ensure such convergence of the Markov chains. Another 2,500,000 simulations were used to describe the posterior distributions of the parameters. A thinning of 500 simulations was required to minimize autocorrelation in the sampling chains.

Point estimates of MSY reference points were determined by incorporating process errors, as was suggested by Bousquet et al. (2008).

Results and Discussion

The three chains were well mixed and model fits to the time series of survey indices were reasonable for all four surveys due to the similarity of trends in the RV41, NSpr4, NAut41 and GB surveys (Figure 52). Posterior distributions were updated relative to the prior distribution for all parameters (Figures 53 and 54), suggesting that the data was informing the parameter estimates.

Despite the updating of the carrying capacity parameter, K, results remained sensitive to the prior distribution specified with larger means on the prior distribution resulting in increased means of the posterior distribution for carrying capacity (Figure 55). The sensitivity of K to the prior suggested that there was not enough information in the data to define the population's carrying capacity. This was likely due to the recent increase in survey biomasses, to among the highest levels observed, which have not reached the characteristic plateau, typical of a population approaching carrying capacity. Additionally, the constant TAC, despite apparent increases in total biomass, does not provide the contrast in data to describe the impact of harvesting on the stock, which affected the models ability to characterize carrying capacity.

The lack of information to fully describe K reduced the applicability of these modelled results for providing information on stock status zones and biomass reference points. This was particularly important as the modelled biomass did not scale to the carrying capacity at a constant rate (Figure 55). The implications of the models' sensitivity to carrying capacity priors can be seen in Figure 56, as the definition of current stock status in relation to the definitions of the USR and LRP were all impacted by the choice of the prior on *K*.

Additionally, when information data lacks contrast and inputs follow a 'one-way-trip', parameters *r* and *K* are typically correlated such that high *K* results in low *r* (Hilborn and Walters 1992). This can be seen here in the reference point plots (Figure 53) as increasing the prior mean on *K* increased the estimated USR and LRP, and decreased the RR, F_{MSY}, through decreases in the posterior mean on *r*, irrespective of the prior mean on *r* (data not shown).

Overall, results from the biomass dynamic modelling were not sufficient for defining stock status zones or removal references at this time.

Alternative Measures of Stock Status and Reference Points

Exploring alternative measures of stock status and determining biomass and removal reference points was required due to the lack of a quantitative model to define stock productivity parameters. A data driven approach has been used elsewhere to provide reference points for Lobster stocks (e.g. Tremblay et al. 2012), where stock status zones are defined based on landings or commercial catch rates. These fishery performance indicators are not appropriate for LFA 41 due to the aforementioned caveats with catch rates and a TAC controlled fishery.

Here survey biomass trends in combination with landings information were explored for defining stock status zones and reference levels. The notation used for describing USR and LRP for each survey index will be USI, upper stock indicator, and LRI, limit reference indicator. In traditional quantitative assessments, the definition of reference points combines all of the information from survey indices and other data sources into estimable parameters. As this was not accomplished here, and stock status relies on multiple survey indices, the non-traditional notation was chosen to reflect index specific reference indicators. Overall stock status will be a combined result across all survey indices relative to their respective LRI and USI. The proposed 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. Removal References for each survey will also be estimated and use the similar RI, removal indicator, notation.

The applicability of survey results to define stock productivity relies on several assumptions. Specifically, the assumption must be made that the trends observed are characteristic of the stock and are proxies of the stock productivity and carrying capacity.

One further consideration in defining stock status zones and reference points, not only from a data driven approach but also from quantitative models, was the determination of shifts in productivity regimes. Specifically, if changes in the stocks' productivity are evident, it is important to identify the appropriate time period for defining reference points. The DFO recommendation was to use the entire time series of data to define reference points, regardless of evidence of productivity regime shifts (DFO 2013); however, it was recognized that this may not be appropriate in all cases. In the case of Lobster in the Maritimes Region, there has been a synoptic increase in catch rates, landings and presumed abundance over the past 10 -15 years in almost all LFAs (Tremblay et al. 2012). The Lobster stock within LFA 41 was no exception, with large increases in survey biomass over the past 15 years (see above). As part of the identification of reference points, trends will examined to determine if a change in productivity regime can be detected (Perälä and Kuparinen 2015).

Biomass Reference Indicators

For each survey examined in this framework, several options were explored for defining biomass and removal reference indicators. The first was based on the DFO (2013) recommendation of using the full time series to define biomass reference points where the USI_f was defined as the median of the full time series. This reference point presumes that the stock is healthy when survey biomasses were above the long term median. Similarly, a base LRI was defined as $B_{recover}$, or the lowest biomass from which the stock has rebuilt (DFO 2002). $B_{recover}$ is typically defined through modelling; however, as this process is reliant on a data driven approach and variable survey data, the $LRI_{recover}$ was defined as the median of the five lowest non zero biomass in each time series.

Alternative reference points were proposed based on productivity regimes such that the LRI_l was defined as the median biomass during lower productivity period. Similarly, USI_h was defined based on assumption that the median biomass during the high productivity period was a proxy for carrying capacity *K*. Following the logic provided in the biomass dynamic modelling section and DFO (2009), $0.8B_{MSY}$ was the default USI and $B_{MSY} = K/2$; USI_h was defined as 0.4 times the median biomass of the high productivity period.

The LRI_l was proposed in addition to the $LRI_{recover}$ as it serves as more precautionary option as a longer time series of data informs the level, which further dampens the sensitivity to interannual changes in survey biomass. Similarly, the USI_h was proposed as it reflects the current productivity of the stock, was more precautionary and allows for increased range between LRI and USI in which to define management actions for stock rebuilding to the healthy zone.

Removal Reference Points

The guidance on setting a removal reference was to define *F* not to exceed F_{MSY} (DFO 2009). Without a quantitative model relating biomass and landings to develop estimates of F_{MSY}, other approaches to defining removal references need to be explored. In data limited stocks, using yield per recruit analyses, both F_{max} and $F_{0.1}$ have been suggested as proxies for F_{MSY}. F_{max}, defined as the maximum fishing mortality from the yield per recruit curve, has been discounted as a reasonable proxy since it often exceeds F_{MSY} (e.g. Cook et al. 2014) in that it does not account for low recruitment at low stock sizes. $F_{0.1}$, defined as the fishing mortality rate at 10% of the slope of the yield per recruit curve at the origin (Gulland and Boerema 1973) is generally considered a more precautionary F reference (but see Mace and Sissenwine 1993). Even more simplistic approaches have been suggested, such as defining a removal reference as a proportion of natural mortality (*M*) (i.e. $F = 0.8M$, Thompson 1993).

Even though defining the removal reference through yield per recruit analysis or other proxies is relatively straight forward, their practical use in terms of relating to estimated levels of *F* require estimates of total biomass. As there is no suitable stock assessment model developed for LFA 41 Lobster, the definition of reference points will rely on the historical trends in survey and landings data.

Relative fishing mortality (*relF*) uses both survey data and landings to show the changes in removals (C_t) relative to the survey index (I_t) as:

$$relF_{jt} = \frac{C_{jt}}{I_{jt}}$$

Assuming that survey catchabilities were constant and the index of commercial biomass was proportional to true commercial biomass, *relF* represented an index *F*. By using the time series of *relF* the level of fishing pressure the stock has experienced can be examined.

Two proposed removal references were developed. The first was the default RI_f where the removal reference is defined as the median relative *F* from the entire time series. The second, RI_l was defined as the median relative *F* from the low productivity period. The RI_f was a more precautionary removal reference point as it reflects the level of fishing pressure the stock can withstand at a median biomass.

The constant TAC in LFA 41, despite large increases in survey biomasses, resulted in difficulties in defining the impact of fishing on stock productivity. As such the *RI* developed here are highly uncertain and may not currently be useful in providing harvest advice. That said, RI_l provides an upper limit of fishing pressure under which the stock was able to be maintained and build to its current high biomasses. The RI_l may reflect an upper threshold of removals.

Methods

Each of the four survey time series (I_{tj}) in LFA 41 cover only a portion of the total stock area. Therefore, biomass reference points and the removal reference were estimated using data from each survey (I_{jt}) 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) bumped up 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.

As was the case with the biomass dynamic modelling, in order to use the entire time series of survey data from RV41 and GB 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 NSpr41 and NAut41 surveys were estimated for the entire time series using available information.

Productivity Regimes

Survey biomass trends were examined for the indication of a productivity regime. This was done using a variant of product partition models termed Bayesian change point analysis (BCP; Barry and Hartigan 1993, Erdman and Emerson 2008). This analysis seeks to find the breaks in a time series that describe the transitions between ‘blocks’ of data sharing the same distributional parameters. The biomass time series was log transformed prior to analysis as BCP assumes data are normally distributed. As this process is done in a Bayesian framework, prior information is provided to condition the signal to noise ratio (*w0*), sampled from a uniform distribution with a hyperprior set to 0.2. Additionally, a uniform hyperprior was set for the probability of a change point occurring at each point in the sequence *p0*, the smaller the value the fewer the change points detected. In this analysis, this hyperprior was set to 0.05. Detection of location of change points was robust to the choice of hyperprior; however, increasing *p0* resulted in more change points being detected (results not shown).

From the identification of LRI, USI and RI’s, phase plots will be produced to display the biomass and *relF* trends in relation to the options for reference points. Rather than relying on the raw survey trends, which are inherently variable estimates for assessing stock status, the three year running medians of biomass were used as the I_{jt} for both the biomass index as well as the denominator in the *relF* estimations. For running median biomasses of 0, relF was undefined. 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

RV41

A productivity regime shift in the biomass time series was evident and was suggested to have occurred with the highest probability in 2000 (Figure 57). Estimating the LRI_l from the low productivity time period (1970-1999) yielded a value of 0.117 kt, whereas the $LRI_{recover}$ occurred at 0.036 kt. The USI_f and USI_h were estimated to be 0.232 kt and 0.50 kt, respectively. Biomasses have not fallen below USI_h since the change in productivity in 2002 (Figure 57).

The removal reference from the low productivity phase (RI_l) was estimated to be 2.41 compared to 0.96 for the full time series (RI_f). The *relF* has only exceeded the RI_f once since 2001 and RI_l once since 1995 (Figure 58).

The phase plot relating biomass and *relF* to stock status zones and the removal reference differs based on the choice of time period for the definition of USR and RR (Figure 59). The choice of the USR_h allowed for increased space within the Cautious Zone, providing more time for management actions to allow for stock rebuilding.

NSpr41

A productivity regime shift in the biomass time series was evident and was suggested to have occurred with the highest probability in 2001 (Figure 60). Estimating the LRI_l from the low productivity time period (1969-2000) yielded a value of 1.28 kt, whereas the $LRI_{recover}$ occurred at 0.202 kt. The USI_f and USI_h were estimated to be 1.86 kt and 3.17 kt, respectively. Biomasses have not fallen below USI_h since the change in productivity in 2002 (Figure 60).

The removal reference from the low productivity phase (RI_l) was estimated to be 0.301 compared to 0.189 for the full time series (RI_f).The *relF* has only exceeded the RI_f and RI_l once since the productivity change in 2001 (Figure 61).

The phase plot relating biomass and relF to stock status zones and the removal reference differed based on the choice of time period for the definition of USI and RI (Figure 62). The choice of the USI_h allowed for increased space within the Cautious Zone, providing more time for management actions to allow for stock rebuilding.

NAut41

A productivity regime shift in the biomass time series was evident and was suggested to have occurred with the highest probability in 2001 (Figure 63). Estimating the LRI_l from the low productivity time period (1969-2000) yielded a value of 0.95 kt, whereas the $LRI_{recover}$ occurred at 0.195 kt. The USI_f and USI_h were estimated to be 1.43 kt and 1.67 kt, respectively. Biomasses have not fallen below USI_h since the change in productivity in 2001 (Figure 63).

The removal reference from the low productivity phase (RI_l) was estimated to be 0.43 compared to 0.25 for the full time series (RI_f). The *relF* has only exceeded the RI_f once since the productivity change in 2001 and has not exceeded the RI_l in the high productivity regime (Figure 64).

The phase plots relating biomass and *relF* to stock status zones and the removal reference differed based on the choice of time period for the definition of USI and RI (Figure 65). The choice of the USI_p allowed for increased space within the Cautious Zone, providing more time for management actions to allow for stock rebuilding.

Georges Bank

A productivity regime shift in the biomass time series was evident and was suggested to have occurred with the highest probability in 2000 (Figure 66). Estimating the LRI_l from the low productivity time period (1987-1999) yielded a value of 0.032 kt, whereas the $LRI_{recover}$ occurred at 0.026 kt. The USI_f and USI_h were estimated to be 0.118 kt and 0.15 kt, respectively. Biomasses have only fallen below USI_h since the change in productivity in 2001 and the running median remained above the USI_h (Figure 66).

The removal reference from the low productivity phase (RI_l) was estimated to be 2.13 compared to 0.466 for the full time series (RI_f). The *relF* has only exceeded the RI_f once since the productivity change in 2000 and has not exceeded the RI_l since 1997 (Figure 67).

The phase plots relating biomass and *relF* to stock status zones and the removal reference differed based on the choice of time period for the definition of USI and RI (Figure 68). The choice of the USI_h allowed for increased space within the Cautious Zone, providing more time for management actions to allow for stock rebuilding.

Overall

The definition of appropriate reference points to define stock status zones need to consider the history of the fishery in combination with the trends in biomass or survey indices. Even at the lowest survey biomasses, 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. Setting a removal reference based on the lower productivity period supposes that the removal rate observed can be translated into higher landings at higher biomass levels. While we have no evidence to support this supposition, the scope for flexibility in harvest rates should not be discounted. Similarly, the limit reference indicator (LRI) defining the boundary between critical and cautious zones should be related to the lower productivity regime as fishing at a TAC of 720 t did not cause the stock to collapse. Using a $B_{recover}$ proxy of $LRI_{recover}$ was an extremely low limit reference point as the commercial biomass levels equate to very few individuals captured in the surveys. Due to the nature of Lobster behaviour and the inability of trawls to capture Lobsters in all habitats, a low LRI based on trawl survey data likely does not limit the stock's ability to recover. The LRI_l was a more conservative reference point; however, it would result in fishery closure at survey biomasses that were known to sustain removals of 720 t and, therefore, may be unnecessarily restrictive.

Treating 40% of median biomass in the high productivity period as the USI suggests that the population has reached it maximum capacity and population biomasses will begin to plateau. There is no evidence to support the levelling off of survey biomasses; however, determining reference points must be based on the best available data, which indicate that the current biomasses are among the highest on record. Further increases in survey biomass will only increase the USI, thereby making the choice of USR based on current productivity regime a conservative USI.

Presenting the running median in the phase plots rather than the raw survey trends decreases the observed variability due to interannual fluctuations and provides a more robust measure of the survey index against and, thus, provide increased confidence in definition of stock status.

Across all surveys, changes from low to high productivity regimes occurred between 2000 and 2001 with some of the highest commercial biomasses observed on record in recent years. The coherence of biomass trends across surveys provides support to their value as stock status indicators as they have been 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. This redundancy improves the robustness of the analysis as changes in stock status from a single survey may not reflect overall stock productivity but may be due to other unobserved factors. Therefore, the recommendation is to maintain the independent analyses and produce phase plots for each of the four surveys. Changes in stock status zones would require the same change in 3 of the 4 surveys trends. Specifically, moving from the Healthy Zone to the Cautious zone would require 3 of 4 survey indices to fall below their respective USI's. Similarly, moving from the Cautious to Critical zone would require 3 of 4 survey indices falling below their respective LRI's. Following this recommendation, the LFA 41 Lobster stock has not been below the LRP and fallen into the critical zone.

Reproductive Potential Boundaries

The 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. This metric can also be viewed as a surrogate for spawning stock biomass (SSB), which is often used in other species as one of the main indicators of stock status (Hilborn and Walters 1992).

Reproductive potential as estimated here is a more explicit measure of production than SSB as it does not assume fecundity at size is directly proportional to weight at size and, although the two are related, changes in fecundity at size may occur for reasons other than poor condition.

It is important to note that the reproductive potential presented here is an ideal reproductive potential rather than a realized reproductive potential, as the fecundity at size information was static. This metric ignores the reproductive failure and variable clutch size, which have been characterized for some stocks and areas (Koopman et al. 2015), but its occurrence in LFA 41 is not known.

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 in order 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, which provide flexibility in the management actions. Similar to the commercial biomass index alternate, UBs and LBs will be defined as described above using the long term mean as well as through the identification of low and high productivity regimes. A removal reference will not be estimated for this indicator.

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 RV41 and 2007 in the GB surveys as detailed biological information was only systematically collected after those dates. Similar partitioning of the historic time series as was done previously for commercial / non-commercial biomasses could not be done for this indicator as it seeks to track the interannual changes in abundance at size. The full time series of NSpr41 and NAut41 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 represented by 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 (Gaudette and Cook 2016 unpublished data). Sized based spawning frequencies were also included in the analysis, such that females ≥120 mm spawned in 2 of 3 years where as mature females <120 mm spawned every second year (Aiken and Waddy 1980).

Stratified mean abundance per tow was calculated following traditional procedures outlined by Cochran (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.

The Bayesian change point analysis was performed as defined above with the hyperpriors on w0 = 0.2 and p0 = 0.05. UB_f and UB_h were defined from the long term median reproductive potential as well as 40% the high productivity period (if identified), respectively. LB_f and LB_l were defined as the median of the five lowest non-zero estimates of reproductive potential as well as the median of the lower productivity period (if defined).

Results

RV41

The 16-year time series of the RV41 survey showed stable levels of reproductive potential from 1999-2010, which increased to more than double the potential egg production in 2013 and remained high in 2015 (Figure 69). No change points were detected from this trend (figure not shown). The short time series and evidence of a change point in 2000 from the commercial biomasses preclude the definition of some boundaries as the full suite of productivity cannot be assessed. Assuming the 2000-2015 time period matches the high productivity period identified in the commercial biomass section above, the UB_h can be defined as 8.6 million eggs. Since 2002, the reproductive potential has been above the upper bound.

NSpr41

The long time series of data on reproductive potential from the NSpr41 survey showed contrast in the potential production with evidence to suggest a change point occurred in 2001 (Figure 70). Prior to 2001, estimated egg production was relatively low and variable compared to the post 2001 period. Between 2013-2015 the highest estimates of reproductive potential in the time series were observed (Figure 70). Since 2002, the reproductive potential was above both the UB_h and UB_f levels.

NAut41

The long time series of data on reproductive potential from the NAut41 survey showed contrast in the potential production with evidence to suggest a change point occurred in 2001 (Figure 71). Prior to 2000, estimated egg production was relatively low and variable compared to the post 2000 period. There has been an increasing trend in egg production since 2007 with the highest estimates occurring in 2015 (Figure 66). Since 2001, the reproductive potential was above both the UB_h and UB_f levels.

Georges Bank

The short time series of reproductive potential from the GB survey limits its value as an index (Figure 72). Increases in reproductive potential were evident in 2009, and subsequent years have remained higher than 2007 and 2008. The short time series precludes the usefulness of UB or LB's, and as such none were presented.

Overall Results and Discussion

Maintaining spawning stock biomass and reproductive potential improves the long term sustainability of a stock. Defining stock status boundaries based on an integrative measure such as presented here allows for flexibility in the estimation of stock status based on the best available knowledge of key life history parameters, such as size at maturity and fecundity at size. This is particularly relevant for Lobsters as it has been well documented that size at maturity is not constant over time or space (e.g. Le Bris et al. 2017). Although results presented here assume fixed relationships for both fecundity at size and size at maturity relationships, the flexibility remains to improve the estimates of egg production as more information is gathered. The size at maturity model parameters used here were based on female Lobster ovarian staging conducted in the Spring 2016, thereby representing the most up to date information on size at maturity (unpublished data; Gaudette and Cook 2016), which suggests size at 50% maturity has decreased from 95 to 92 mm since the mid-1980s (Pezzack and Duggan 1989).

In the NSpr41 and NAut41 surveys, reproductive potential was higher in recent years compared to the historic time series. In the NSpr41 and NAut41 surveys change points were evident in 2001 and 2000, respectively, which resulted in dramatic increases in egg production. Since the change point, both the NSpr41 and NAut41 surveys have been above the UB_h, which is the recommended upper bound for defining reproductive potential zones. Similar to the reference points for commercial biomasses, a lower bound at LB_l, or the median of the five lowest estimates of reproductive potential, would suggest egg production would remain sufficient for stock rebuilding.

Reproductive potential for both the RV41 and GB surveys could only be estimated for the recent high productivity periods. This limits their effectiveness to define both upper and lower bounds on stock productivity as the contrast in data was not evident. Lacking this contrast does not provide an indication on the required level of reproductive potential that yielded the current increases in productivity. That said, the UB_h defined for the RV41 remains relevant as the time series of reproductive potential levels cover the majority of high productivity years in the time series.

The increases in reproductive potential across surveys was largely due to the increases in abundance of Lobsters in LFA 41 as both median and maximum body sizes have decreased in recent years (see indicator section above).

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. Therefore, it is recommended to report all four surveys and provide results relative to appropriate reference points. 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.

RESEARCH RECOMMENDATIONS

Several key knowledge gaps exist in LFA 41 that can be addressed with future studies. The first is the level of connectivity between adjacent stocks. Previous tagging studies showed adult movements between offshore banks following season migrations; however, these studies were conducted when abundance and biomass levels were much lower than are currently suggested from bottom trawl surveys. Improved understanding of the migrations between stock areas will allow for better definition of the productivity units and stock structure.

Improving our understanding of benthic recruitment into LFA 41 is another key knowledge gap. Bottom trawl surveys suggest a truncated size distribution relative to other areas, as fewer small Lobster than expected based on the trawl gear size selectivity from other regions are captured in the surveys. Larval drift models suggest significant import from inshore regions and self-seeding within LFA 41; however, this does not appear to translate to large numbers of small Lobster.

Exploring species distribution modelling approaches toward defining the habitat characteristics that constitute the offshore Lobster preferences should be the focus of future research. These types of models could be used to refine abundance estimates in relation to habitat variables and explore the role of climate change on the productivity of offshore Lobster stocks.

Effort should be directed toward understanding the impact of environmental forcing on the productivity of the offshore Lobster stocks. The apparent relationships between temperature/AMO and the abundance of offshore Lobster stocks should be further evaluated to determine their relative importance as drivers of Lobster productivity.

Future work should be directed toward determining if biases in bycatch rates result from employing a predetermined sampling schedule in the LFA 41 fishery. In order to determine if biases exist in bycatch data, a random deployment of at-sea sampling could be performed along with the existing scheduled deployments. By comparing several results from these two types of deployment, differences in bycatch profiles could be examined.

Comparison of indicators from LFA 41 with the adjacent closed area LFA 40 would show the relative impact of localized fishing on population processes and should be a focus of future study.

CONCLUSIONS

A suite of indicators were developed and updated to provide stock status information within LFA 41. As simple stock assessment models were not suitable for providing biomass trends or removal reference points, a data driven primary indicator and methods to develop upper stock and limit reference indicators (USI and LRI, respectively) were described. Several options for reference indicators were explored for each of the four surveys covering LFA 41, with the recommendation of a USI being based on survey biomasses from the high productivity period and a LRI defined similar to $B_{recover}$. Although each of the surveys had very similar trends in commercial biomass, with recent years being the highest on record, the recommendation was to continue using all four surveys and evaluate the overall stock status based on the status of 3 of the 4 survey trends. Specifically, 3 of 4 survey trends would need to be below their respective USI's in order for the stock to be considered in the cautious zone.

Methods to describe removal references were described; however due to the stable TAC and currently increasing biomass, the impact of harvesting on stock status was not readily determined. The recommendation was to not provide a removal reference based on the information currently available.

A reproductive potential primary indicator was developed along with boundaries relating to stock productivity. Reproductive potential has long been considered an important component of Lobster stock productivity that is in need of protection, and although this may be more important for inshore Lobster fisheries that are largely recruitment fisheries, the LFA 41 Lobster stock is predominated by large female Lobsters. Removal references and stock status zones were not defined for the reproductive potential indicator; however, it was recommended to be tracked independent of the other indicators as changes may be indicative of the state of future stock productivity.

A suite of other indicators were developed or updated from the previous LFA 41 stock assessment (Pezzack et al. 2015). The sensitivities of indicators to the definition of stock area were determined, resulting in the recommendation to use indicators based on survey trends within LFA 41 rather than relying on information from adjacent areas. This recommendation was made as the current movement patterns across the offshore banks are not known.

Multivariate and graphical analyses of the contextual indicators suggested coherent trends over time, with both the median size and maximum size of Lobsters in all four surveys and at-sea observations decreasing over time. Conversely the abundance of Lobsters in all four surveys in LFA 41 and commercial catch rates 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.

Research recommendations and future work on bycatch analyses were identified.

ASSESSMENT SCHEDULE

Following this framework, a full assessment of stock status using the methods developed here will be conducted prior to December 2017. The next LFA 41 framework will be scheduled for the 2022-2023 fiscal year. Between autumn 2017 and autumn 2022, annual stock status updates will be produced.

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TABLES

Table 1. LFA 41 Lobster landings in tons (t), the Total Allowable Catch (TAC) and the number of active vessels from 1981 to 2015 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 1st, 1985 to October 15th, 1986; October 16th to October 15th for 1986-87 to 2003-04; October 16th, 2004 to December 31st, 2005; January 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	1010	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

[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. A trip can include Lobsters from several LFA 41 subareas (Crowell Basin, SW Browns, Georges Basin, SE Browns, Georges Bank).

Year	Number of Trips	Number of Subareas
2002	5	10
2003	7	10
2004	3	3
2005	9	14
2006	8	13
2007	5	9
2008	4	7
2009	4	8
2010	3	7
2011	3	5
2012	5	11
2013	6	14
2014	6	12
2015	4	9

Table 3. At-sea sampling based on percent of annual Lobster trips and percent of total Lobster weight within LFA 41.

Year	% Coverage by Trips	% Coverage by Weight
2002	2.4	2.4
2003	3.9	1.6
2004	1.8	0.6
2005	4.8	2.2
2006	5.6	3.0
2007	4.1	1.8
2008	3.3	1.6
2009	5.1	2.0
2010	3.9	1.6
2011	5.9	1.8
2012	16	3.6
2013	17	4.5
2014	17	4.1
2015	11	3.3

Table 4. Annual observed bycatch composition for LFA 41 in kilograms (kg).

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AMERICAN LOBSTER	22,426	10,510	5,114	4,032	9,302	8,405	5,978	11,317	14,824	5,757
JONAH CRAB	6,918	3,063	336	5,055	3,399	1,190	816	3,220	1,070	124
CUSK	1,211	1,517	1,253	653	715	315	1,030	1,473	868	526
ATL. COD	96	758	338	407	490	73	219	974	462	109
WHITE HAKE	72	102	15	81	388	80	509	829	837	347
ATL. ROCK CRAB	0	0	1,509	0	0	0	10	0	1	41
RED HAKE	56	133	0	0	31	0	17	408	136	36
SEA RAVEN	5	2	0	7	9	4	56	251	31	39
HADDOCK	2	31	19	96	165	4	13	28	6	12
REDFISH	44	33	6	6	10	5	14	55	26	12
HAKE (NS)	80	0	0	0	0	0	0	0	0	108
BRACHIURAN CRABS	0	0	19	0	0	0	0	140	0	0
ROSEFISH	9	37	0	0	18	0	1	25	3	40
GROUNDFISH (NS)	0	0	0	0	0	0	0	0	0	78
POLLOCK	0	0	18	0	2	0	3	25	0	5
STARFISH	4	7	26	2	0	2	0	0	0	1
ATLANTIC WOLFFISH	5	0	0	0	4	0	0	26	1	3
SPINY DOGFISH	0	11	0	0	0	0	0	12	1	0
SEA SCALLOP	0	0	0	0	0	0	0	18	0	0
FINFISHES (NS)	12	0	0	0	0	0	0	0	0	0
OFFSHORE HAKE	0	0	0	0	0	11	0	0	0	0
SEAROBINS	0	0	0	0	9	0	0	0	0	0
AMERICAN EEL	0	0	0	0	0	0	0	8	0	0
WHELKS	0	0	0	0	0	0	0	8	0	0
MONKFISH	2	0	0	0	0	0	0	2	0	2
SCULPINS	1	6	0	3	2	0	2	0	0	1
JELLYFISH	0	3	0	0	0	0	0	0	0	0
WINTER SKATE	0	0	0	0	0	0	0	1	0	1
AMERICAN PLAICE	0	0	0	0	0	0	0	1	0	0
MUSSELS (NS)	0	0	0	1	0	0	0	0	0	0
RED DEEPSEA CRAB	1	0	0	0	0	0	0	0	0	0
SMOOTH SKATE	0	0	0	0	0	0	0	0	1	0
SPINY CRAB	0	0	0	0	0	0	1	0	0	0
SPOTTED HAKE	0	0	0	0	0	0	0	1	0	0

Table 5. Annual total estimated catch composition for LFA 41 in kilograms (kg).

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AMERICAN LOBSTER	335,823	259,474	141,767	89,493	269,472	208,466	76,350	113,007	162,840	78,923
JONAH CRAB	103,595	75,620	9,314	112,199	98,467	29,515	1,0422	32,154	11,754	1,700
CUSK	18,134	37,452	34,735	14,494	20,713	7,813	13,155	14,709	9,535	7,211
ATL. COD	1,438	18,714	9,370	9,034	14,195	1,811	2,797	9,726	5,075	1,494
WHITE HAKE	1,078	2,518	416	1,798	11,240	1,984	6,501	8,278	9,194	4,757
ATL. ROCK CRAB	0	0	41,832	0	0	0	128	0	11	562
RED HAKE	839	3,284	0	0	898	0	217	4,074	1,494	494
HADDOCK	30	765	527	2131	4,780	99	166	280	66	165
SEA RAVEN	75	49	0	155	261	99	715	2,506	341	535
REDFISH	659	815	166	133	290	124	179	549	286	165
HAKE (NS)	1,198	0	0	0	0	0	0	0	0	1,481
ROSEFISH	135	913	0	0	521	0	13	250	33	548
BRACHIURAN CRABS	0	0	539	0	0	0	0	1,398	0	0
STARFISH	60	173	721	44	0	50	0	0	0	14
GROUNDFISH (NS)	0	0	0	0	0	0	0	0	0	1,069
POLLOCK	0	0	499	0	58	0	38	250	0	69
ATL. WOLFFISH	75	0	0	0	116	0	0	260	11	41
SPINY DOGFISH	0	272	0	0	0	0	0	120	11	0
OFFSHORE HAKE	0	0	0	0	0	273	0	0	0	0
SEAROBINS	0	0	0	0	261	0	0	0	0	0
FINFISHES (NS)	180	0	0	0	0	0	0	0	0	0
SEA SCALLOP	0	0	0	0	0	0	0	180	0	0
SCULPINS	15	148	0	67	58	0	26	0	0	14
AMERICAN EEL	0	0	0	0	0	0	0	80	0	0
WHELKS	0	0	0	0	0	0	0	80	0	0
JELLYFISH	0	74	0	0	0	0	0	0	0	0
MONKFISH	30	0	0	0	0	0	0	20	0	27
WINTER SKATE	0	0	0	0	0	0	0	10	0	14

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
MUSSELS (NS)	0	0	0	22	0	0	0	0	0	0
RED DEEPSEA CRAB	15	0	0	0	0	0	0	0	0	0
SPINY CRAB	0	0	0	0	0	0	13	0	0	0
SMOOTH SKATE	0	0	0	0	0	0	0	0	11	0
AMERICAN PLAICE	0	0	0	0	0	0	0	10	0	0
SPOTTED HAKE	0	0	0	0	0	0	0	10	0	0

Table 6. 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	126.0
2007	5.6	143.8
2008	3.5	100.4
2009	6.3	139.3
2010	5.2	151.7
2011	1.5	39.1
2012	2.6	34.5
2013	7.3	71.5
2014	3.4	37.4
2015	1.4	19.1

Table 7. Proportion of returned Lobster catch composition from observed samples by year.

Year	Undersize	Berried	Jumbo	V-Notch	Soft Shell	Cull
2006	0.03	0.28	0.17	0.07	0.05	0.37
2007	0.03	0.38	0.15	0.09	0.01	0.34
2008	0.02	0.25	0.20	0.12	0.26	0.36
2009	0.15	0.23	0.11	0.22	0.06	0.22
2010	0.03	0.34	0.09	0.17	0.08	0.31
2011	0.07	0.39	0.05	0.16	0.01	0.33
2012	0.03	0.26	0.08	0.15	0.08	0.43
2013	0.01	0.42	0.07	0.19	0.04	0.30
2014	0.01	0.45	0.06	0.09	0.04	0.37
2015	0.01	0.32	0.07	0.22	0.01	0.33

Table 8. Number of sets performed (N Sets), number of sets containing Lobster (N Lob Sets) and the number of Lobster observed (N Lobster) from the RVbase, RV41 and RVAdj surveys from 1970 to 1998.

	RVBase			RV41			RVAdj		
Year	**N Sets**	**N Lob Sets**	**N Lobster**	**N Sets**	**N Lob Sets**	**N Lobster**	**N Sets**	**N Lob Sets**	**N Lobster**
1970	25	1	4	10	1	4	15	0	0
1971	22	1	1	9	1	1	13	0	0
1972	26	8	14	12	6	12	14	2	2
1973	25	4	23	10	3	21	15	1	1
1974	26	0	0	8	0	0	18	0	0
1975	25	3	10	9	2	9	16	1	1
1976	27	1	1	12	1	1	15	0	0
1977	27	8	11	9	6	7	18	2	4
1978	25	7	59	12	4	12	13	3	47
1979	30	7	18	11	3	6	19	4	12
1980	24	3	3	10	3	3	14	0	0
1981	26	8	14	13	4	5	13	4	9
1982	29	5	5	11	1	1	18	4	4
1983	27	1	1	9	0	0	18	1	1
1984	27	5	18	8	2	2	19	3	16
1985	27	7	16	13	4	7	14	3	9
1986	27	6	10	12	2	2	15	4	8
1987	38	12	28	20	7	22	18	5	6
1988	39	10	20	12	1	2	27	9	17
1989	37	8	18	17	5	10	20	3	8
1990	42	7	9	15	4	4	27	3	5
1991	41	0	0	13	0	0	28	0	0
1992	41	3	4	16	0	0	25	3	4
1993	41	4	6	17	4	6	24	0	0
1994	41	8	20	15	3	4	26	5	16
1995	40	4	110	11	1	4	29	3	107
1996	41	18	109	14	6	35	27	12	73
1997	41	6	0	11	0	0	30	6	0
1998	41	15	74	14	6	12	27	9	62
1999	41	14	94	14	5	7	27	9	87
2000	40	15	32	16	8	13	24	7	20
2001	41	20	143	17	10	78	24	10	66

Year	RVBase			RV41			RVAdj		
	N Sets	N Lob Sets	N Lobster	N Sets	N Lob Sets	N Lobster	N Sets	N Lob Sets	N Lobster
2002	44	22	98	17	8	23	27	14	75
2003	43	26	209	14	10	57	29	16	152
2004	36	20	100	16	9	49	20	11	51
2005	50	28	212	22	15	46	28	13	167
2006	44	26	299	15	10	41	29	16	259
2007	37	20	171	14	6	21	23	14	149
2008	42	25	149	13	10	63	29	15	86
2009	42	25	149	22	13	40	20	12	109
2010	42	26	182	13	9	32	29	17	150
2011	49	37	341	19	16	75	30	21	266
2012	45	36	296	16	15	70	29	21	226
2013	45	37	453	15	13	104	30	24	348
2014	43	38	1106	14	13	51	29	25	1055
2015	45	39	933	24	21	166	21	18	767

Table 9. Number of sets performed (N Sets), number of sets containing Lobster (N Lob Sets) and the number of Lobster observed (N Lobster) from the NSprbase, NSpr41 and NSprAdj surveys from 1969 to 1997.

Year	NSprbase			NSpr41			NSprAdj		
	N Sets	N Lob Sets	N Lobster	N Sets	N Lob Sets	N Lobster	N Sets	N Lob Sets	N Lobster
1969	66	9	31	26	4	13	40	5	18
1970	64	4	8	21	1	1	43	3	6
1971	68	9	22	24	6	22	44	3	8
1972	71	15	71	30	10	58	41	5	14
1973	64	4	5	24	3	4	40	1	1
1974	58	13	35	21	4	16	37	9	26
1975	62	14	53	18	5	33	44	9	20
1976	62	21	48	20	8	58	42	13	28
1977	64	26	161	19	8	90	45	18	71
1978	75	23	67	28	7	28	47	16	44
1979	98	16	59	33	7	14	65	9	45
1980	65	21	68	22	10	29	43	11	39
1981	59	14	57	12	4	35	47	10	27
1982	64	15	27	24	6	13	40	9	16
1983	64	7	15	16	4	10	48	3	5
1984	65	7	19	21	1	2	44	6	17
1985	61	17	117	21	5	15	40	12	103
1986	65	20	68	21	7	25	44	13	43
1987	64	15	39	21	8	24	43	7	15
1988	63	23	86	19	8	26	44	15	60
1989	61	9	17	20	3	6	41	6	11
1990	61	15	34	21	7	16	40	8	18
1991	62	15	37	24	8	17	38	7	20
1992	59	14	30	20	6	14	39	8	16
1993	61	19	57	21	9	18	40	10	39
1994	62	18	72	16	6	21	46	12	51
1995	61	15	41	23	6	14	38	9	27
1996	60	19	67	22	10	42	38	9	25
1997	63	16	35	18	4	9	45	12	26
1998	66	16	47	21	6	21	45	10	26
1999	62	14	43	21	5	19	41	9	24
2000	61	24	77	17	6	12	44	18	65

Year	NSprbase N Sets	NSprbase N Lob Sets	NSprbase N Lobster	NSpr41 N Sets	NSpr41 N Lob Sets	NSpr41 N Lobster	NSprAdj N Sets	NSprAdj N Lob Sets	NSprAdj N Lobster
2001	62	24	181	19	8	26	43	16	156
2002	61	32	129	16	10	41	45	22	89
2003	60	27	234	15	9	89	45	18	146
2004	62	33	198	22	16	106	40	17	91
2005	62	27	134	17	8	58	45	19	76
2006	62	29	161	16	9	83	46	20	78
2007	72	31	165	28	19	129	44	12	37
2008	72	39	248	30	20	175	42	19	73
2009	74	40	217	22	14	127	52	26	90
2010	71	45	279	24	15	94	47	30	186
2011	66	34	279	22	16	170	44	18	109
2012	68	30	352	22	11	256	46	19	96
2013	73	45	293	25	19	192	48	26	101
2014	67	43	363	23	17	225	44	26	137
2015	74	42	362	25	20	267	49	22	94

Table 10. Number of sets performed (N Sets), number of sets containing Lobster (N Lob Sets) and the number of Lobster observed (N Lobster) from the NAutbase, NAut41 and NAutAdj surveys from 1969 to 1997.

Year	NAutbase			NAut41			NAutAdj		
	N Sets	N Lob Sets	N Lobster	N Sets	N Lob Sets	N Lobster	N Sets	N Lob Sets	N Lobster
1969	64	9	22	18	1	9	46	8	13
1970	63	15	33	21	5	10	42	10	25
1971	68	17	47	24	3	5	44	14	42
1972	69	4	5	24	3	4	45	1	1
1973	67	14	37	22	5	11	45	9	26
1974	69	19	50	25	6	26	44	13	30
1975	68	18	45	23	7	14	45	11	35
1976	62	21	58	21	7	12	41	14	47
1977	79	36	177	27	9	32	52	27	146
1978	127	48	211	41	11	71	86	37	140
1979	113	34	127	36	12	34	77	22	93
1980	85	40	165	30	16	71	55	24	94
1981	69	22	48	19	3	11	50	19	36
1982	63	19	97	23	3	14	40	16	82
1983	59	12	35	18	3	4	41	9	31
1984	65	18	83	26	4	11	39	14	72
1985	60	20	62	21	4	19	39	16	43
1986	64	20	218	22	5	8	42	15	209
1987	63	17	117	23	8	20	40	9	97
1988	61	15	97	25	2	10	36	13	87
1989	62	24	112	22	7	18	40	17	94
1990	68	19	64	24	6	12	44	13	52
1991	61	20	76	21	6	24	40	14	52
1992	61	15	106	20	1	2	41	14	105
1993	62	24	90	23	5	20	39	19	69
1994	64	24	71	22	5	11	42	19	60
1995	64	28	87	13	1	1	51	27	85
1996	61	28	95	21	7	17	40	21	78
1997	62	21	152	19	3	4	43	18	149
1998	65	16	61	26	6	20	39	10	40
1999	61	35	200	25	10	22	36	25	178
2000	60	24	132	19	4	7	41	20	125

Year	NAutbase			NAut41			NAutAdj		
	N Sets	N Lob Sets	N Lobster	N Sets	N Lob Sets	N Lobster	N Sets	N Lob Sets	N Lobster
2001	61	28	159	18	9	30	43	19	129
2002	62	38	322	21	11	68	41	27	254
2003	62	27	108	25	12	24	37	15	84
2004	64	27	99	21	9	23	43	18	75
2005	63	29	90	21	11	33	42	18	57
2006	73	38	143	23	14	43	50	24	100
2007	73	30	116	25	12	46	48	18	70
2008	73	37	218	25	16	56	48	21	162
2009	70	44	260	21	15	86	49	29	174
2010	67	49	305	23	19	115	44	30	190
2011	57	40	409	21	14	88	36	26	321
2012	69	42	251	22	20	130	47	22	121
2013	71	52	324	25	23	126	46	29	198
2014	70	52	567	27	26	192	43	26	376
2015	77	58	460	28	26	267	49	32	193

Table 11. Number of sets performed (N Sets), number of sets containing Lobster (N Lob Sets) and the number of Lobster observed (N Lobster) from the Georges RV Survey 1987 to 2015.

	Georges Bank Survey		
Year	**N Sets**	**N Lob Sets**	**N Lobster**
1987	16	1	5
1988	52	1	1
1989	43	0	0
1990	45	4	5
1991	48	5	10
1992	43	4	13
1993	46	5	12
1994	30	0	0
1995	41	2	2
1996	42	1	8
1997	41	4	0
1998	47	9	12
1999	39	10	11
2000	45	9	6
2001	42	13	26
2002	44	12	29
2003	48	11	7
2004	45	16	55
2005	62	25	150
2006	51	20	77
2007	45	12	43
2008	34	12	20
2009	25	9	21
2010	32	14	40
2011	45	19	153
2012	46	21	140
2013	39	17	44
2014	30	9	81
2015	29	13	95

FIGURES

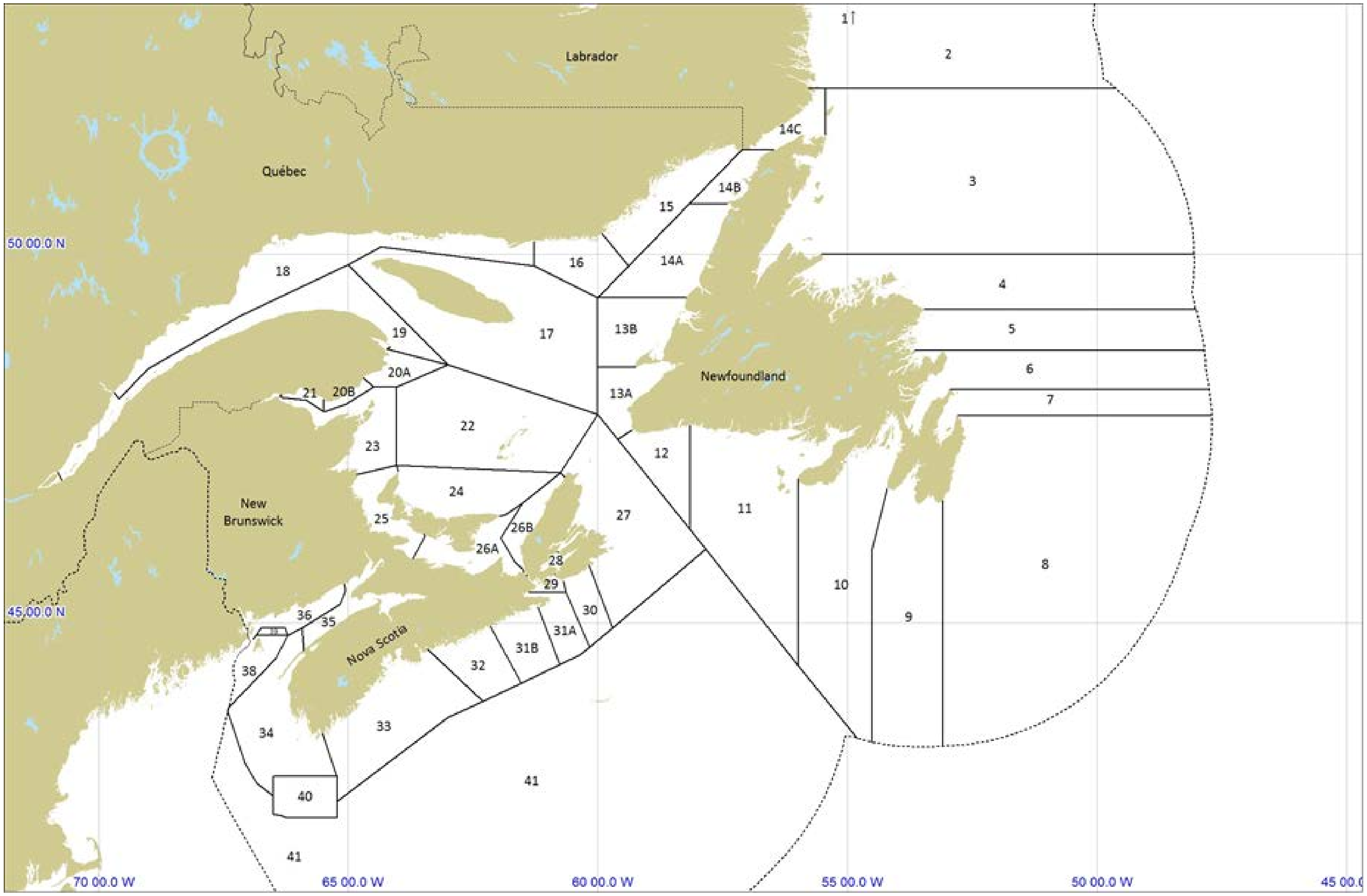


Figure 1. Map of the Lobster Fishing Areas in Atlantic Canada using the boundaries identified in the Atlantic fishery regulations.

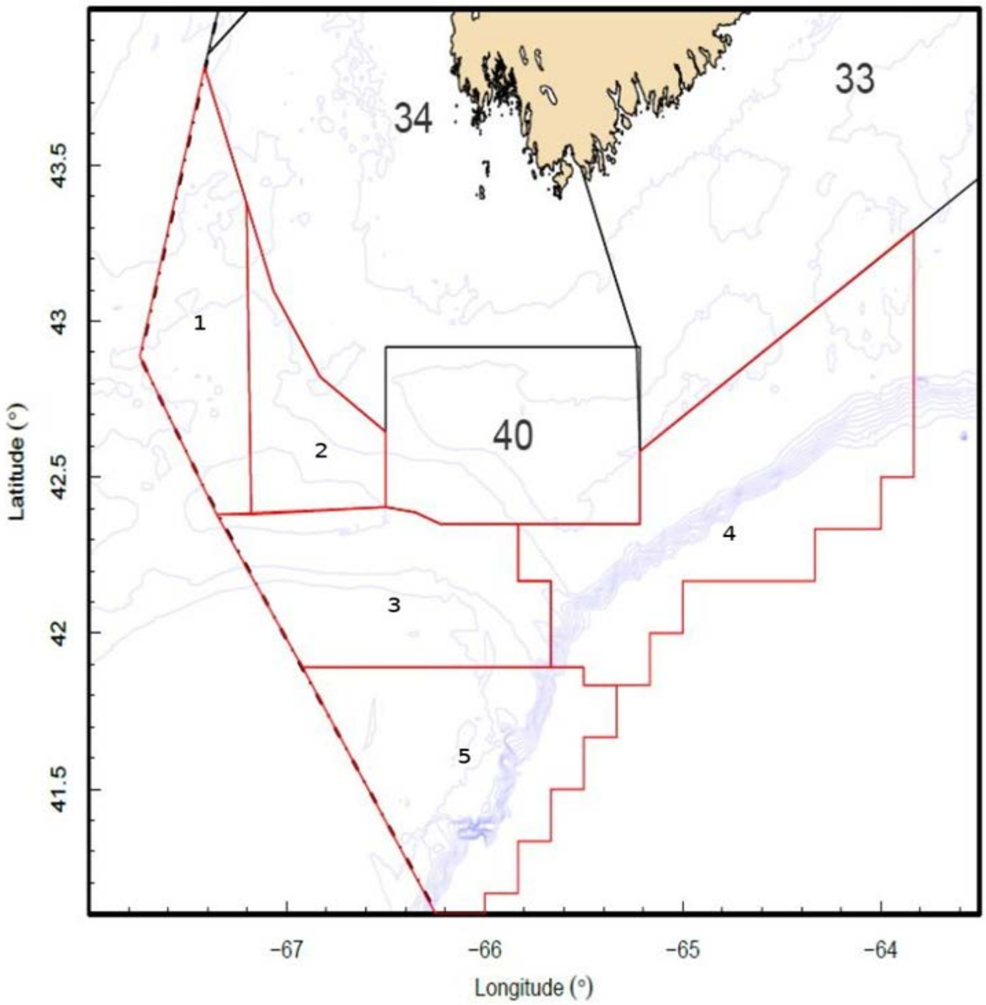


Figure 2. Map showing the offshore zones used in assessments. Zone 1 represents Crowell Basin, Zone 2 SW Browns, Zone 3 Georges Basin, Zone 4 SE Browns and Zone 5 Georges Bank.

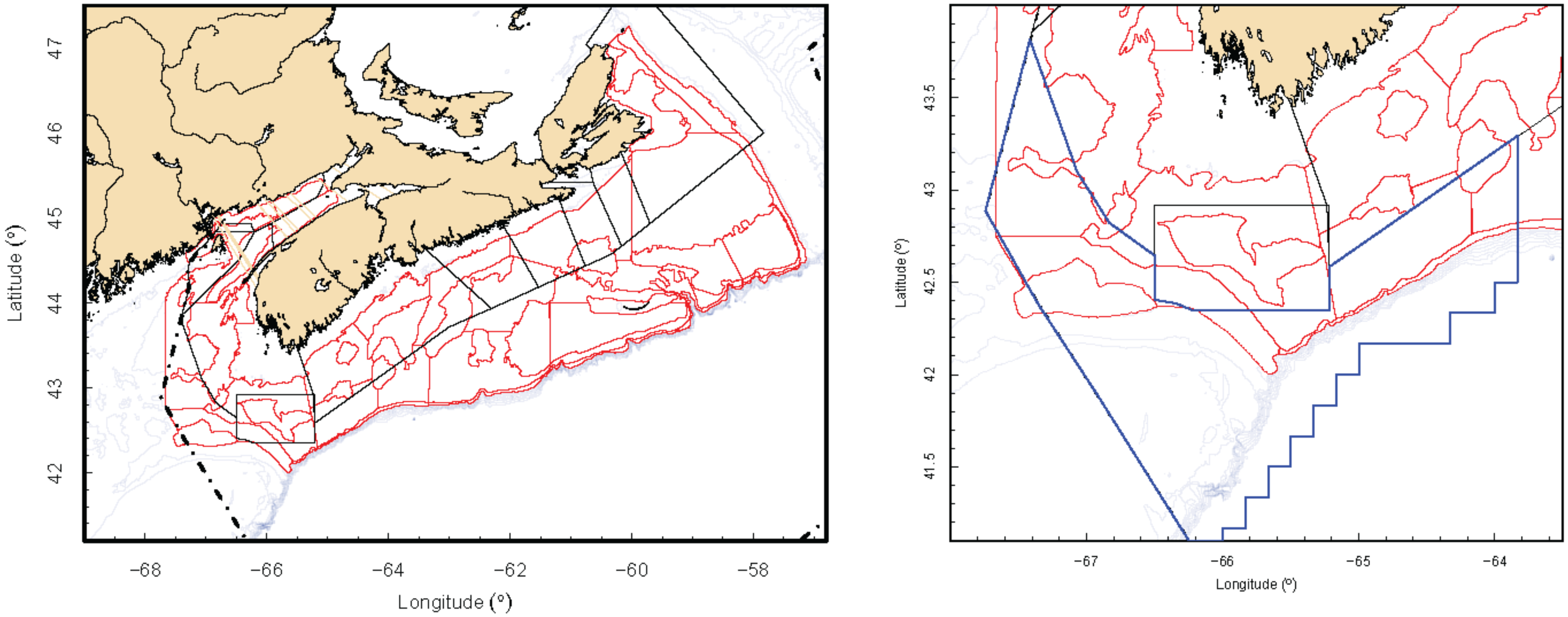


Figure 3. Map of Lobster Fishing Areas (LFAs) in black overlain with the full DFO Summer RV survey strata shown in red (left). Close-up of the fished areas of LFA 41 (blue line) with the DFO Summer RV survey strata included in survey trends outlined in red (right).

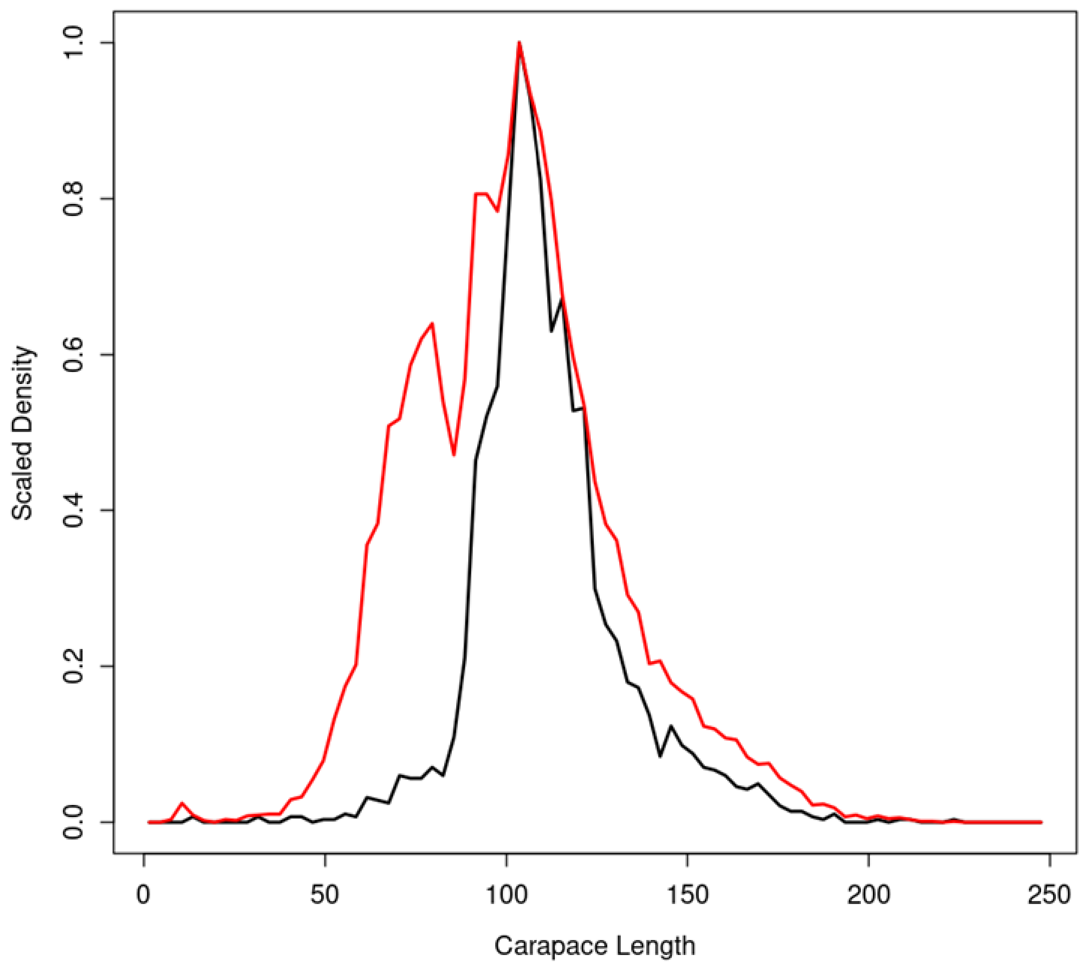


Figure 4. Comparison of sampled length frequencies from the DFO summer RV survey for the entire surveyed area (red) and the Lobsters sampled within LFA 41 (black). Densities were scaled to the maximum density within each data set.

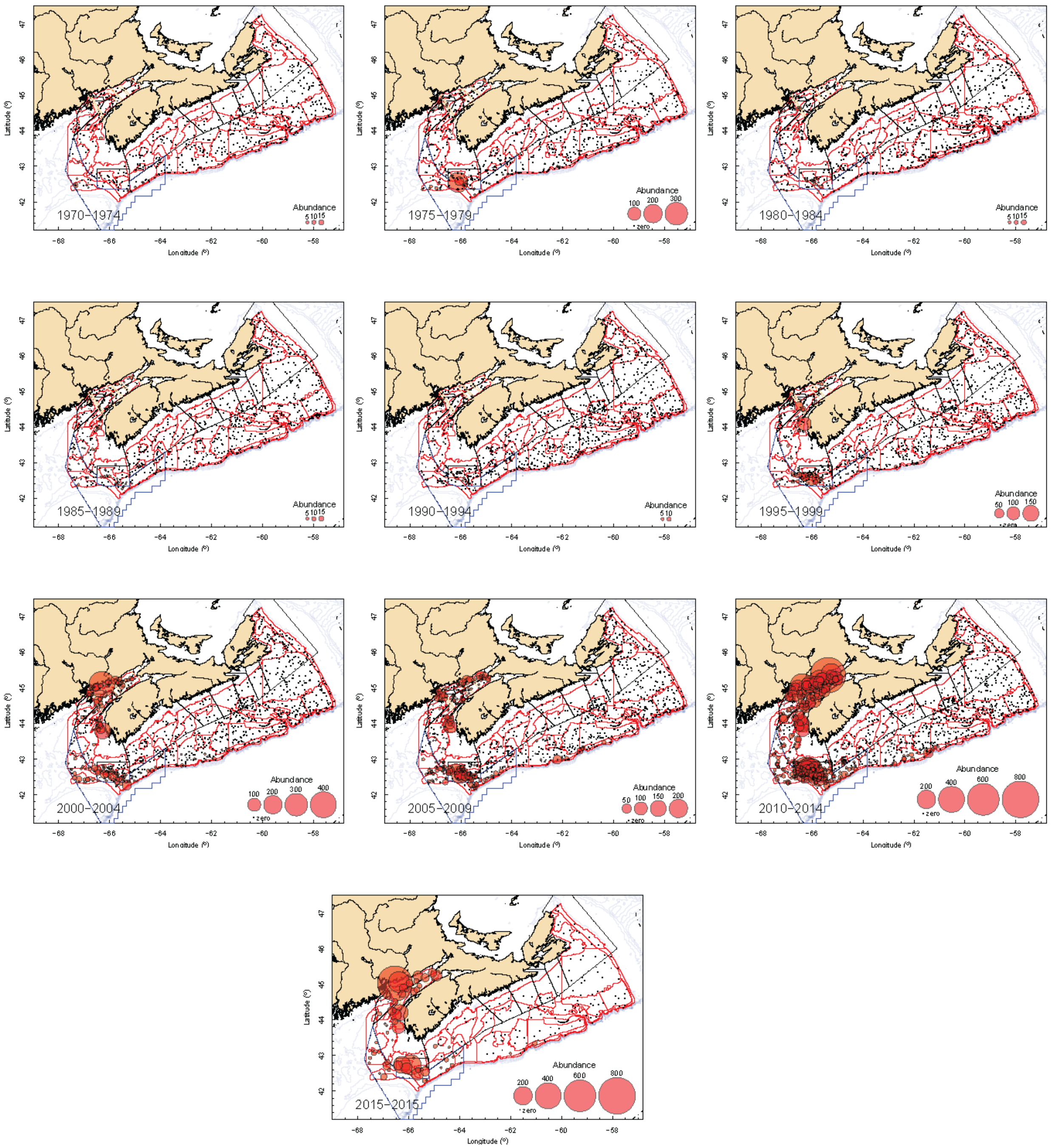


Figure 5. Map of the abundance of Lobster captured during DFO's Summer RV survey of the Scotian Shelf. Strata boundaries are outlined in red and LFA 41 stock boundaries are outlined in blue. Size of the symbols are scaled to the number of Lobster observed within each tow. Black points represent tow locations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

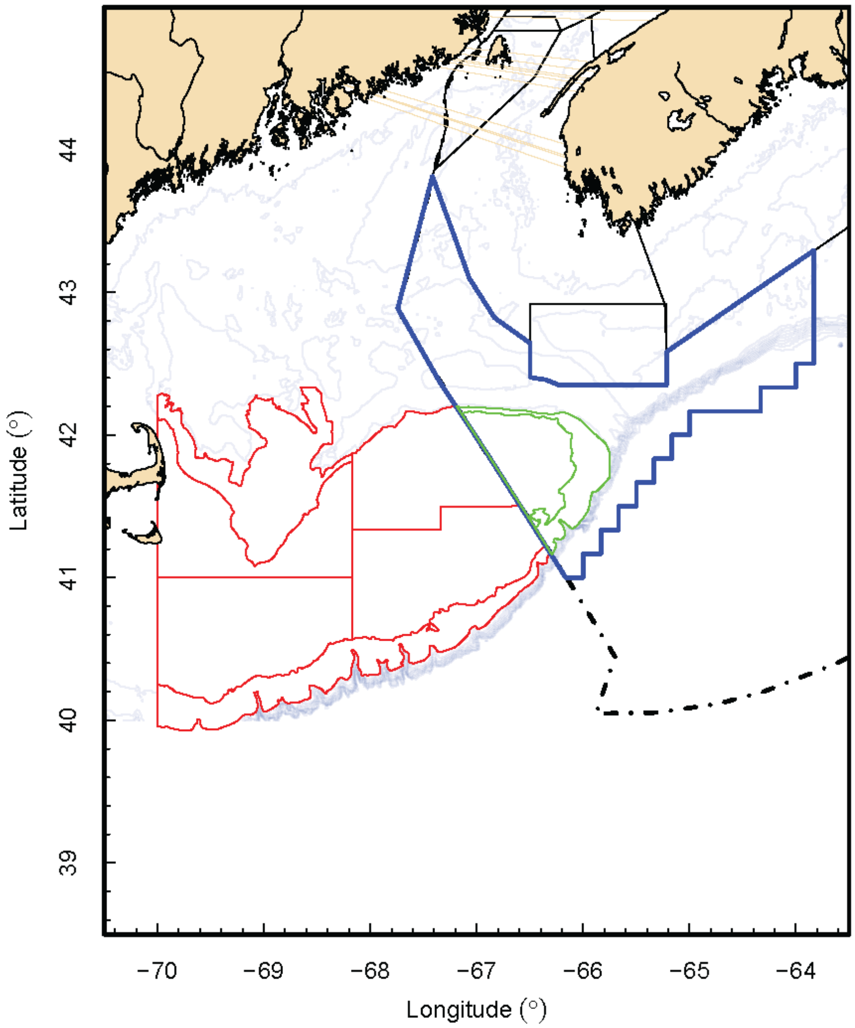


Figure 6. DFO Georges Bank Spring strata from the depth stratified survey are shown in red and green. The strata outlined in green are those used in survey trends from the Georges Bank Survey. Lobster Fishing Area 41 (blue line) is outlined in blue.

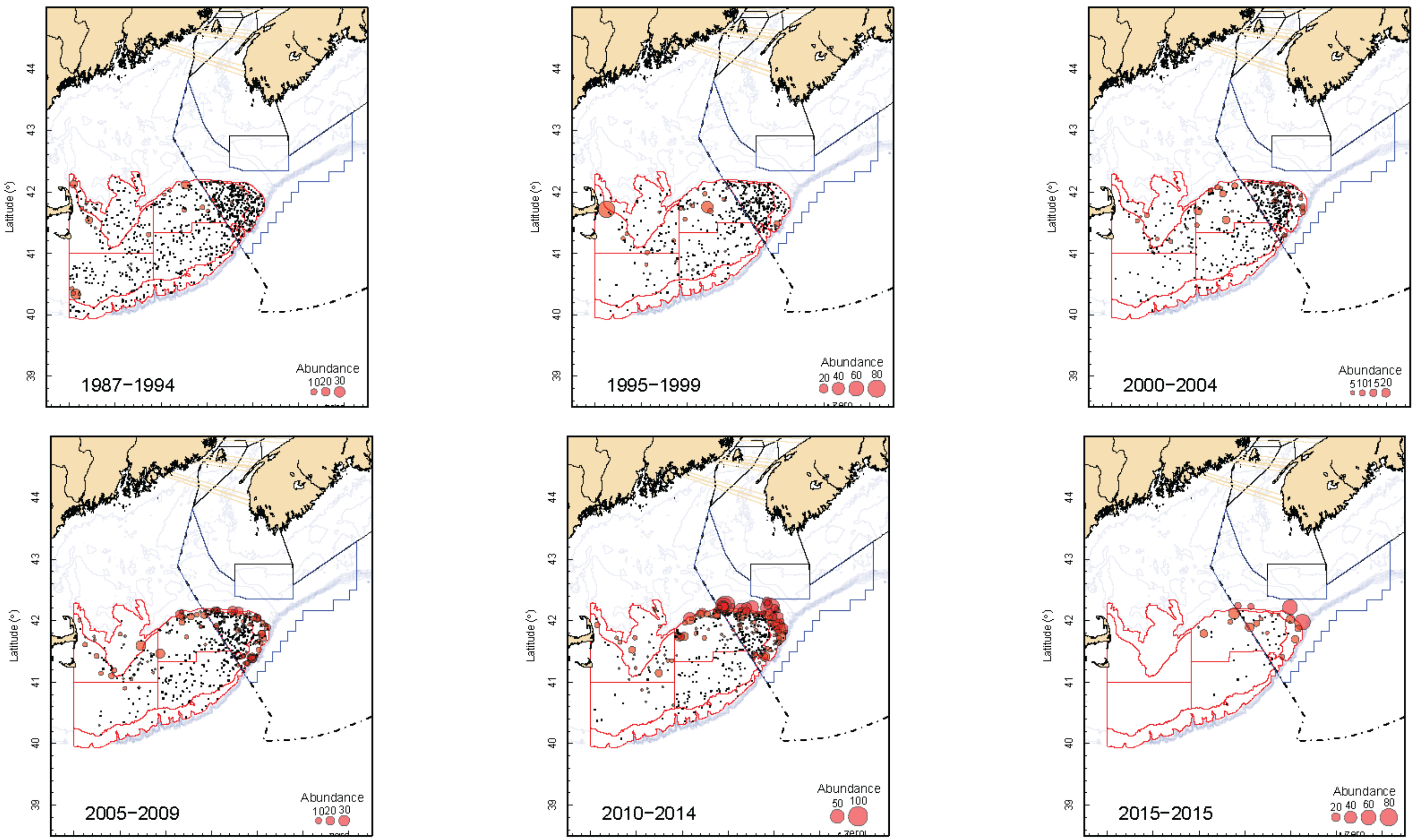
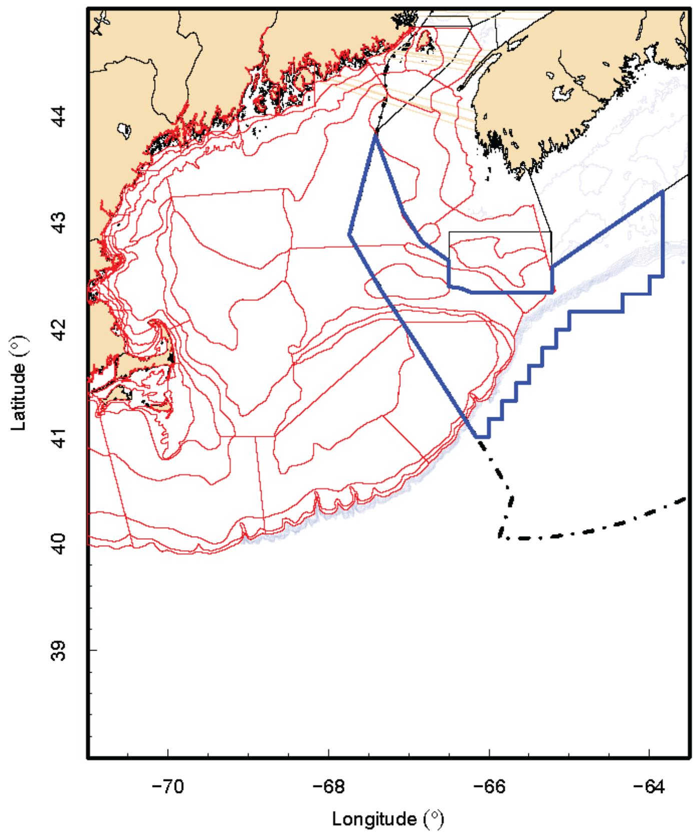


Figure 7. Map of the abundance of Lobster captured during DFO's Georges Bank Survey. Strata boundaries are outlined in red and LFA 41 stock boundaries are outlined in blue. Size of the symbols are scaled to the number of Lobster observed within each tow. Black points represent tow locations with no Lobsters.



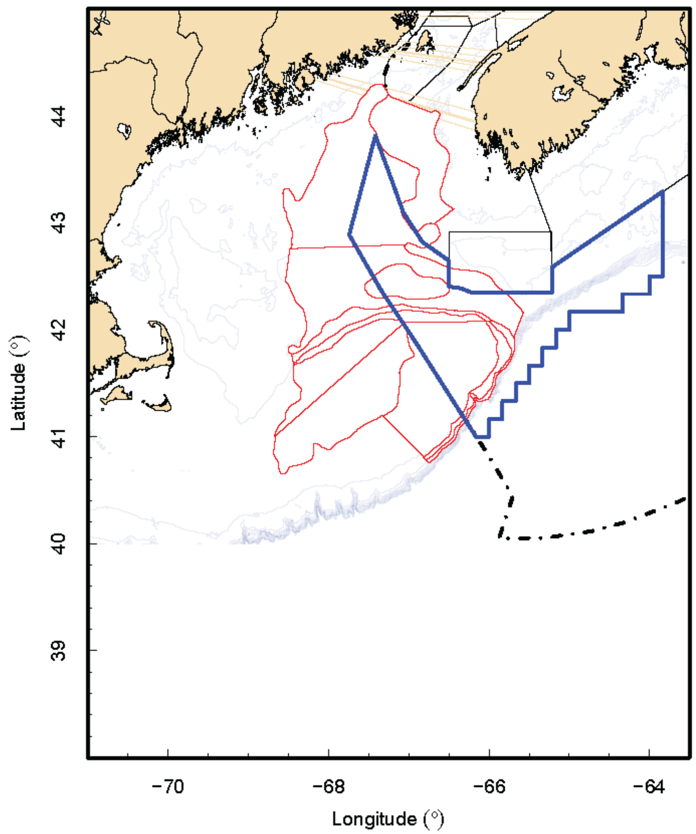


Figure 8. NEFSC spring and autumn strata from the depth stratified survey shown in red (left). Lobster Fishing Area 41 (blue line) with the NEFSC spring and autumn strata (shown in red) used for the analysis of survey trends (right).

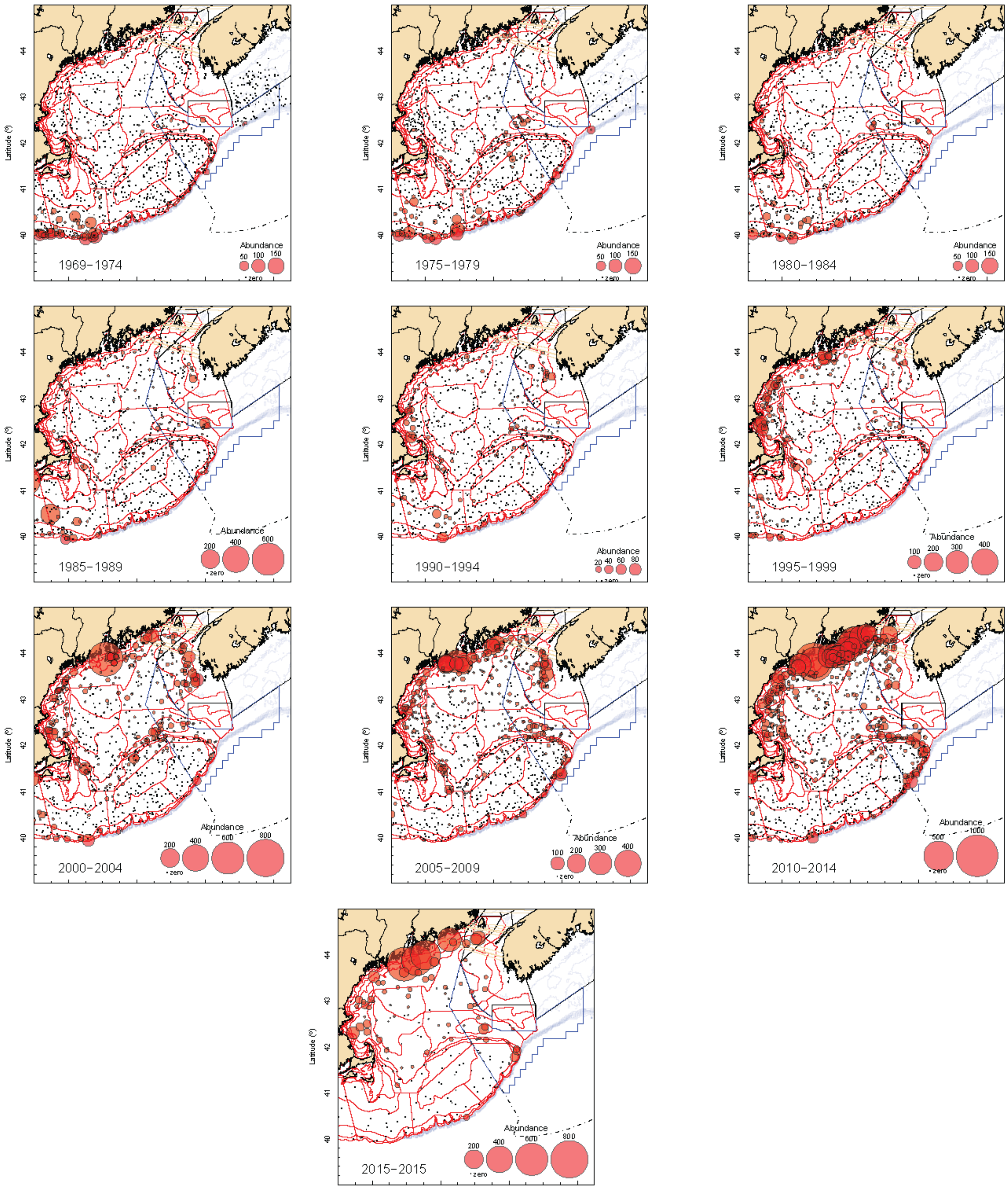


Figure 9. Map of the abundance of Lobster captured during during NEFSC's Spring Survey of the Gulf of Maine, Georges Bank and Scotian Shelf. Strata boundaries are outlined in red and LFA 41 stock boundaries are outlined in blue. Size of the symbols are scaled to the number of Lobster observed within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

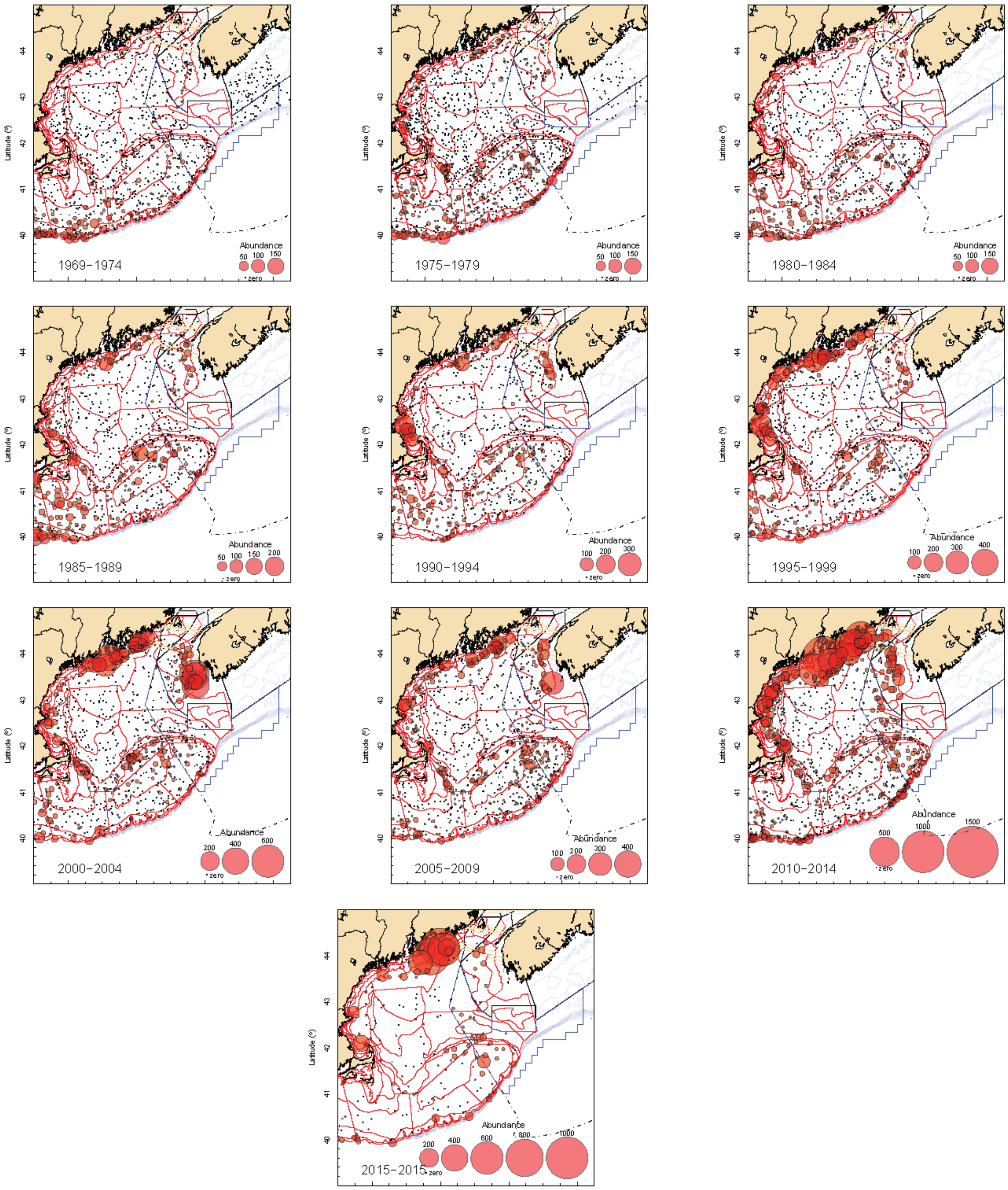


Figure 10. Map of the abundance of Lobster captured during NEFSC's Fall Survey of the Gulf of Maine, Georges Bank and Scotian Shelf. Strata boundaries are outlined in red and LFA 41 stock boundaries are outlined in blue. Size of the symbols are scaled to the number of Lobster observed within each tow.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

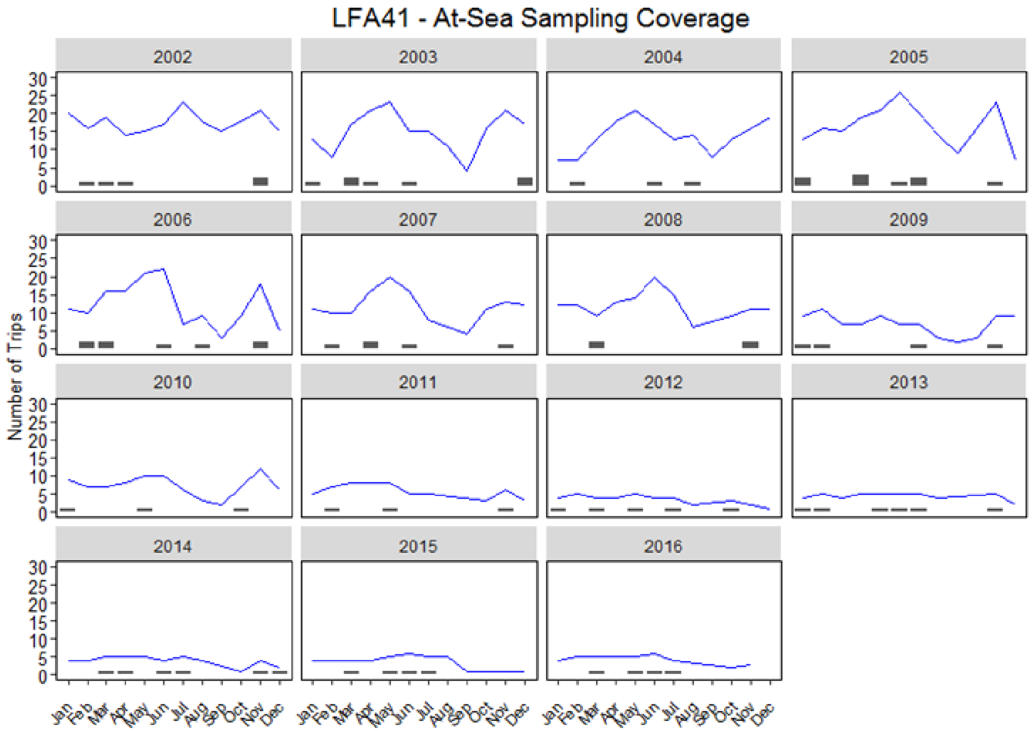


Figure 11. Monthly distribution of at-sea sampling trips (bars) and the total number of trips made by offshore vessels (blue line) separated by year for the LFA 41 Lobster fishery.

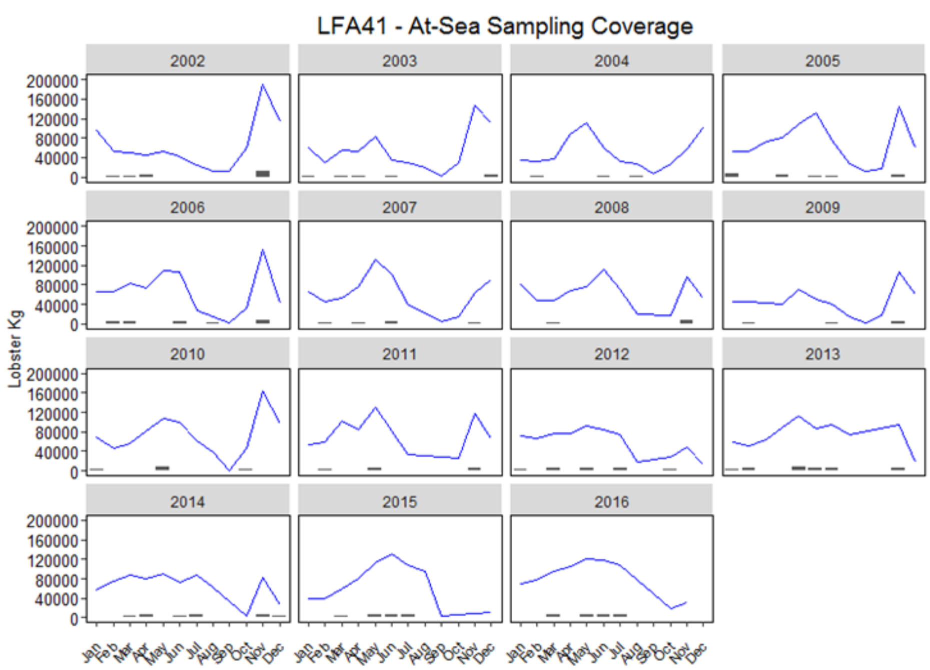


Figure 12. Monthly distribution of the weight of at-sea landings observed (bars) and the total weight of Lobster landings (blue line) by offshore vessels separated by year for the LFA 41 offshore fishery.

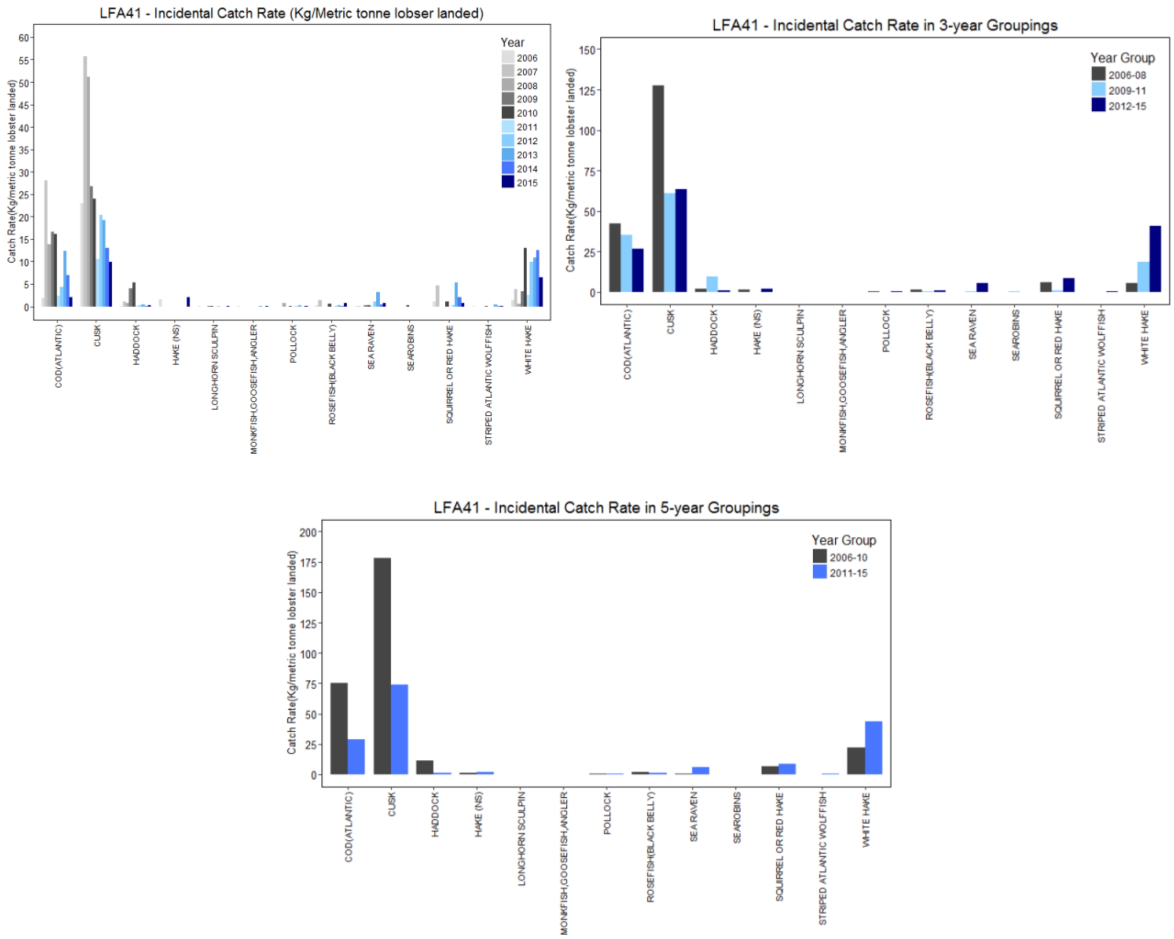


Figure 13. Estimated incidental catch rate (kg/t of Lobsters) of fish species from the at-sea sampled data of the LFA 41 Lobster fishery between 2006 to 2015 in 1, 3 and 5 year time blocks.

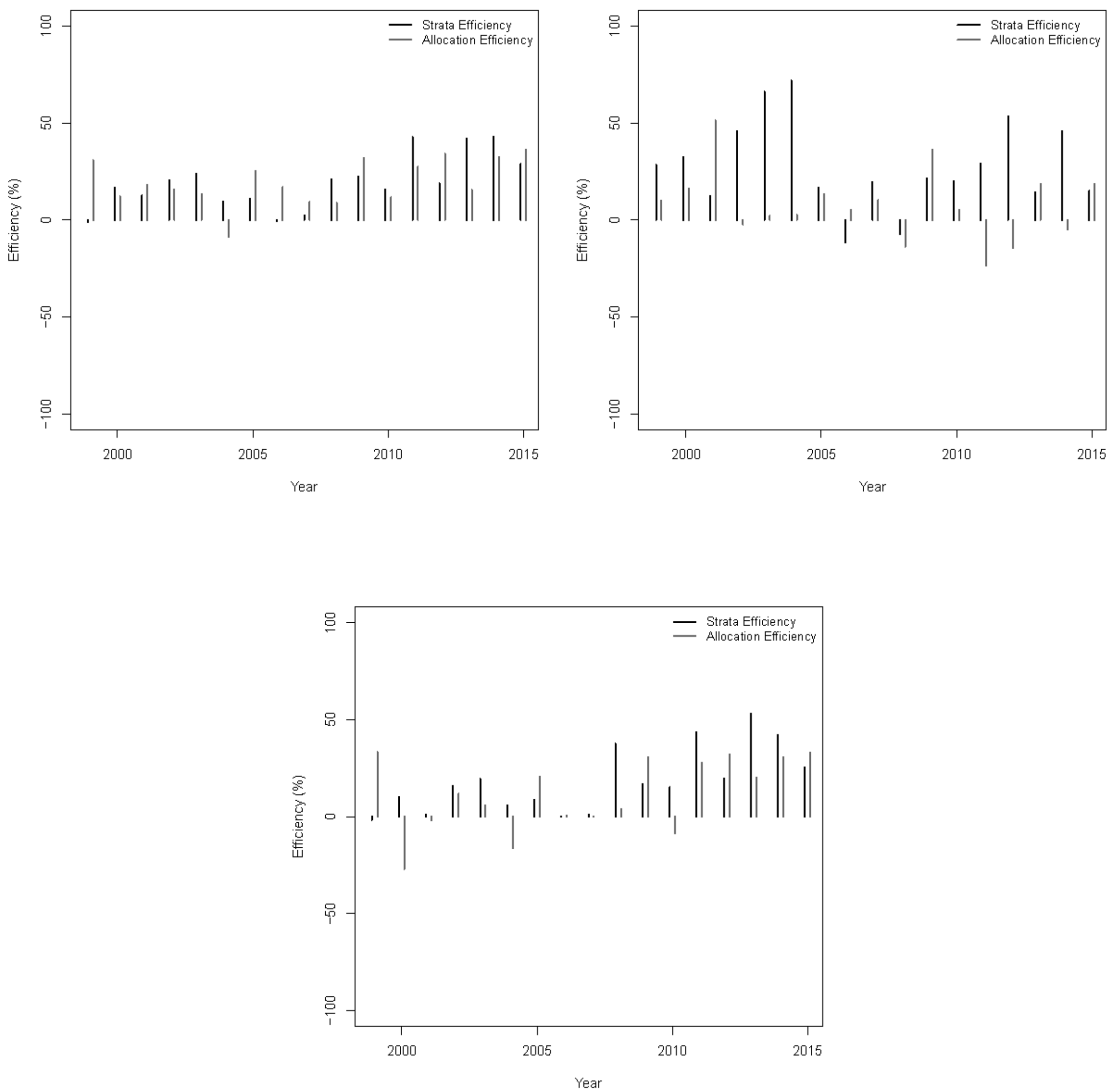


Figure 14. Survey efficiency of DFO RV base survey (RVbase, topleft), DFO RV pruned survey (RV41, topright) and DFO RV survey pruned to adjacent areas (RVAdj bottom) from 1999 to 2015. Percent efficiency refers to changes in either strata or allocation scheme relative to a simple random survey.

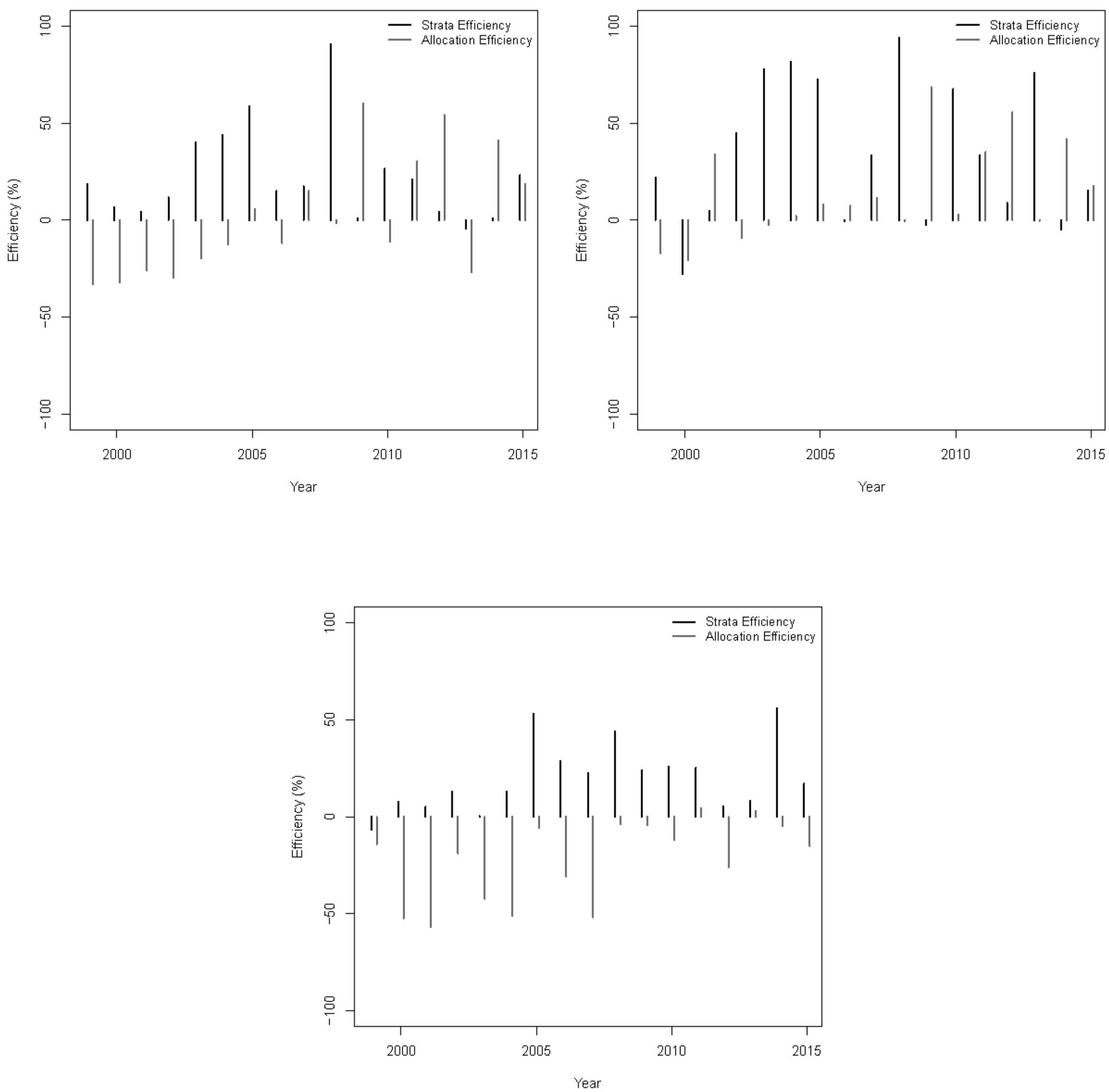


Figure 15. Survey efficiency of NEFSC Spring base survey (NSprbase topleft), NEFSC Spring pruned survey (NSpr41 topright) and NEFSC Spring survey pruned to adjacent areas (NSprAdj bottom) from 1999 to 2015. Percent efficiency refers to changes in either strata or allocation scheme relative to a simple random survey.

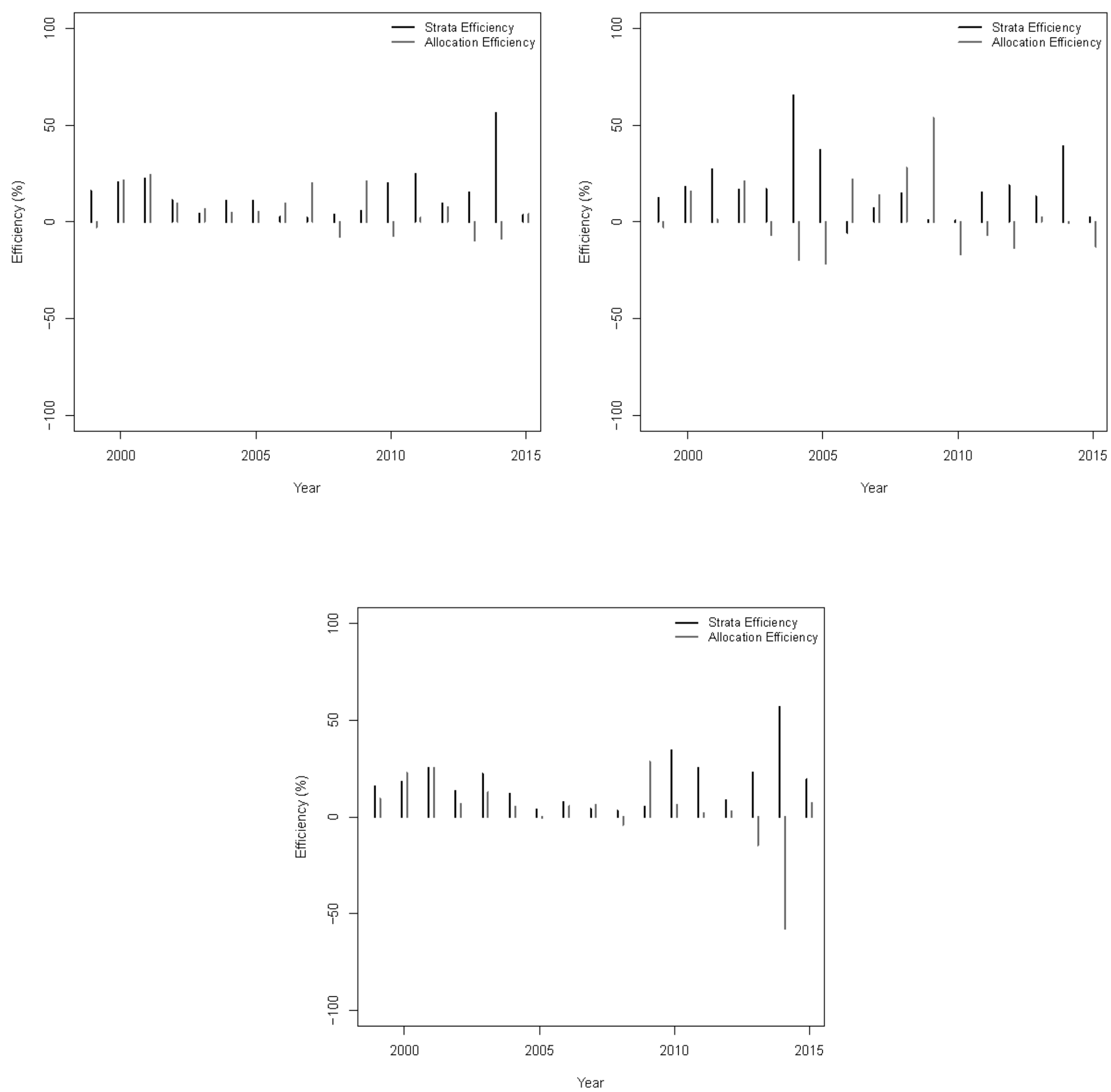


Figure 16. Survey efficiency of NEFSC Autumn base survey (NAutbase topleft), NEFSC Autumn pruned survey (NAut41 topright) and NEFSC Autumn survey pruned to adjacent areas (NAutAdj bottom) from 1999 to 2015. Percent efficiency refers to changes in either strata or allocation scheme relative to a simple random survey.

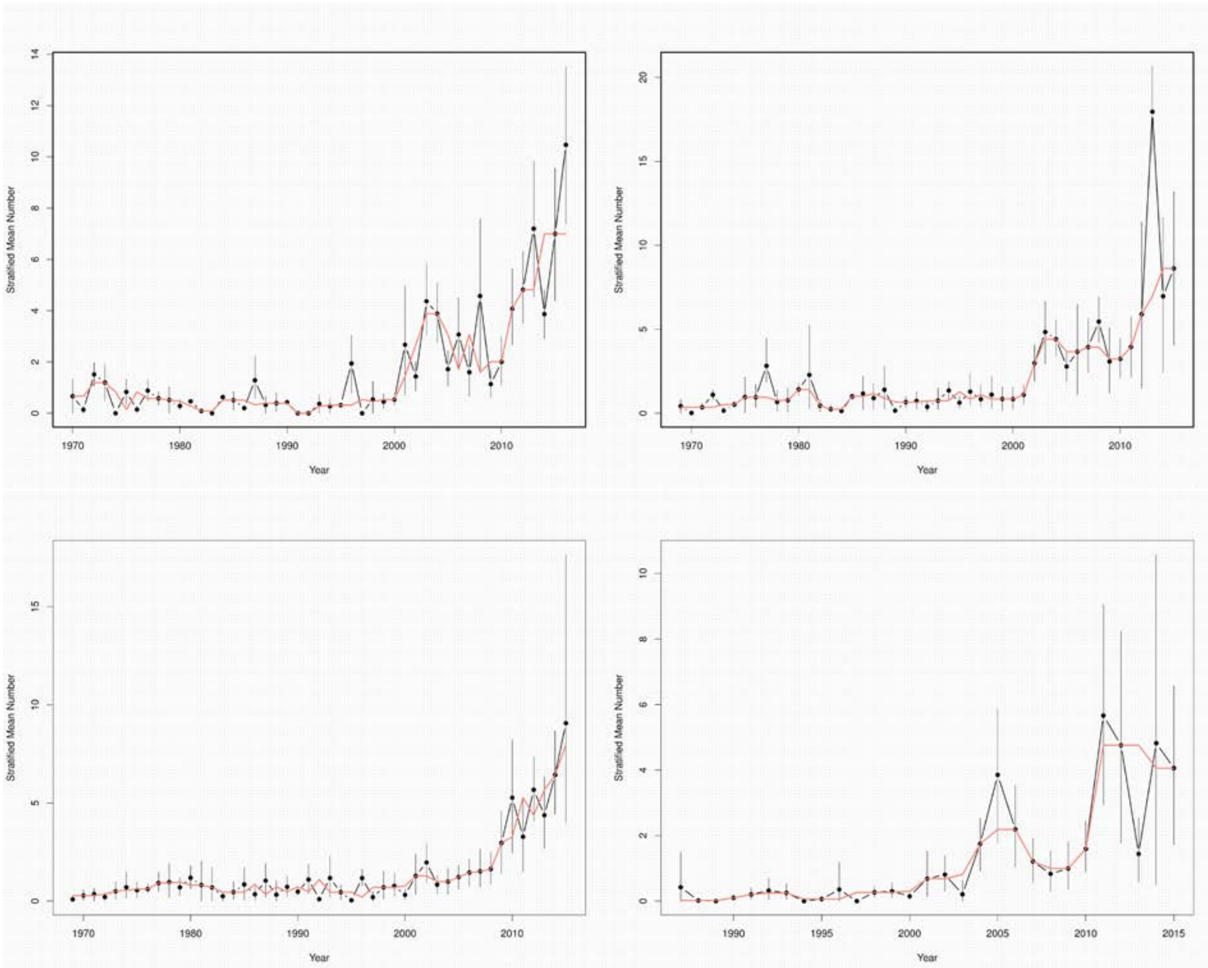


Figure 17. Stratified mean number per tow for the DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Confidence bounds are presented for each point estimate.

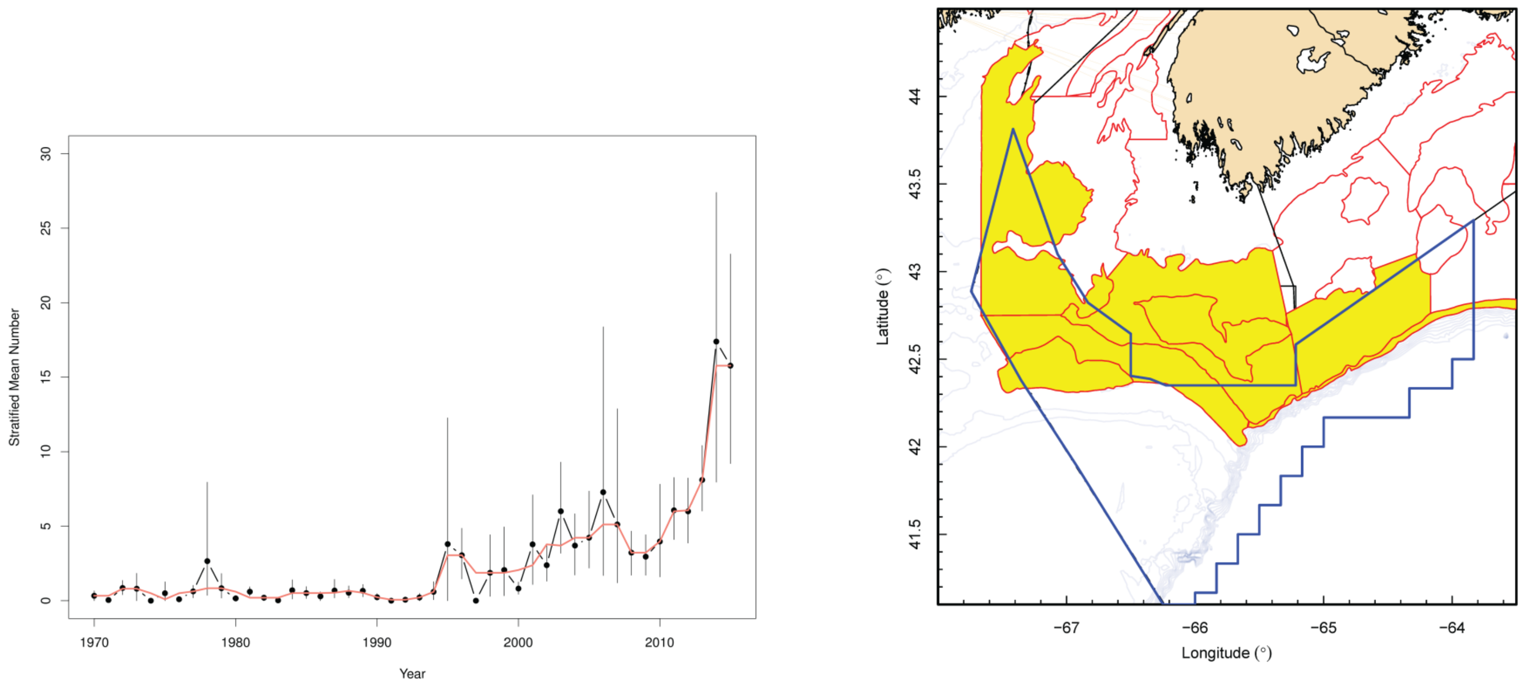
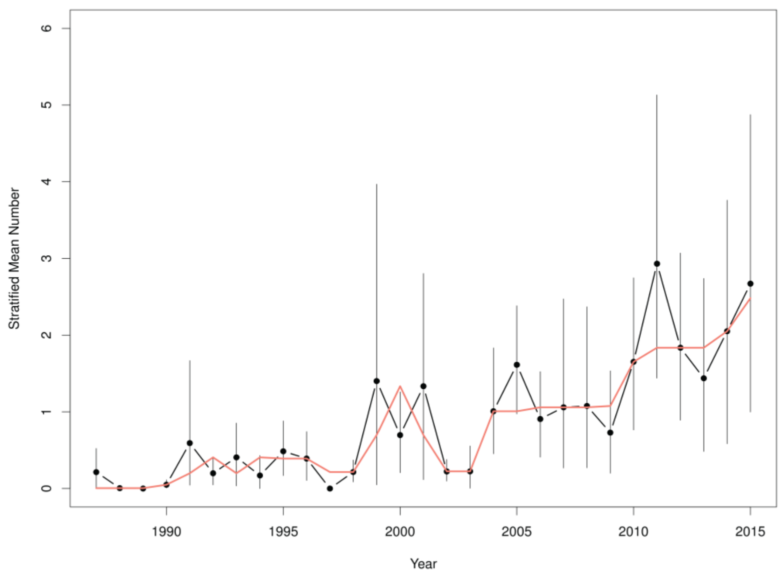


Figure 18. DFO RV Summer survey American Lobster stratified mean number per tow (left) using the strata definitions of Pezzack et al. (2015) (shaded yellow; right) from 1970 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate.



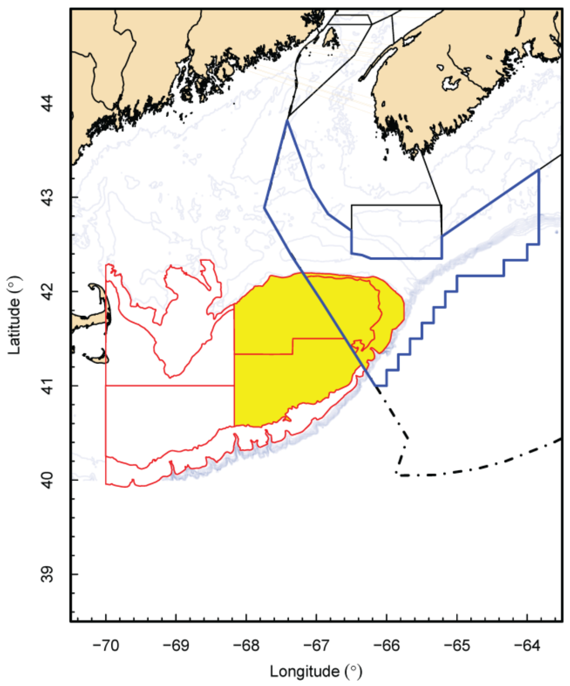


Figure 19. DFO Georges survey American Lobster stratified mean number per tow (left) using the strata definitions of Pezzack et al. (2015) (shaded yellow; right) from 1987 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate.

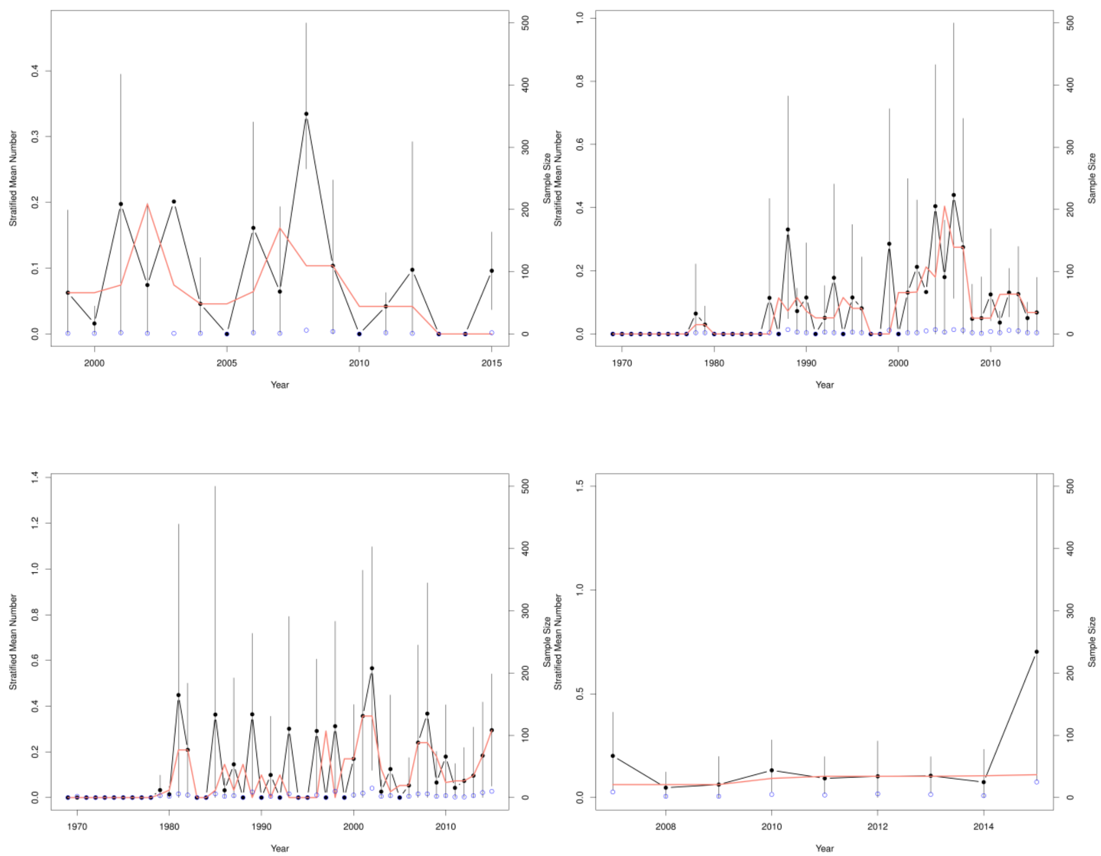


Figure 20. Stratified mean number of recruiting (<83mm) Lobster per tow DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Confidence bounds are presented for each point. Within each plot the blue points represent the annual sample sizes of observed Lobster.

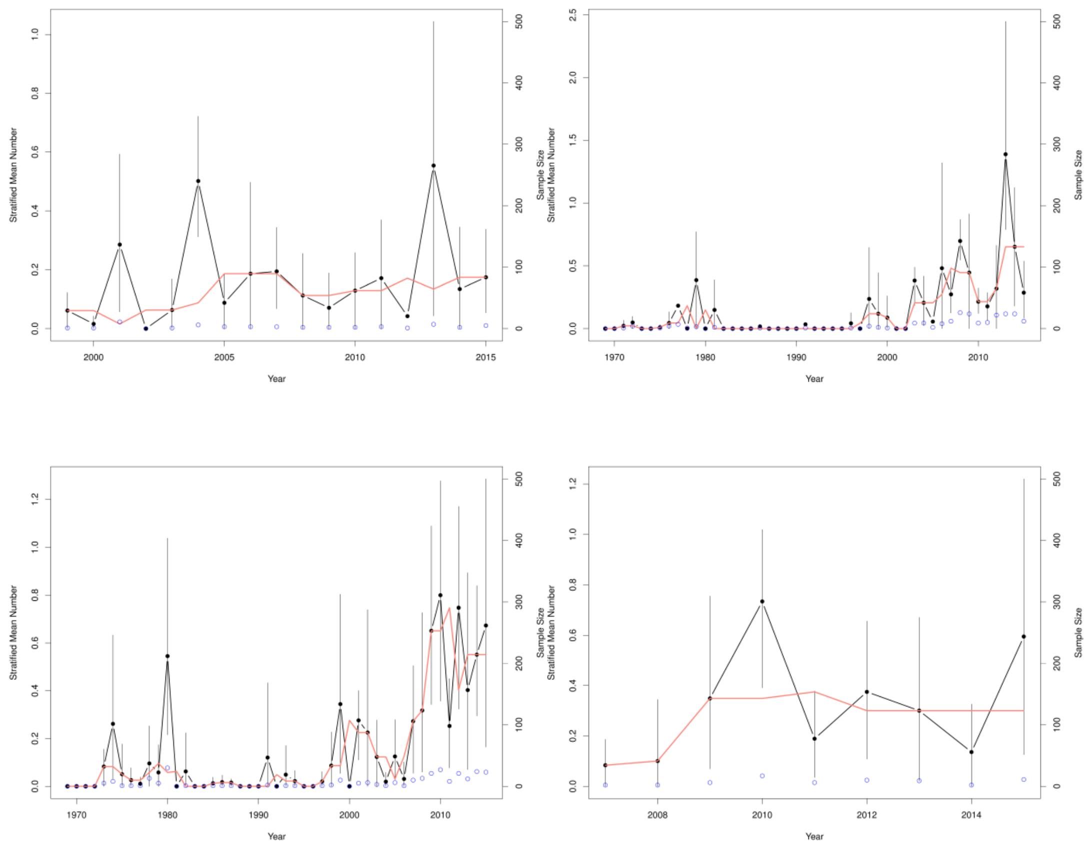


Figure 21. Large female (≥ 140mm) American Lobster stratified mean abundance from DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Confidence bounds are presented for each point. Blue points represents the annual number of female Lobster ≥ 140mm observed within the survey.Within each plot the blue points represent the annual sample sizes of observed Lobster.

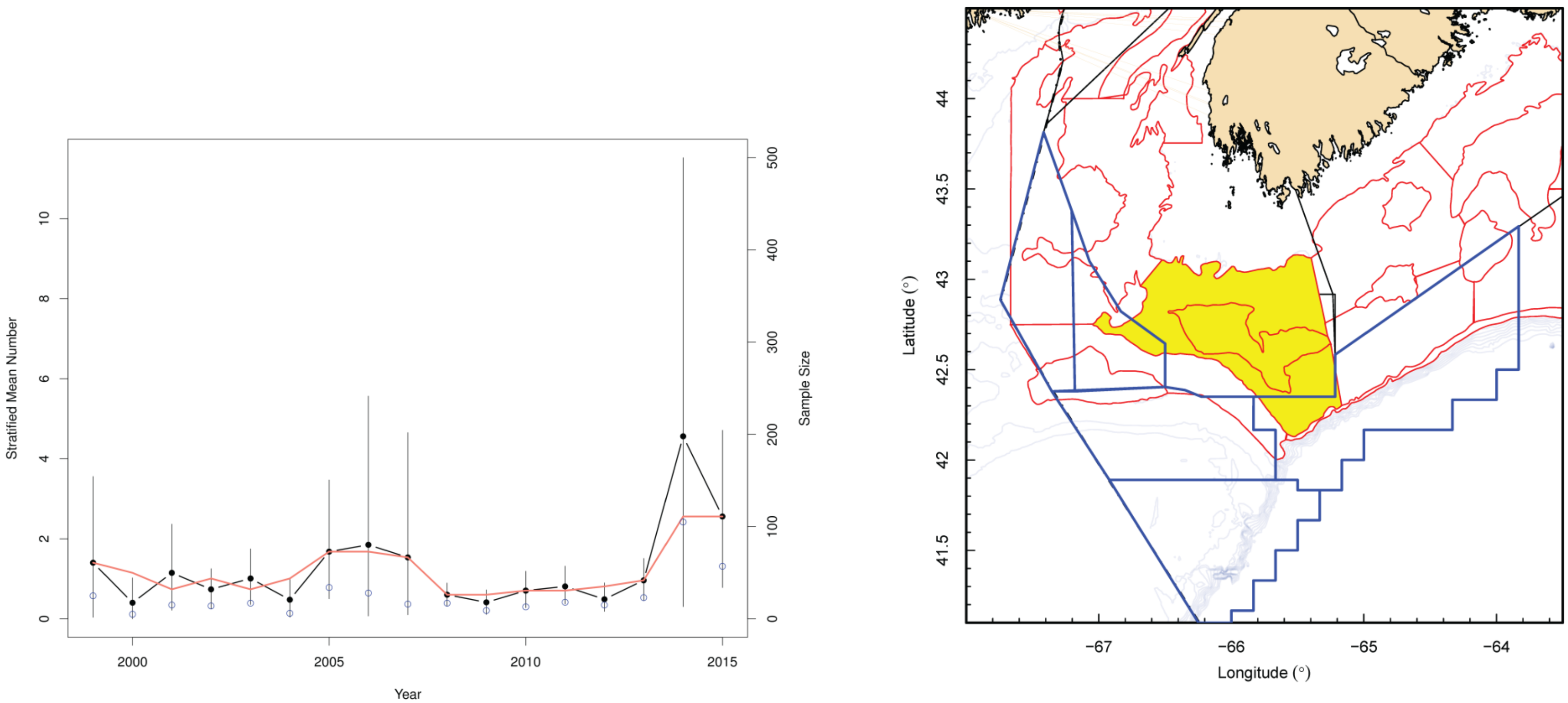


Figure 22. DFO Summer RV survey American Lobster stratified mean number per tow for large females (≥ 140) (left) using the strata definitions of Pezzack et al. (2015) (shaded yellow; right) from 1999 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Within each plot the blue points represent the annual sample sizes of observed Lobster.

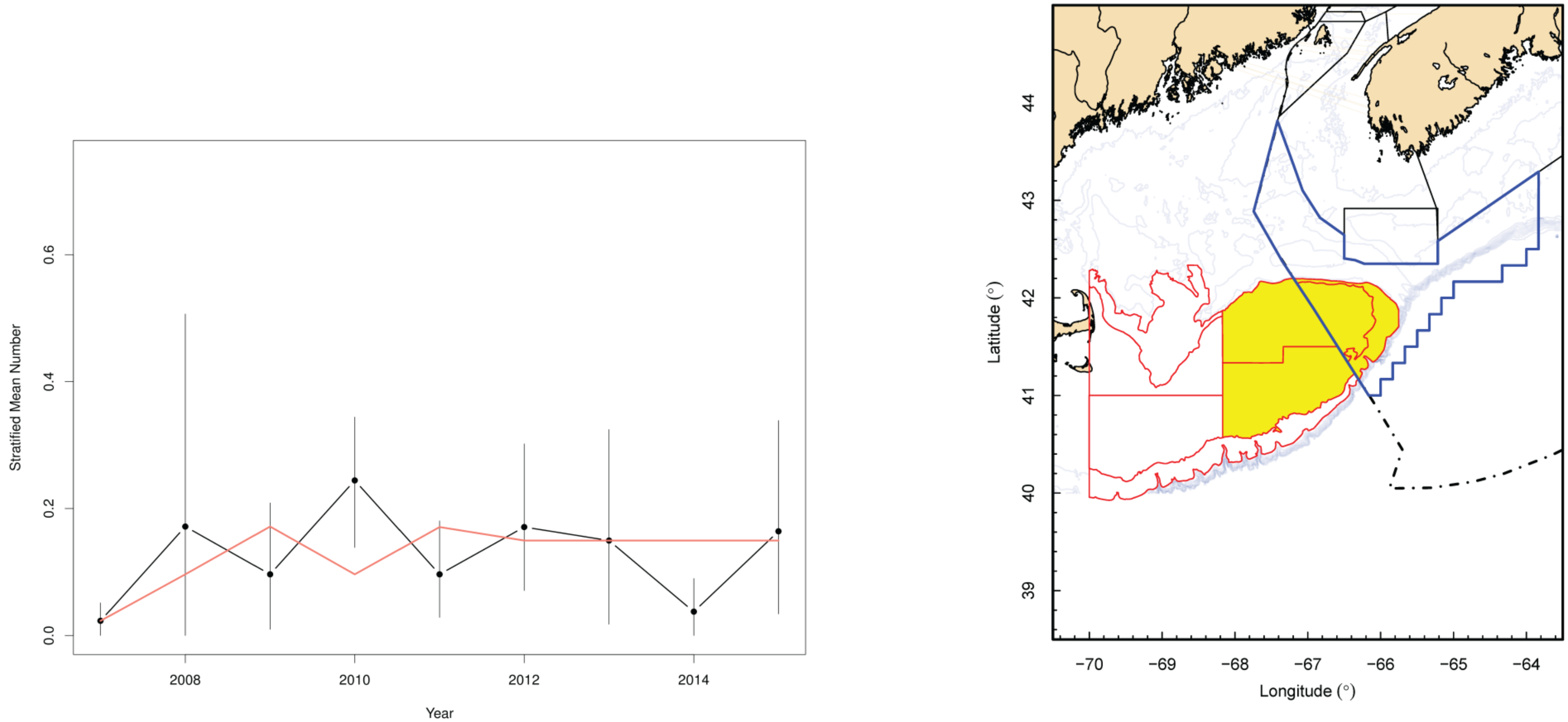


Figure 23. DFO Georges Bank survey American Lobster stratified mean number per tow for large females (≥ 140) (left) using the strata definitions of Pezzack et al. (2015) (shaded yellow; right) from 1999 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate.

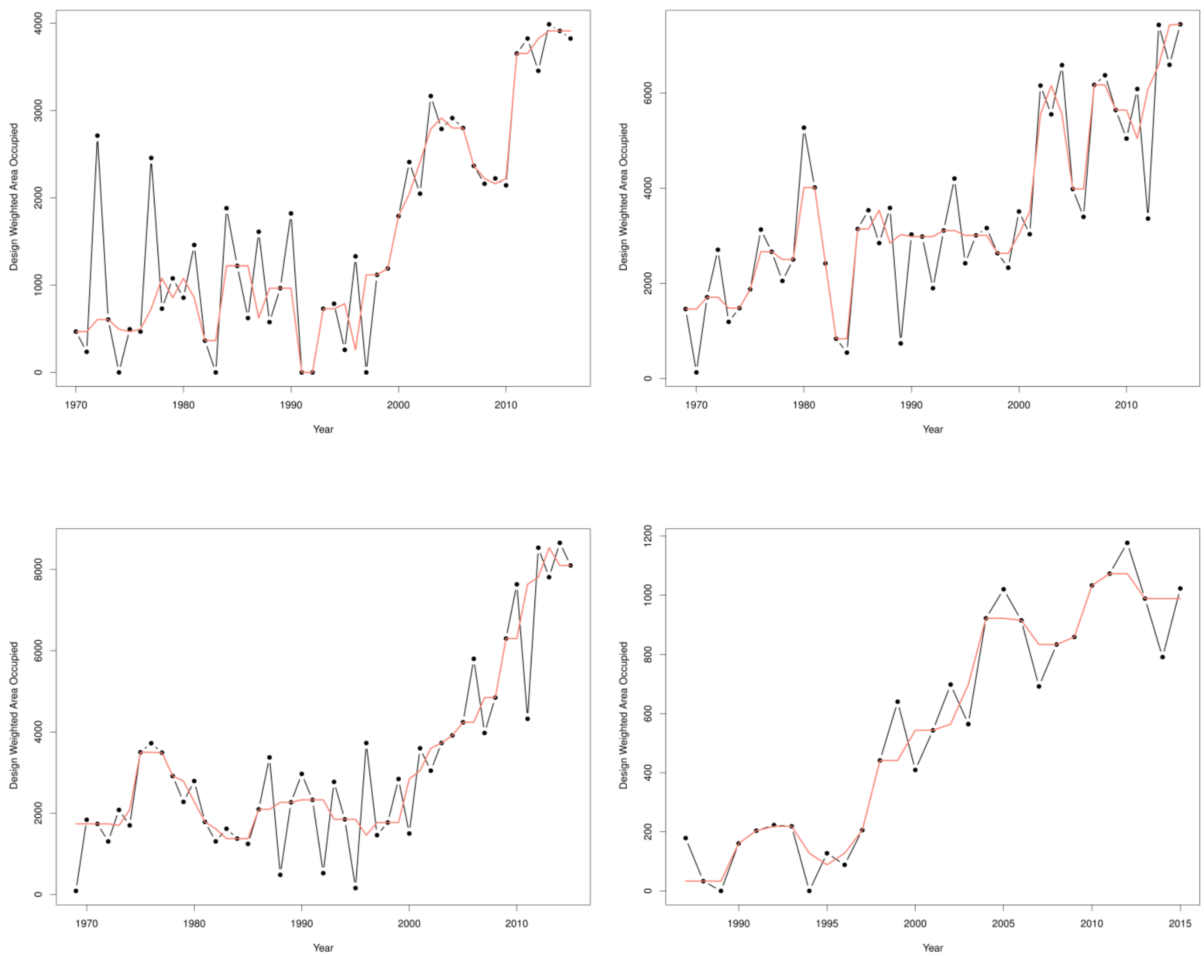


Figure 24. Design weighted area occupied (km2) of American Lobster from DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median.

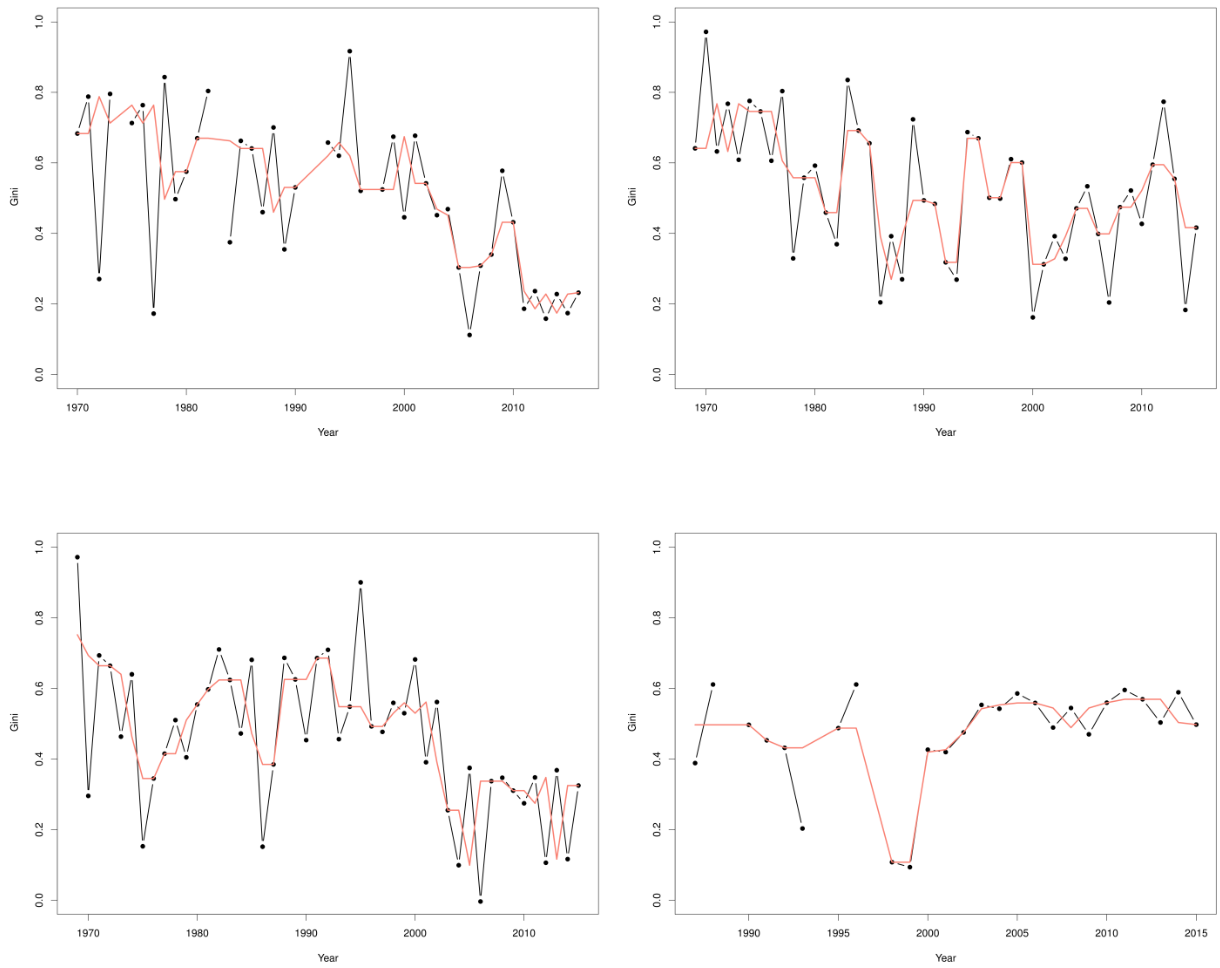


Figure 25. Patchiness as estimated through the Gini index from DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster were captured in the survey strata.

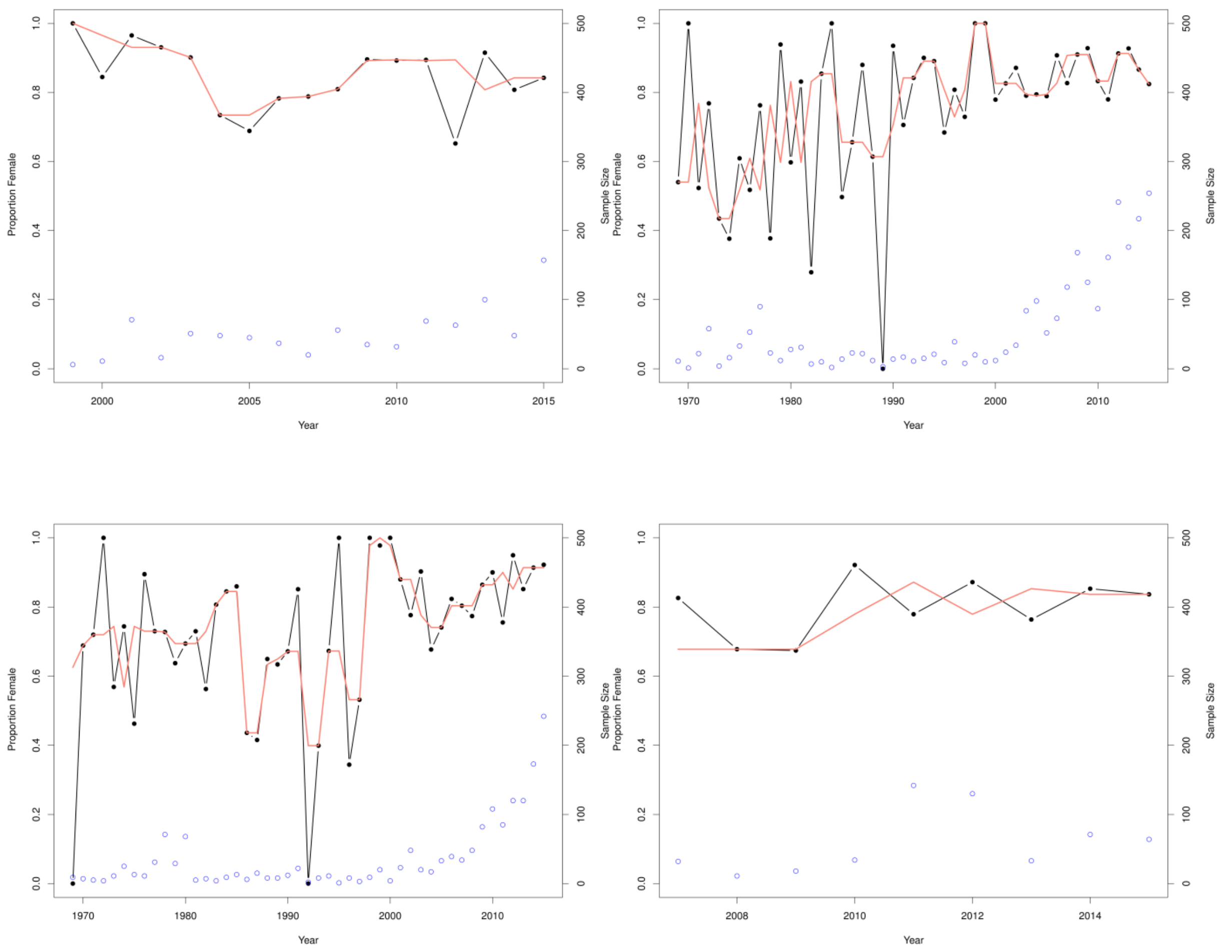


Figure 26. Proportion females from mature component (≥ 92 mm) from DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster were captured in the survey strata. Within each plot the blue points represent the annual sample sizes of observed Lobster.

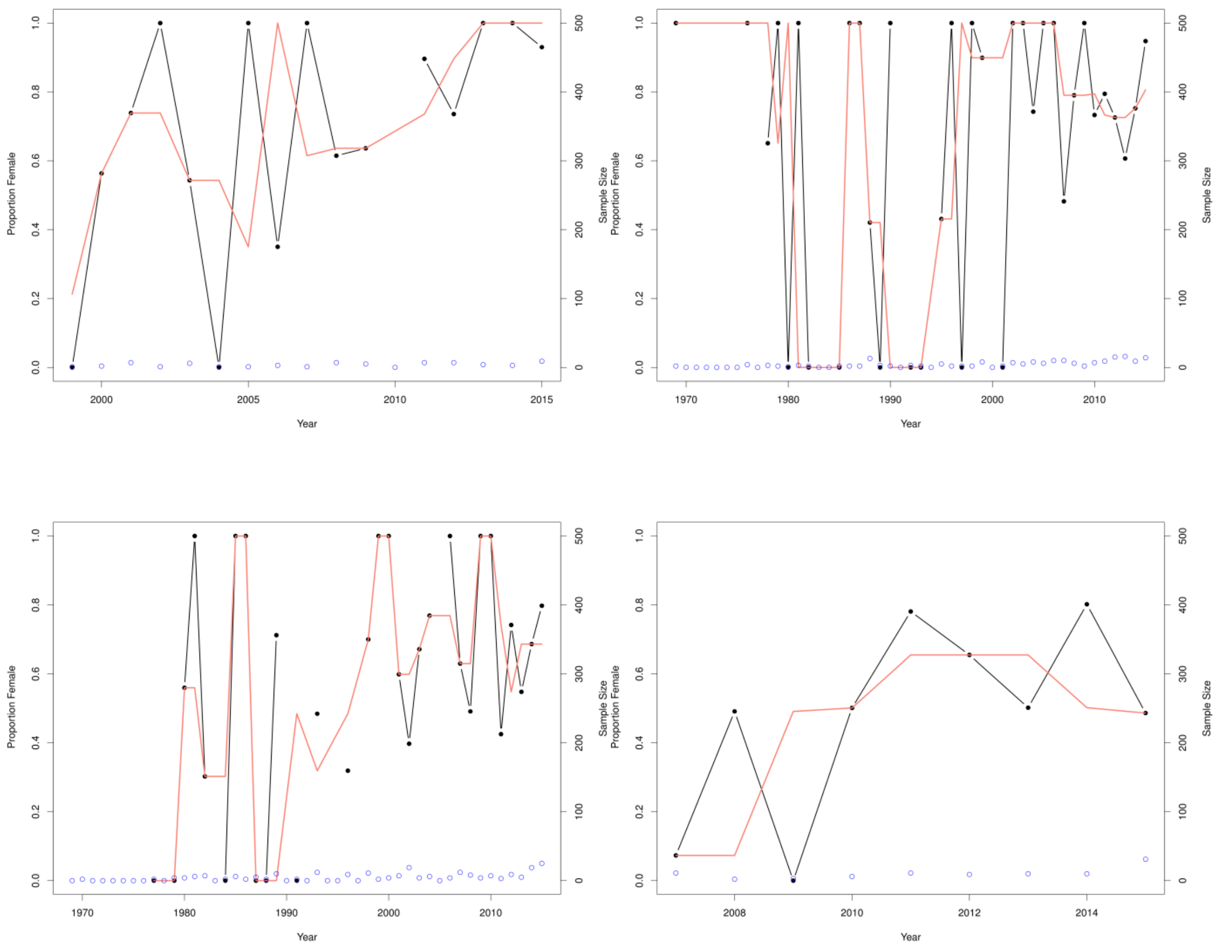


Figure 27. Proportion females from mature component (<92 mm) from DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster were captured in the survey strata. Within each plot the blue points represent the annual sample sizes of observed Lobster.

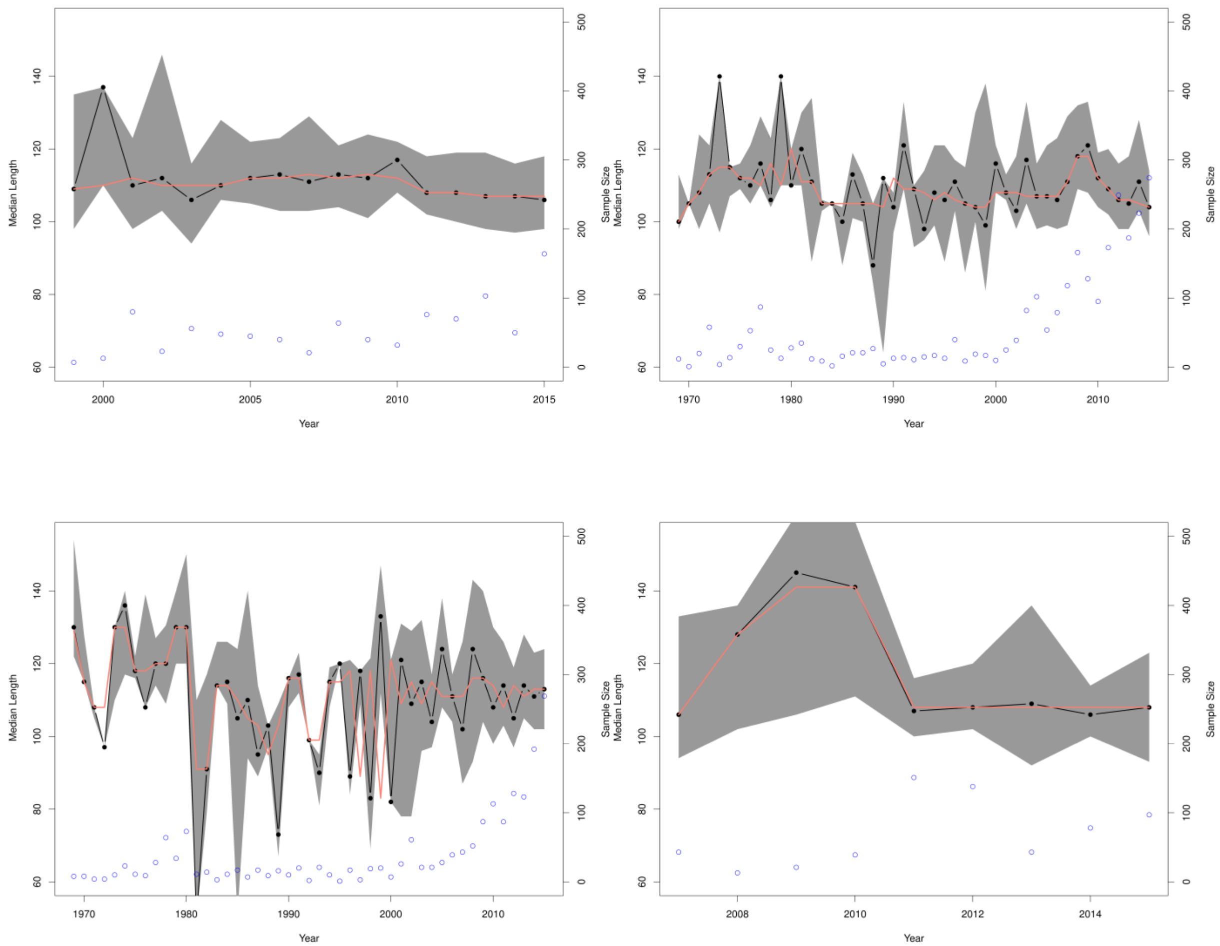


Figure 28. Population weighted median carapace length (solid line and points) with accompanying first and third quartiles (shaded polygon) DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom right) with 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 were captured in the survey strata. Within each plot the blue points represent the annual sample sizes of observed Lobster.

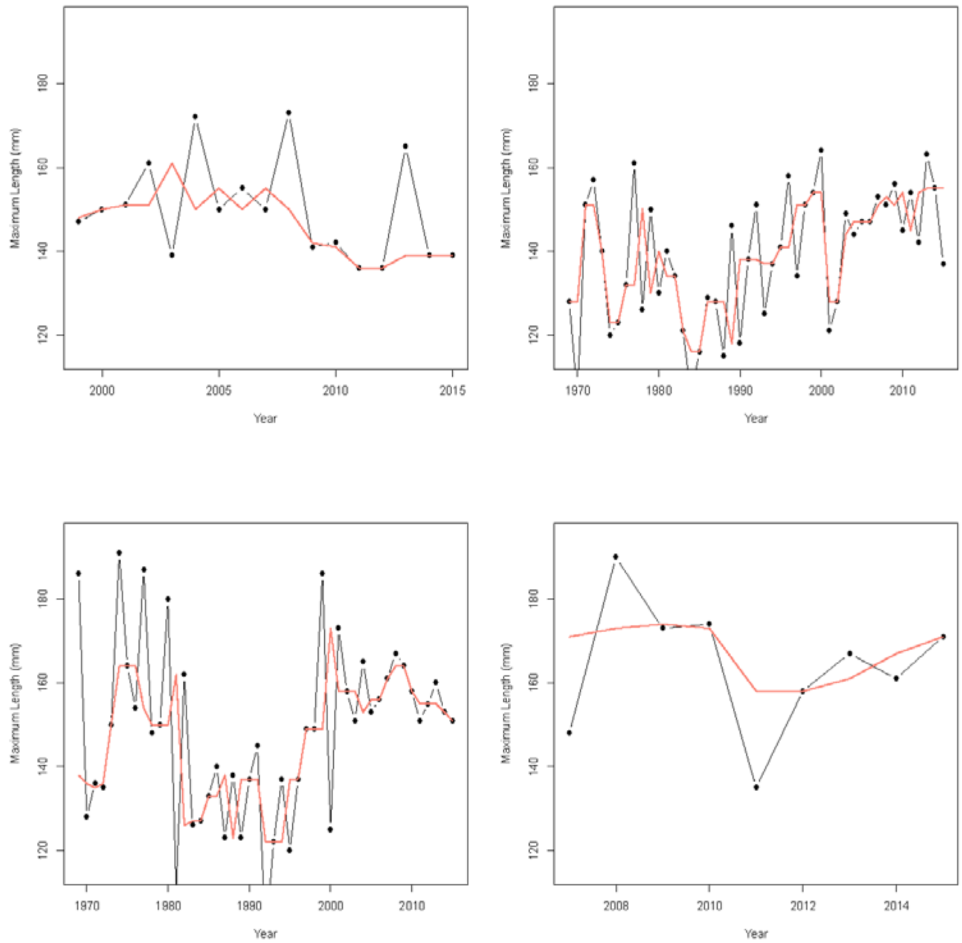


Figure 29. Maximum carapace length (upper 95 quantile) of American Lobster from DFO RV Survey (RV41 top left), NEFSC Spring Survey (NSpr41 top right), NEFSC Autumn Survey (NAut41 bottom left) and DFO Georges Bank Survey (GB bottom rightr) with surveys pruned to LFA 41. Within each plot the red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster were captured in the survey strata.

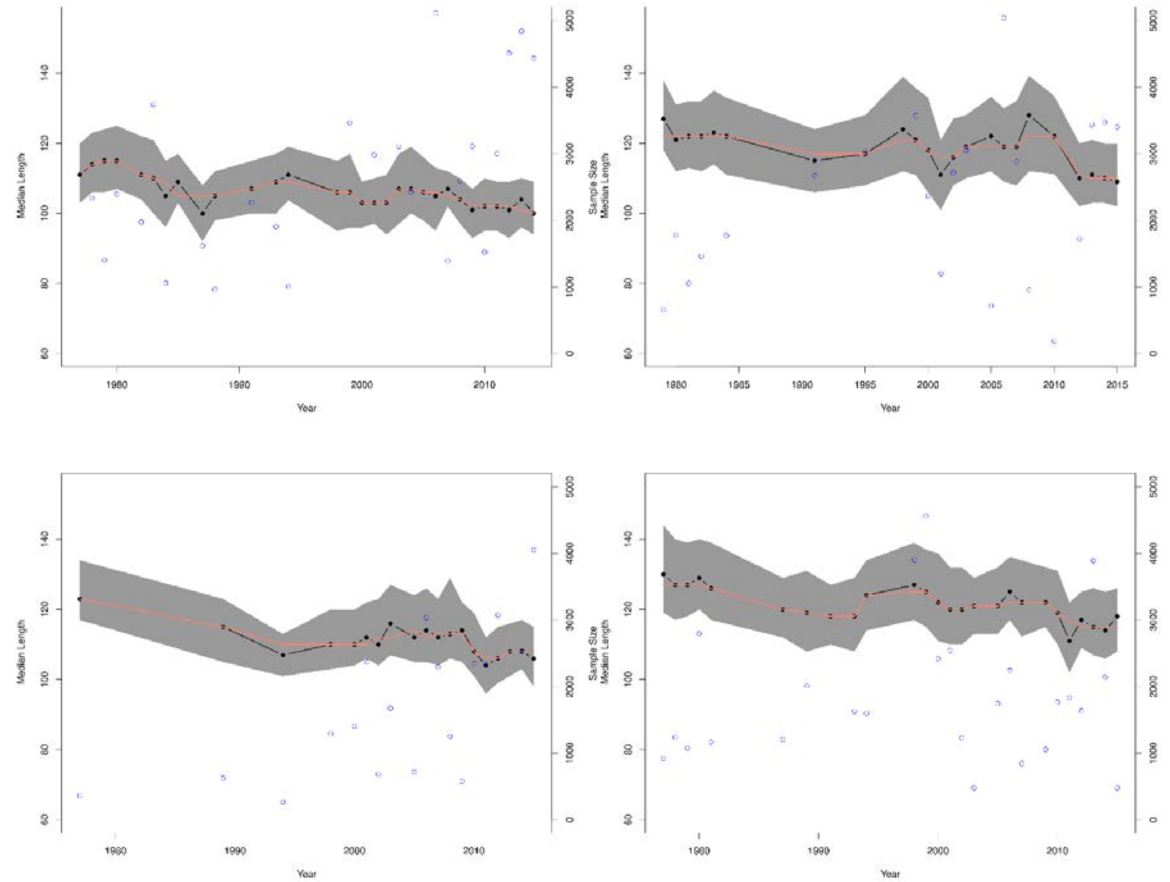


Figure 30. Median length (black line) with observed 25th and 75th quantiles (shaded poly- gon) from American Lobster observed during at sampling of fishing activities. Upper: Left - Southwest Browns; Right Southeast Browns; Lower: Left - Georges Basin; Right - Georges Bank Summer. Within each plot red line represents a three year running median, whereas blue circles represent the annual sample sizes.

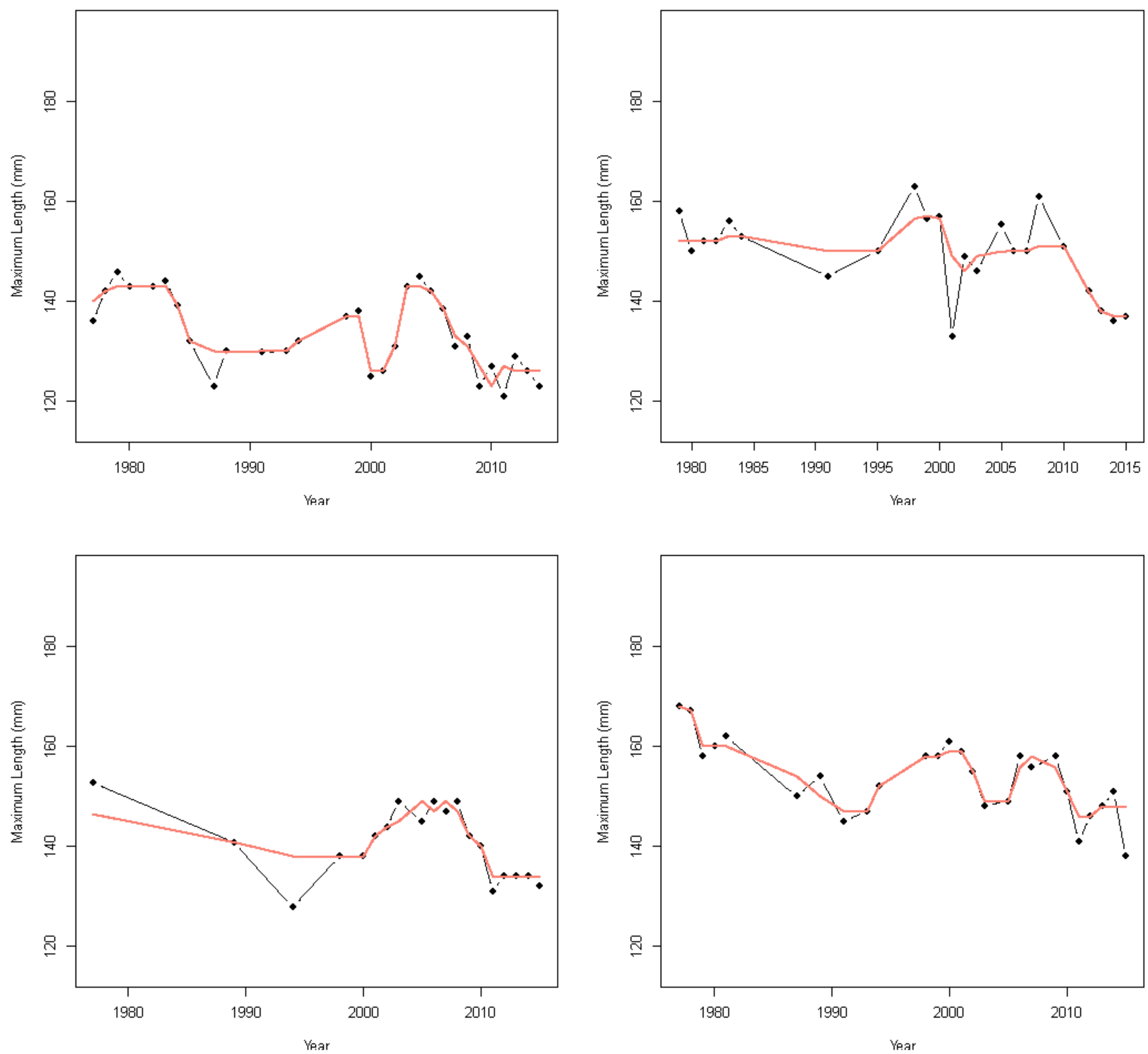
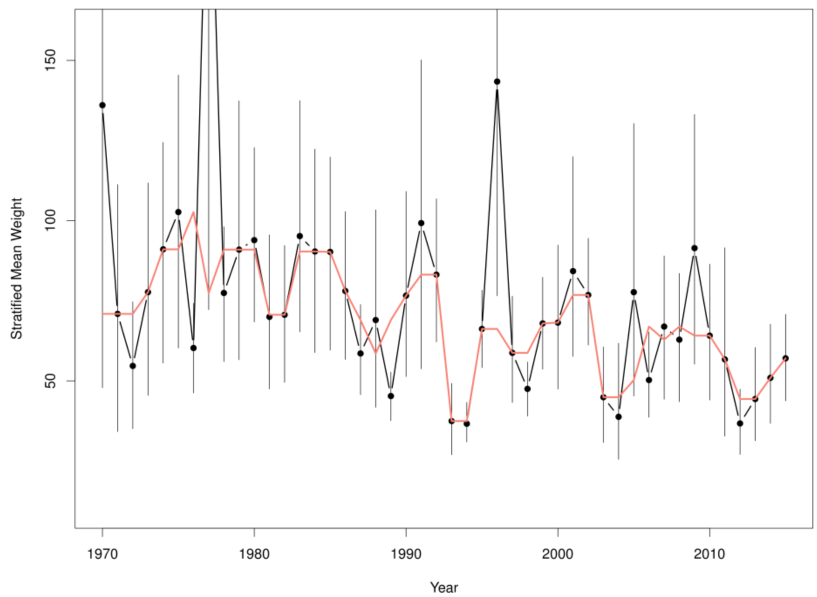


Figure 31. Maximum length (upper 95 quantile) of American Lobster observed during at sampling of fishing activities. Upper: Left - Southwest Browns ; Right Southeast Browns; Lower: Left - Georges Basin; Right - Georges Bank . Within each plot red line represents a three year running median.



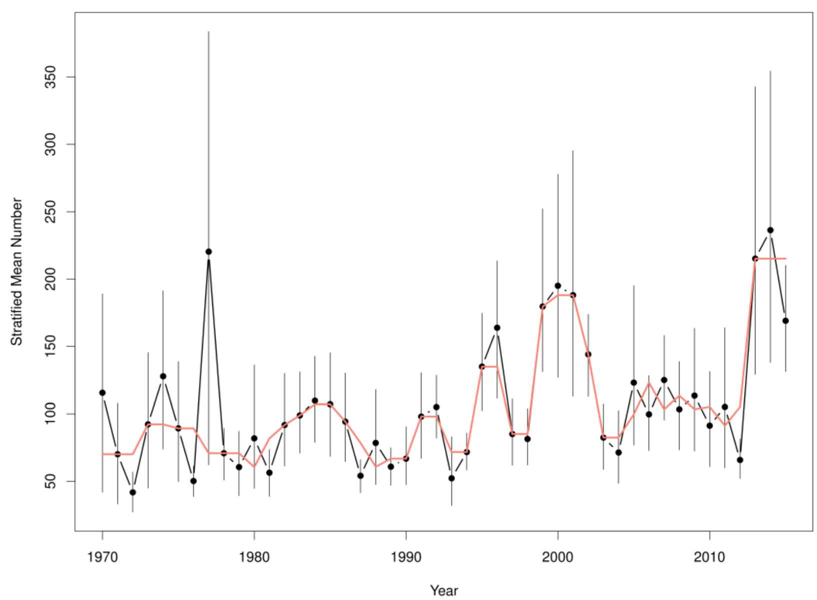


Figure 32. Time series of biomass (lower) and abundance (upper) of predators of American Lobster captured on the western Scotian Shelf during the summer RV survey.

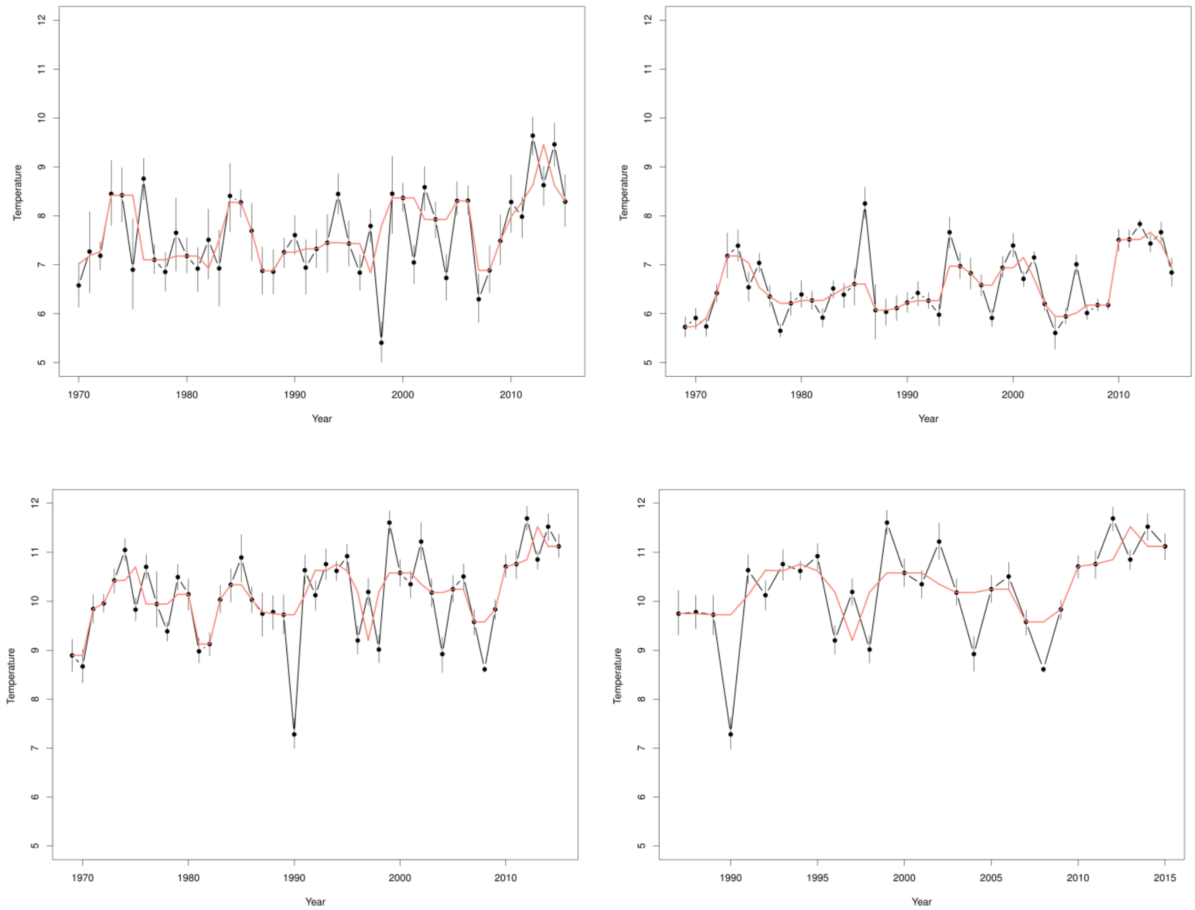


Figure 33. Stratified mean temperatures from DFO RV summer (upper-left), NEFSC spring (upper-right), NEFSC fall (lower-left) and Georges Bank (lower-right), surveys with base strata for LFA 41. Within each plot red line represents running median and error bars are the 95 % bootstrapped confidence intervals.

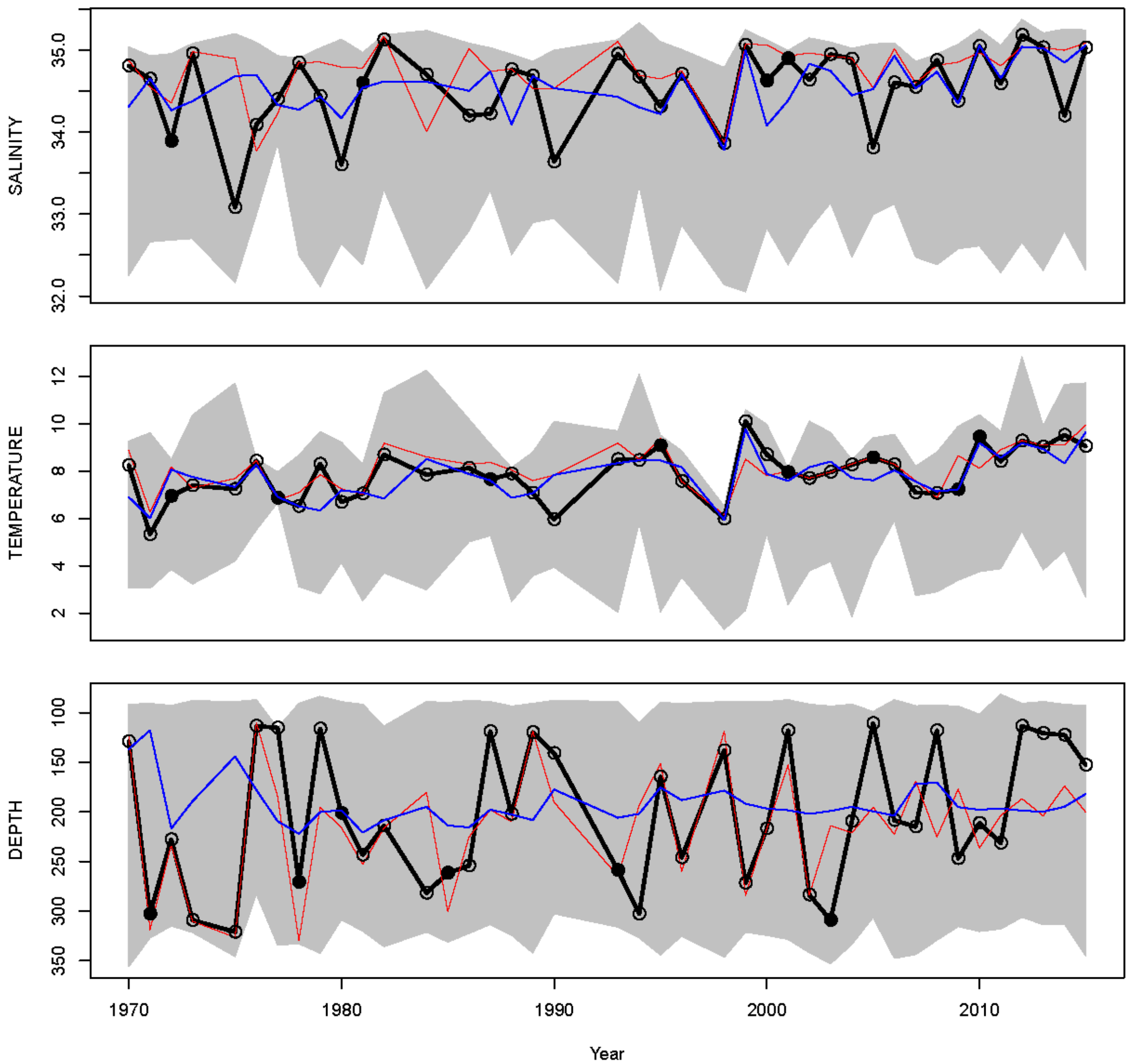


Figure 34. Time series of habitat associations for American Lobster as obtained from the RV summer survey series pruned to LFA41 between 1970 and 2015. Circles represent the location of maximum deviation of cumulative distributions from catch weighted effort and effort. Filled circles represent statistically significant habitat associations and open circles represent non significant associations. Red line indicates the median habitat occupied by Lobster. Blue line is the median sampled habitat. Shaded polygon in background is the 95th percentile for range of sampled habitat.

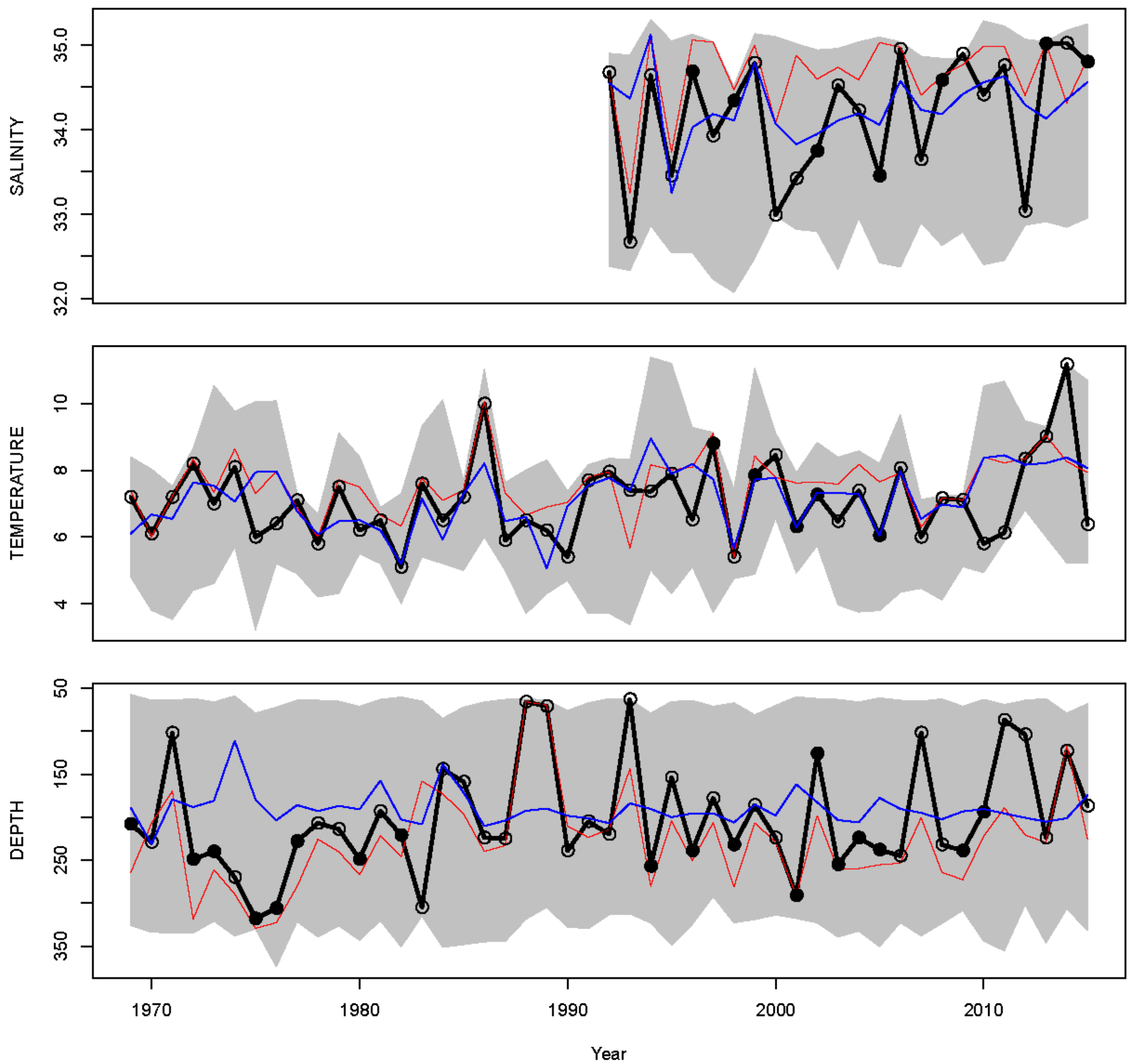


Figure 35. Time series of habitat associations for American Lobster as obtained from the NEFSC spring survey pruned to LFA41 between 1969 and 2015. Circles represent the location of maximum deviation of cumulative distributions from catch weighted effort and effort. Filled circles represent statistically significant habitat associations and open circles represent non significant associations. Red line indicates the median habitat occupied by Lobster. Blue line is the median sampled habitat. Shaded polygon in background is the 95th percentile for range of sampled habitat.

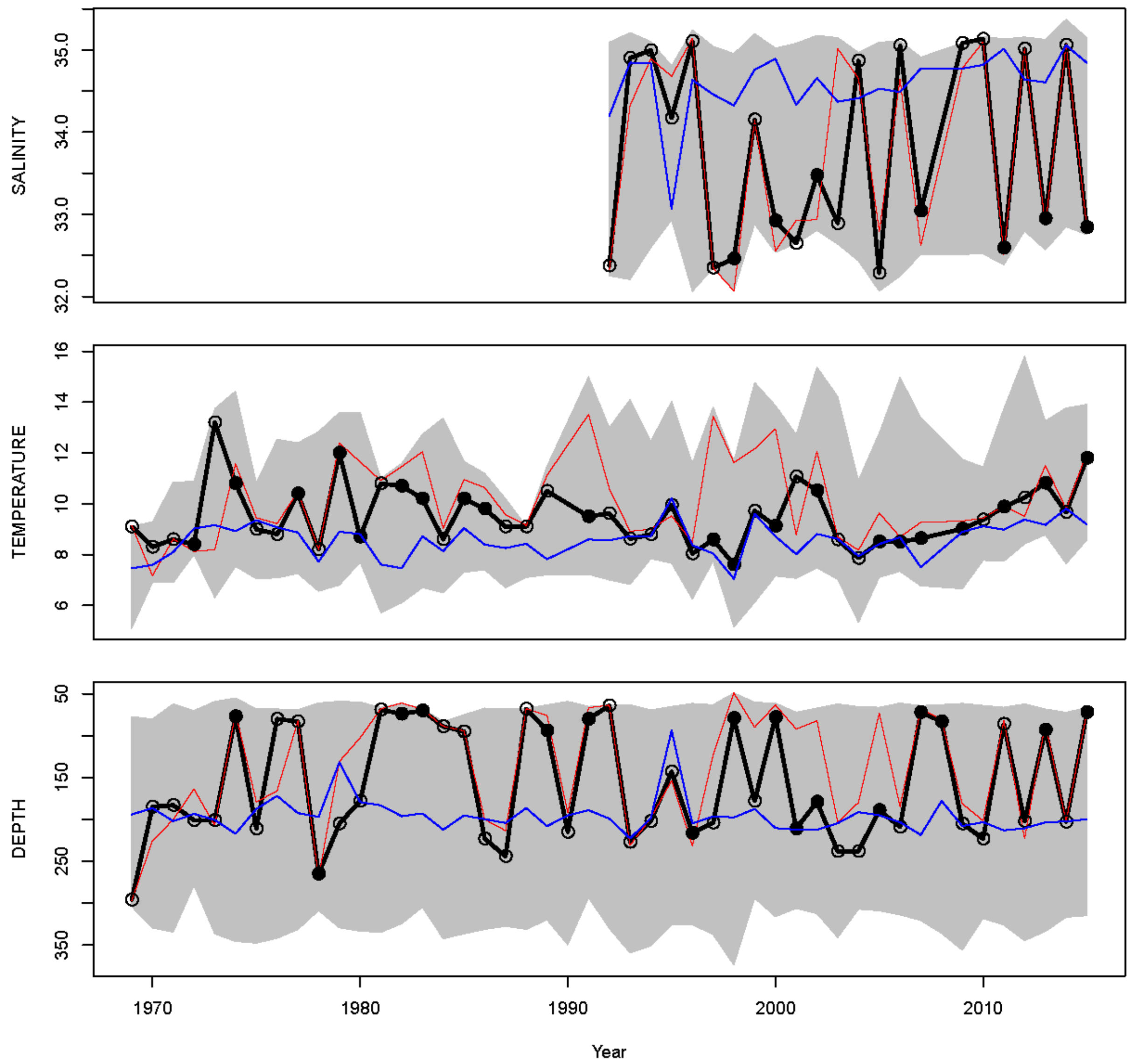


Figure 36. Time series of habitat associations for American Lobster as obtained from the NEFSC fall survey pruned to LFA41 between 1969 and 2015. Circles represent the location of maximum deviation of cumulative distributions from catch weighted effort and effort. Filled circles represent statistically significant habitat associations and open circles represent non significant associations. Red line indicates the median habitat occupied by Lobster. Blue line is the median sampled habitat. Shaded polygon in background is the 95th percentile for range of sampled habitat.

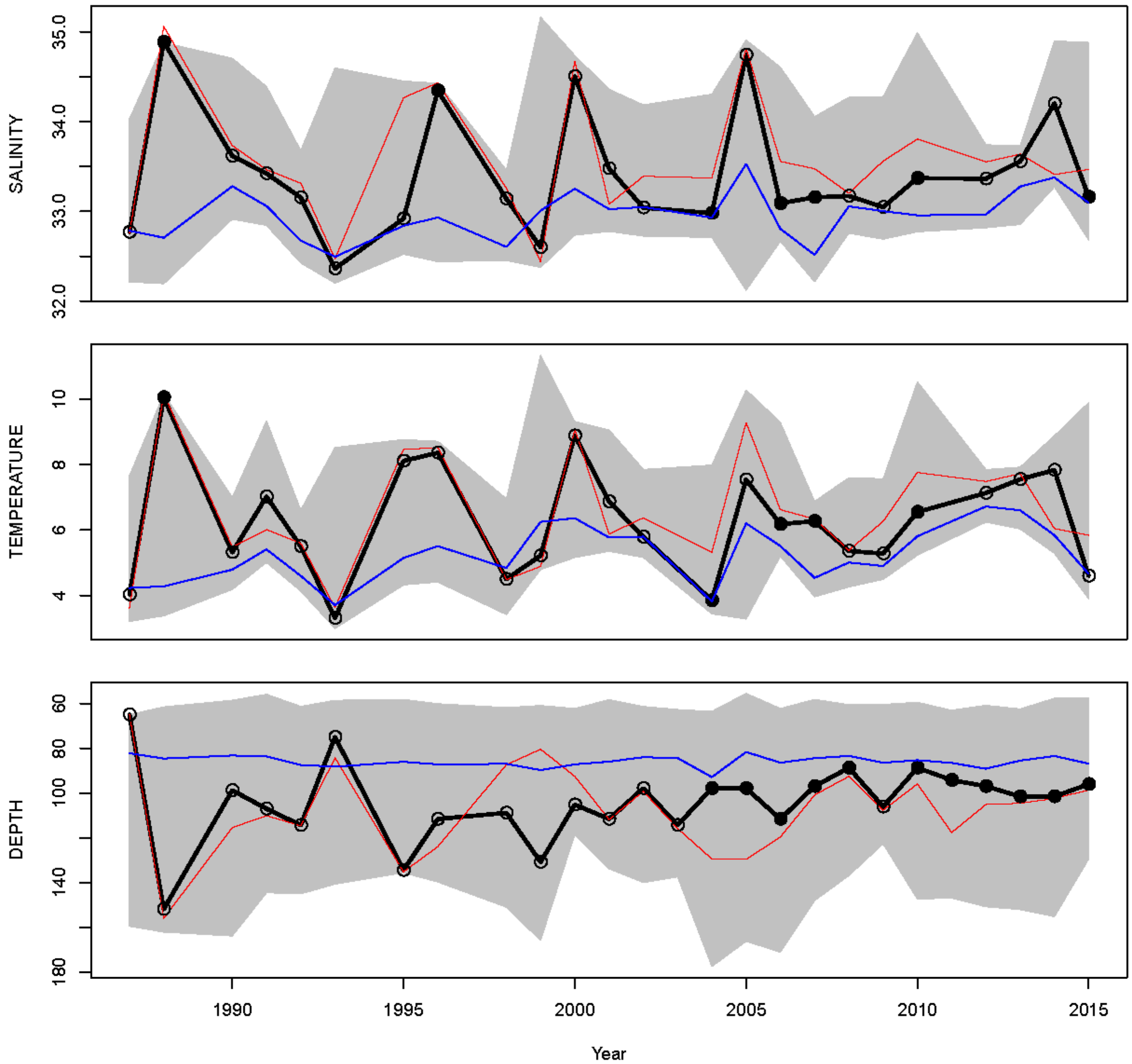


Figure 37. Time series of habitat associations for American Lobster as obtained from the Georges Bank survey between 1987 and 2015. Circles represent the location of maximum deviation of cumulative distributions from catch weighted effort and effort. Filled circles represent statistically significant habitat associations and open circles represent non significant associations. Red line indicates the median habitat occupied by Lobster. Blue line is the median sampled habitat. Shaded polygon in background is the 95th percentile for range of sampled habitat.

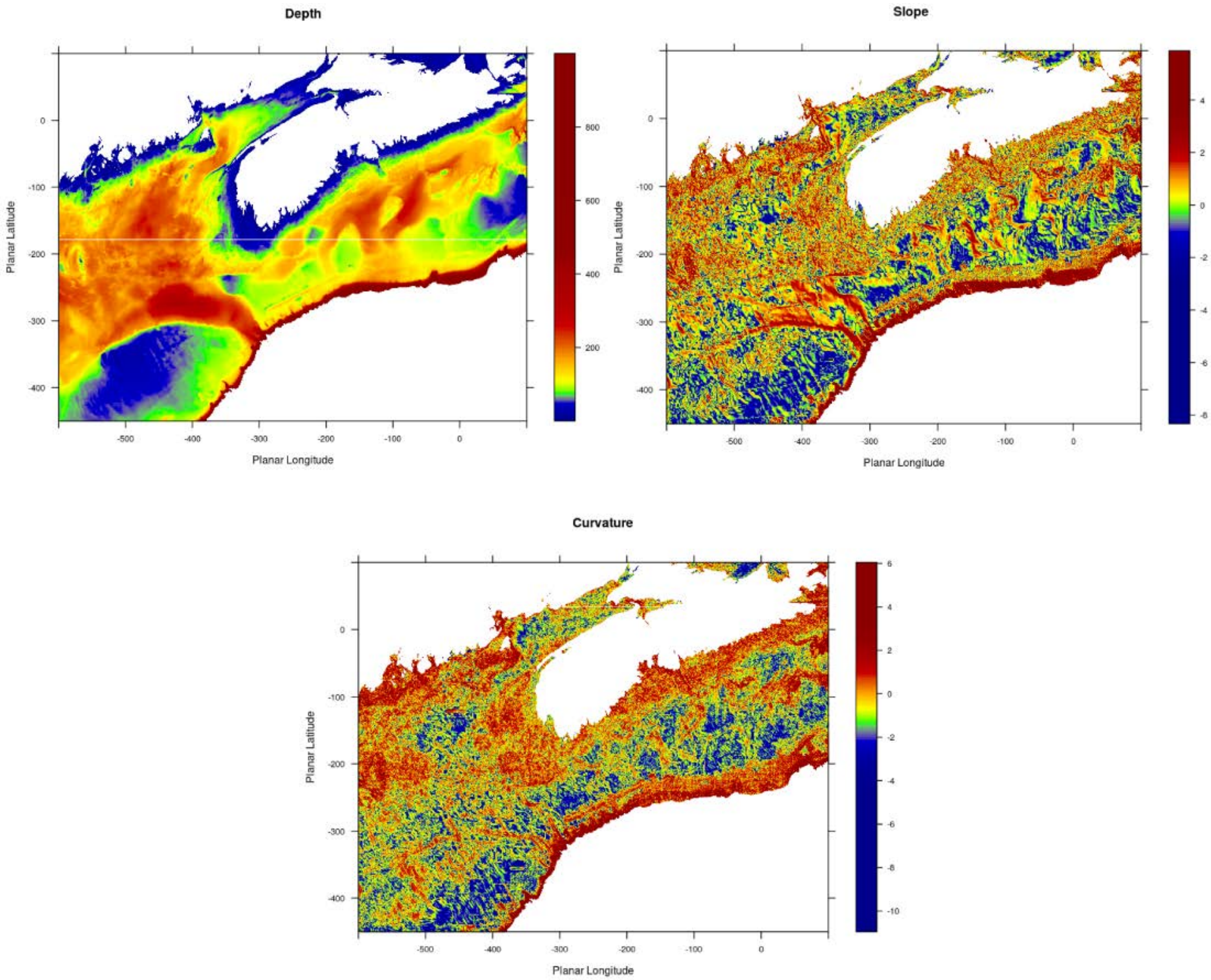


Figure 38. Interpolated surfaces for bathymetry, slope (log-scale) and curvature (log-scale) for the Scotian Shelf, Gulf of Maine and Georges Bank used as the projection layers for species distribution modeling. Planar coordinates are used for mapping with zone 20 specified.

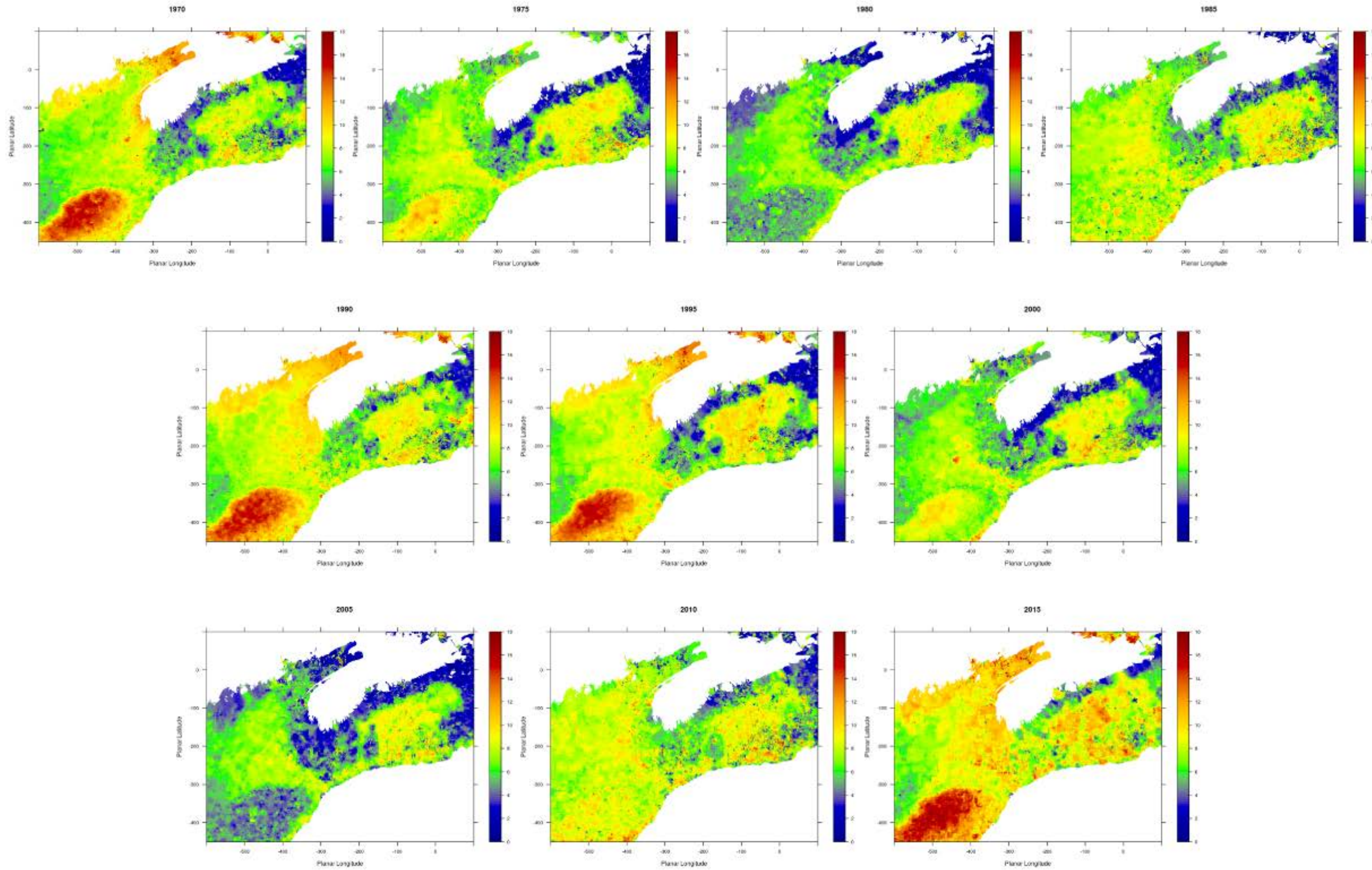


Figure 39. Interpolated temperature surfaces by year for the Scotian Shelf, Gulf of Maine and Georges Bank used as the projection layers for species distribution modeling. Planar coordinates are used for mapping with zone 20 specified.

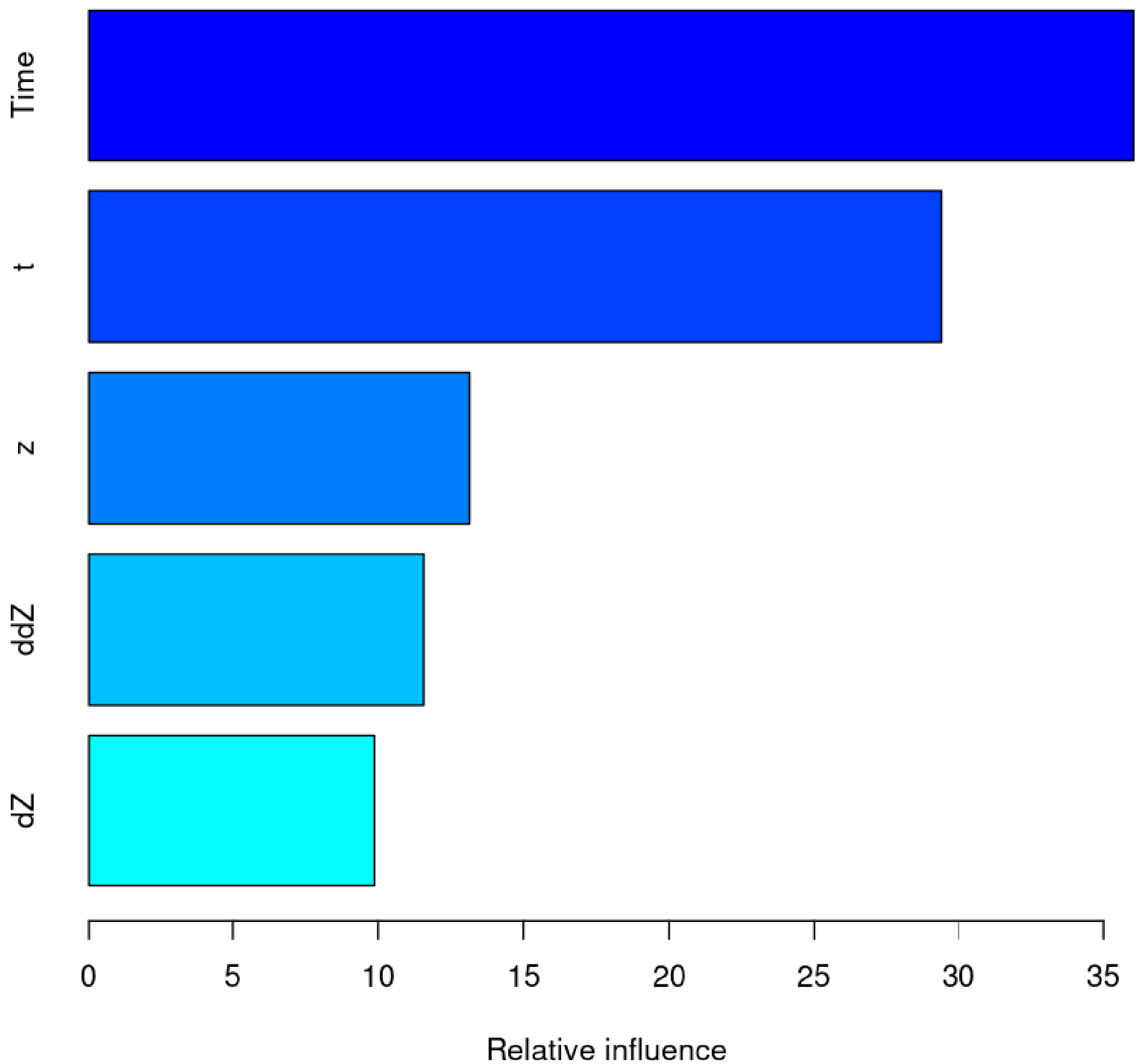


Figure 40. The relative influence of predictor variables Time (decimal year), temperature (t), depth (z), slope (dZ) and curvature (ddZ) from the boosted regression trees on the species distribution model.

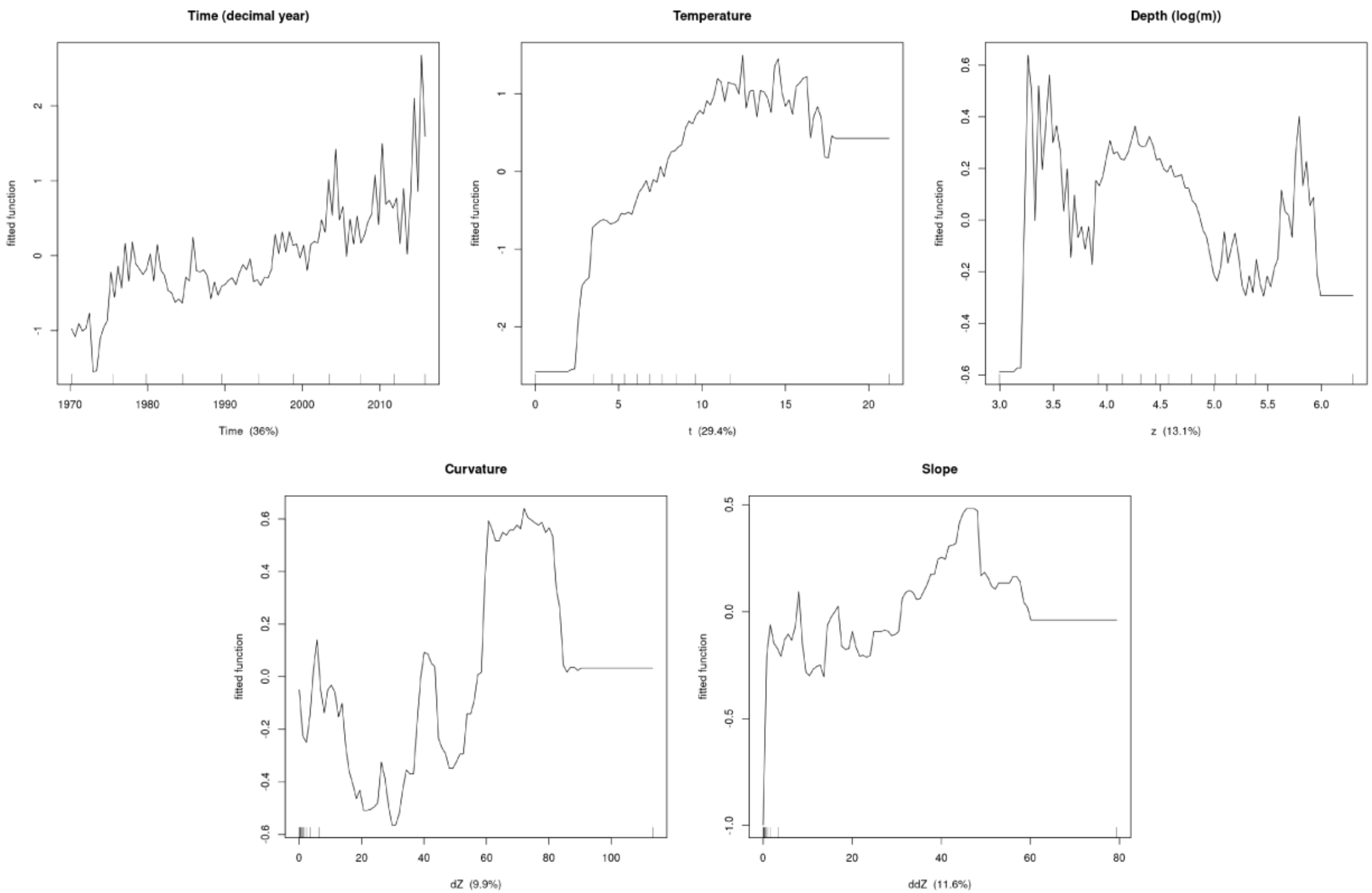


Figure 41. Fitted functions from the boosted regression tree models of Lobster species distribution based on the variables ot Time (decimal years), bottom temperature, depth, curvature and slope.

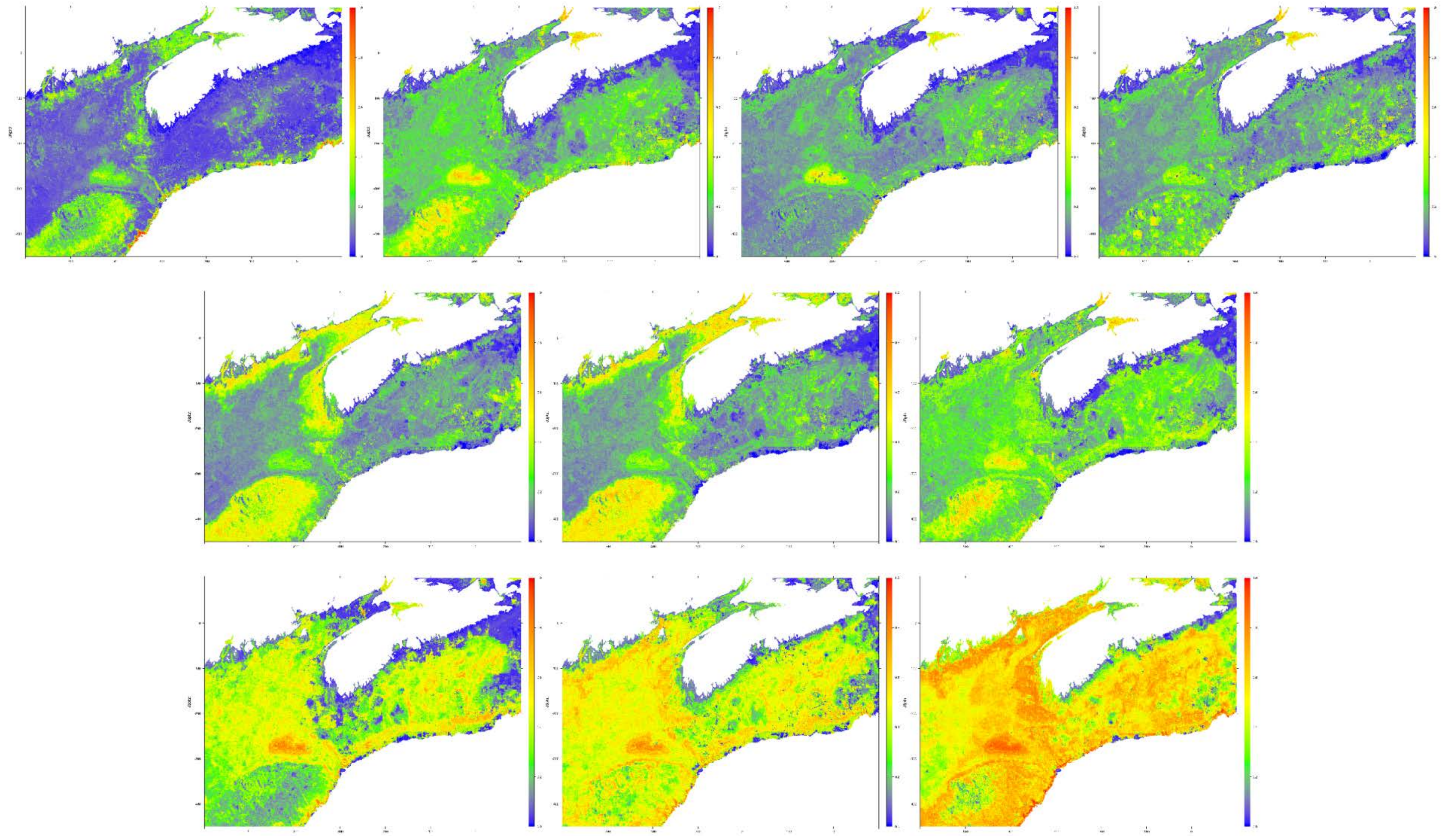


Figure 42. Predicted annual species distribution surfaces for American Lobster from the Boosted regression tree model results. From left to right: top row – 19970, 1975, 1980, 1985; middle row – 1990, 1995, 2000; bottom row – 2005, 2010, 2015.

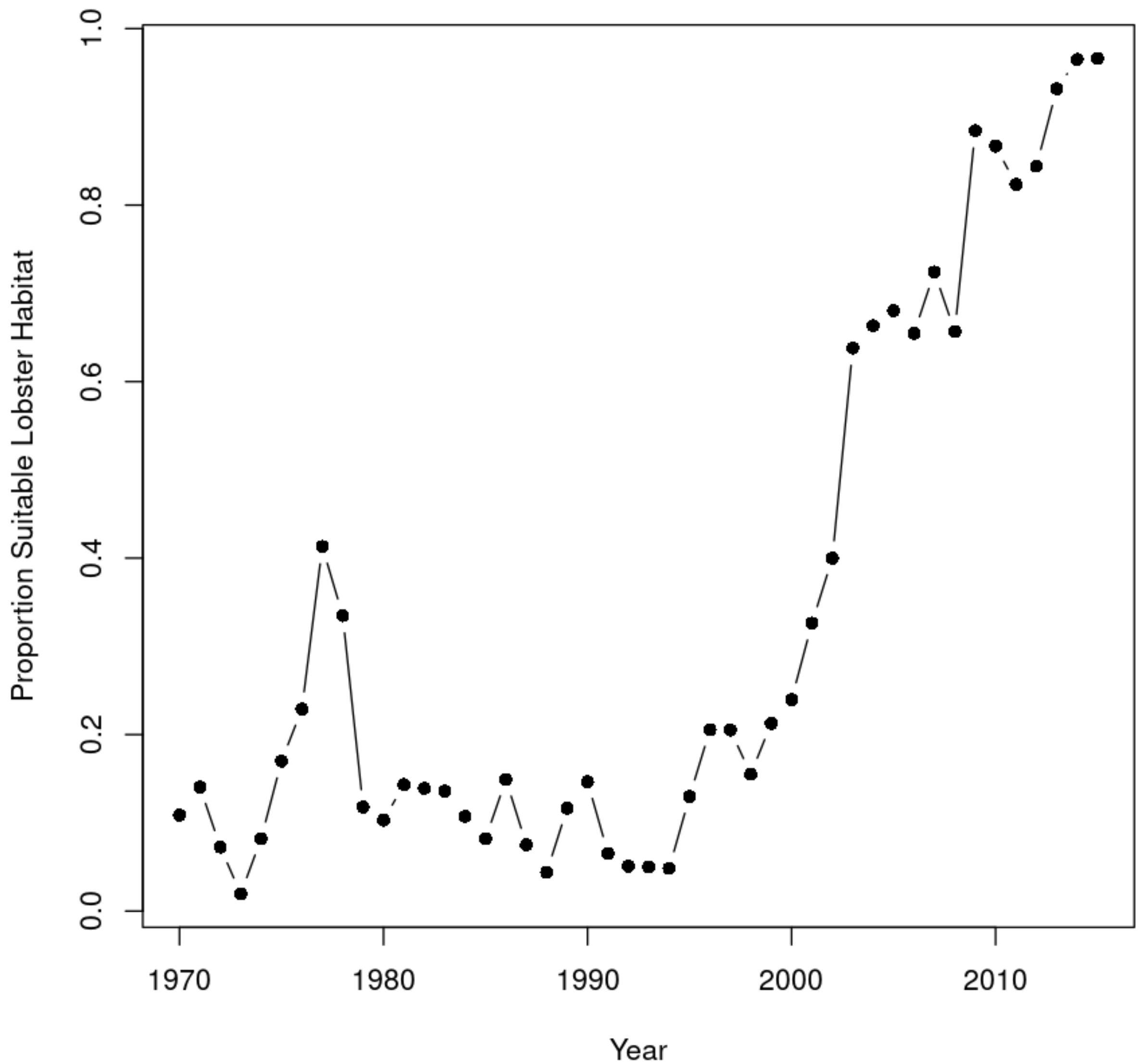


Figure 43. The proportion of total area within LFA 41 representing ≥ 0.35 probability of being suitable Lobster habitat from the boosted regression tree results.

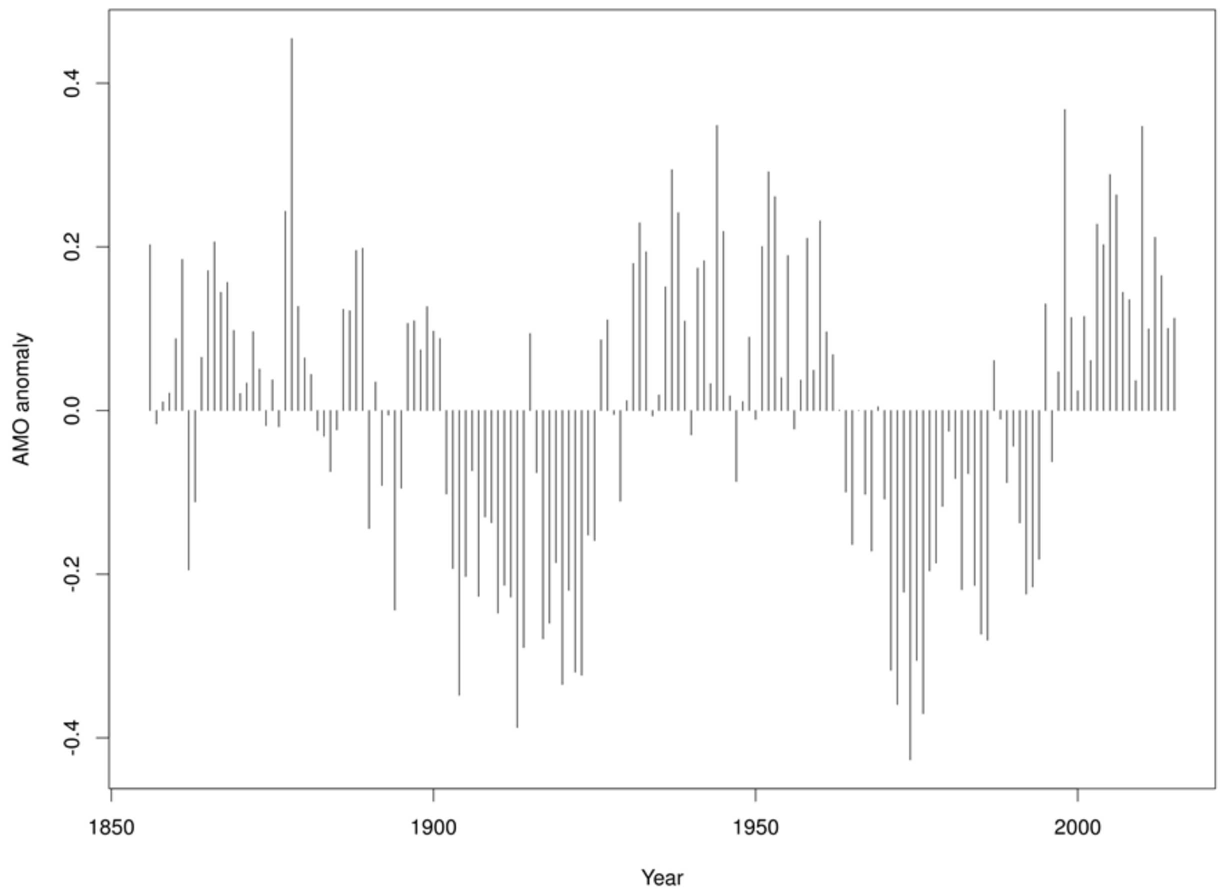


Figure 44. Annual mean anomalies of the Atlantic multidecadal osscillation (AMO). Data obtained from http://www.esrl.noaa.gov/psd/data/correlation//amon.us.long.data.

Figure 45. Catch per unit effort for Lobster in the LFA 41 fishery. Y-axis labels were removed due to privacy concerns of the commercial catch rate levels.

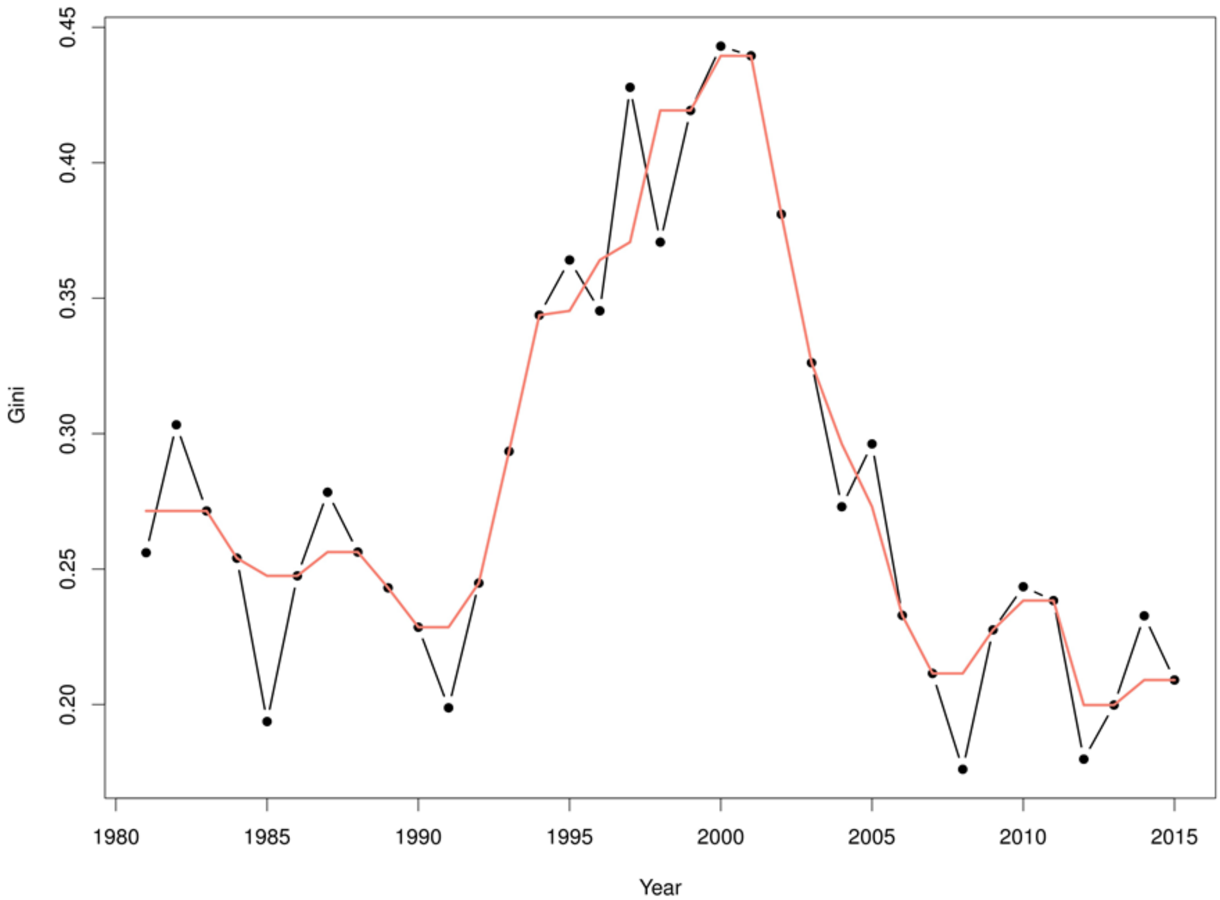


Figure 46. Time series of spatial evenness of fishery catch rates (kg \TH) estimated through the Gini Index for LFA 41. Red line represents the three year running median. Annual catch rates were estimated by grouping fishing trips into 0.05 deg^2.

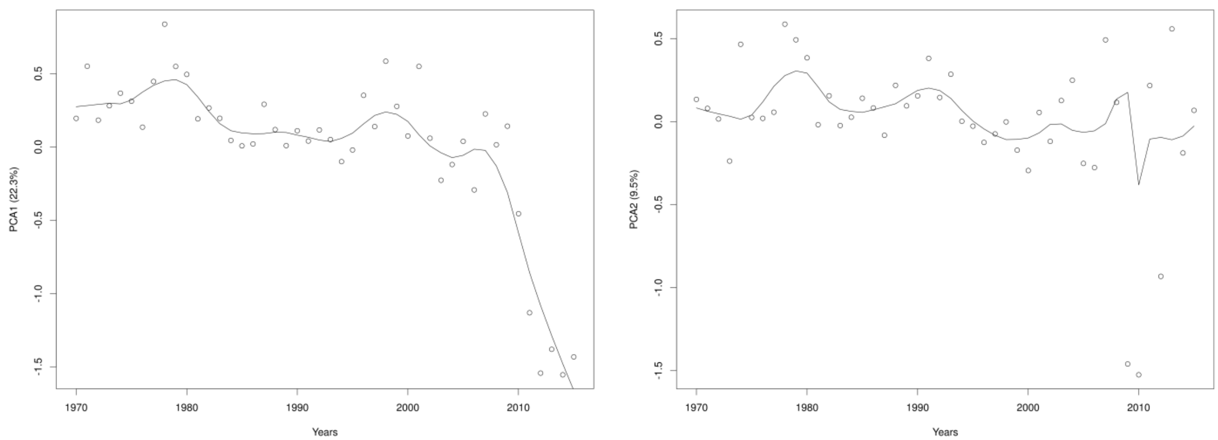


Figure 47. First and second axes of variation of the component scores from the ordination of biological and ecosystem indicators associated with the offshore LFA 41 Lobster. Within each plot, the line represents a loess smoother through the component scores.

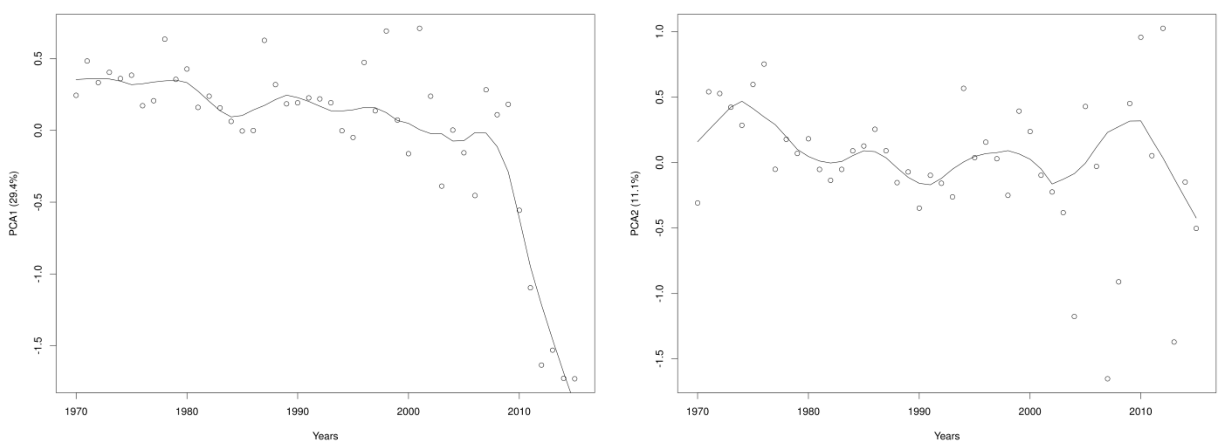


Figure 48. First and second axes of variation of the component scores from the ordination of the subset of biological and ecosystem indicators associated with the offshore LFA 41 Lobster. Within each plot, the line represents a loess smoother through the component scores.

Figure 49. Time series of sorted ordination of the anomalies from the biological and ecosys tem 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.

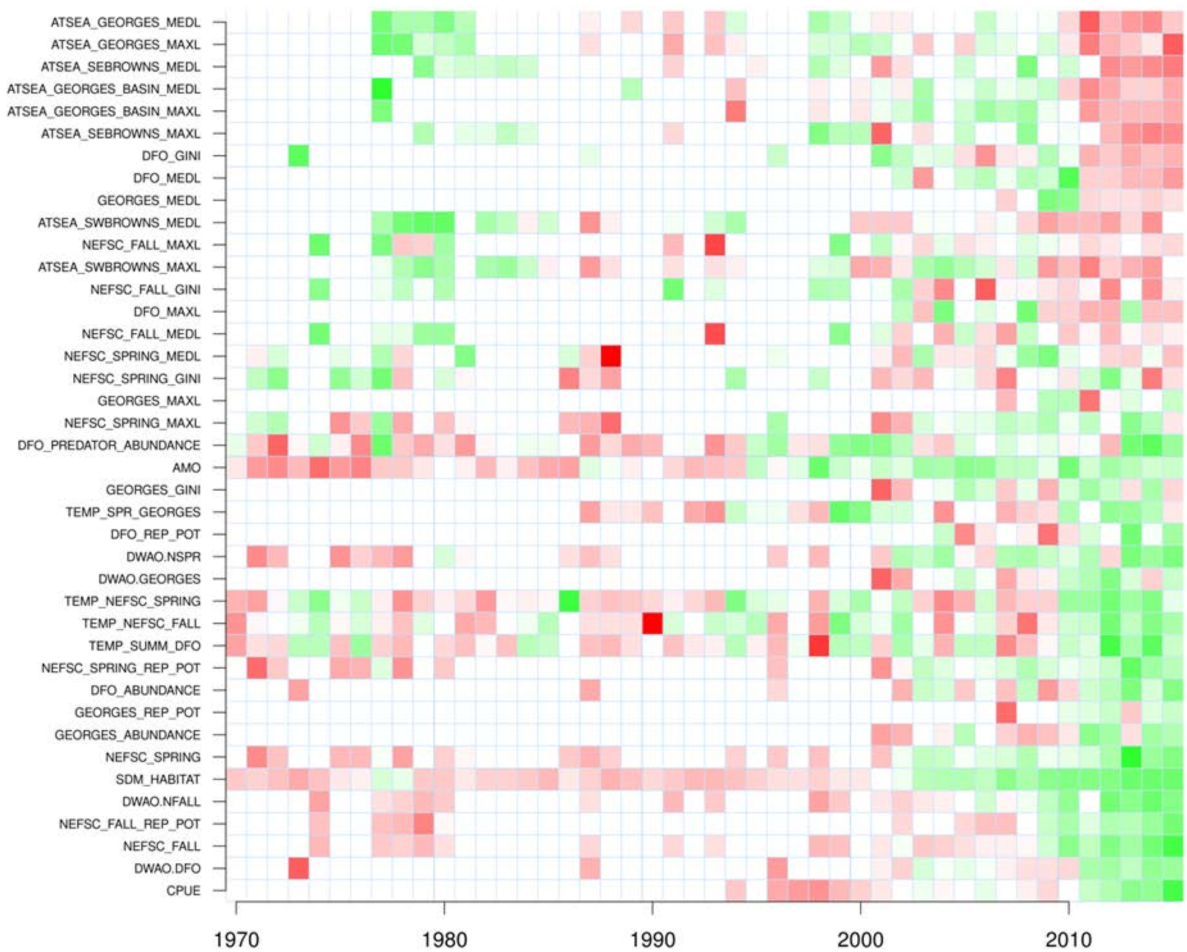


Figure 50. Time series of sorted ordination of the anomalies from the subset of biological and ecosystem indicators associated with LFA 41. Green indicates levels above the mean, whereas red indicates levels below the mean. White blocks indicate <20 observations were available for that indicator and time period.

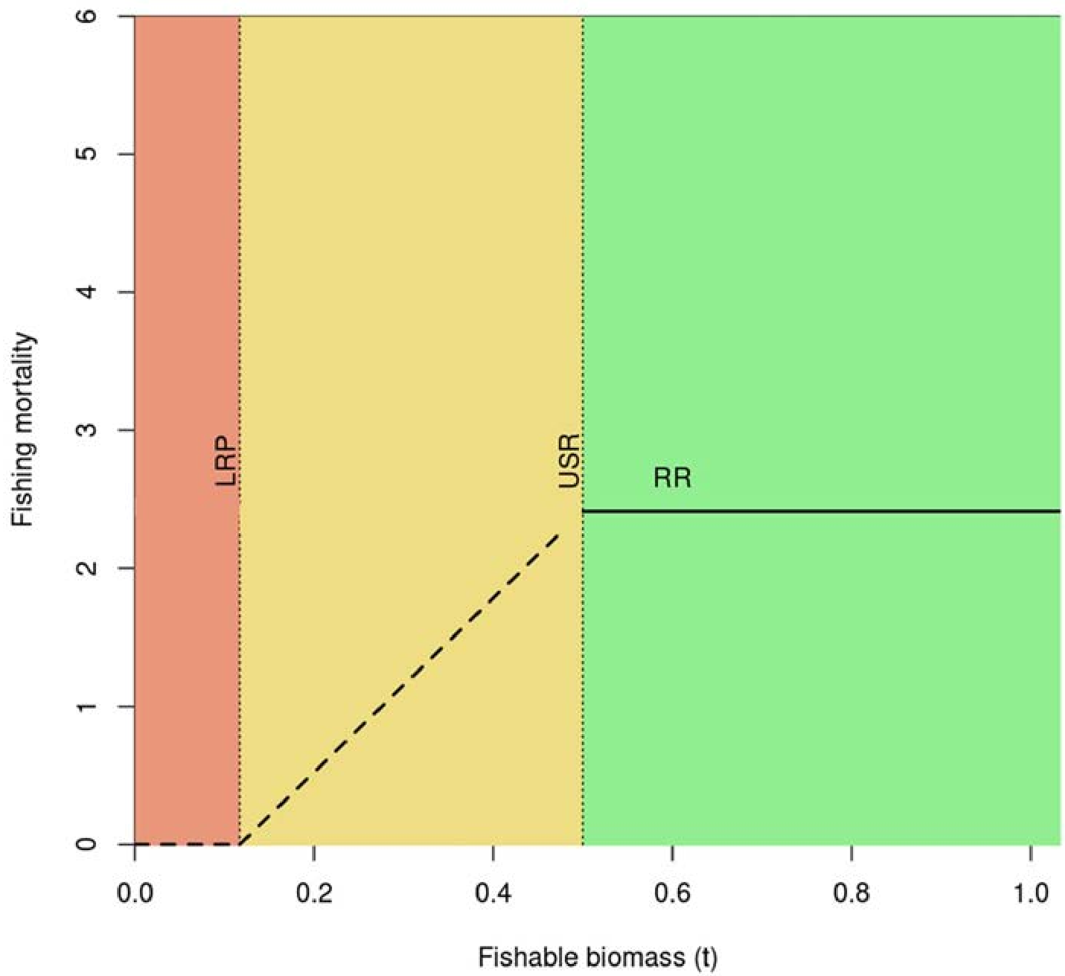


Figure 51. Example precautionary approach phase plot delimiting the healthy zone (green) above upper stock reference (USR) the cautious zone (yellow), between the USR and the limit reference point (LRP) and critical zone (red), below the LRP. The removal reference (RR) is shown as a solid black line 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.

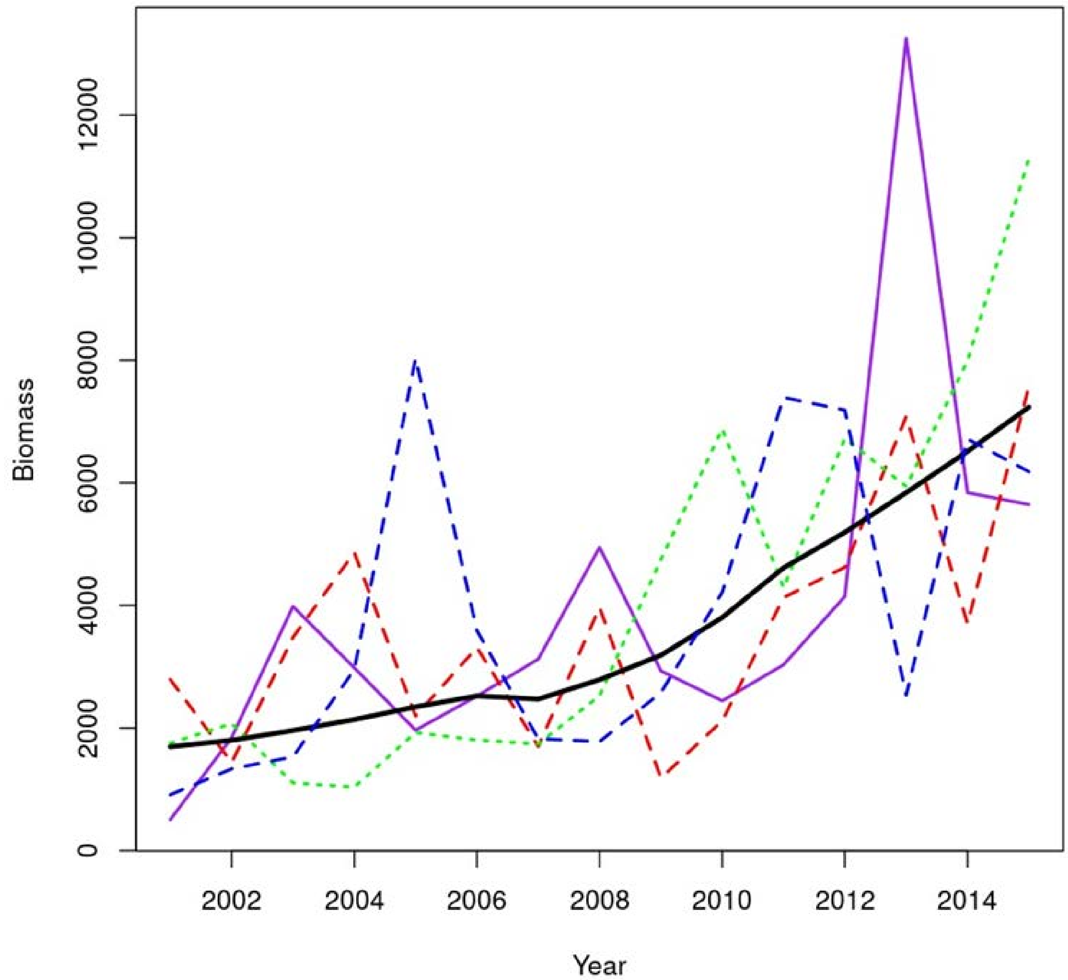


Figure 52. Plot of biomass dynamic model fits (black line) along with DFO Summer RV survey commercial (red), NEFSC Spring survey commercial biomass (purple), NEFSC Au tumn survey commercial biomass (green) and DFO Georges Bank survey commercial biomass (blue). Each survey index was adjusted by their specific modeled estimate of q to match the scale of the modelled biomass.

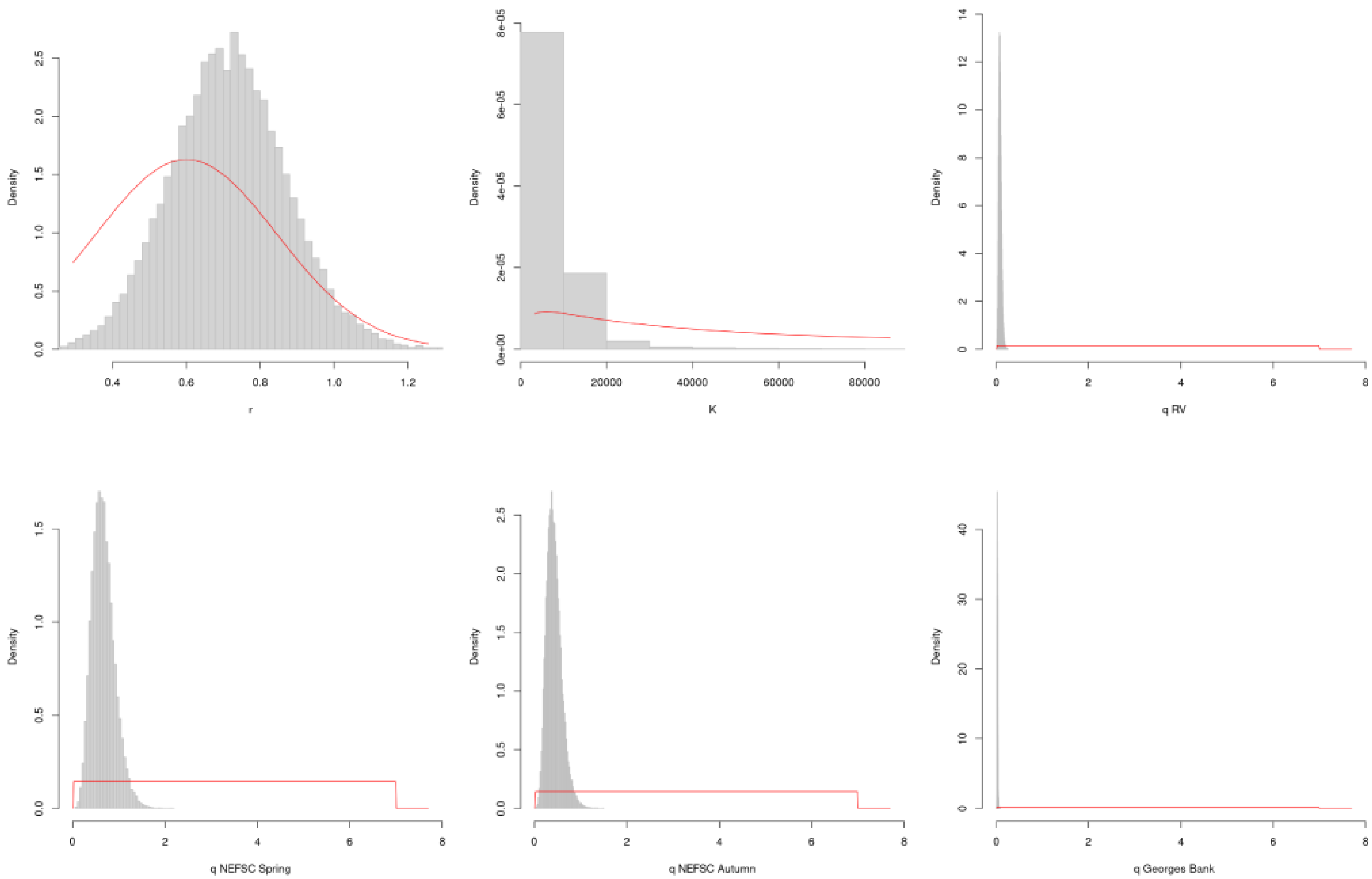


Figure 53. Prior (red lines) and posterior distributions (bars) from the biomass dynamic modeling of from LFA41 Lobster stock. Top row from left to right represent the intrinsic growth parameter r, carrying capacity K and the DFO Summer RV survey proportionality constant q. Bottom row from left to right represent q for the NEFSC spring survey, q for the NEFSC Autumn survey and q for the DFO Georges Bank survey.

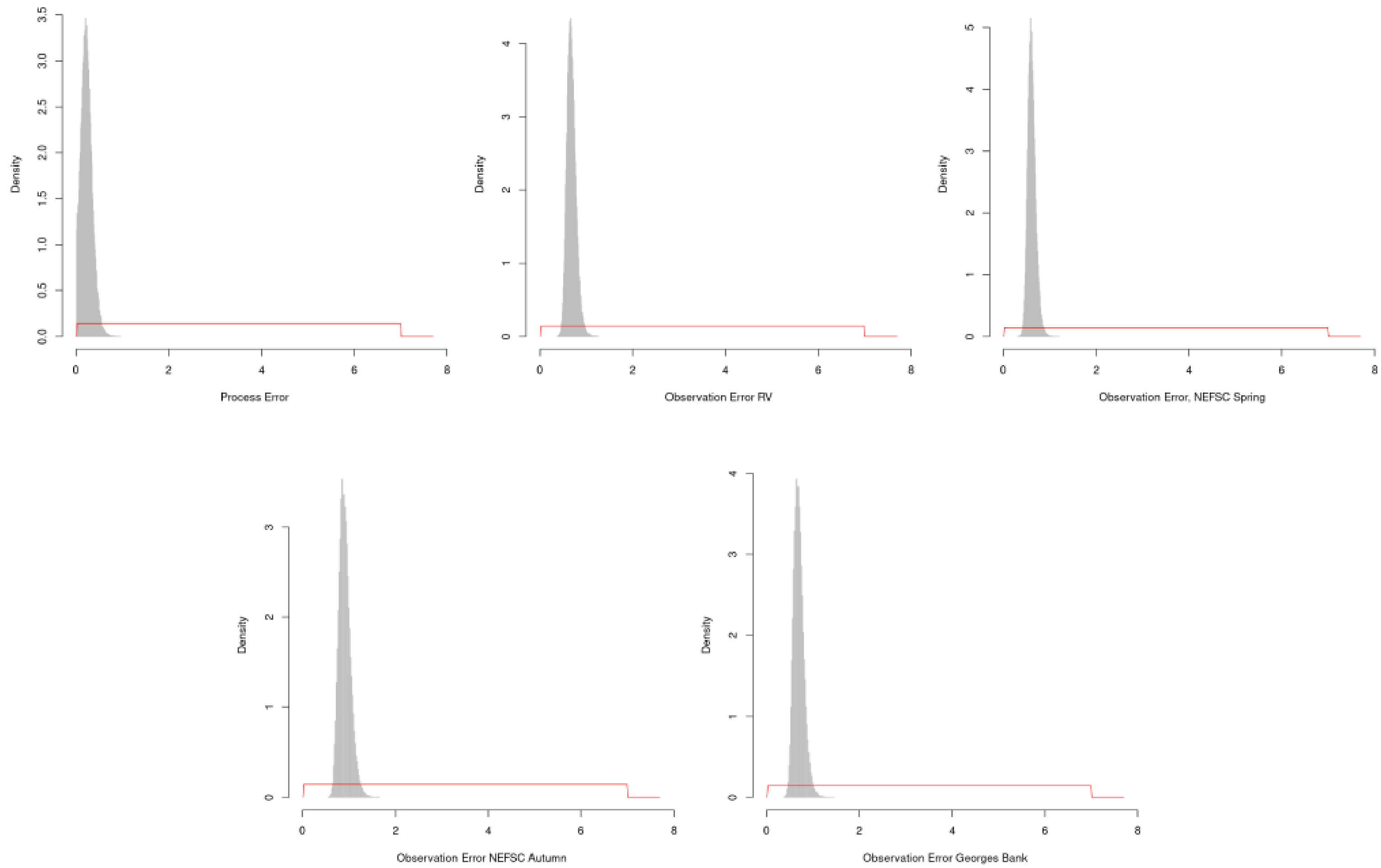


Figure 54. Prior (red lines) and posterior distributions (bars) from the biomass dynamic modeling of from LFA41 Lobster stock. Top row from left to right represent the process error τ, the observation error σ associated with DFO Summer RV survey and the observation error σ associated with NEFSC Spring survey. Bottom row from left to right represent observation error σ for the NEFSC Autumn survey and the observation error σ for the DFO Georges Bank survey.

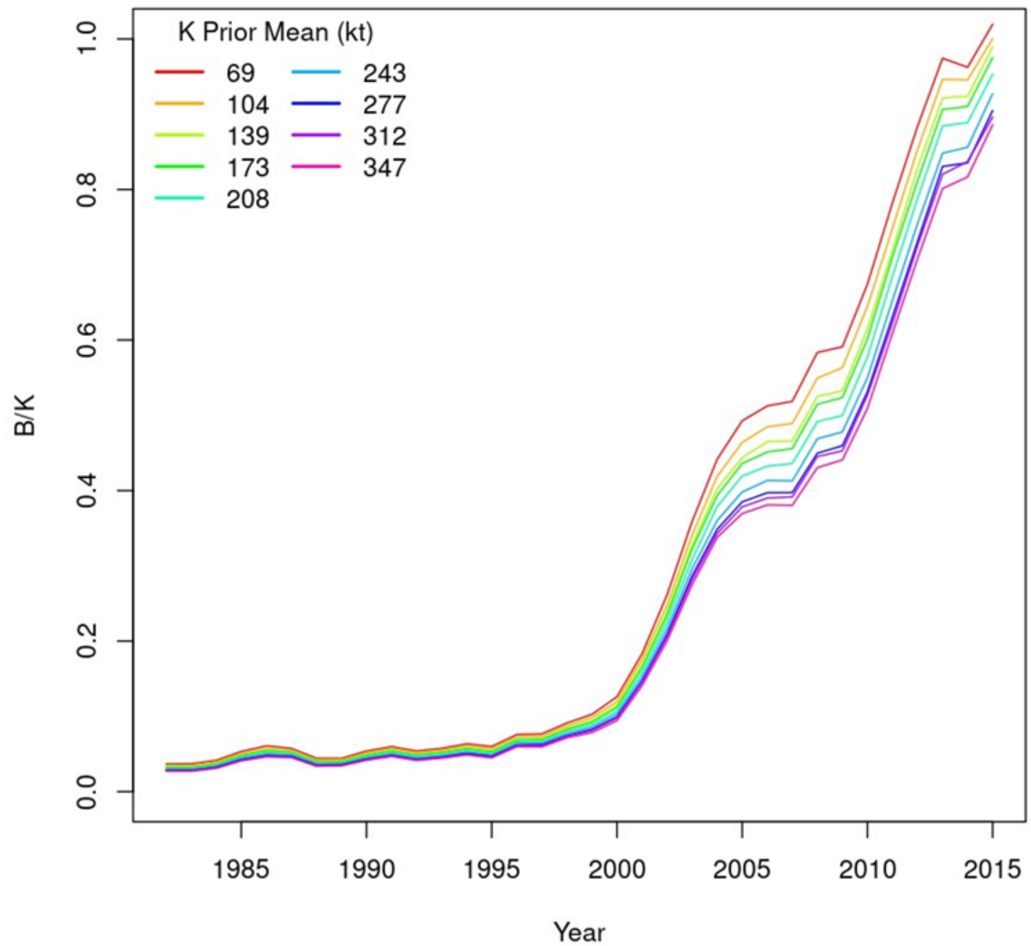


Figure 55. Impact of changing the prior mean for carrying capacity, K on modeled biomass trends using the biomass dynamic model for LFA41 Lobster. The lines represent the time series of the ratio modeled median biomasses to the median of the posterior distribution on K using increasing means for prior distribution on K.

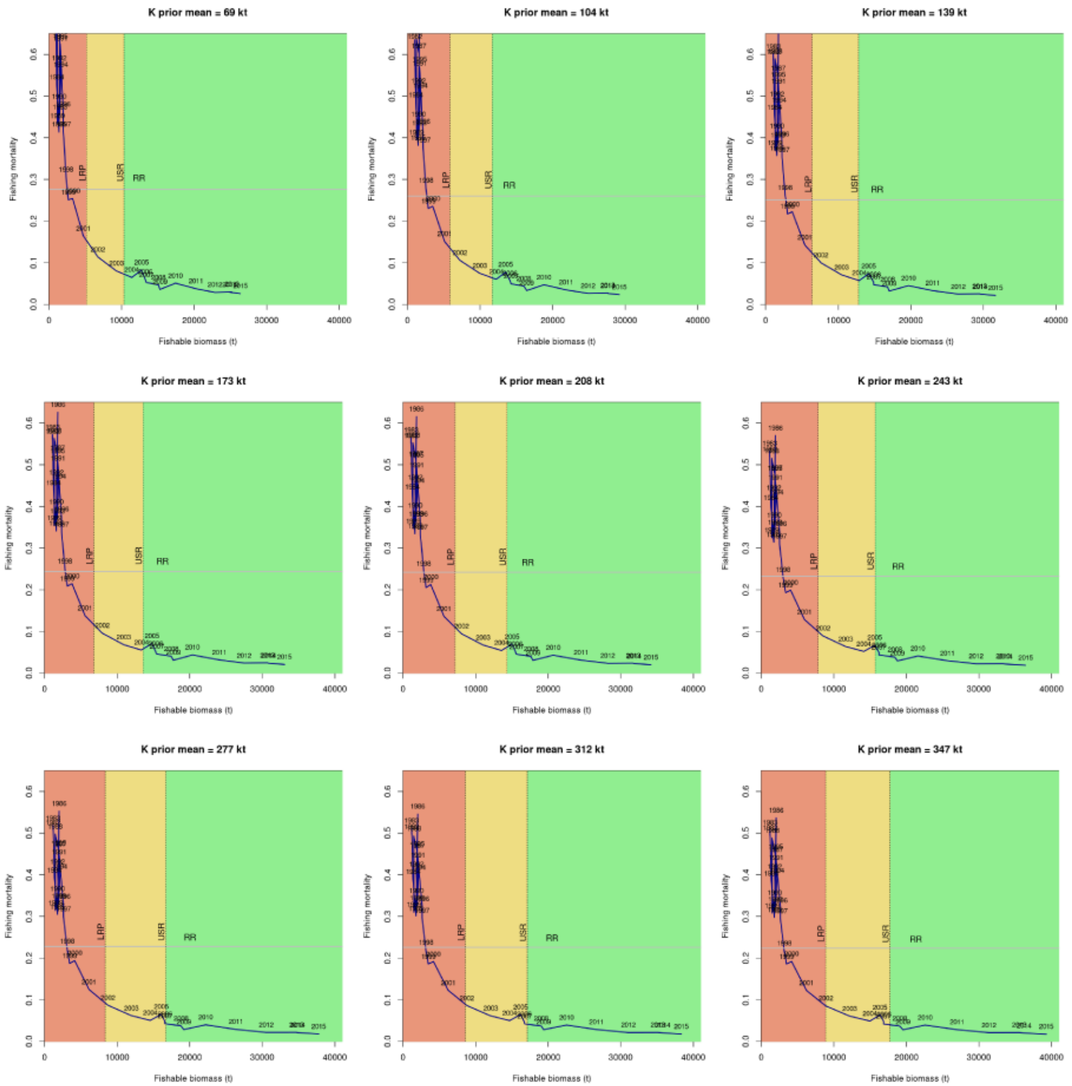


Figure 56. Phase plot showing the impact of changing the prior mean for carrying capacity, K on modeled biomass trends in relation to estimated reference points. Each plot represents the estimated median biomass and reference points determined from biomass dynamic model parameters for a model run using a different mean prior on K. The mean of the prior for each model run was shown in each figure title.

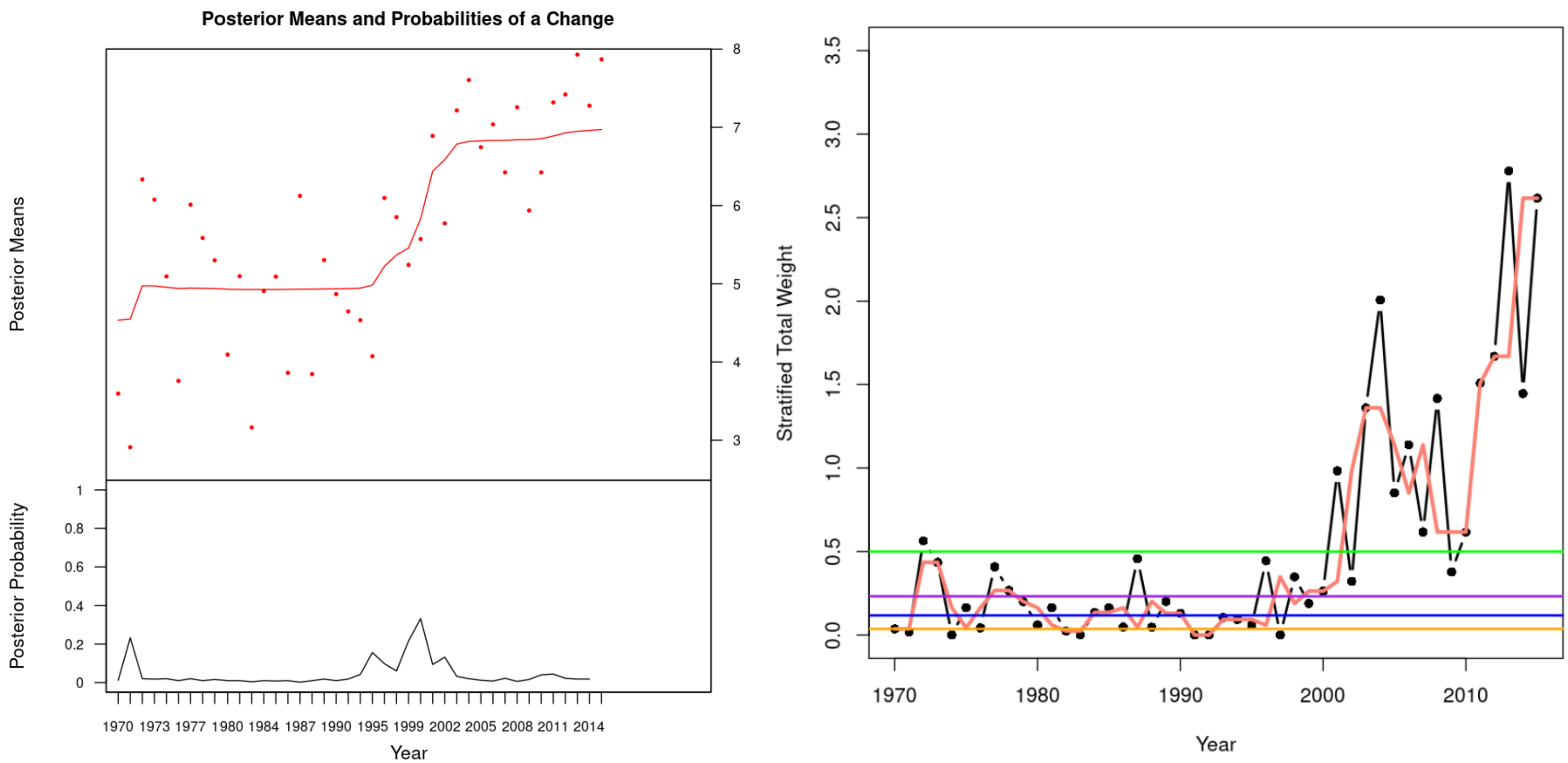


Figure 57. Commercial biomasses (kt) for the DFO Summer RV (RV41) survey. (Left) Results from Bayesian change point analysis to determine the probability of a change in commercial biomasses as an indicator of changing productivity regime. Upper panel represent the posterior means of the Bayesian change point model (red line) along with the input values for log(commercial biomass). Lower panel represents the probability of a change point occurring at specific time (black line). (Right) Commercial biomass time series along with the running median (red line) the median of the five lowest non zero biomasses (proposed LRI ; orange) and the medians for the full time series (USI; purple), the lower productivity period (1970-1999; blue; LRI) and 40% of the median of the higher productivity period (2000-2015; green; proposed USI).

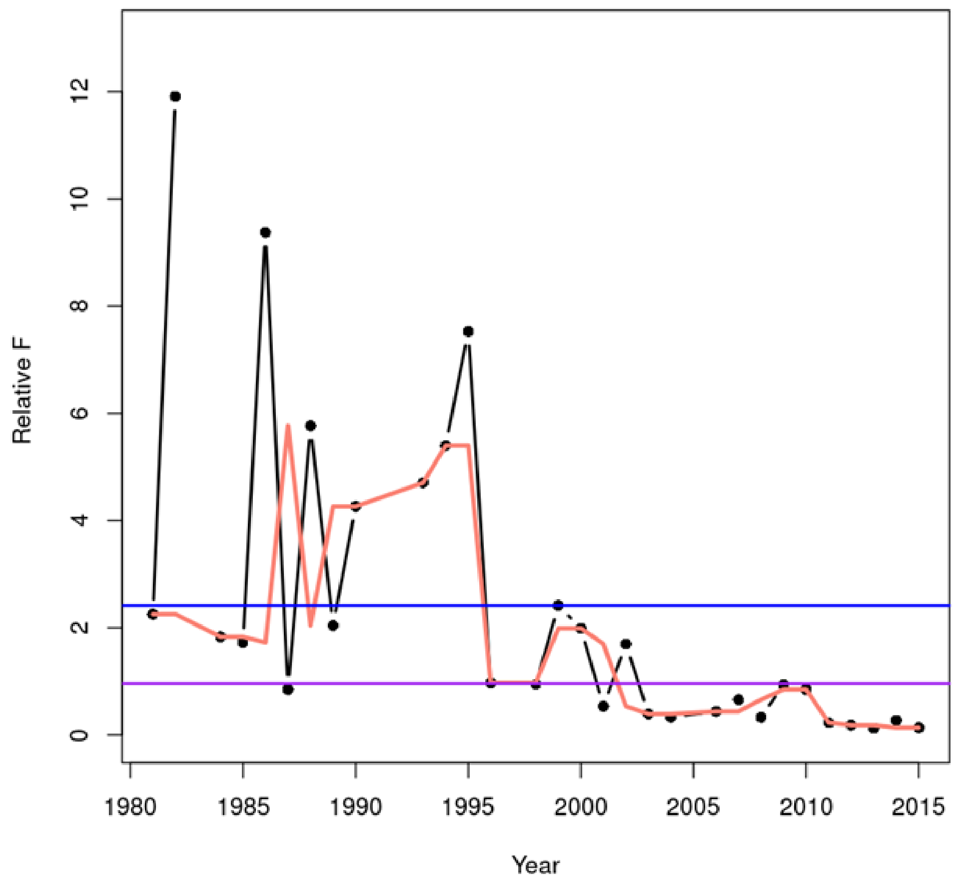


Figure 58. Relative fishing mortality (relF) for the DFO Summer RV (RV41) survey and landings. Results from Bayesian change point analysis from commercial biomass trends were used to inform a change in productivity regime and hence relative F. Relative F time series along with the running median (red line) and the medians for the full time series (purple) and the lower productivity period (1981 - 1999; blue; RI).

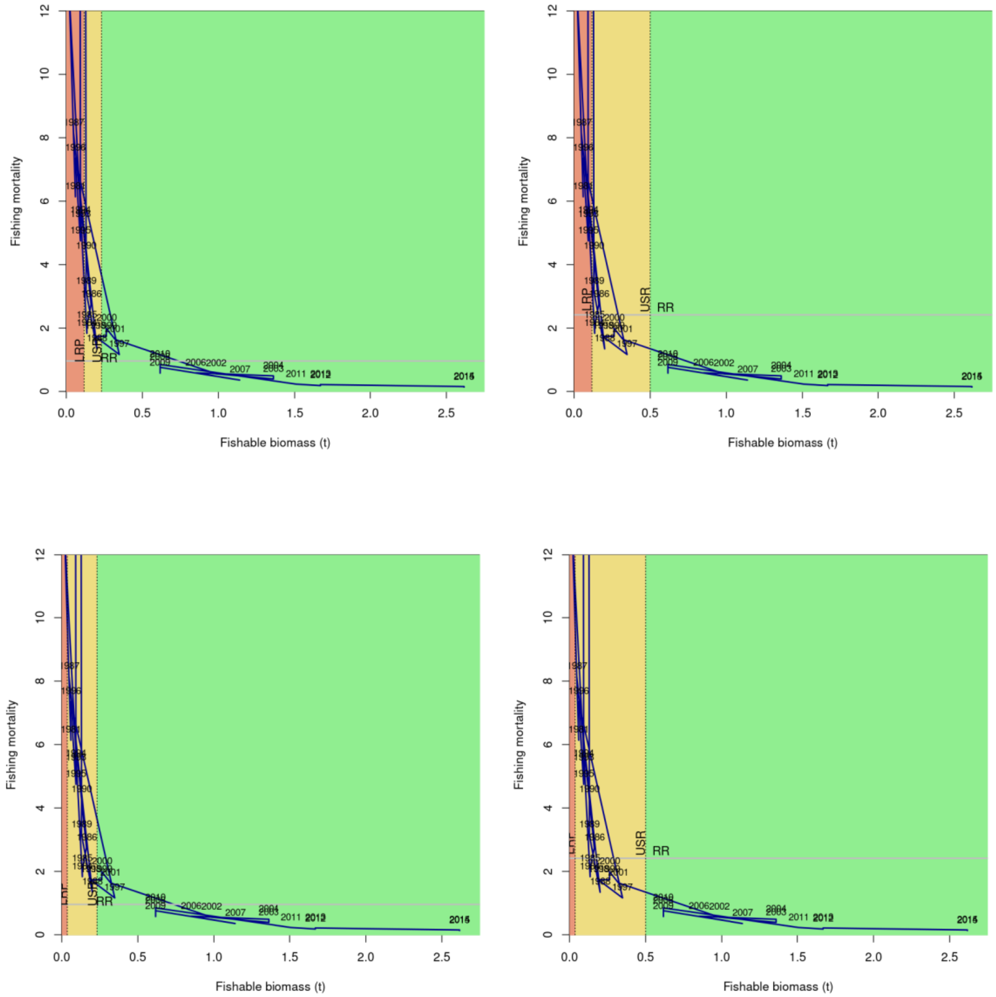


Figure 59. Phase plots showing the impact of different choices of reference points on the stock status zones for offshore American Lobster LFA 41 using DFO Summer RV survey (RV41) commercial biomass (kt) and relative F. Left panels - USI and RI were defined using the medians of the entire time series of biomass or relative fishing mortality. Right panels - USI and RI were defined using the medians of commercial biomass and relative F for the upper (2000 - 2015) and lower (1981 - 1999) productivity periods, respectively. In upper panels LRI was defined as the median biomass during the lower productivity period. In lower panels LRI was defined as the median of the five lowest non zero biomasses. Time series trends of fishable biomass and fishing mortality were represented by the three year running medians.

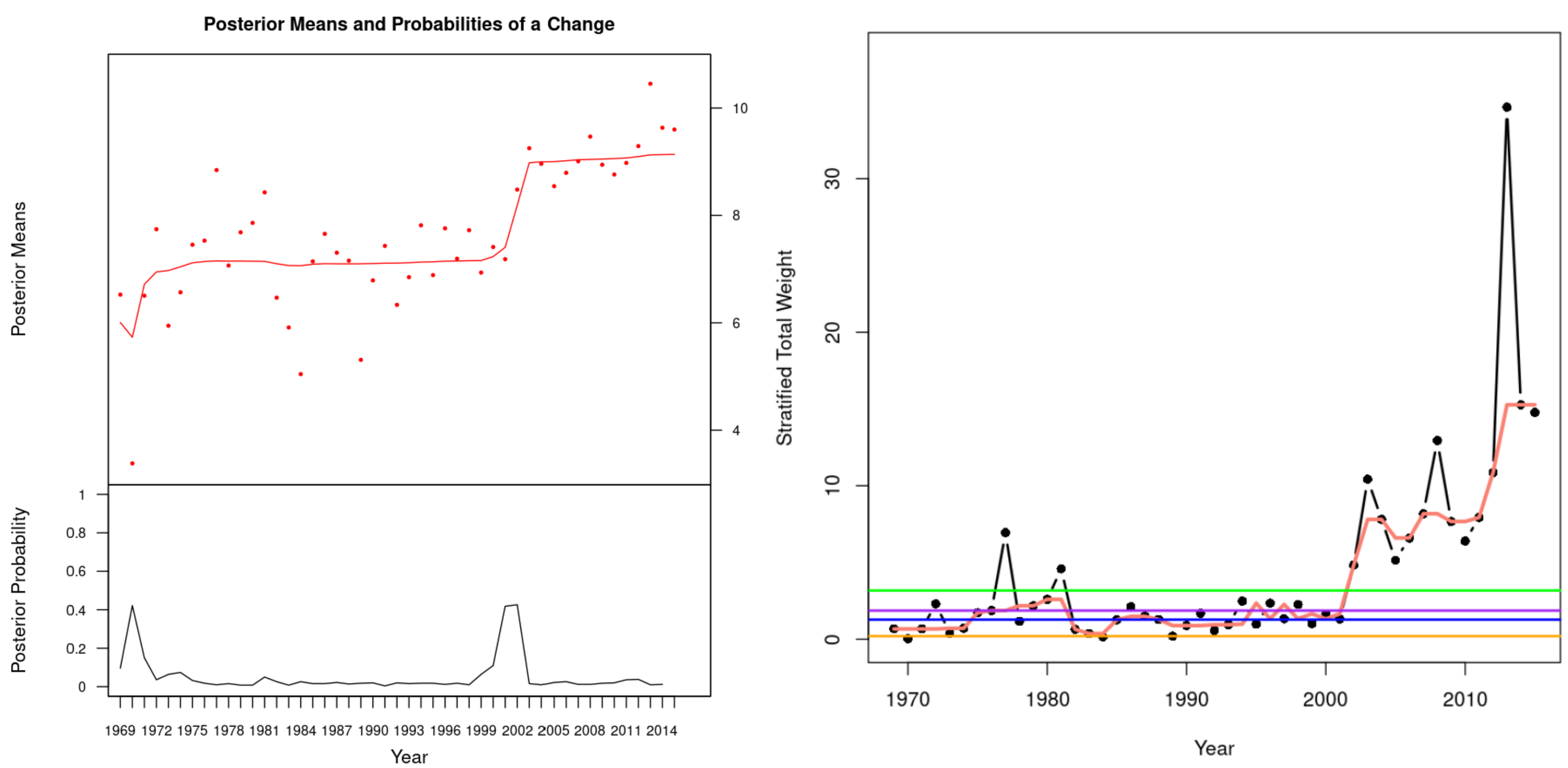


Figure 60. Commercial biomasses (kt) for the NEFSC Spring (NSpr41) survey. (Left) Results from Bayesian change point analysis to determine the probability of a change in commercial biomasses as an indicator of changing productivity regime. Upper panel represent the posterior means of the Bayesian change point model (red line) along with the input values for log(commercial biomass). Lower panel represents the probability of a change point occurring at specific time (black line). (Right) Commercial biomass time series along with the running median (red line), the median of the five lowest non zero biomasses (proposed LRI ; orange) and the medians for the full time series (USI; purple), the lower productivity period (1969-2001; blue; LRI) and 40% of the median of the higher productivity period (2002-2015; green; proposed USI).

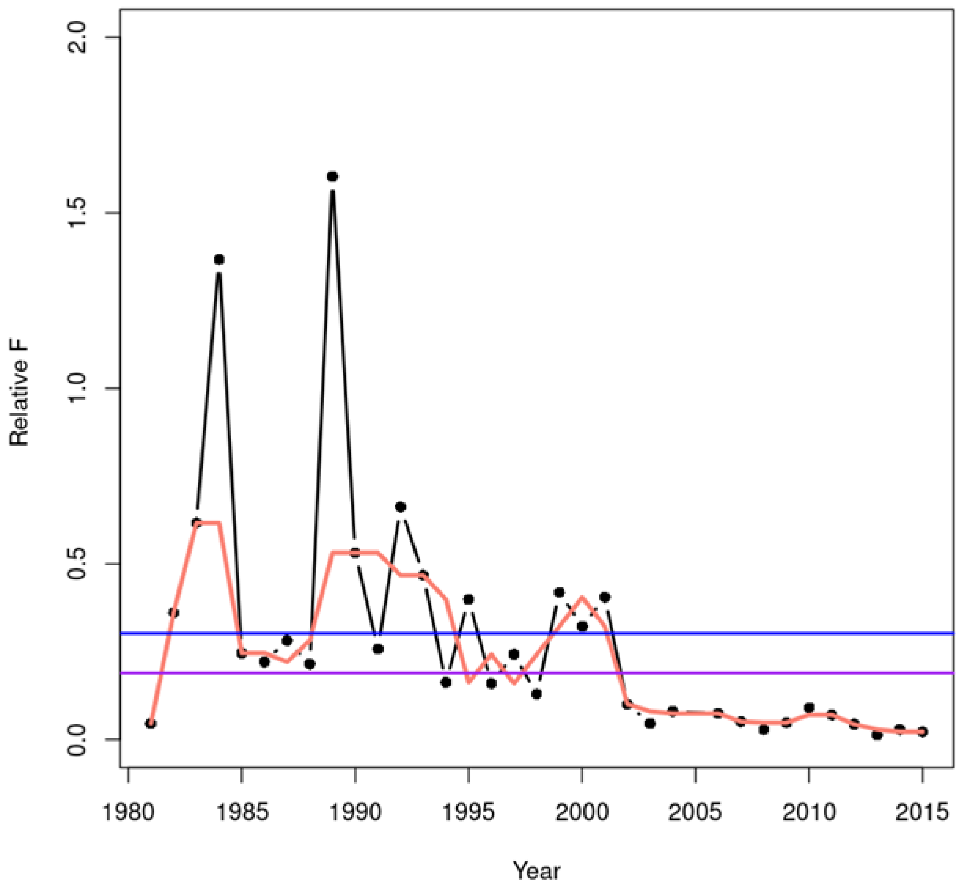


Figure 61. Relative fishing mortality (relF) for the NEFSC Spring (NSpr41) survey and landings. Results from Bayesian change point analysis from commercial biomass trends were used to inform a change in productivity regime and hence relative F. Relative F time series along with the running median (red line) and the medians for the full time series (purple) and the lower productivity period (1981 - 2001; blue; RI).

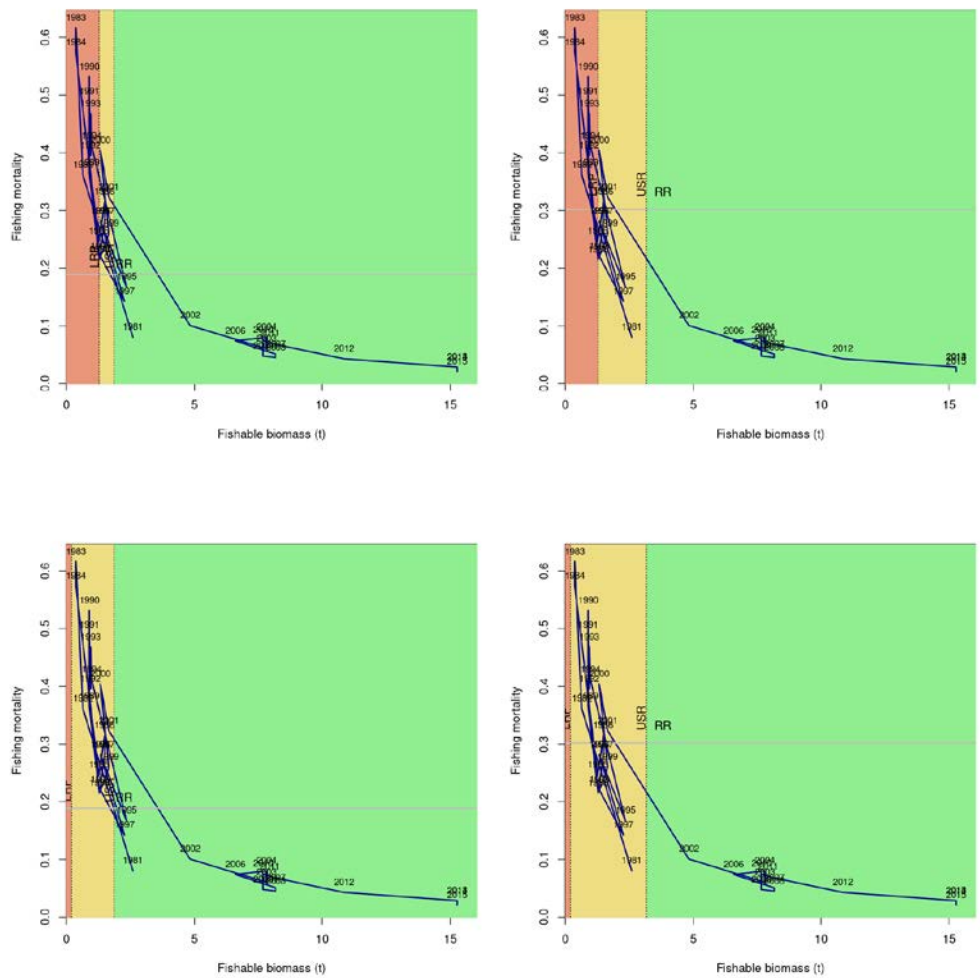


Figure 62. Phase plots showing the impact of different choices of reference points on the stock status zones for offshore American Lobster LFA 41 using NEFSC Spring survey (NSpr41) commercial biomass (kt) and relative F. Left panels - USI and RI were defined using the medians of the entire time series of biomass or relative fishing mortality. Right panels - USI and RI were defined using the medians of commercial biomass and relative F for the upper (2002 - 2015) and lower (1981 - 2001) productivity periods, respectively. In upper panels LRI was defined as the median biomass during the lower productivity period. In lower panels LRI was defined as the median of the five lowest non zero biomasses in the time series. Time series trends of fishable biomass and fishing mortality were represented by the three year running medians.

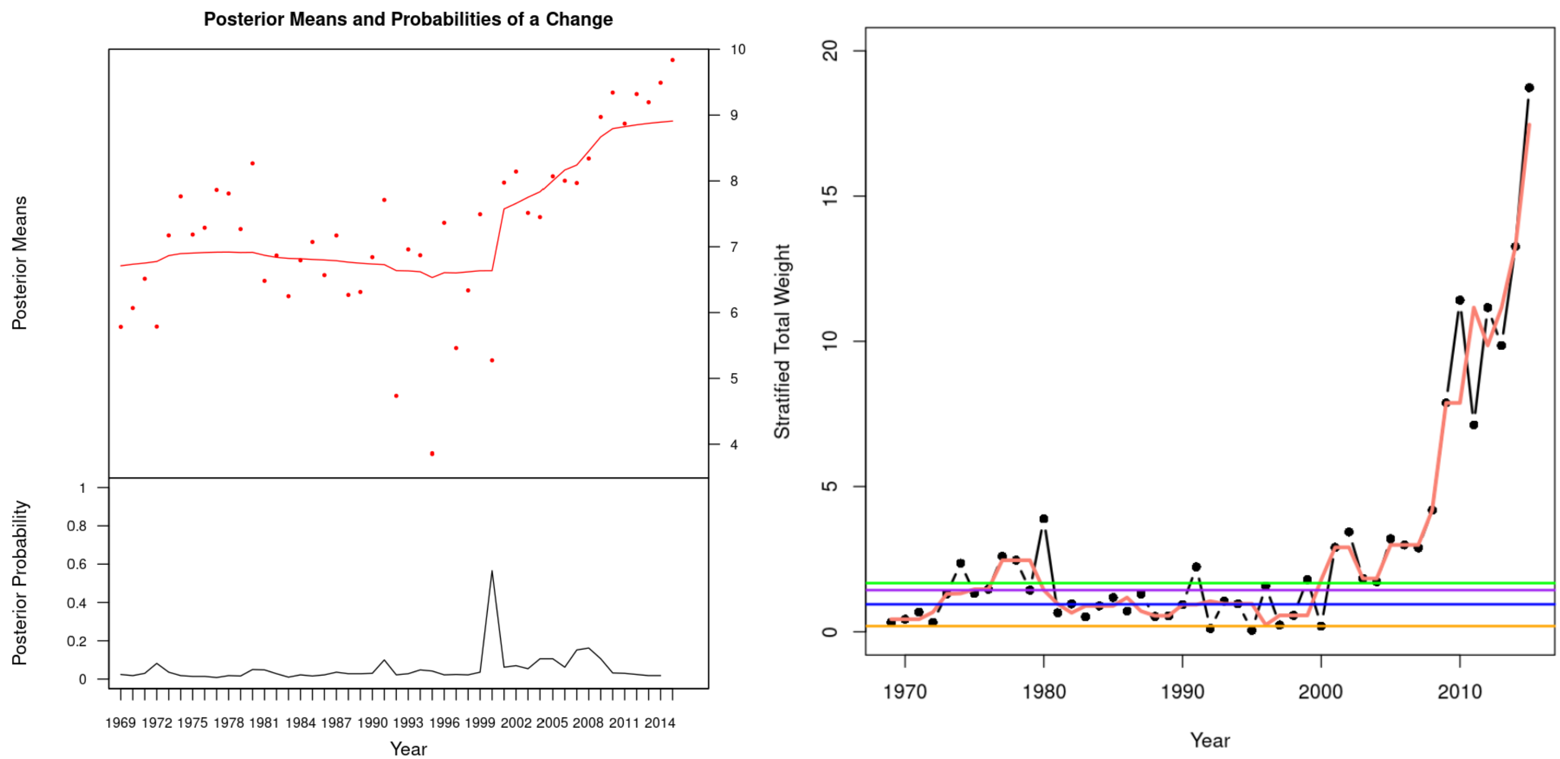


Figure 63. Commercial biomasses (kt) for the NEFSC Autumn (NAut41) survey. (Left) Results from Bayesian change point analysis to determine the probability of a change in commercial biomasses as an indicator of changing productivity regime. Upper panel represent the posterior means of the Bayesian change point model (red line) along with the input values for log(commercial biomass). Lower panel represents the probability of a change point occurring at specific time (black line). (Right) Commercial biomass time series along with the running median (red line), the median of the five lowest non zero biomasses (proposed LRI ; orange) and the medians for the full time series (USR; purple), the lower productivity period (1969-2000; blue; LRI) and 40% of the median of the higher productivity period (2000-2015; green; proposed USI).

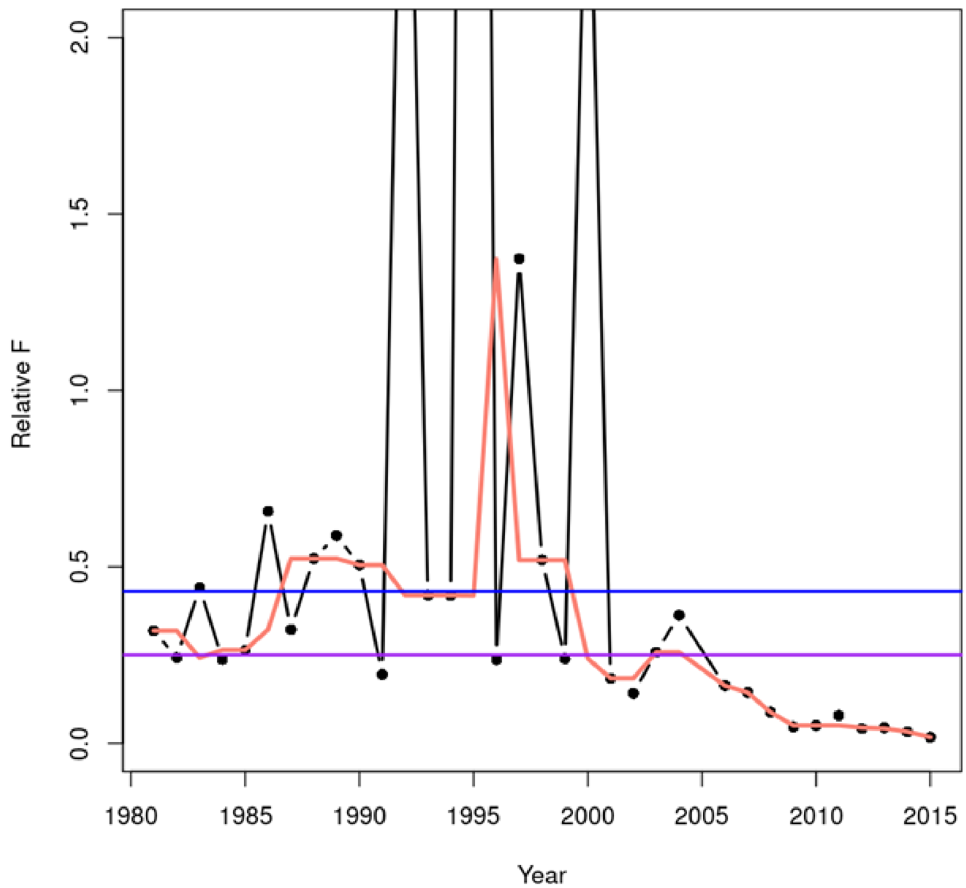


Figure 64. Relative fishing mortality (relF) for the NEFSC Autumn (NAut41) survey and landings. Results from Bayesian change point analysis from commercial biomass trends were used to inform a change in productivity regime and hence relative F. Relative F time series along with the running median (red line) and the medians for the full time series (purple) and the lower productivity period (1981 - 2000; blue; RI).

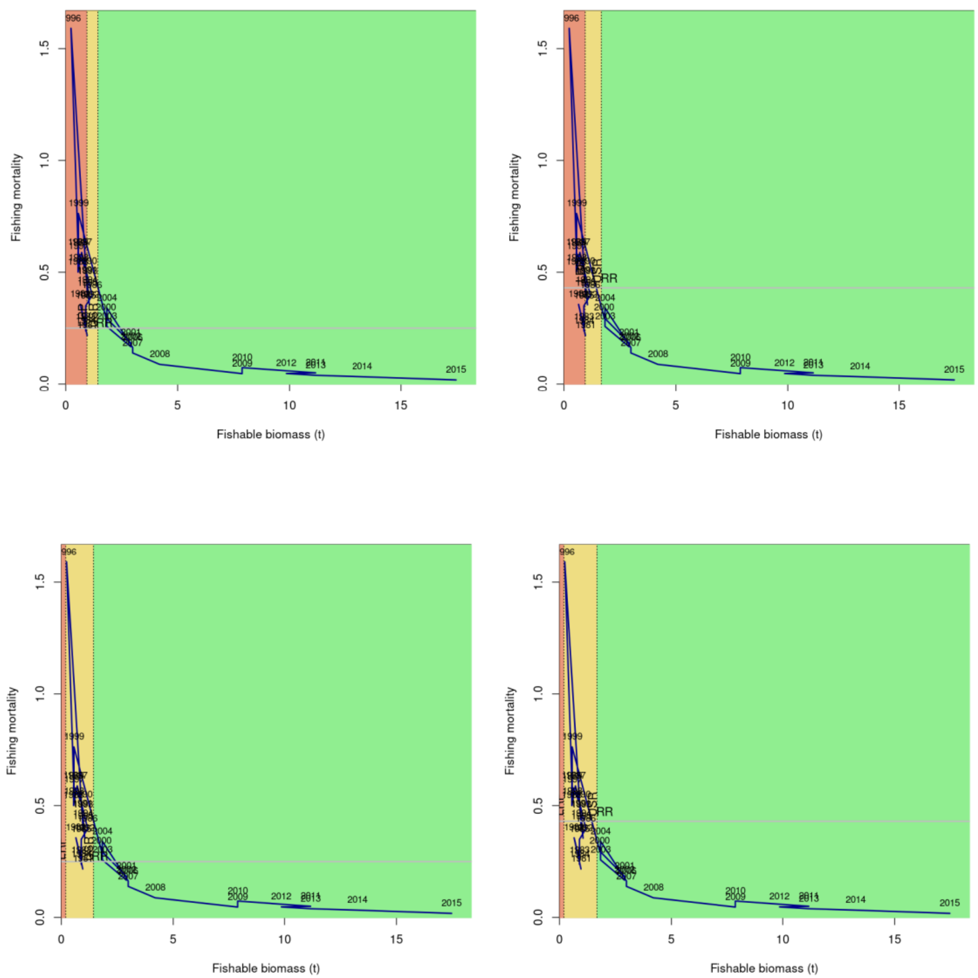


Figure 65. Phase plots showing the impact of different choices of reference points on the stock status zones for offshore American Lobster LFA 41 using NEFSC Autumn survey (NAut41) commercial biomass (kt) and relative F. Left panels - USI and RI were defined using the medians of the entire time series of biomass or relative fishing mortality. Right panels - USI and RI were defined using the medians of commercial biomass and relative F for the upper (2001 - 2015) and lower (1981 - 2000) productivity periods, respectively. In upper panels LRI was defined as the median biomass during the lower productivity period. In lower panels LRI was defined as the median of the five lowest non zero biomasses in the time series. Time series trends of fishable biomass and fishing mortality were represented by the three year running medians.

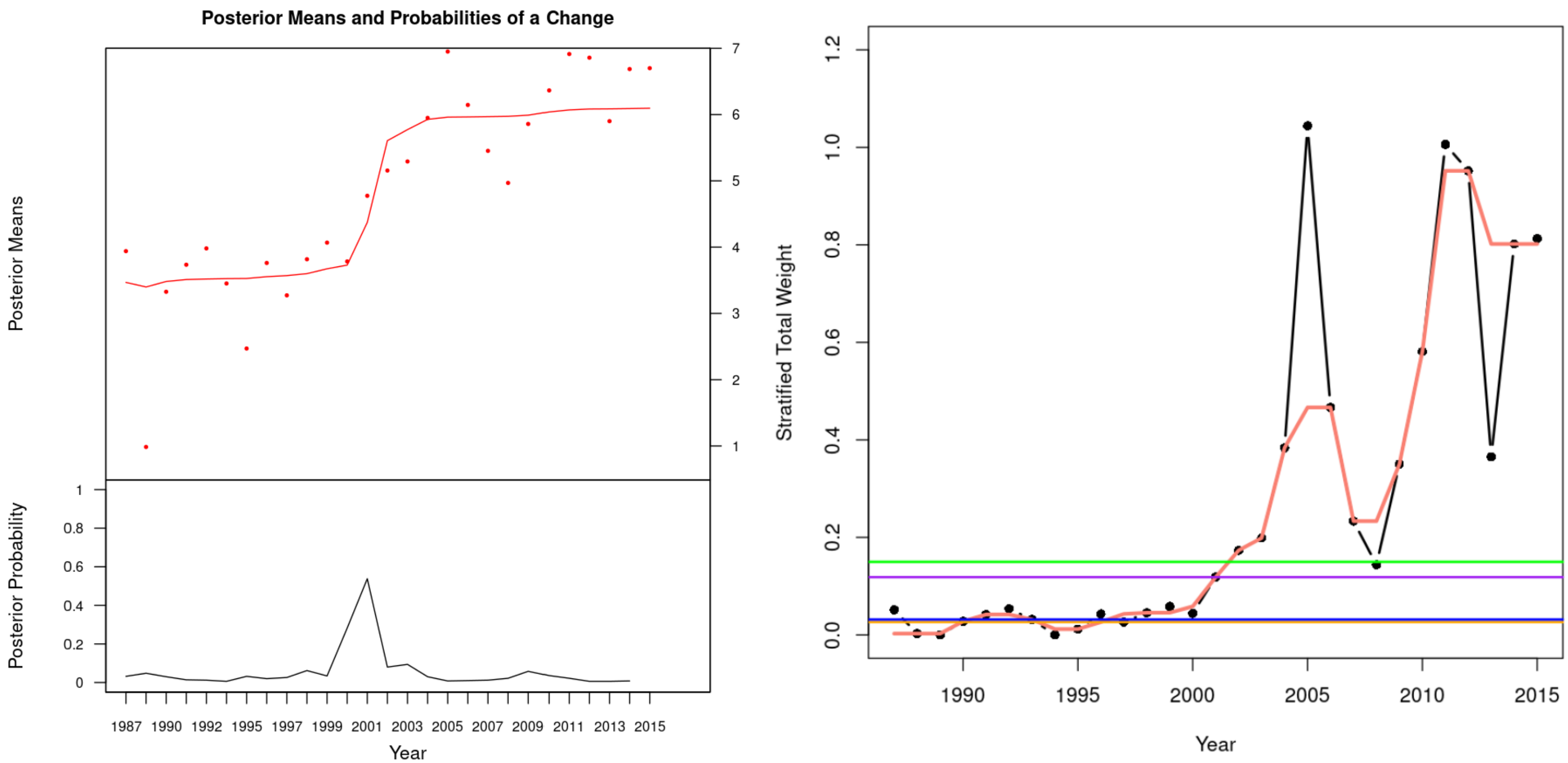


Figure 66. Commercial biomasses (kt) for the DFO Georges Bank (GB) survey. (Left) Results from Bayesian change point analysis to determine the probability of a change in commercial biomasses as an indicator of changing productivity regime. Upper panel represent the posterior means of the Bayesian change point model (red line) along with the input values for log(commercial biomass). Lower panel represents the probability of a change point occurring at specific time (black line). (Right) Commercial biomass time series along with the running median (red line), the median of the five lowest non zero biomasses (proposed LRI; orange) and the medians for the full time series (USI; purple), the lower productivity period (1987-1999; blue; LRI) and 40% of the median of the higher productivity period (2000-2015; green; proposed USI).

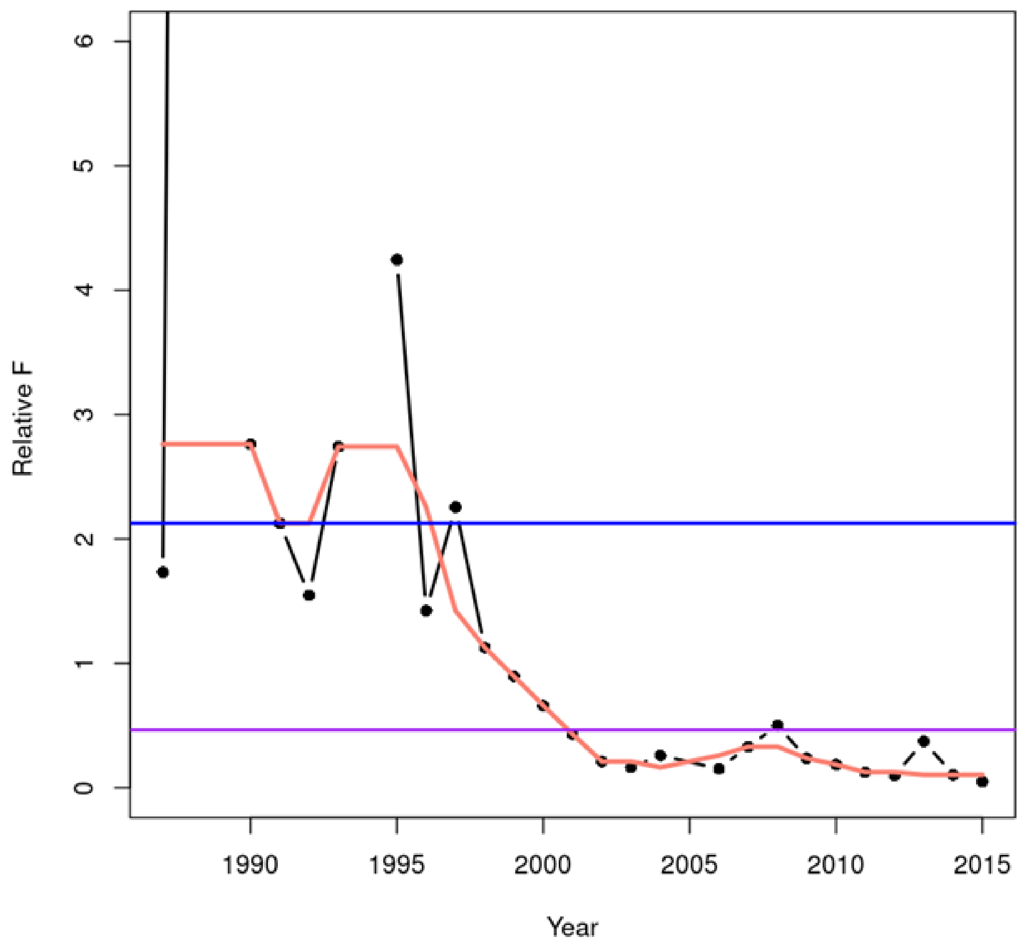


Figure 67. Relative fishing mortality (relF) for the DFO Georges (GB) survey and landings. Results from Bayesian change point analysis from commercial biomass trends were used to inform a change in productivity regime and hence relative F. Relative F time series along with the running median (red line) and the medians for the full time series (purple) and the lower productivity period (1987 - 1999; blue; RI).

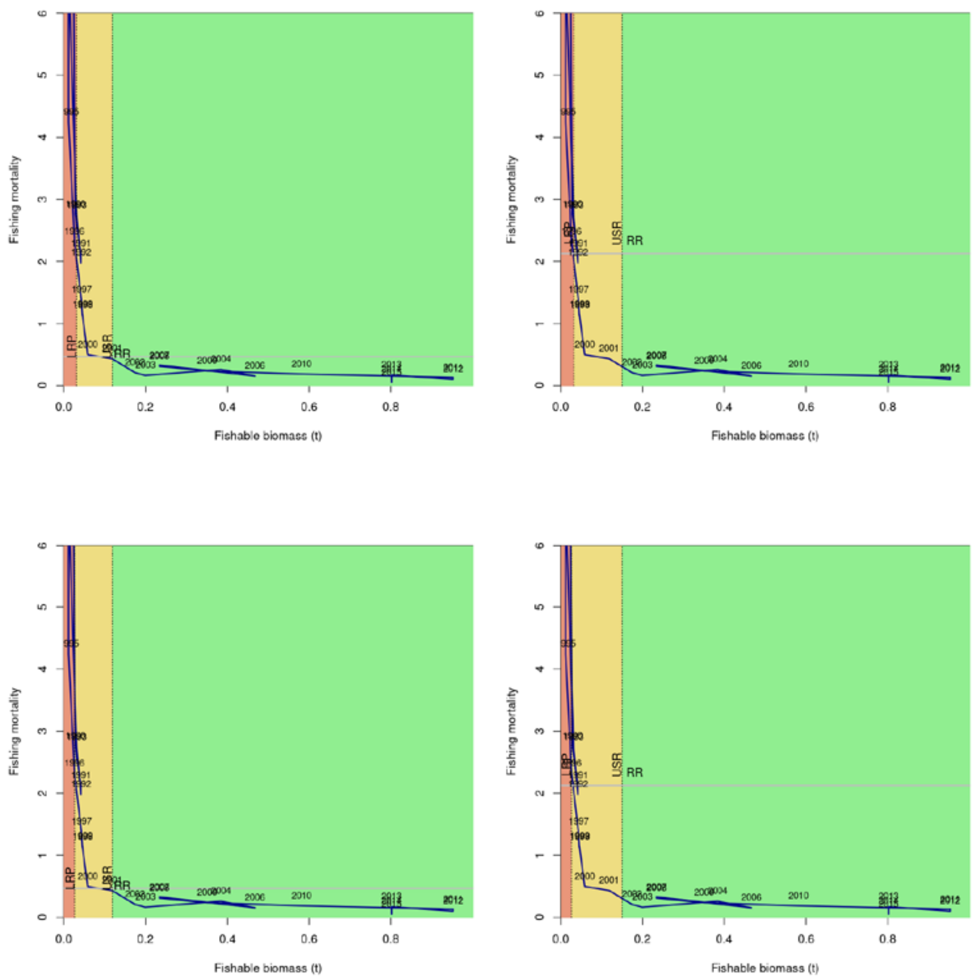


Figure 68. Phase plots showing the impact of different choices of reference points on the stock status zones for offshore American Lobster LFA 41 using DFO Georges Bank survey (GB) commercial biomass (kt) and relative F. Left panels - USI and RI were defined using the medians of the entire time series of biomass or relative fishing mortality. Right panels - USI and RI were defined using the medians of commercial biomass and relative F for the upper (2000 - 2015) and lower (1987 - 1999) productivity periods, respectively. In upper panels LRI was defined as the median biomass during the lower productivity period. In lower panels LRI was defined as the median of the five lowest non zero biomasses in the time series. Time series trends of fishable biomass and fishing mortality were represented by the three year running medians.

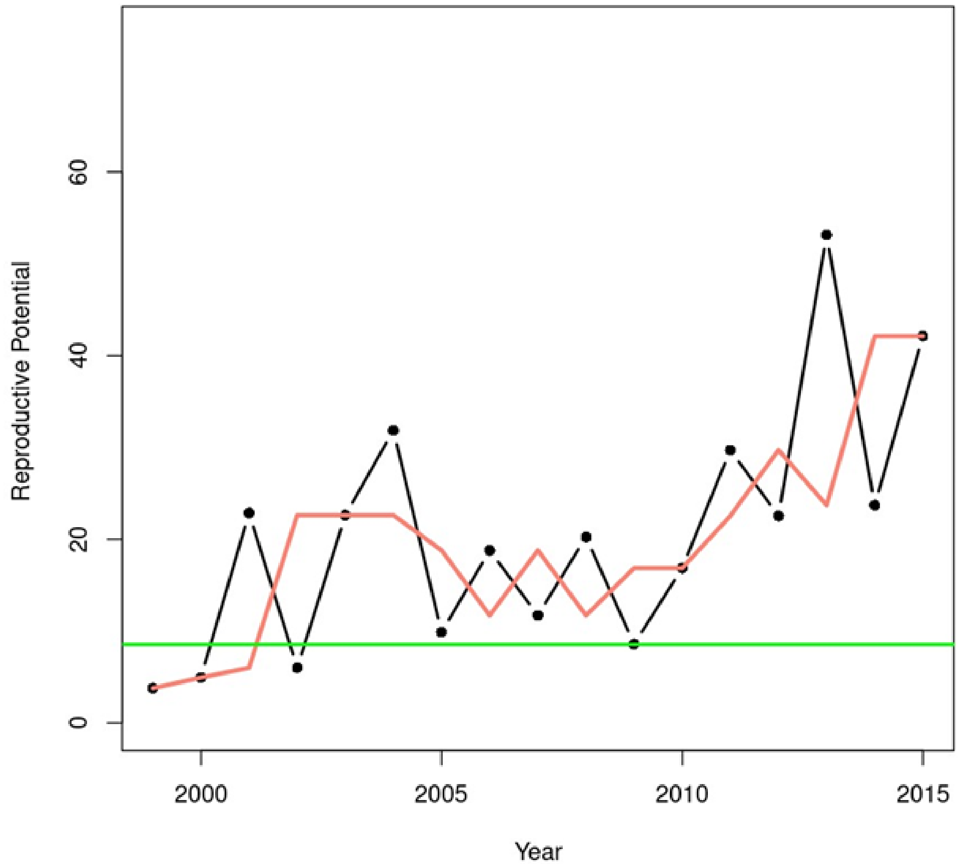


Figure 69. Reproductive potential in millions of eggs estimated from DFO Summer RV (RV41) survey American Lobster population weighted fecundity estimates. Red line represents a three year running median. Green line represents the upper boundary estimated as 40% of the median of 2000 - 2015.

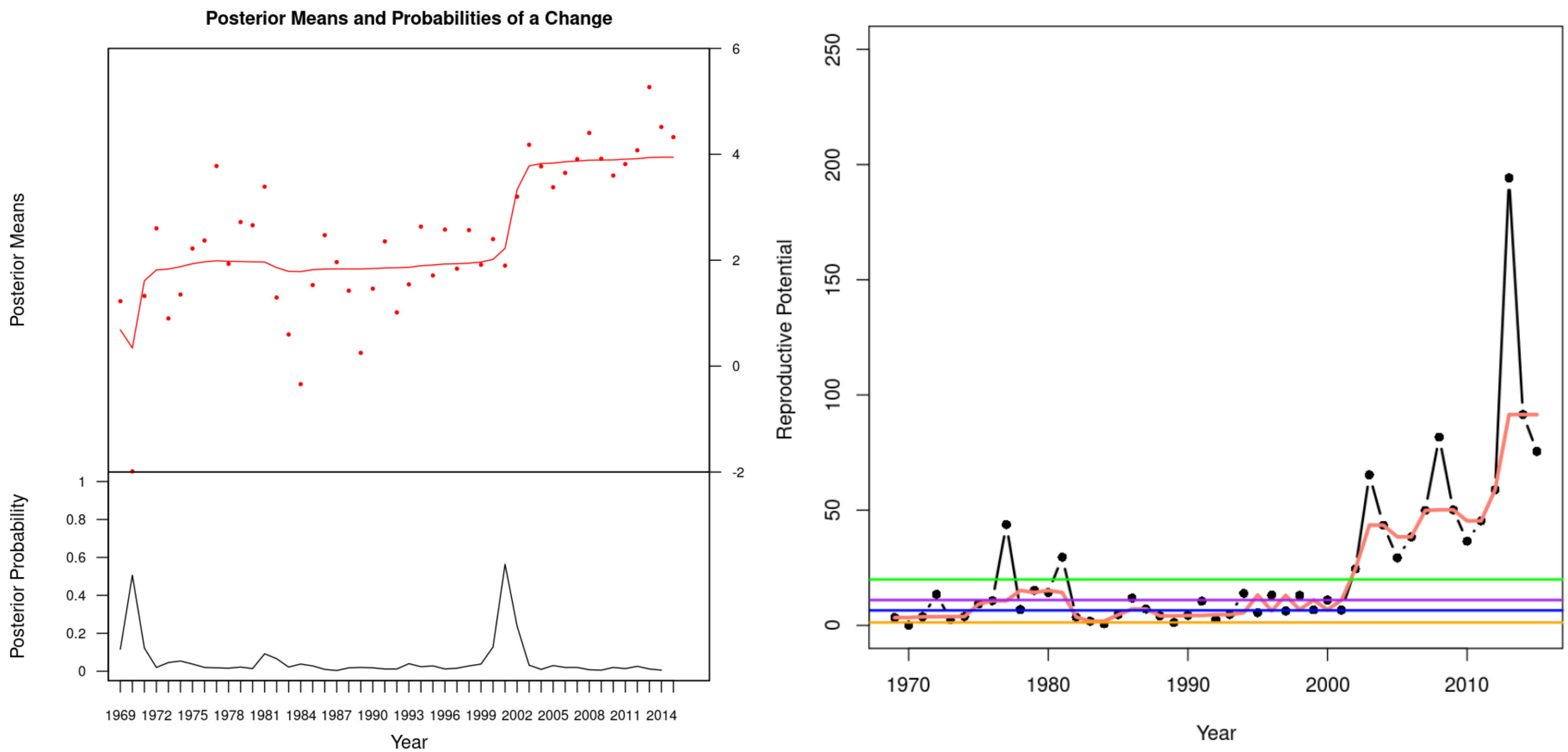


Figure 70. Reproductive potential in millions of eggs estimated from NEFSC Spring survey (NSpr41) American Lobster population weighted fecundity. (Left) Bayesian change point analysis to determine if a shift in productivity regime was evident. Upper panel represents the posterior means of the Bayesian change point model (red line) along with the input values for log(Reproductive potential). Lower panel represents the probability of a change point occurring at specific time (black line). (Right) Reproductive potential time series along with the running median (red line), the median of the five lowest non zero biomasses (lower boundary; orange) and the medians for the full time series (upper boundary; purple), the lower productivity period (1969-2001; blue; lower boundary) and 40% of the median of the higher productivity period (2002-2015; green; proposed upper boundary).

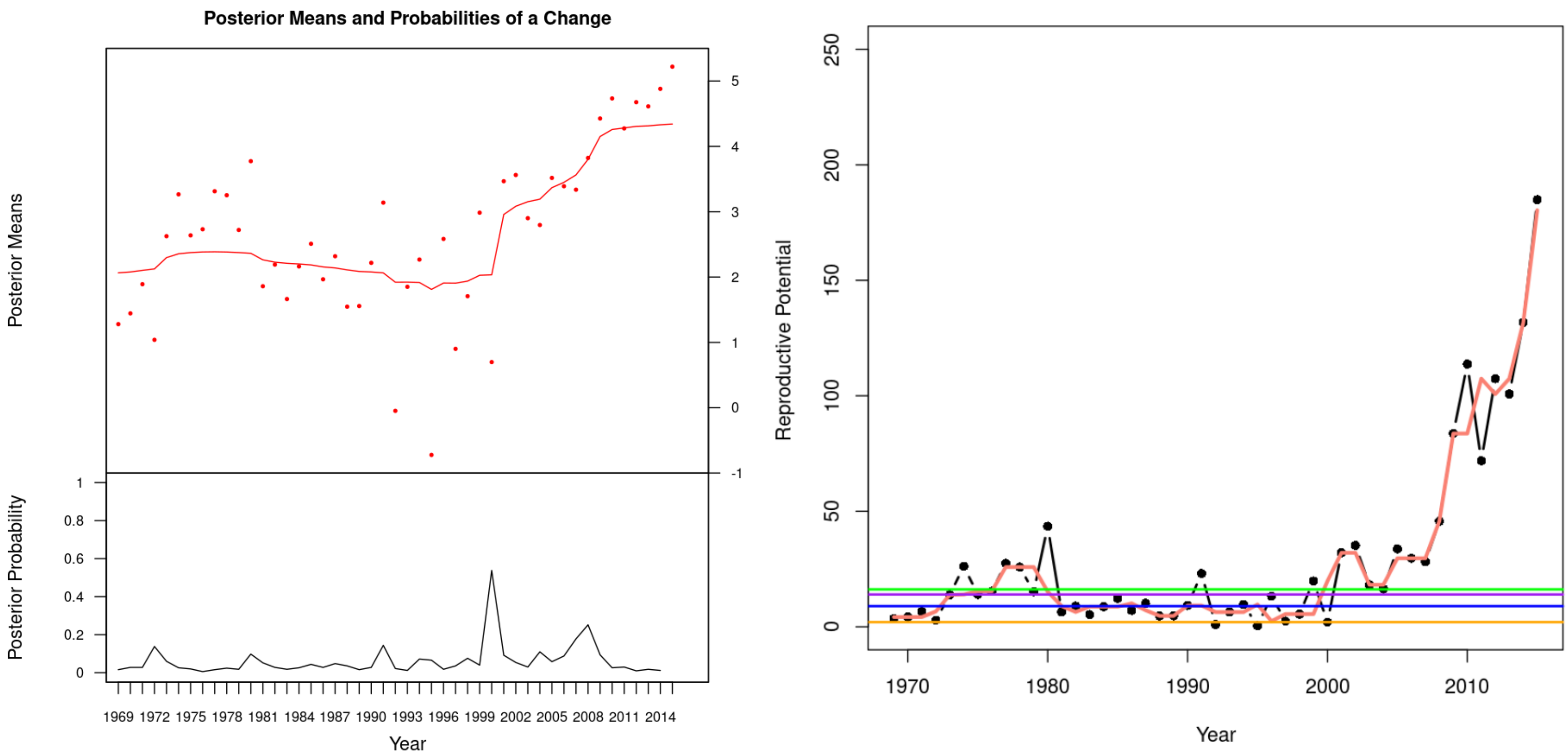


Figure 71. Reproductive potential in millions of eggs estimated from NEFSC Autumn survey (NAut41) American Lobster population weighted fecundity. (Left) Bayesian change point analysis to determine if a shift in productivity regime was evident. Upper panel represents the posterior means of the Bayesian change point model (red line) along with the input values for log(Reproductive potential). Lower panel represents the probability of a change point occurring at specific time (black line). (Right) Reproductive potential time series along with the running median (red line), the median of the five lowest non zero biomasses (lower boundary; orange) and the medians for the full time series (upper boundary; purple), the lower productivity period (1969-2000; blue; lower boundary) and 40% of the median of the higher productivity period (2001-2015; green; proposed upper boundary).

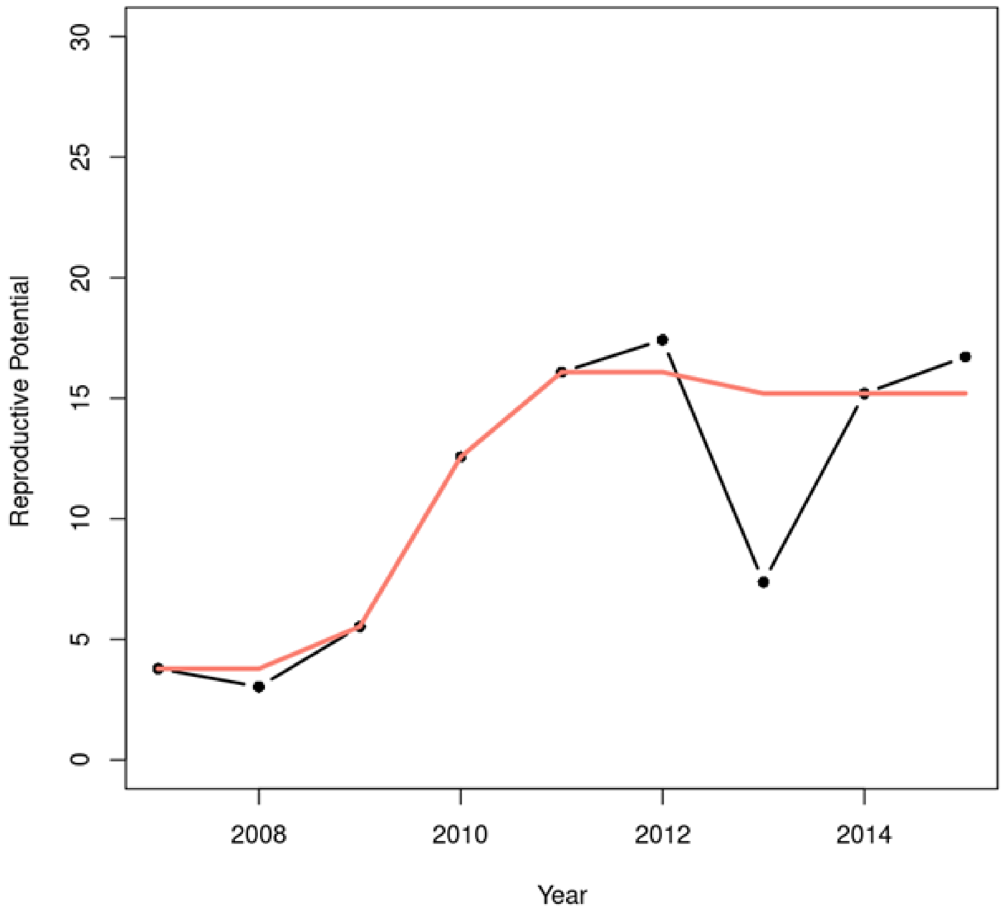


Figure 72. Reproductive potential in millions of eggs estimated from DFO Georges Bank RV (GB) survey American Lobster population weighted fecundity estimates. Red line represents a three year running median.

APPENDICES

APPENDIX A: RESULTS OF THE SURVEY PRUNING.

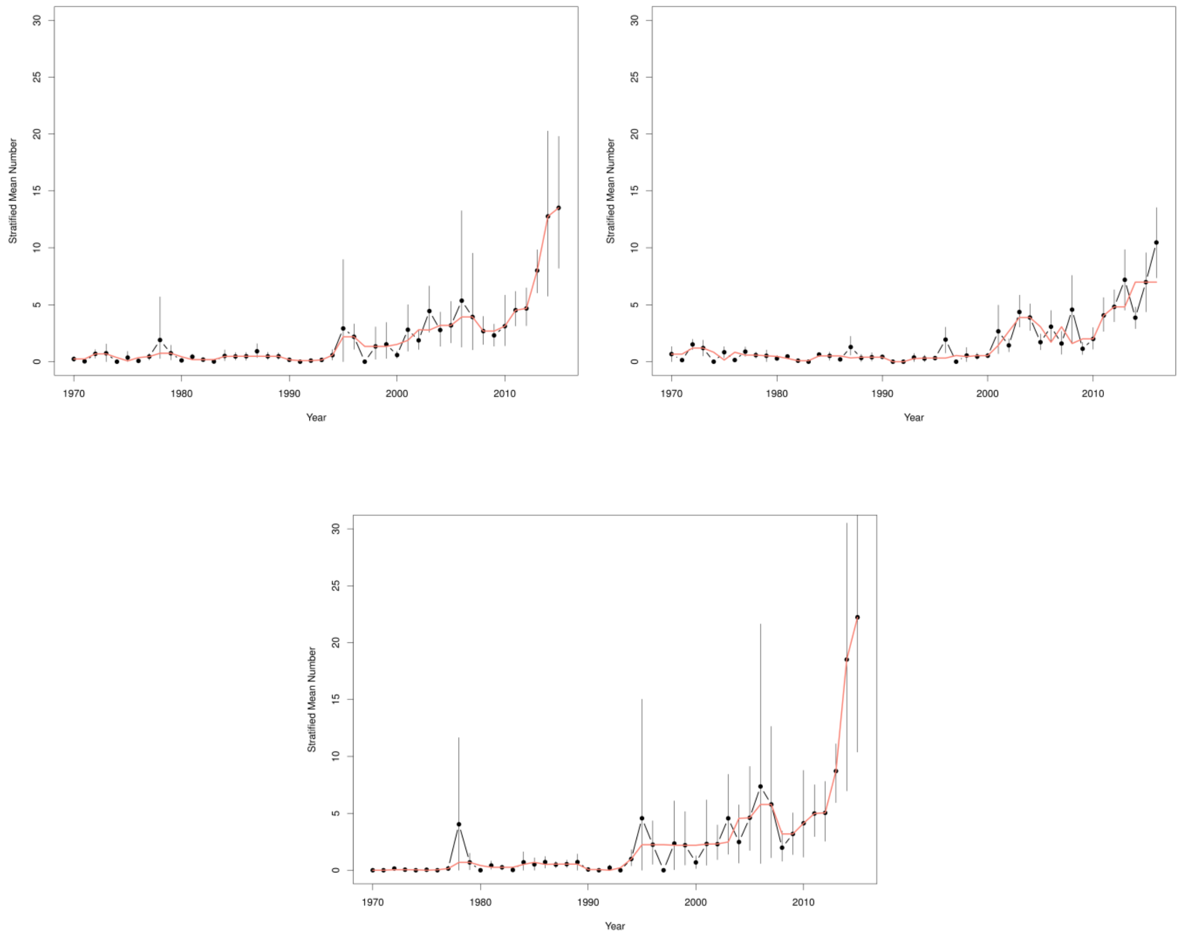


Figure A1. DFO Summer RV survey American Lobster stratified mean number per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1971 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Annual sample sizes are shown as blue points.

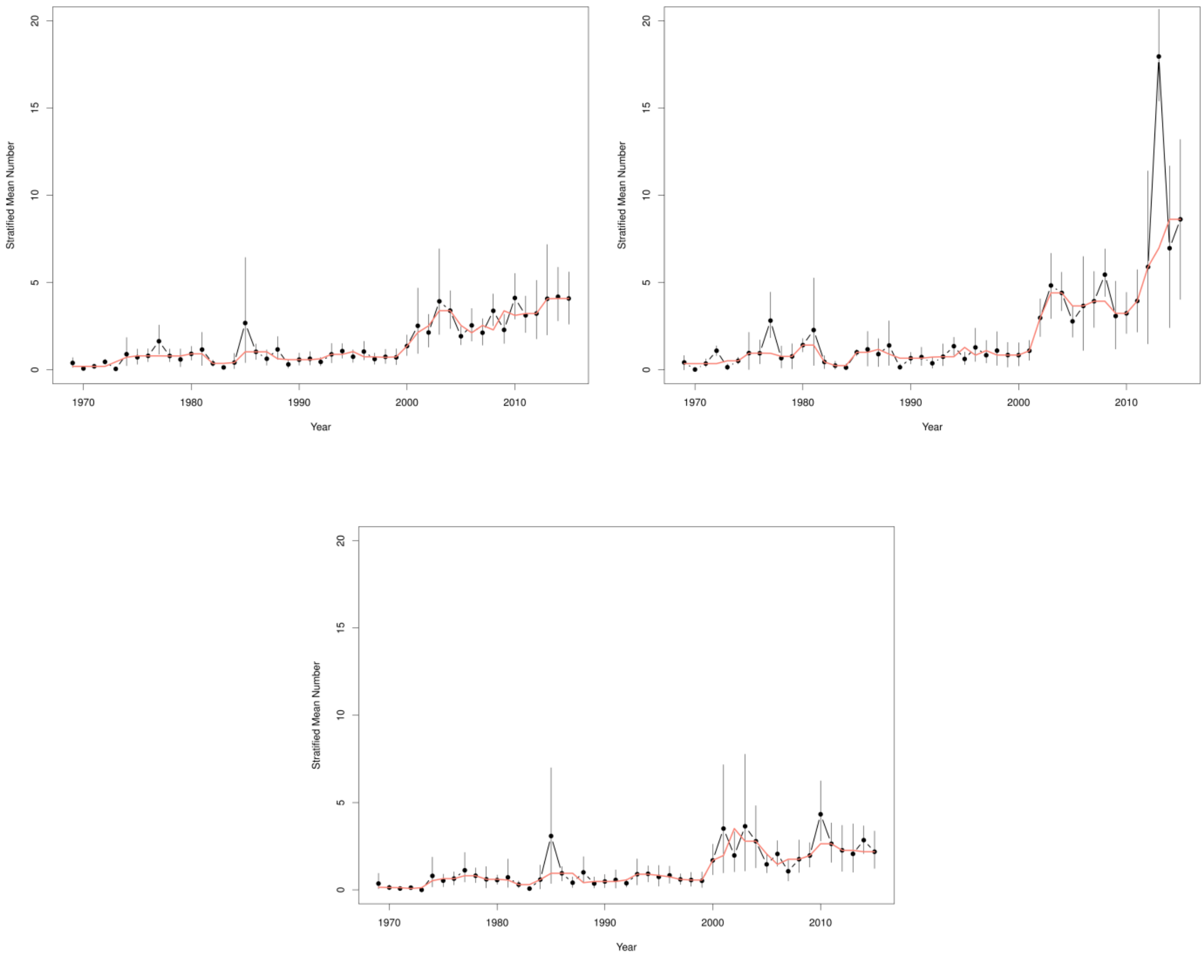


Figure A2. NEFSC spring survey American Lobster stratified mean number per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Annual sample sizes are shown as blue points.

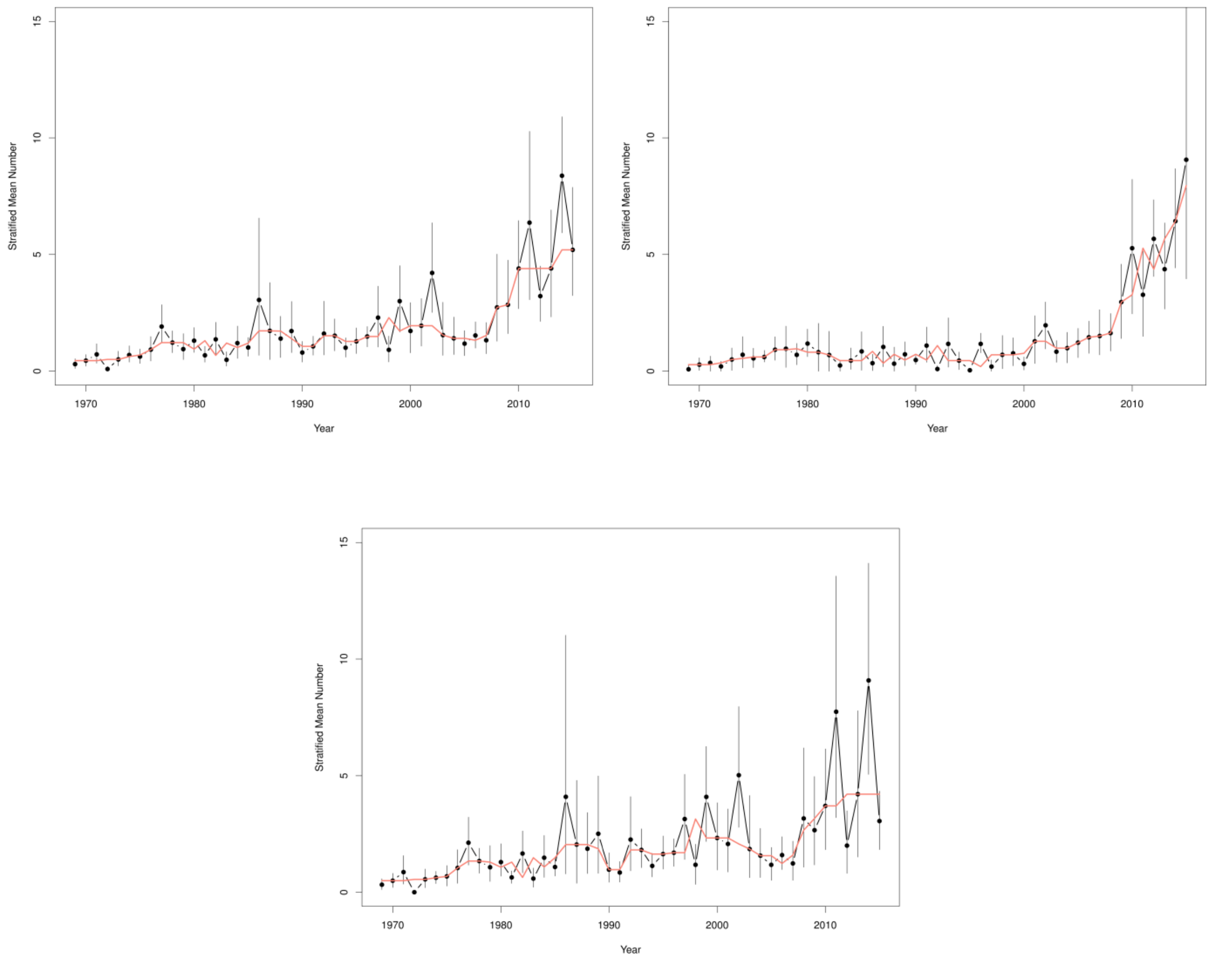


Figure A3. NEFSC Fall survey American Lobster stratified mean number per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Annual sample sizes are shown as blue points.

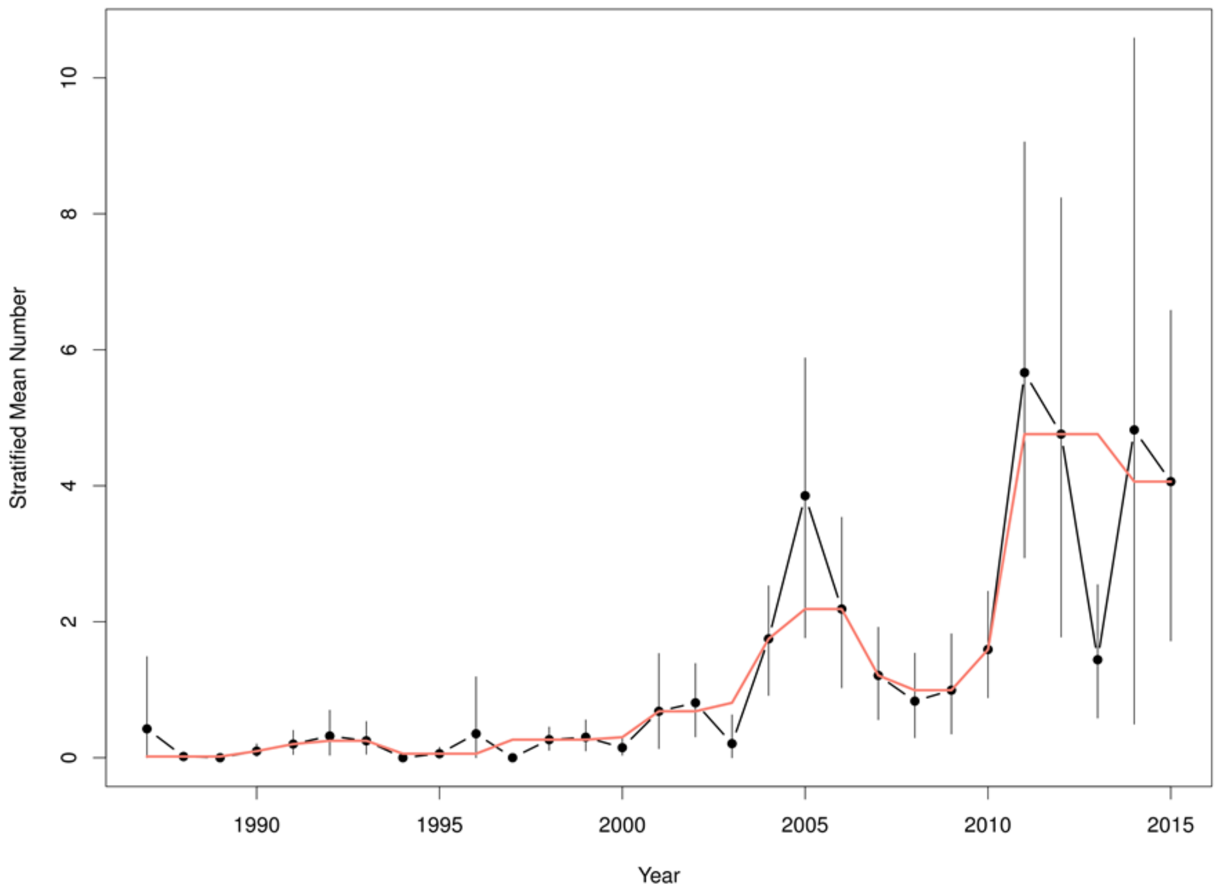


Figure A4. DFO RV Georges Bank survey American Lobster stratified mean number per tow for the Canadian portion of the survey from 1987 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Annual sample sizes are shown as blue points.

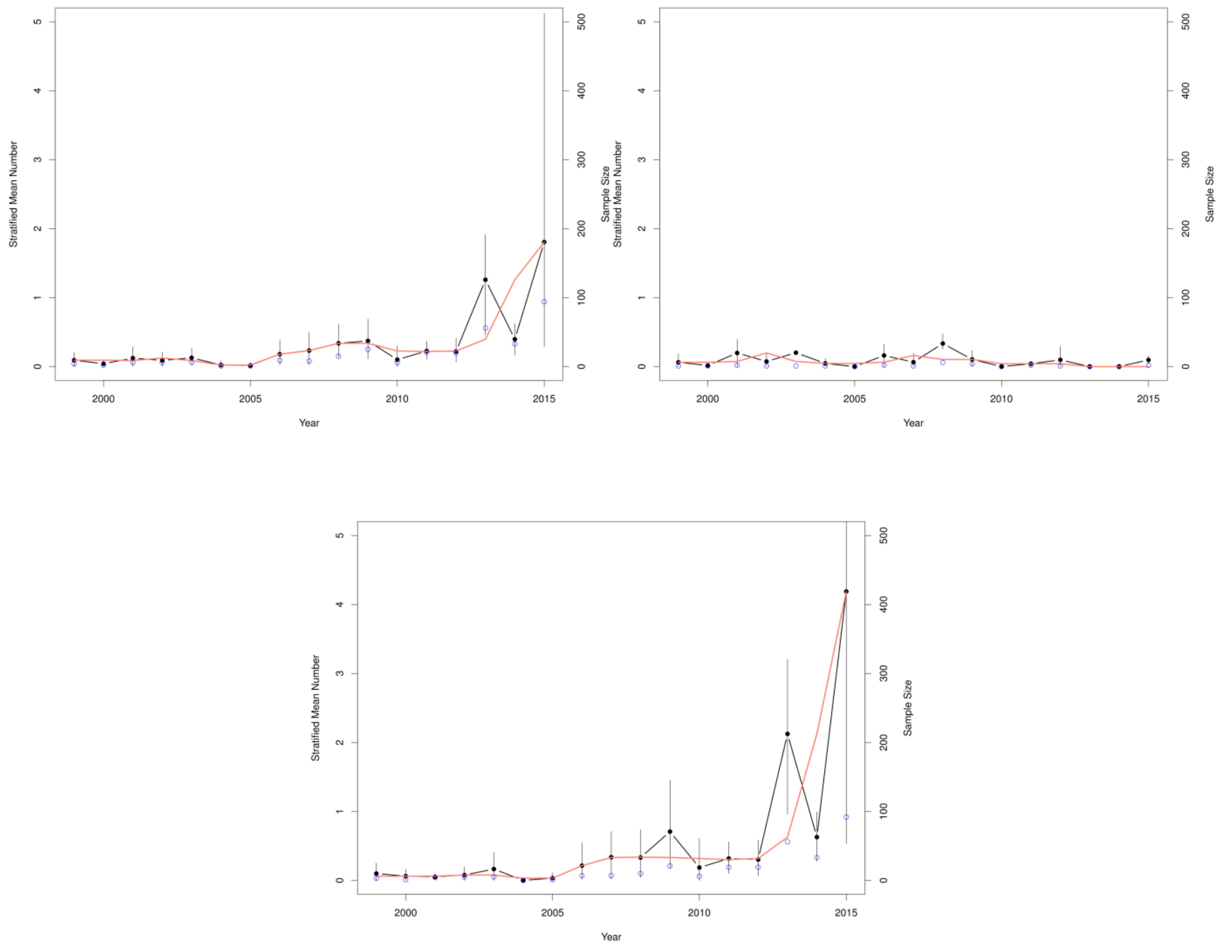


Figure A5. DFO Summer RV survey American Lobster stratified mean number of recruits per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1999 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Annual sample sizes are shown as blue points.

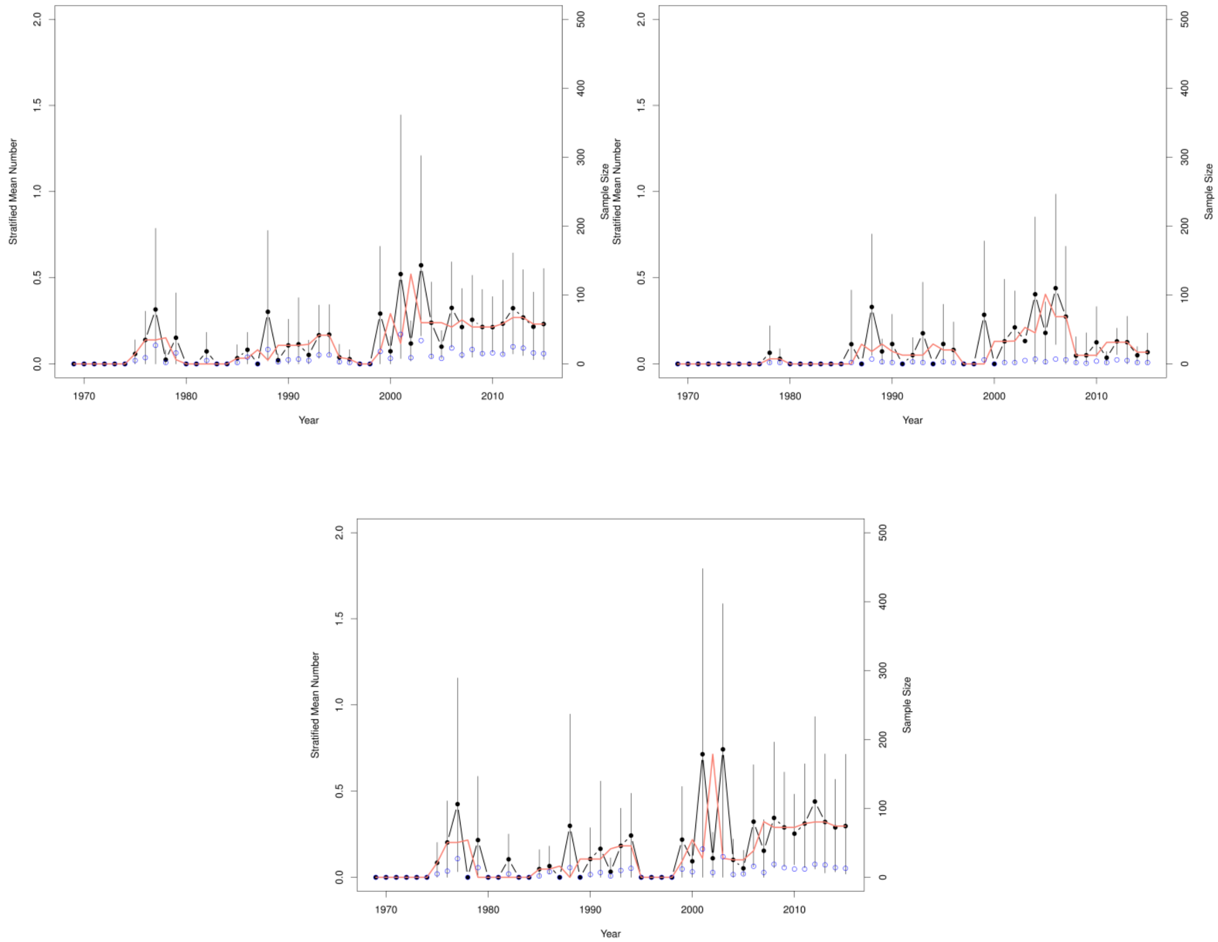


Figure A6. NEFSC spring survey American Lobster stratified mean number of recruits per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Annual sample sizes are shown as blue points.

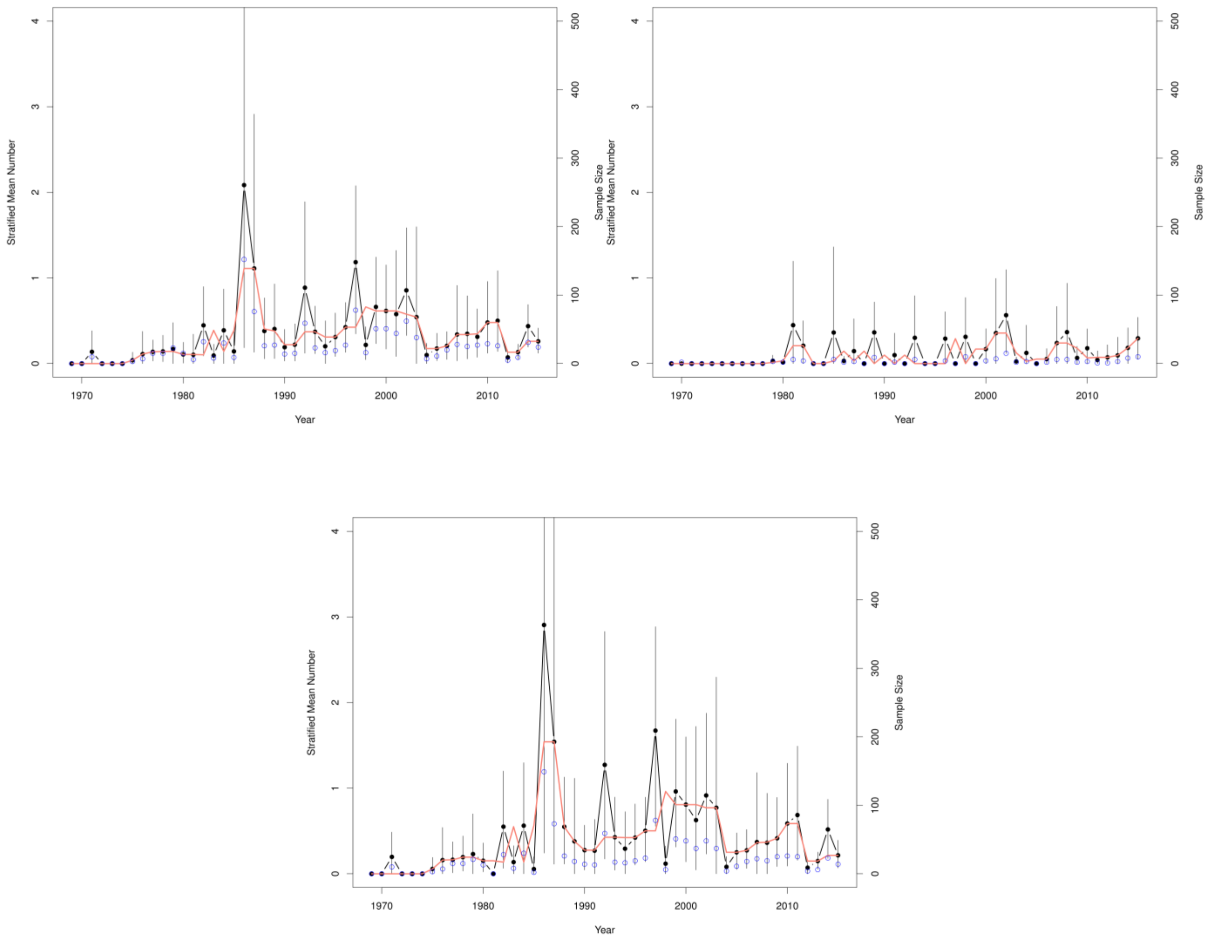


Figure A7. NEFSC Fall survey American Lobster stratified mean number of recruits per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Annual sample sizes are shown as blue points.

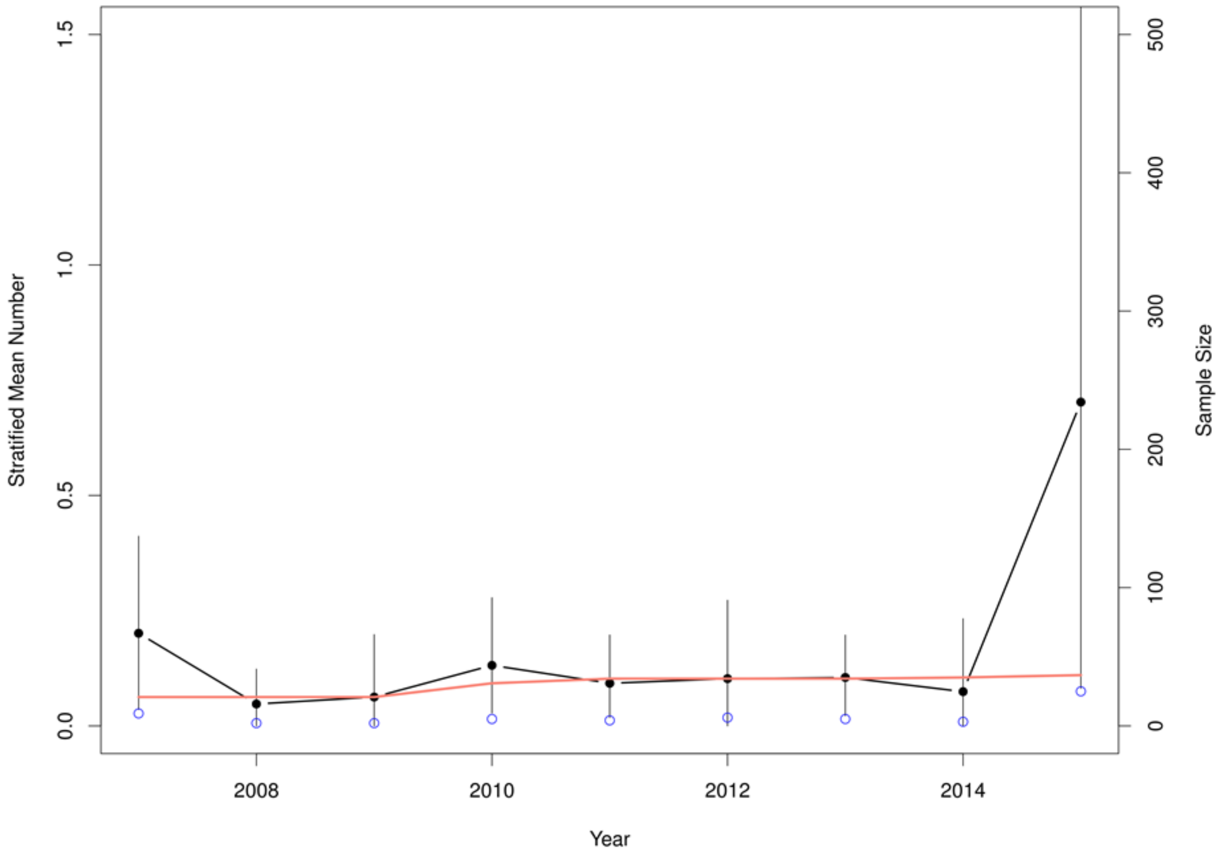


Figure A8. DFO RV Georges Bank survey American Lobster stratified number of recruits number per tow for the Canadian portion of the survey from 2007 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate.

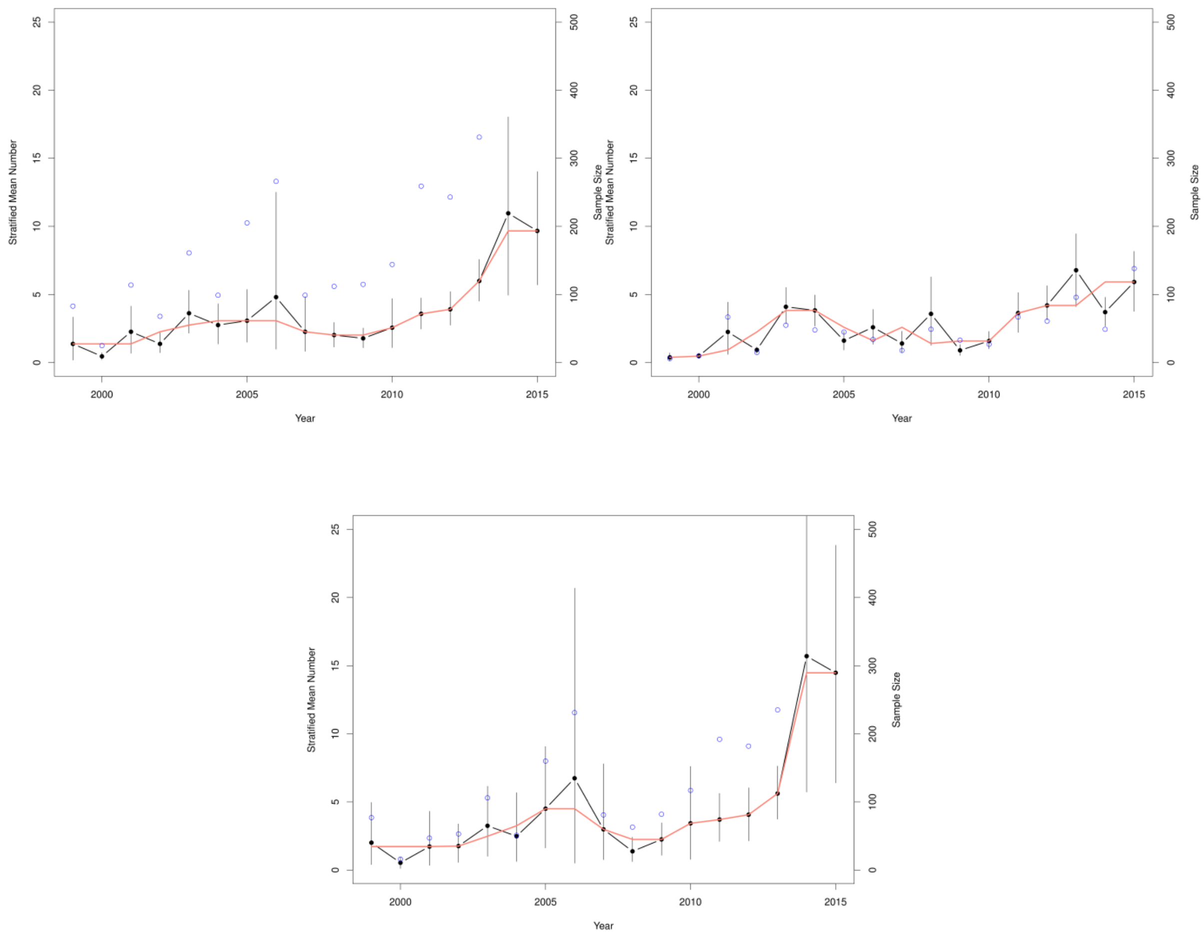


Figure A9. DFO Summer RV survey commercial sized American Lobster stratified mean number per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1970 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Blue points represent the annual number of commercial Lobster observed within the survey and area.

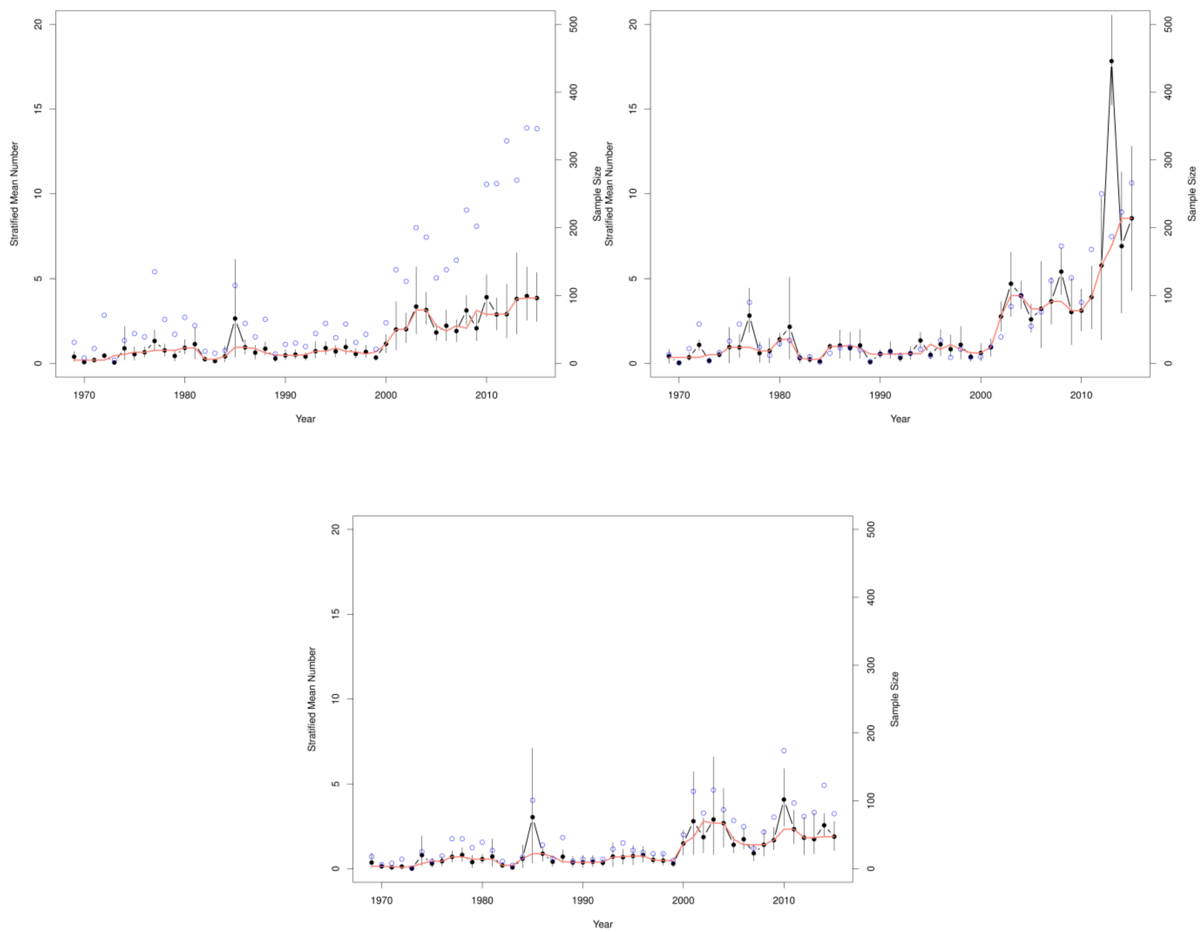


Figure A10. NEFSC spring survey commercial sized American Lobster stratified mean number per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Blue points represent the annual number of commercial Lobster observed within the survey and area.

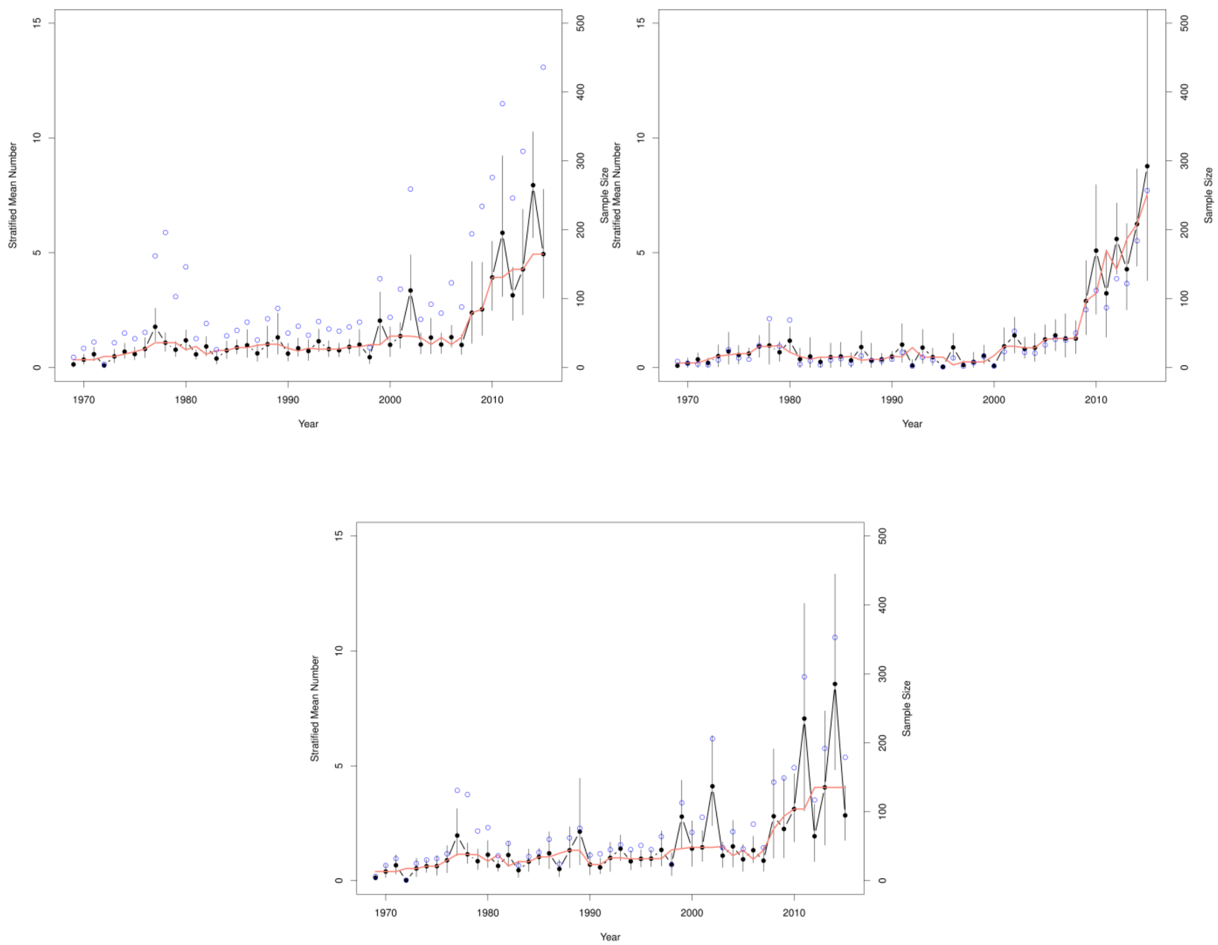


Figure A11. NEFSC Fall survey commercial sized American Lobster stratified mean number per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Blue points represent the annual number of commercial Lobster observed within the survey and area.

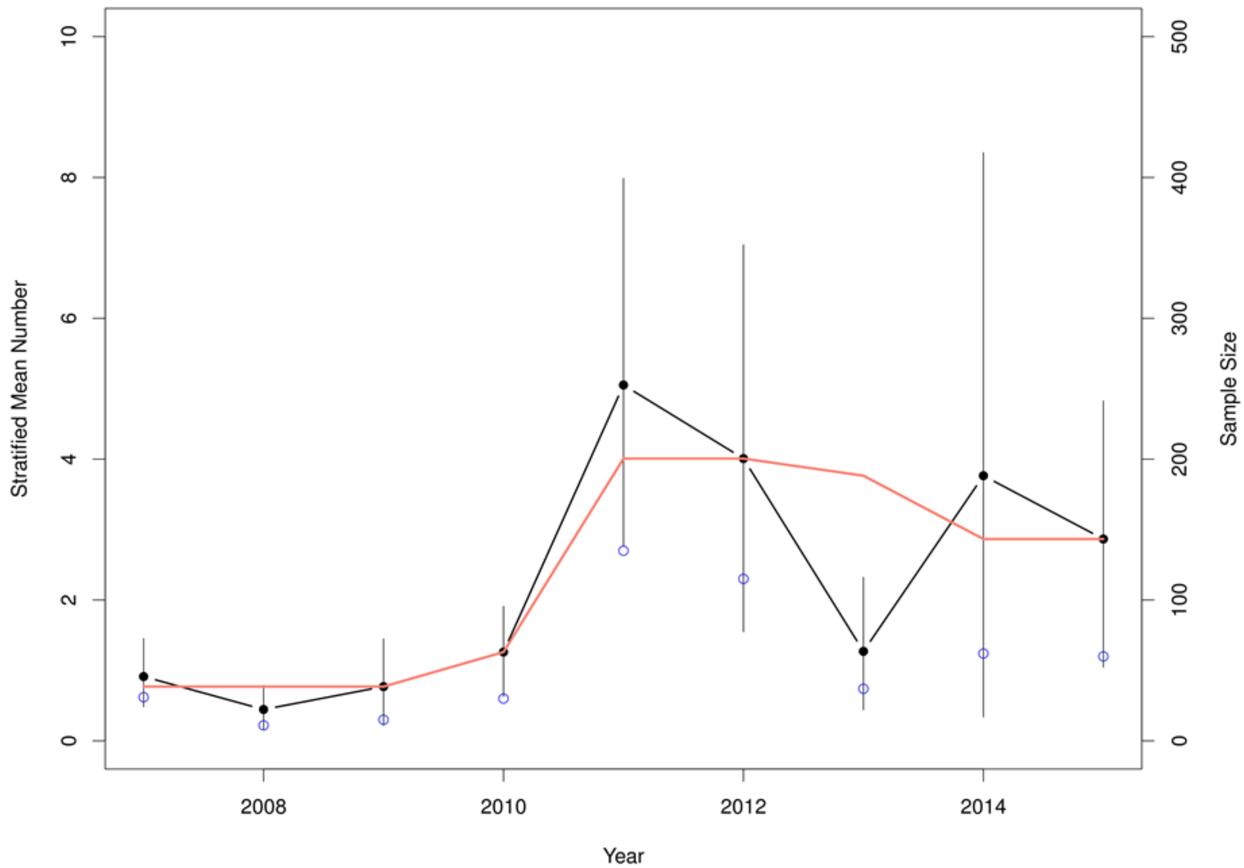


Figure A12. DFO RV Georges Bank survey commercial sized American Lobster stratified mean number per tow for the Canadian portion of the survey from 1987 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Blue points represent the annual number of commercial Lobster observed within the survey and area.

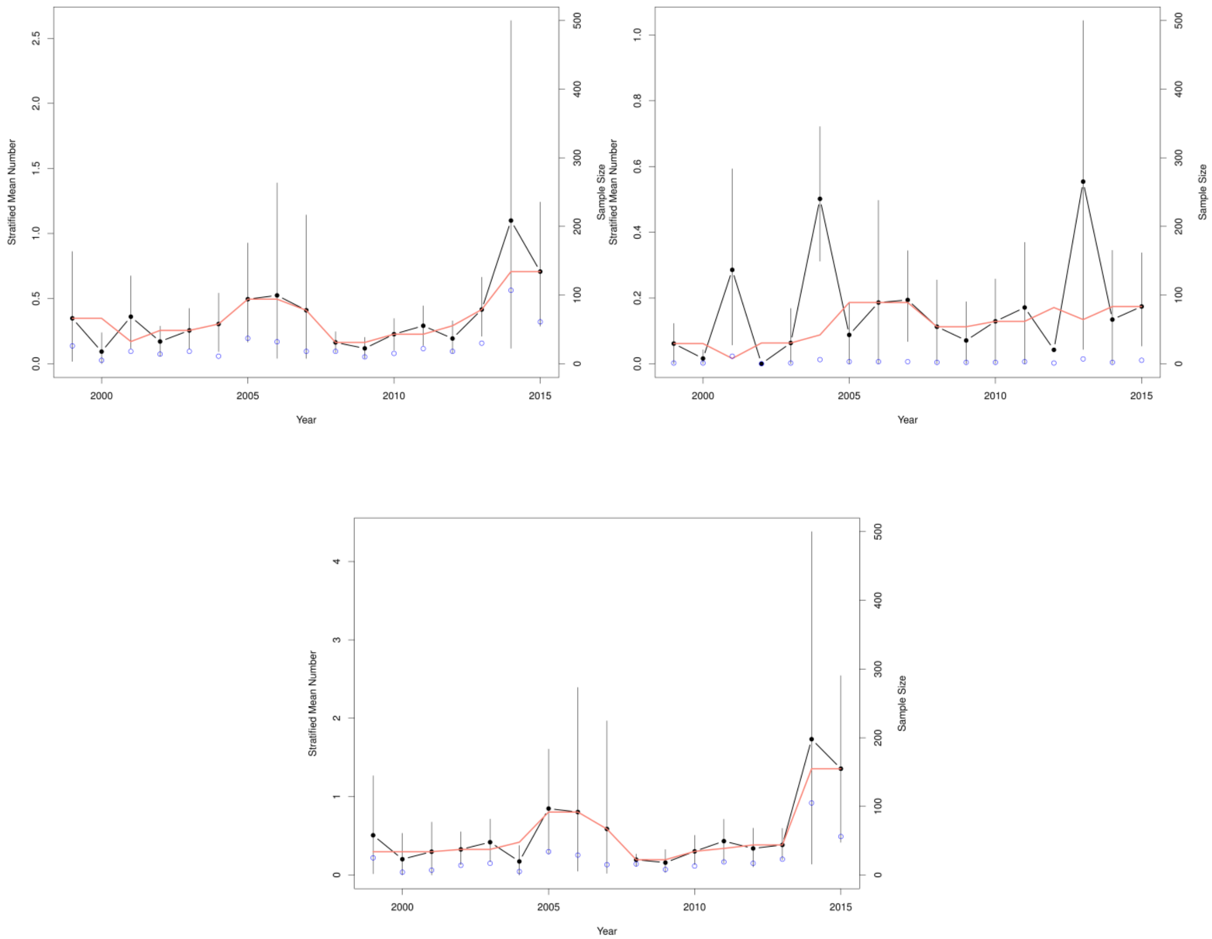


Figure A13. DFO Summer RV survey large female (≥ 140mm) American Lobster stratified mean number per tow for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1970 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Blue points represents the annual number of female Lobster ≥ 140mm observed within the survey and area.

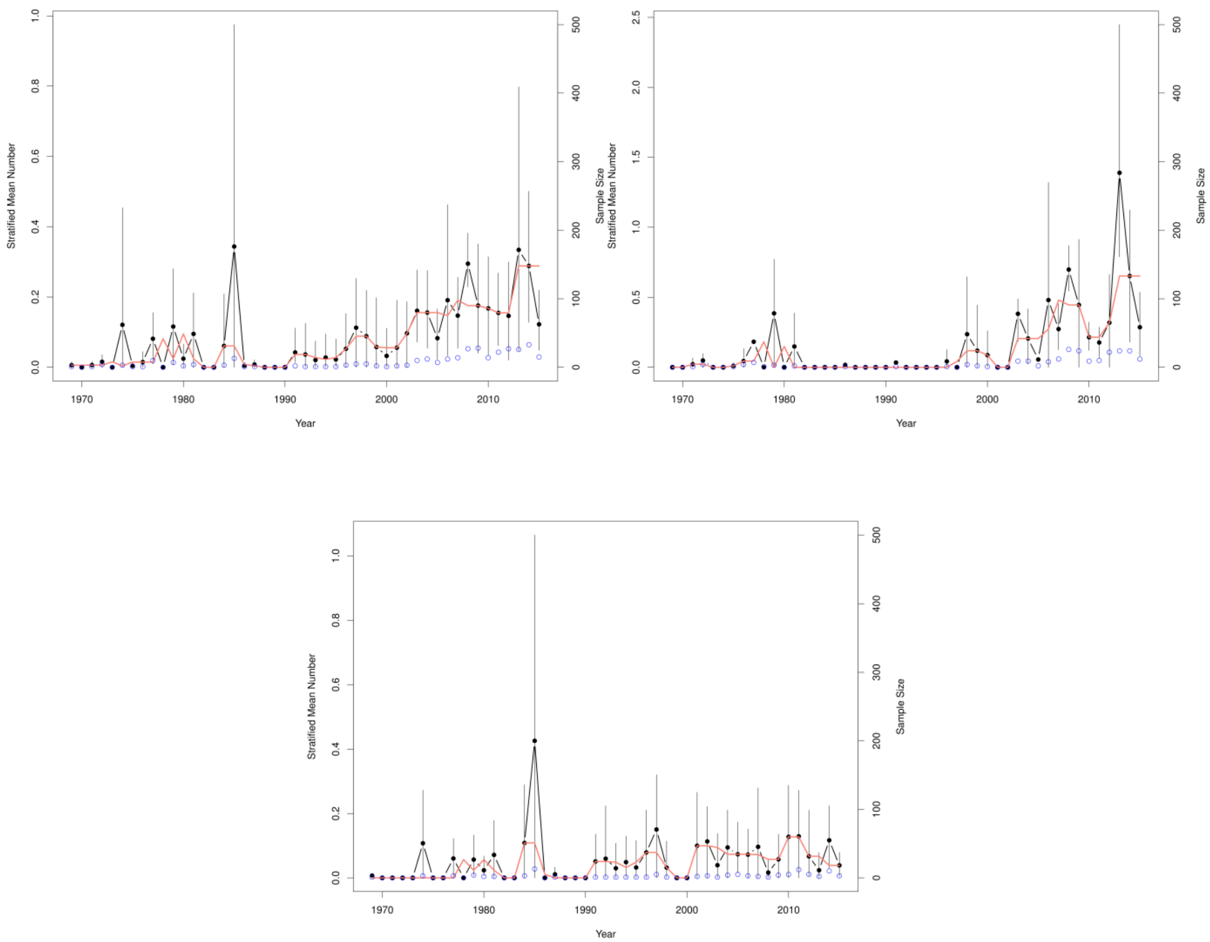


Figure A14. NEFSC spring survey large female (≥ 140mm) American Lobster stratified mean number per tow for the base survey (top left), pruned survey (top right) pruned to adja- cent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Blue points represents the annual number of female Lobster ≥ 140mm observed within the survey and area.

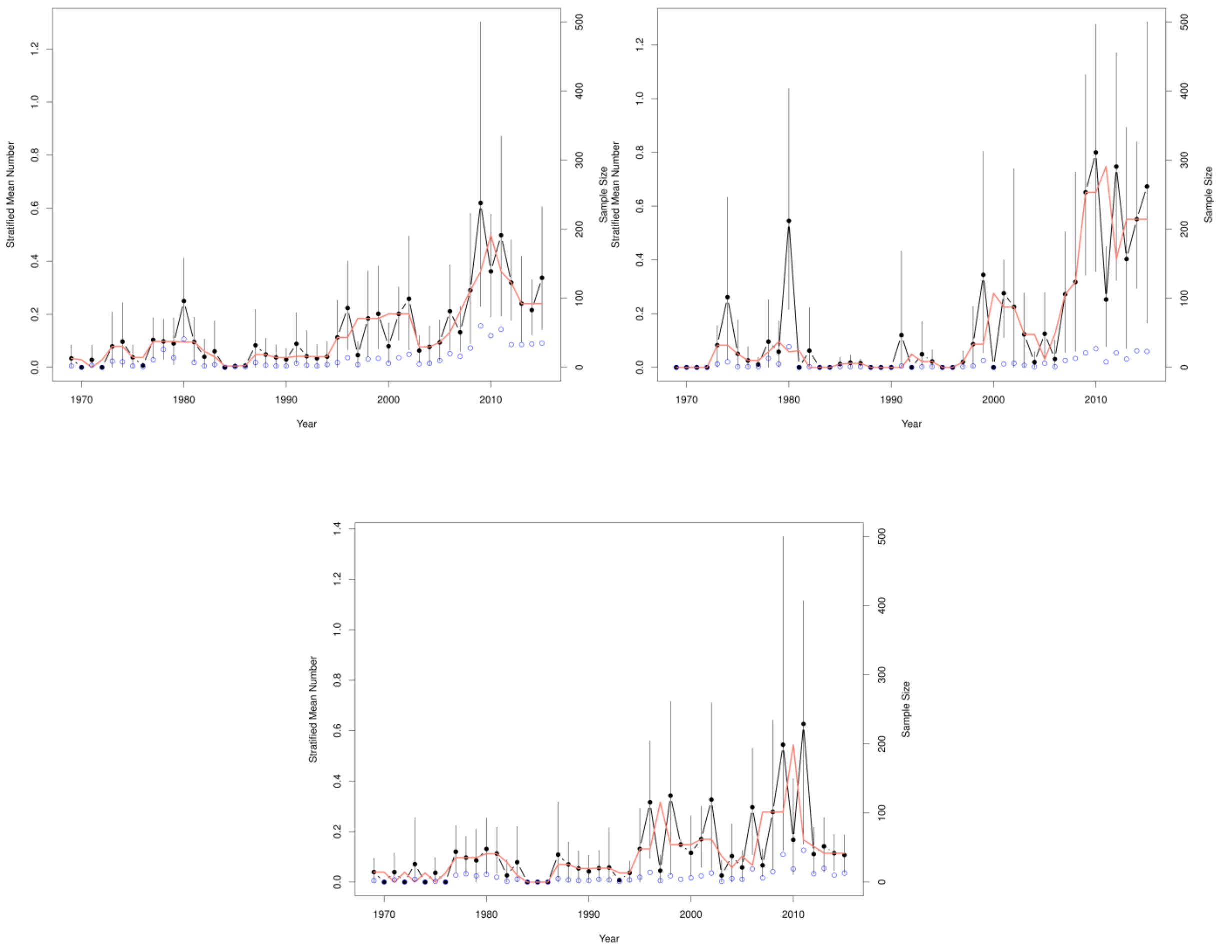


Figure A15. NEFSC Fall survey large female (≥ 140mm) American Lobster stratified mean number per tow for the base survey (top left), pruned survey (top right) pruned to adja- cent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Blue points represents the annual number of female Lobster ≥ 140mm observed within the survey and area.

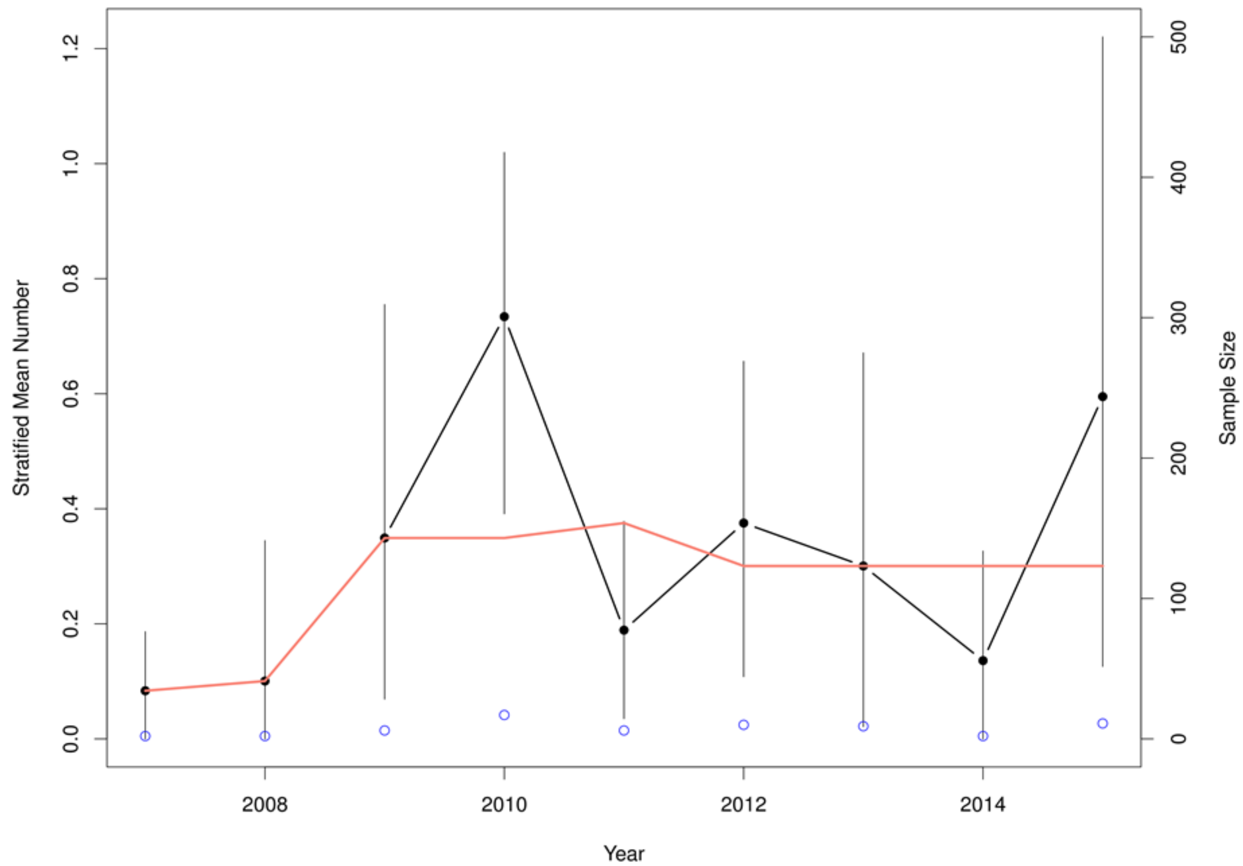


Figure A16. DFO RV Georges Bank survey large female (≥ 140mm) American Lobster stratified mean number per tow for the Canadian portion of the survey from 2007 to 2015. Red line represents a three year running median. Confidence bounds are presented for each point estimate. Blue points represents the annual number of female Lobster ≥ 140mm observed within the survey and area.

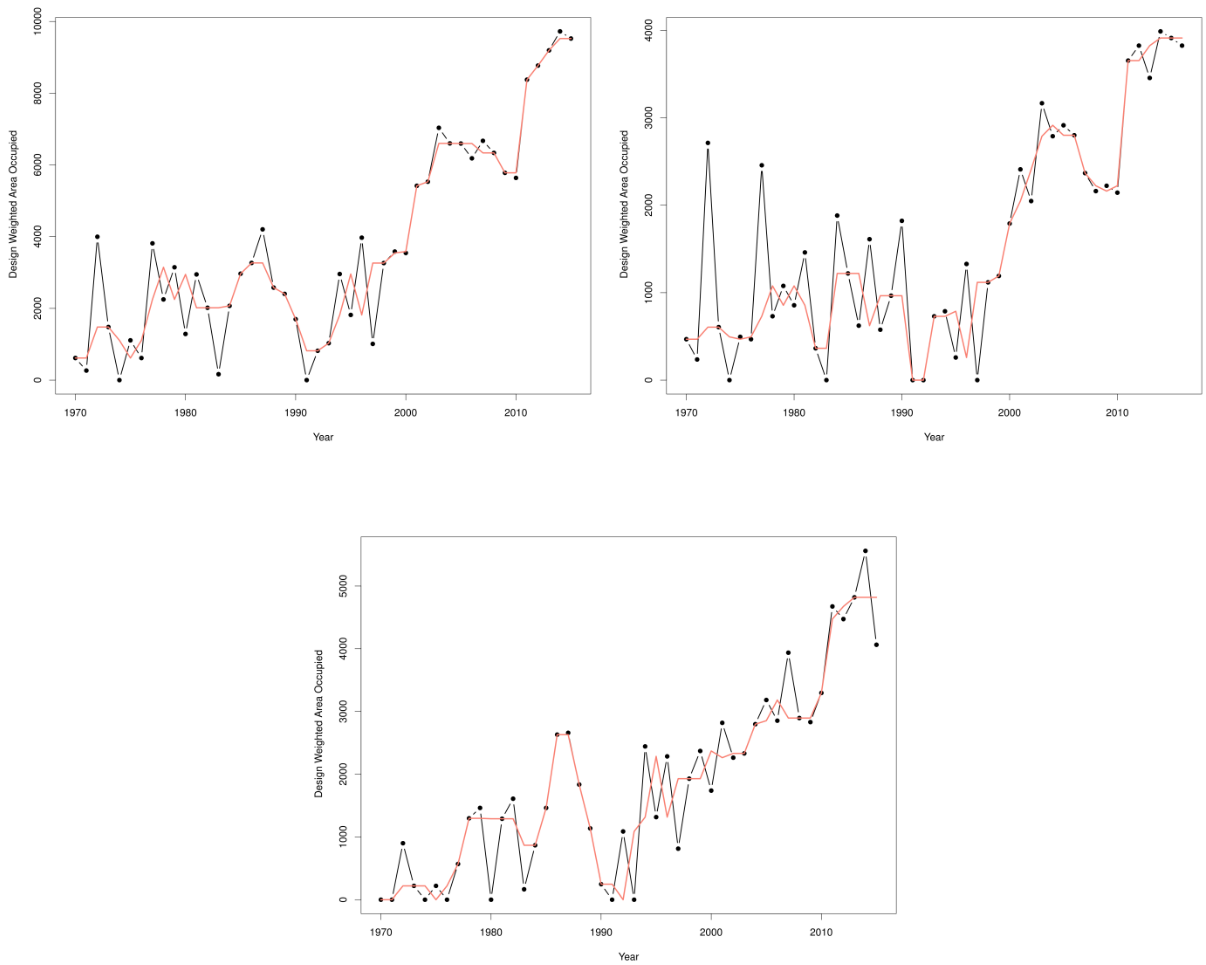


Figure A17. DFO Summer RV survey American Lobster design weighted area occupied (DWAO) for the base survey (top left), pruned survey (top right) pruned to adjacent ar eas (bottom) from 1970 to 2015. Red line represents a three year running median.

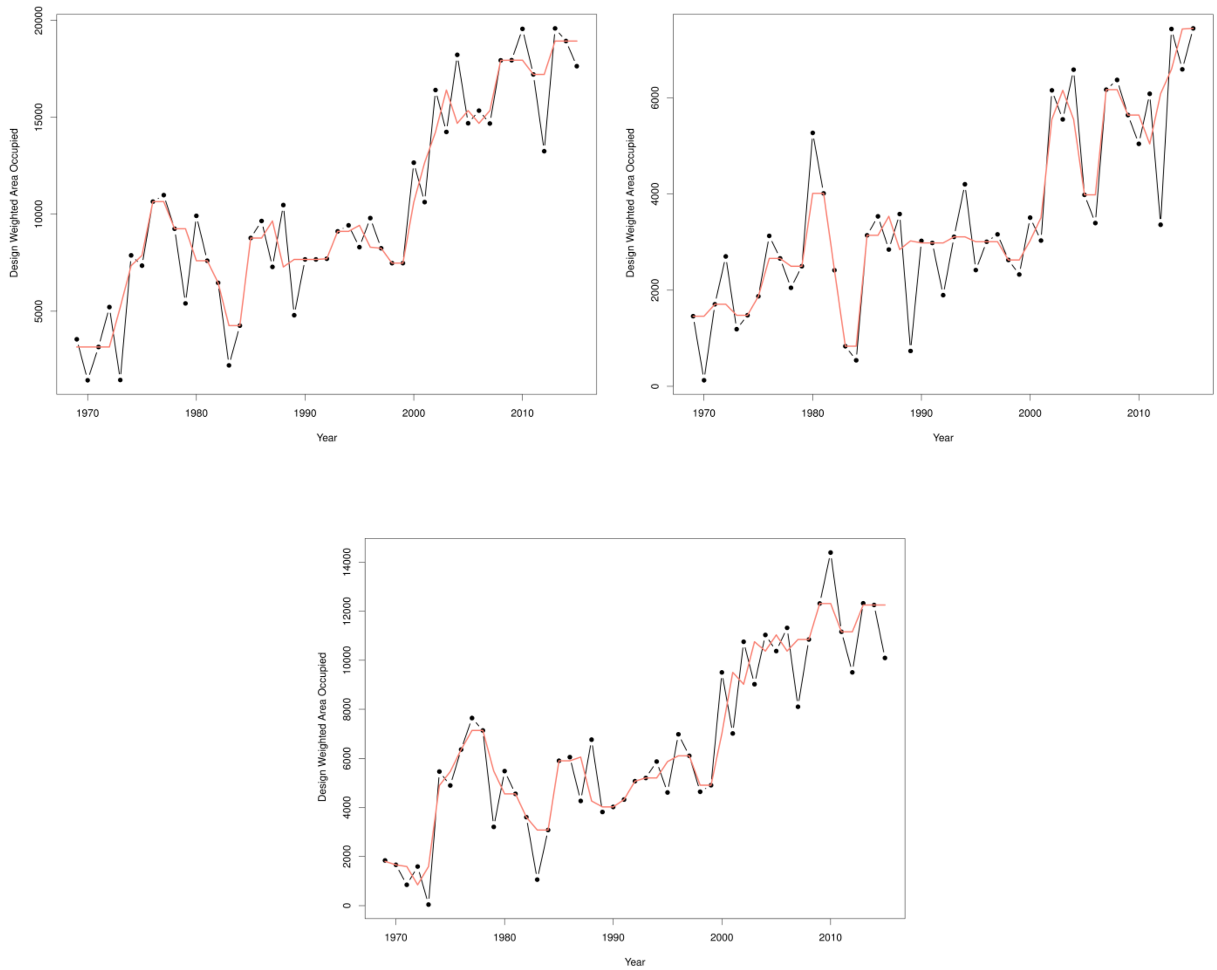


Figure A18. NEFSC spring survey American Lobster design weighted area occupied (DWAO) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median.

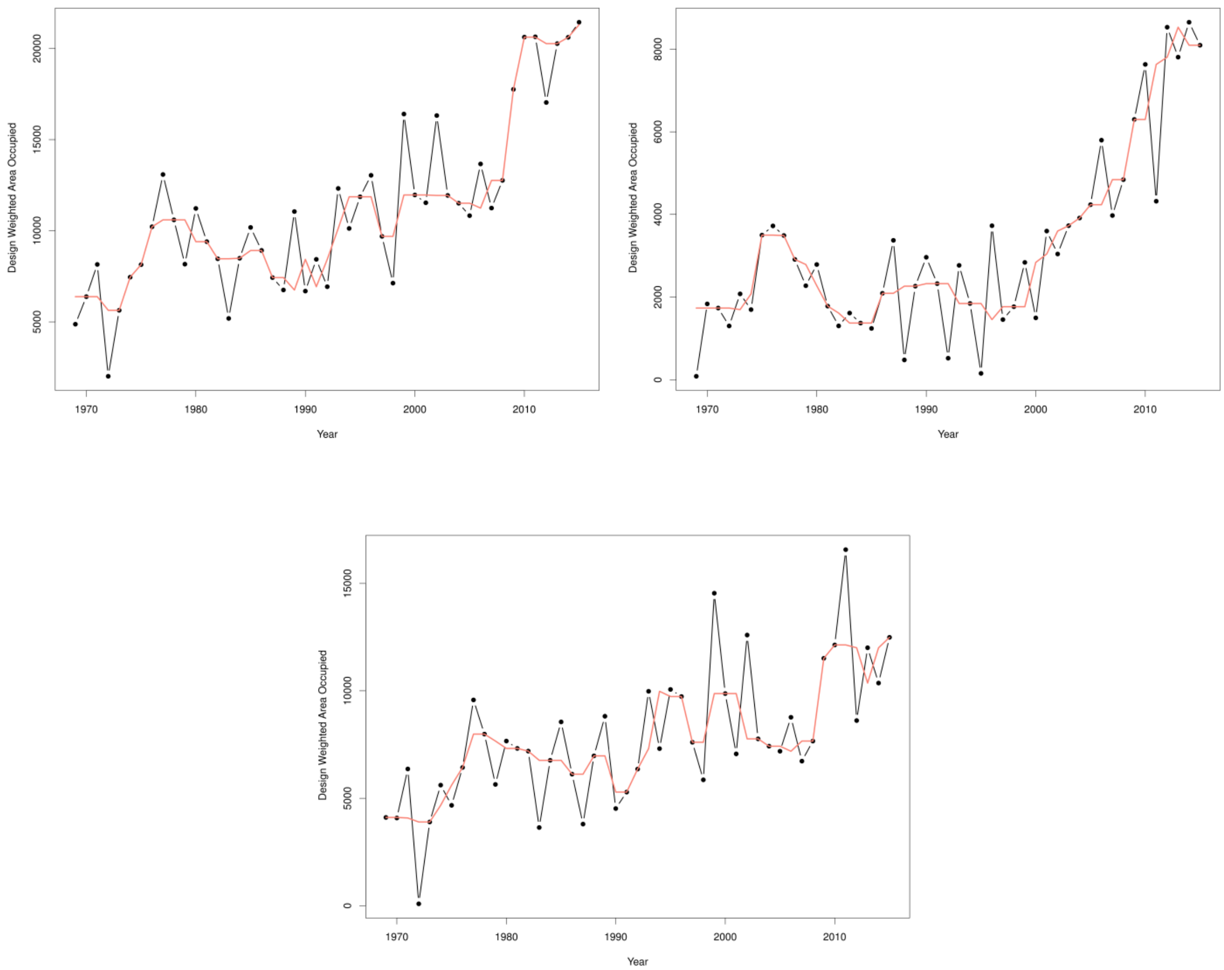


Figure A19. NEFSC Fall survey American Lobster design weighted area occupied (DWAO) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median.

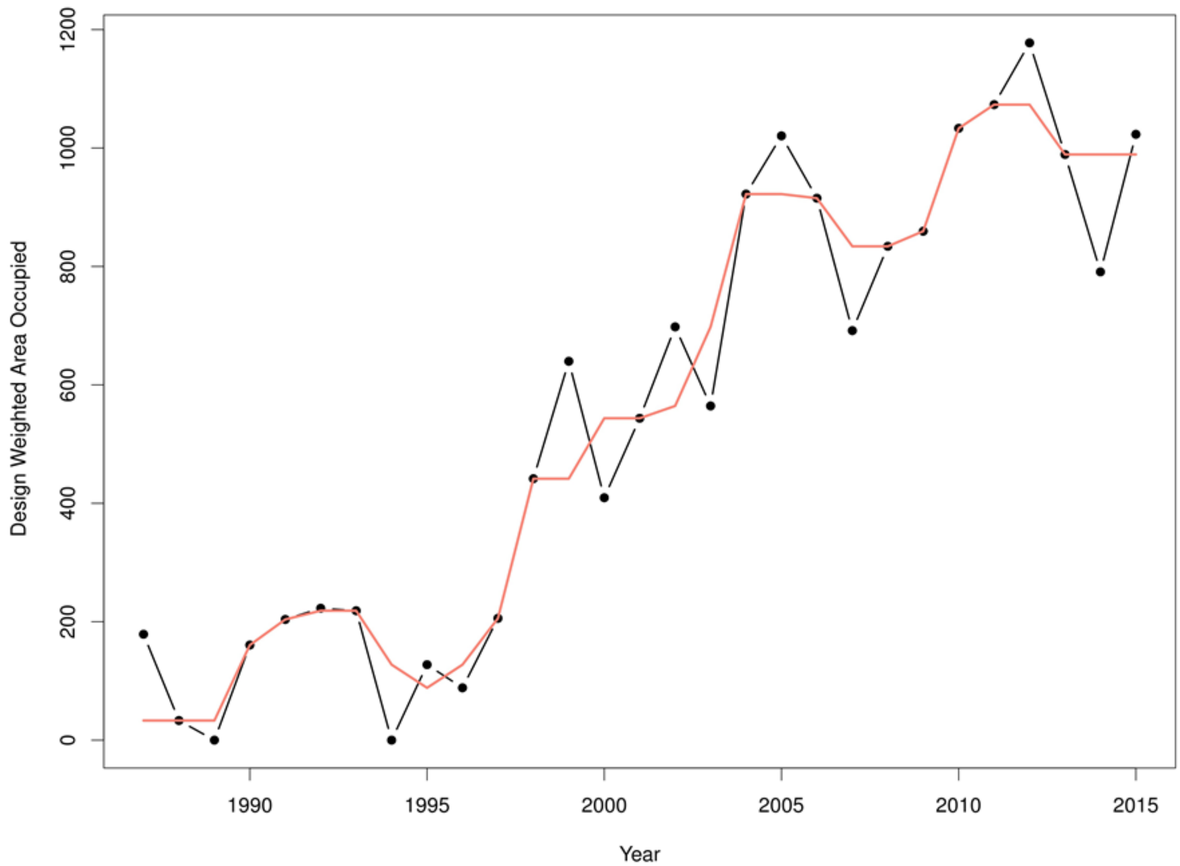


Figure A20. DFO RV Georges Bank survey American Lobster design weighted area occupied for the Canadian portion of the survey from 1987 to 2015. Red line represents a three year running median.

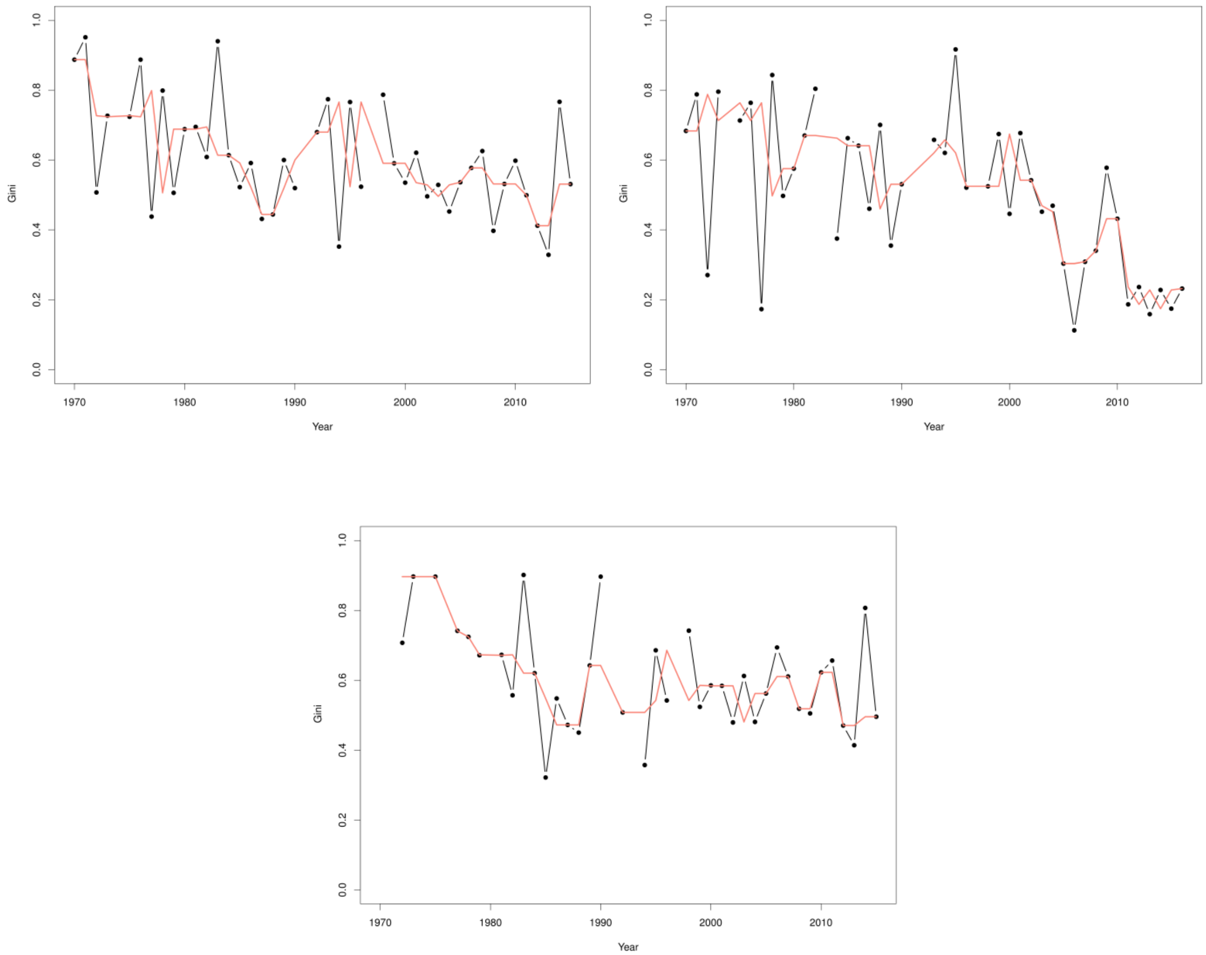


Figure A21. DFO Summer RV survey American Lobster Gini index of spatial evenness for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1970 to 2015. Red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster were captured in the survey strata.

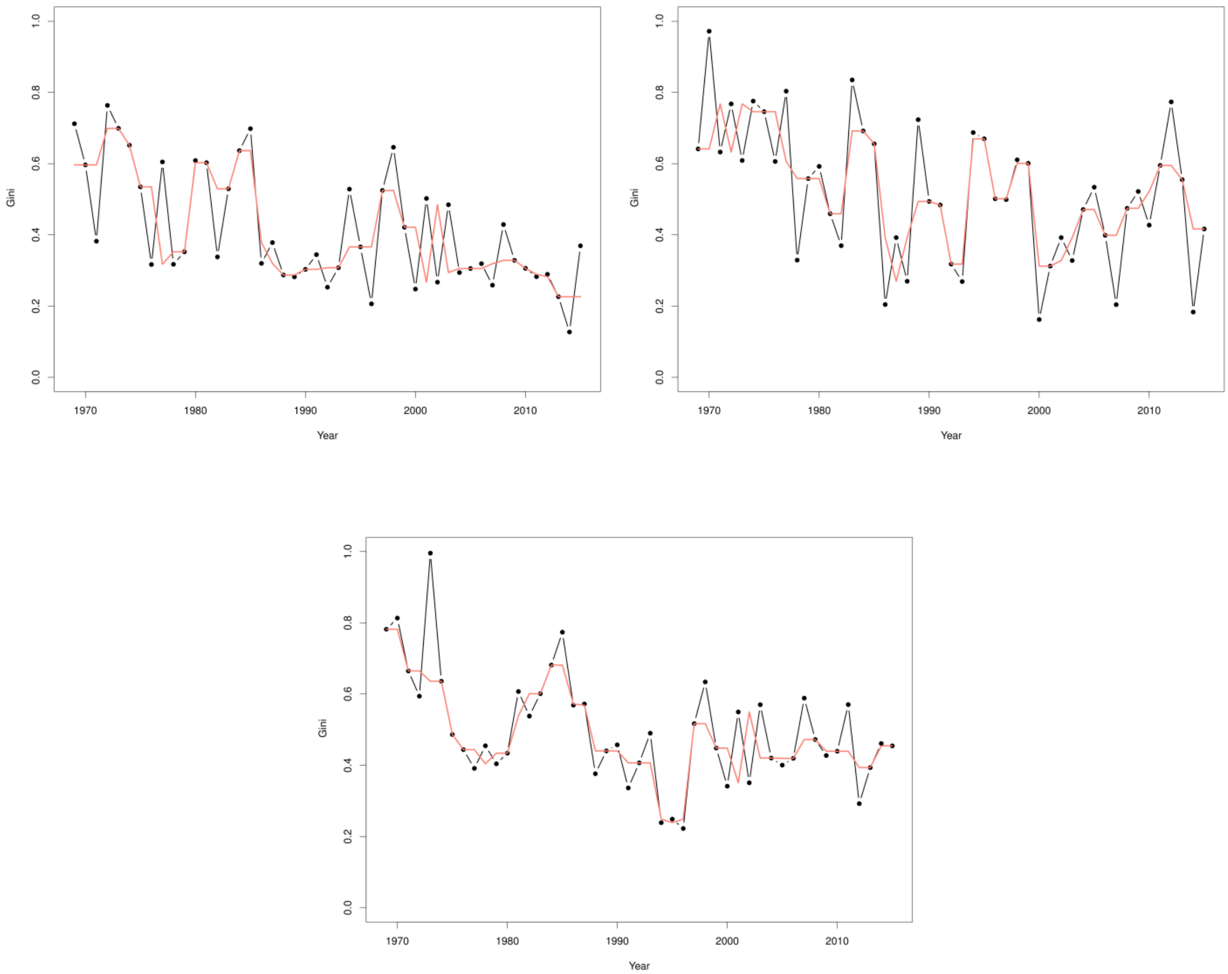


Figure A22. NEFSC spring survey American Lobster Gini coefficient of spatial evenness for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median.

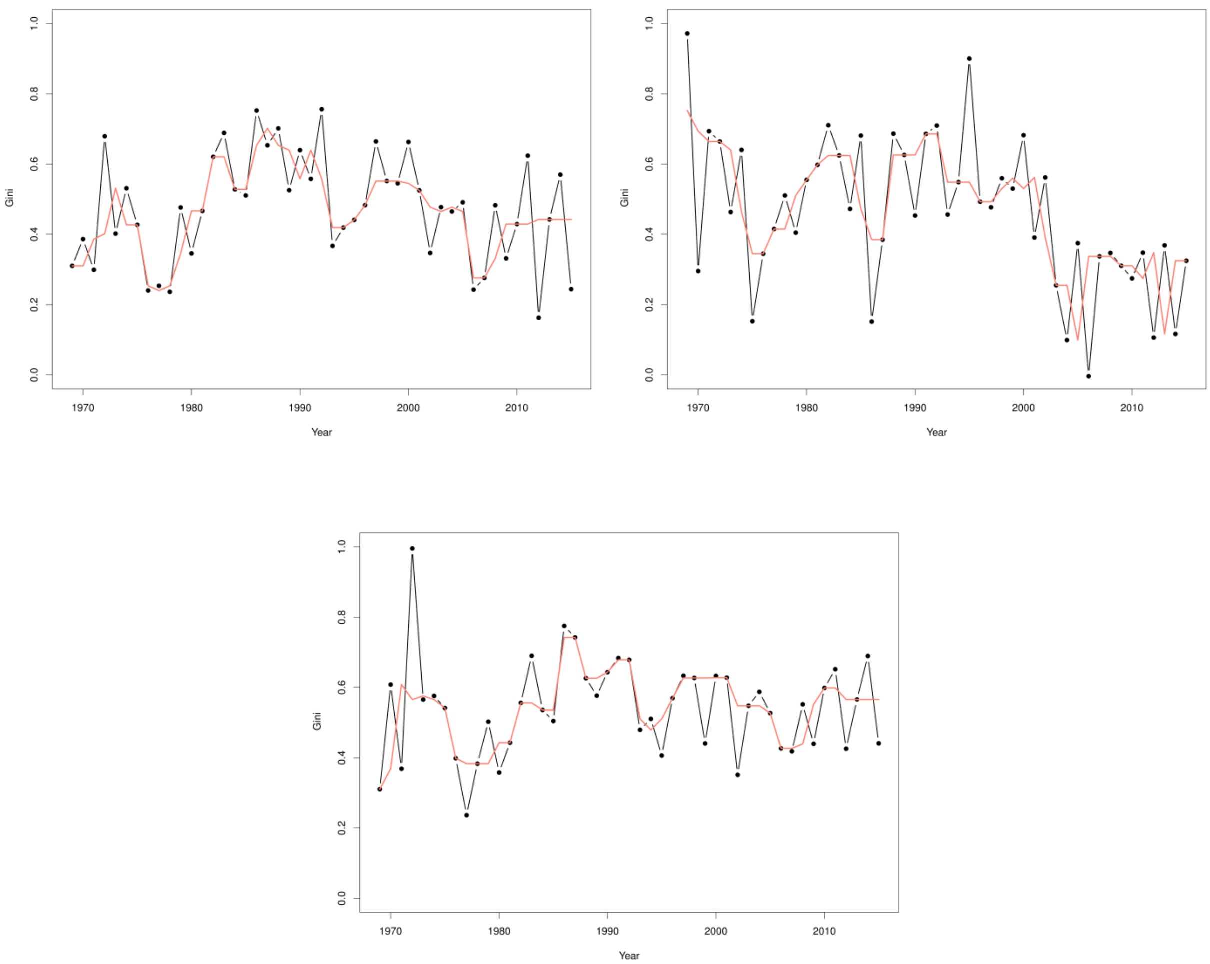


Figure A23. NEFSC Fall survey American Lobster Gini coefficient of spatial evenness for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median.

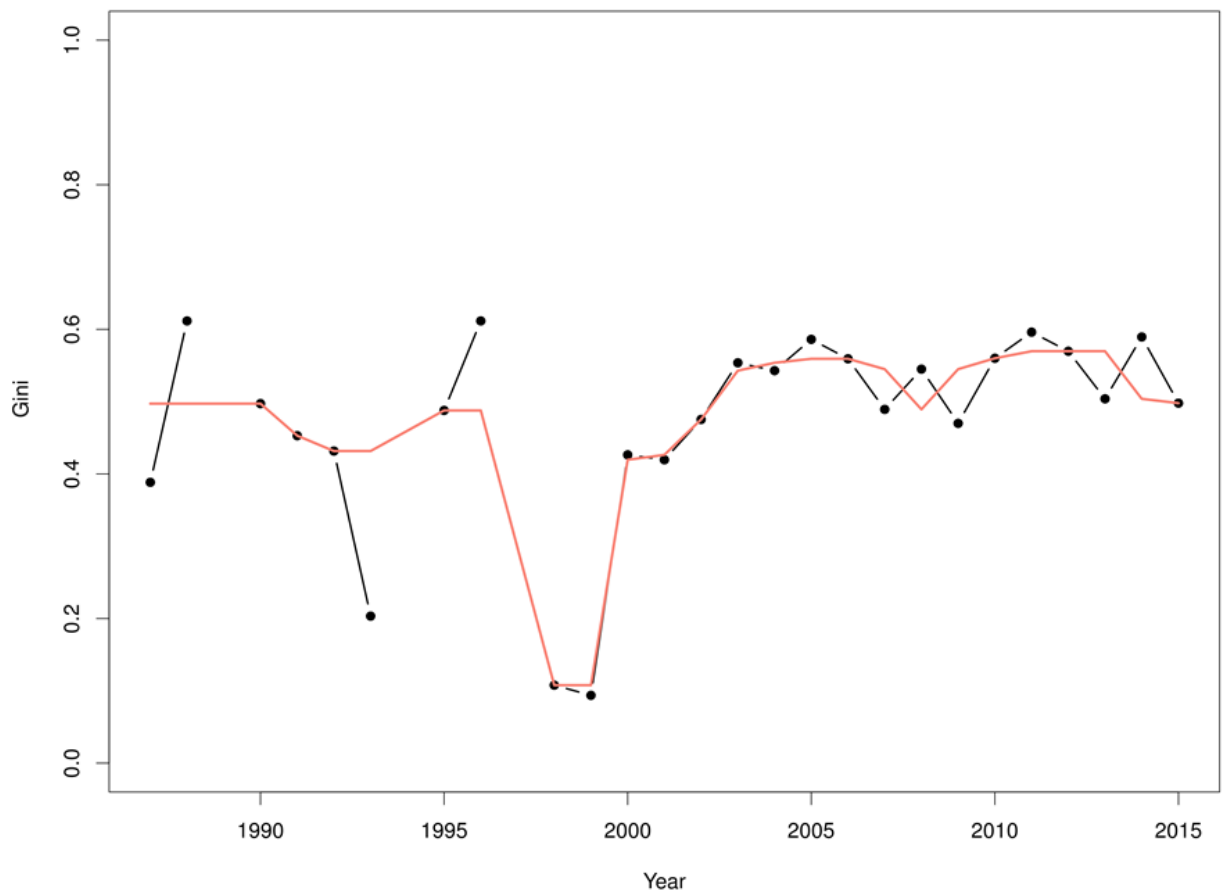


Figure A24. DFO RV Georges Bank survey American Lobster Gini coefficient of spatial evenness for the Canadian portion of the survey from 1987 to 2015. Red line represents a three year running median.

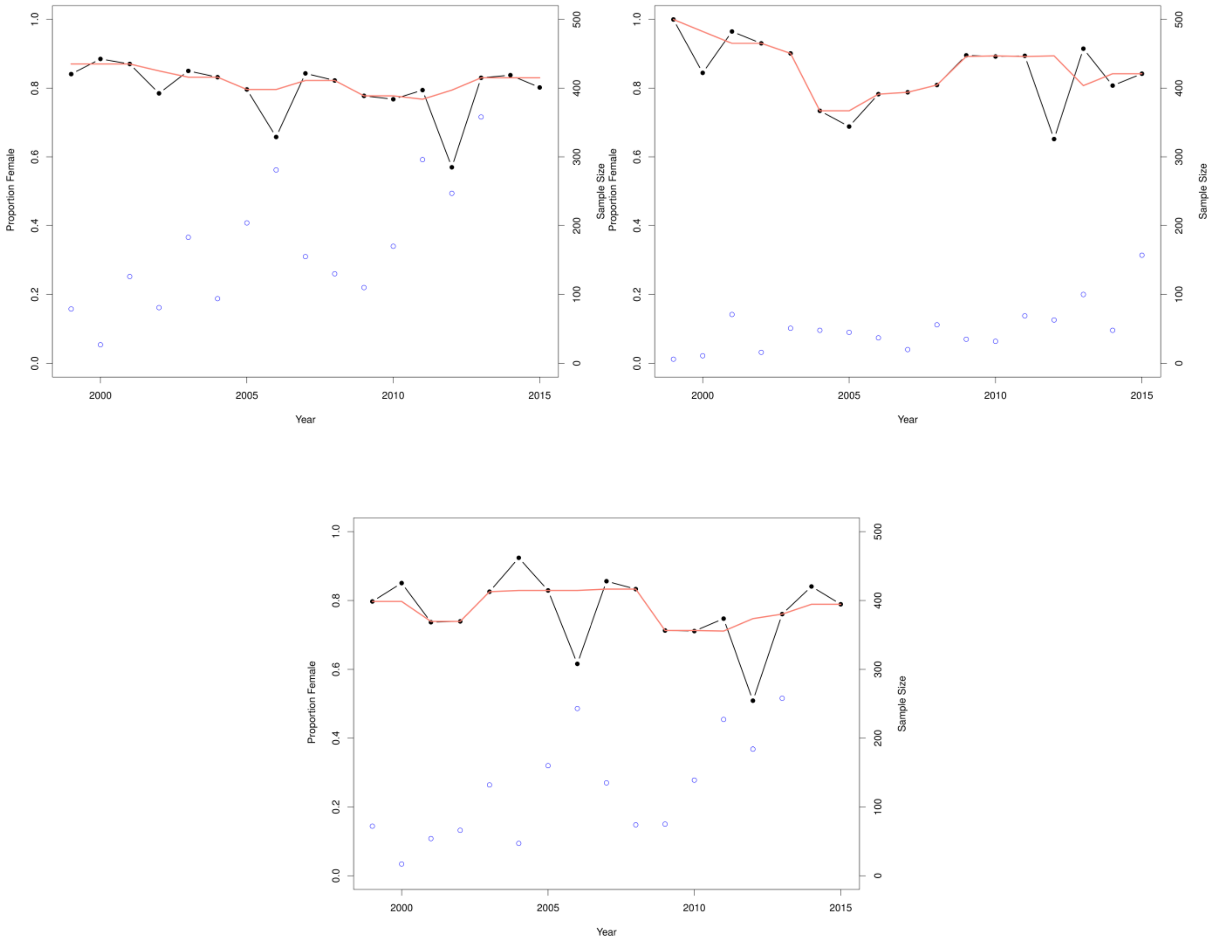


Figure A25. DFO Summer RV survey American Lobster proportion females from mature component (≥ 95 mm) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1970 to 2015. Red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster were captured in the survey strata. Within each plot the blue points represent the sample size of observed Lobster within that year and area.

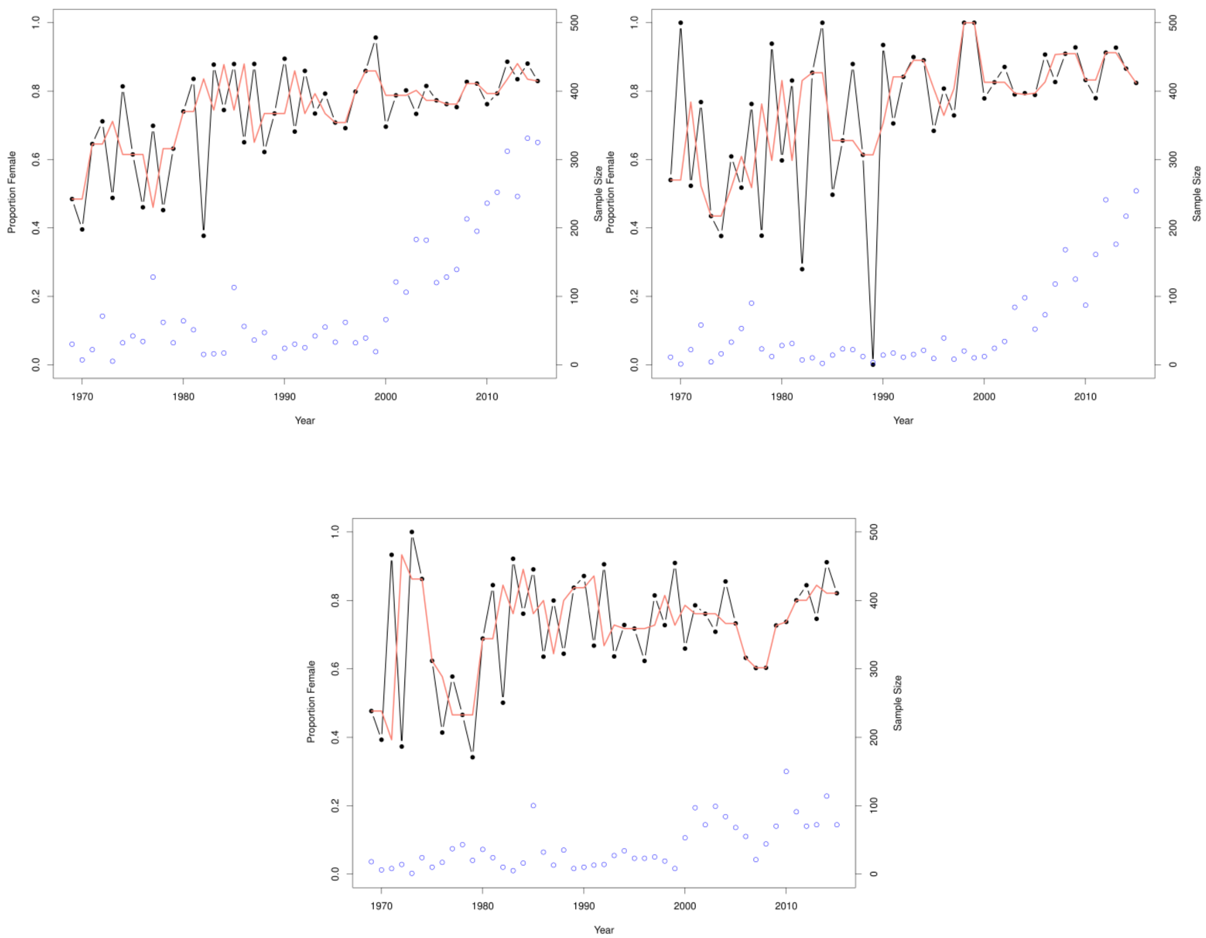
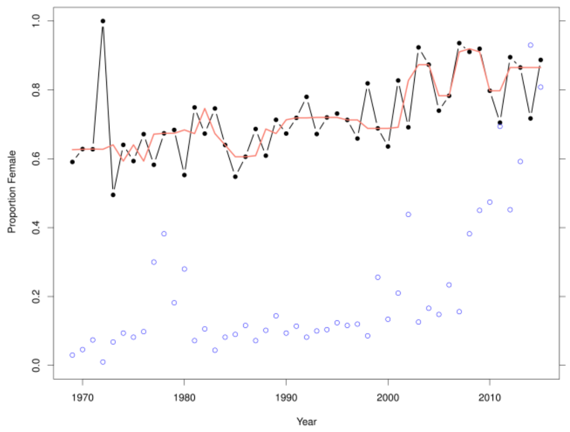
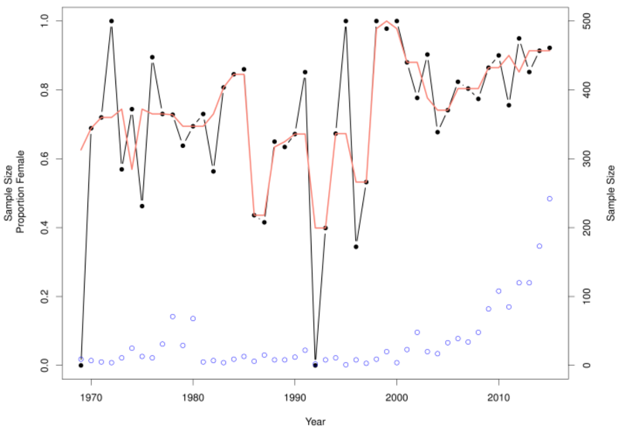


Figure A26. NEFSC spring survey American Lobster proportion females from mature component (≥ 95 mm) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Within each plot the blue points represent the sample size of observed Lobster within that year and area.





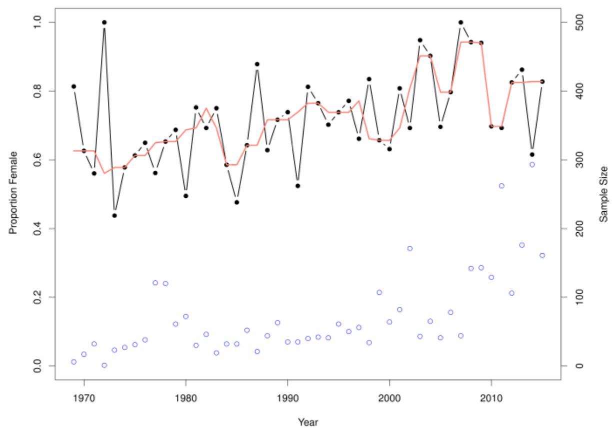


Figure A27. NEFSC Fall survey American Lobster proportion females from mature component (≥ 95 mm) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Within each plot the blue points represent the sample size of observed Lobster within that year and area.

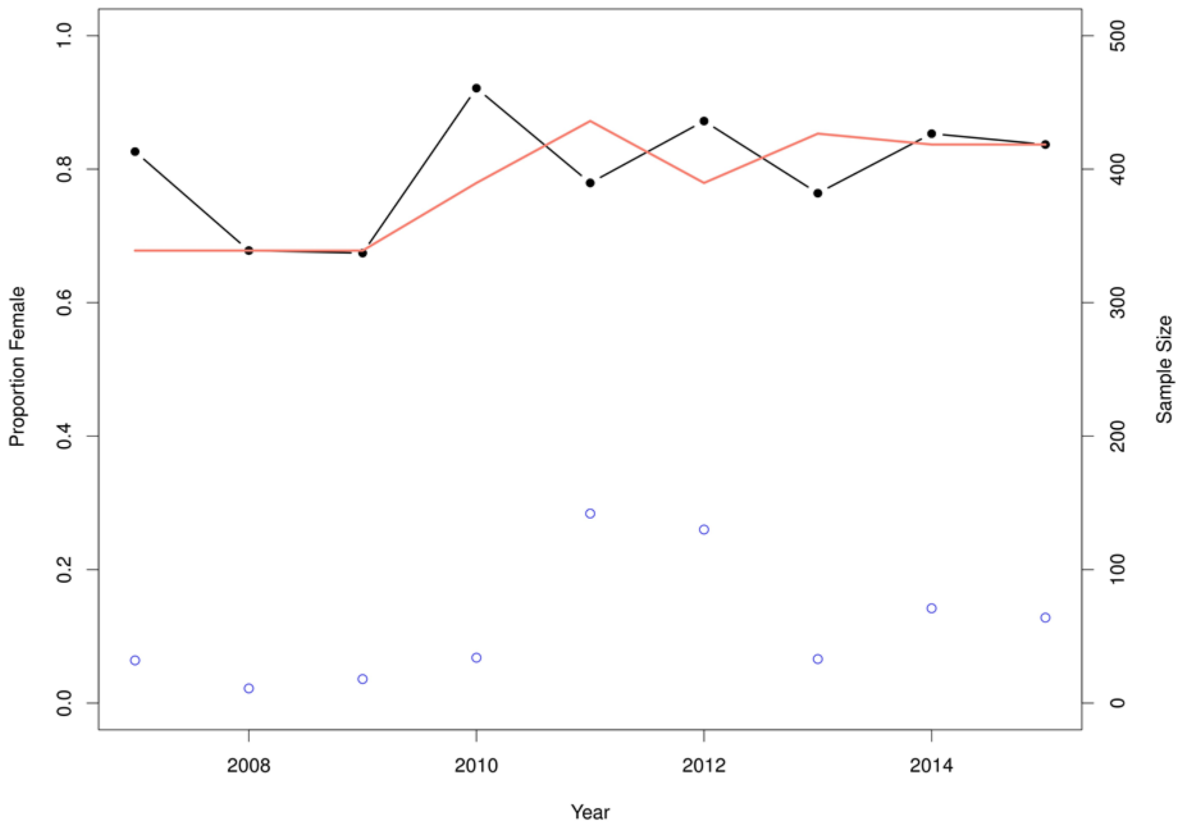


Figure A28. DFO RV Georges Bank survey American Lobster proportion females from mature component (≥ 95 mm) for the Canadian portion of the survey from 2007 to 2015. Red line represents a three year running median. Blue points represent the sample size of observed Lobster within that year and area.

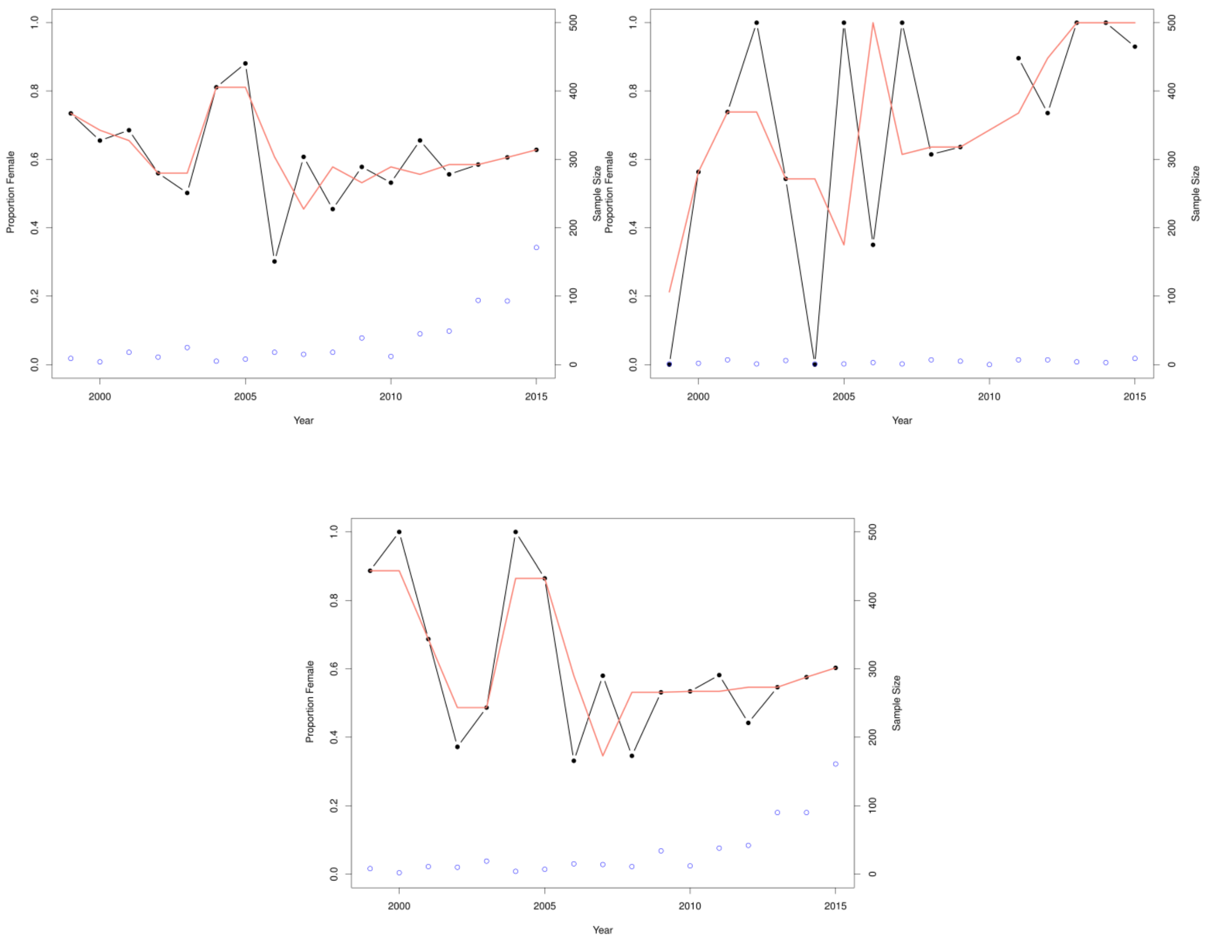


Figure A29. DFO Summer RV survey American Lobster proportion females from immature component (< 95 mm) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1970 to 2015. Red line represents a three year running median. Breaks in the three year running median are for years where no American Lobster were captured in the survey strata. Within each plot the blue points represent the sample size of observed Lobster within that year and area.

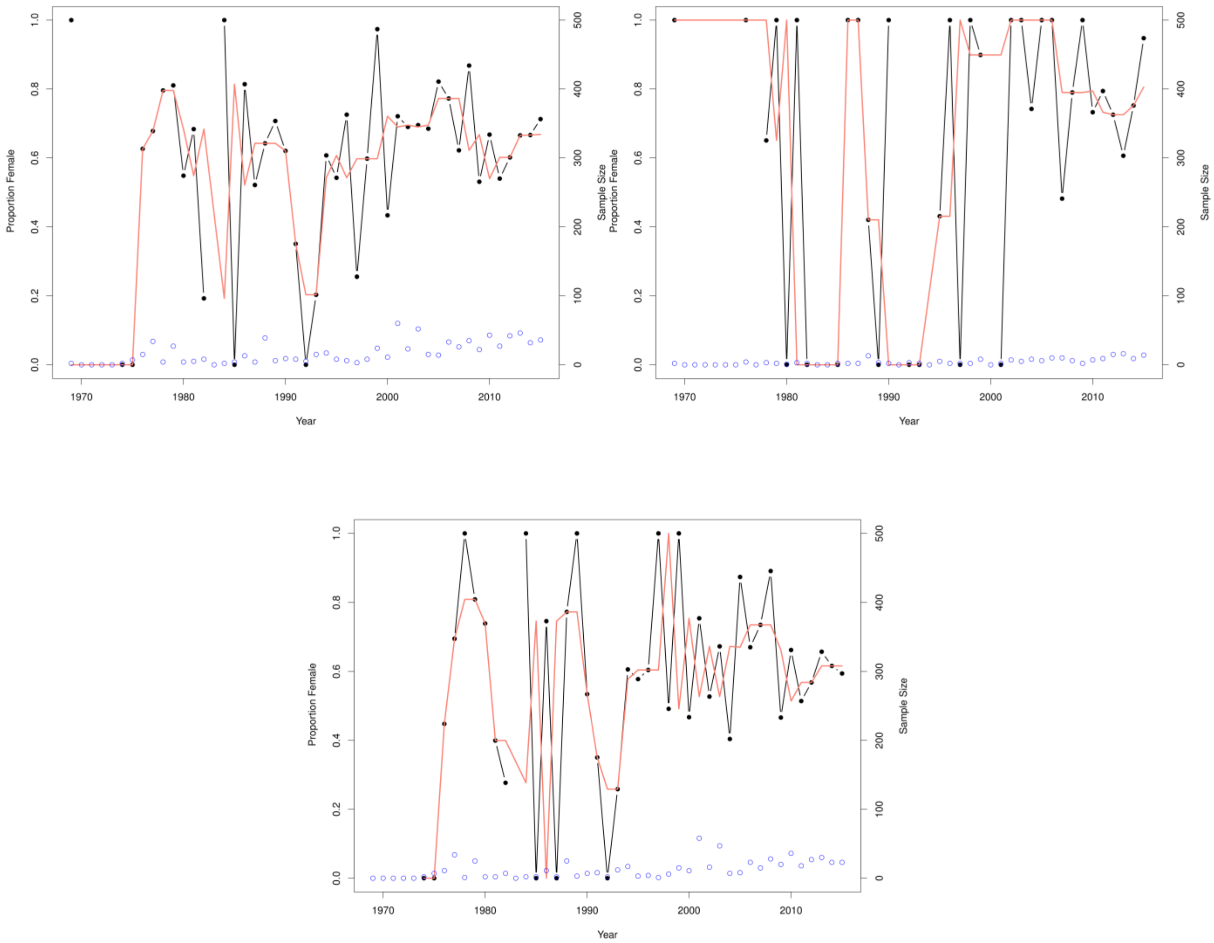


Figure A30. NEFSC spring survey American Lobster proportion females from immature component (< 95 mm) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Within each plot the blue points represent the sample size of observed Lobster within that year and area.

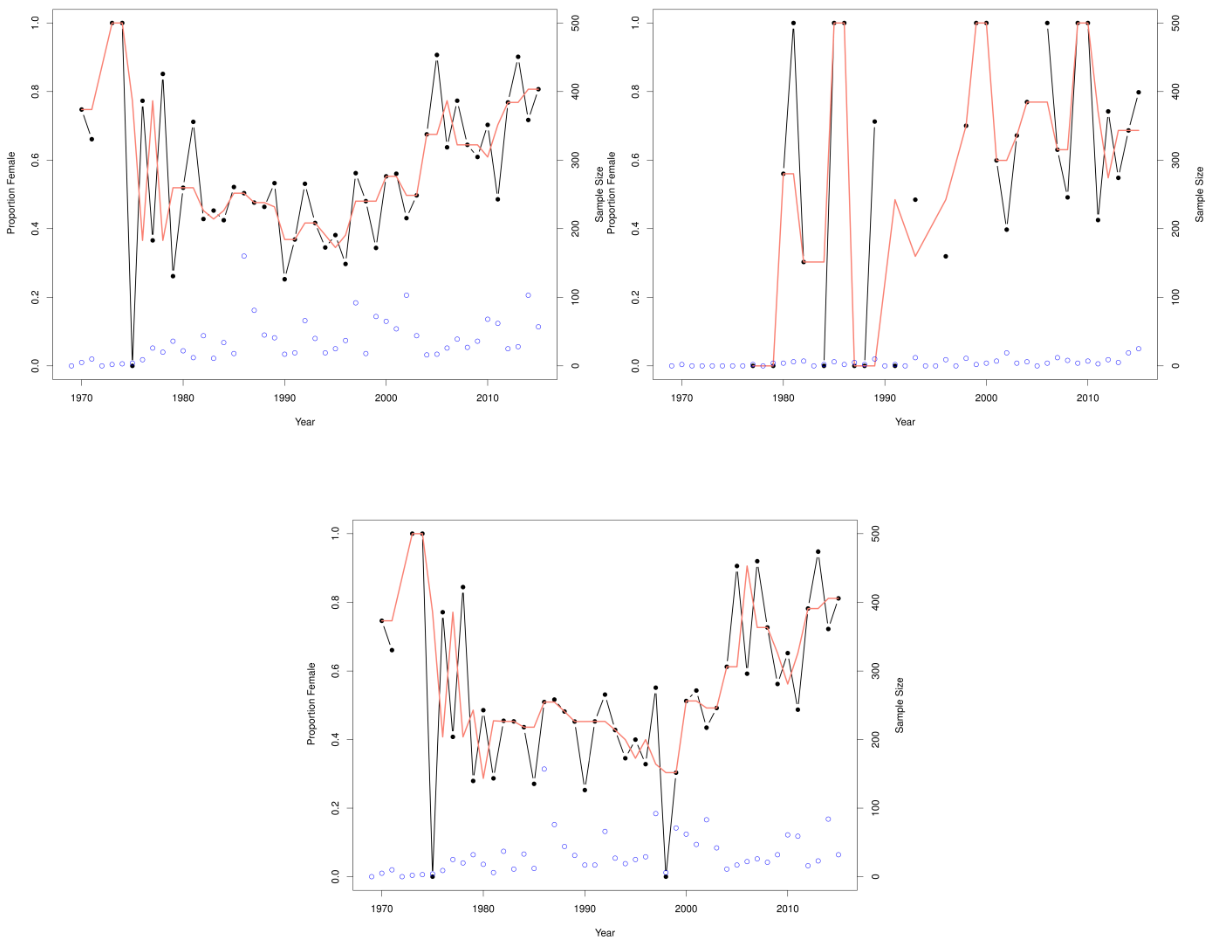


Figure A31. NEFSC Fall survey American Lobster proportion females from immature component (< 95 mm) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Within each plot the blue points represent the sample size of observed Lobster within that year and area.

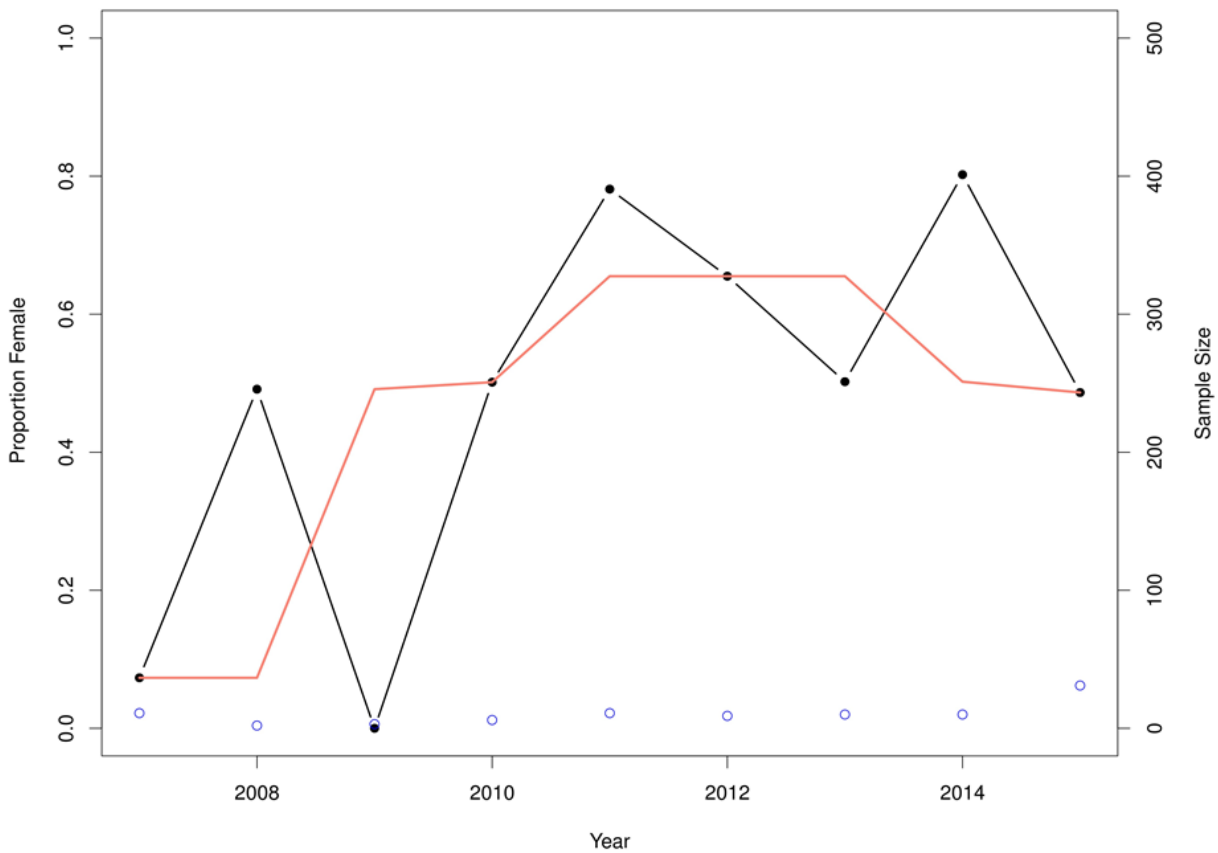


Figure A32. DFO RV Georges Bank survey American Lobster proportion females from immature component (< 95 mm) for the Canadian portion of the survey from 2007 to 2015. Red line represents a three year running median. Blue points represent the sample size of observed Lobster within that year and area.

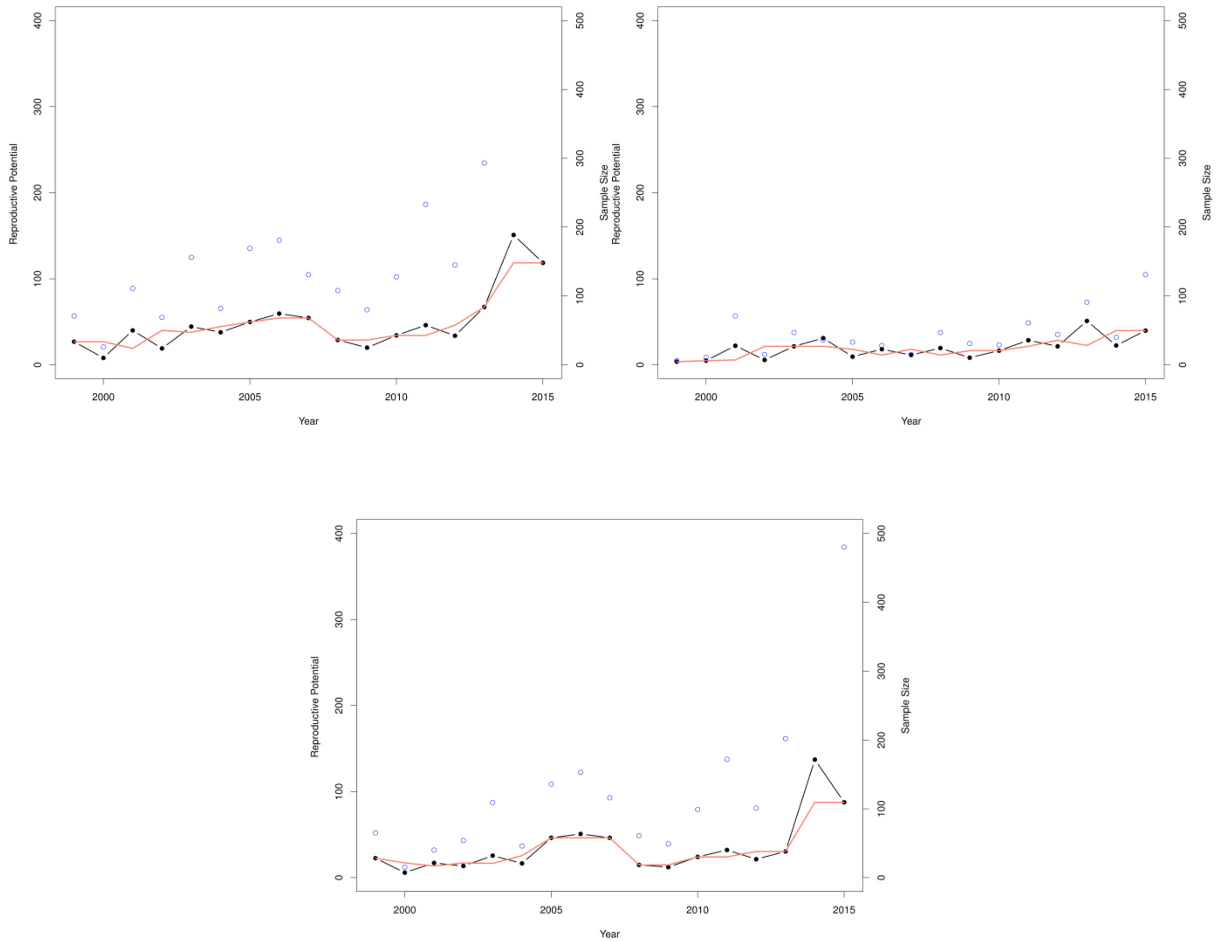


Figure A33. DFO Summer RV survey American Lobster reproductive potential for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1999 to 2015. Red line represents a three year running median. Annual sample sizes are shown as blue points.

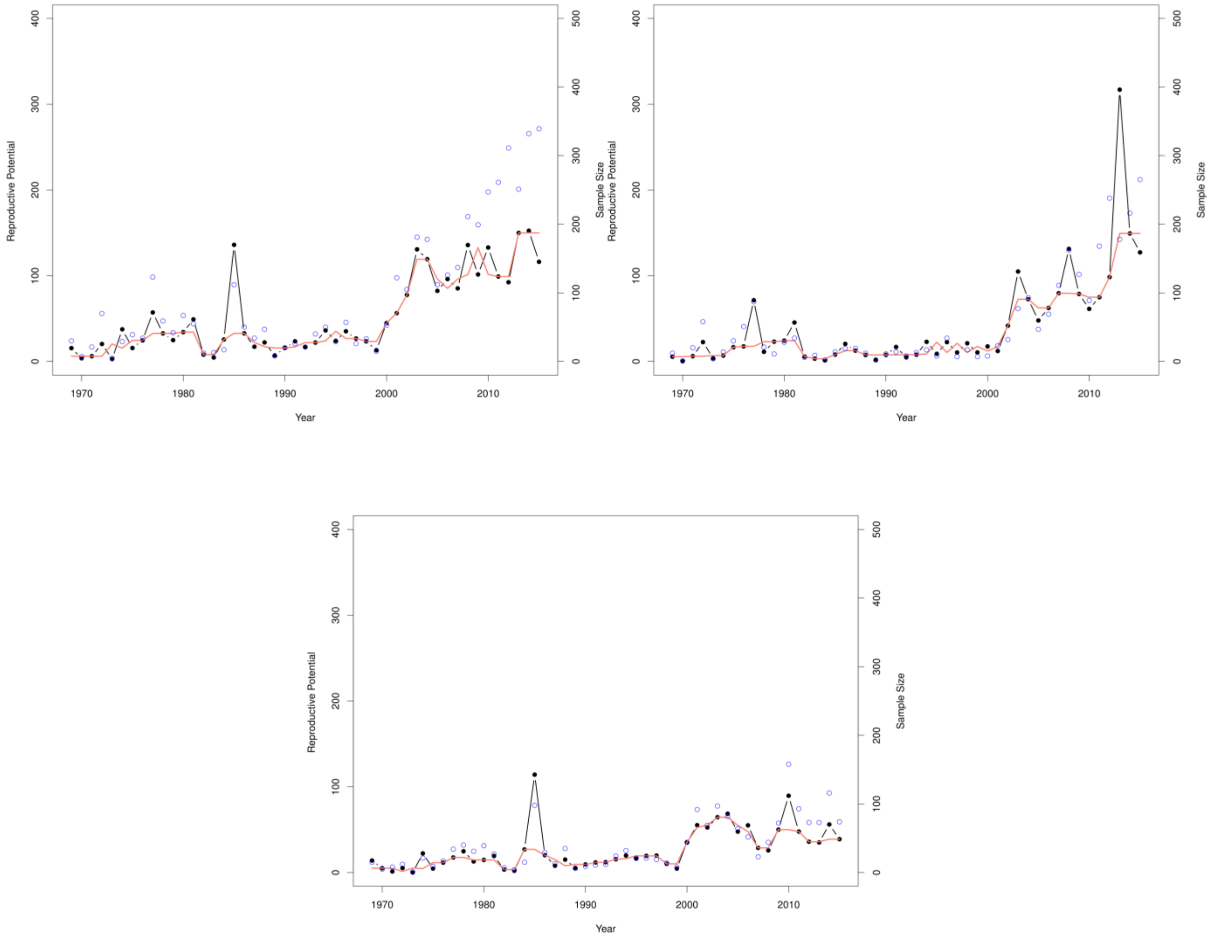


Figure A34. NEFSC spring survey American Lobster reproductive potential for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Annual sample sizes are shown as blue points.

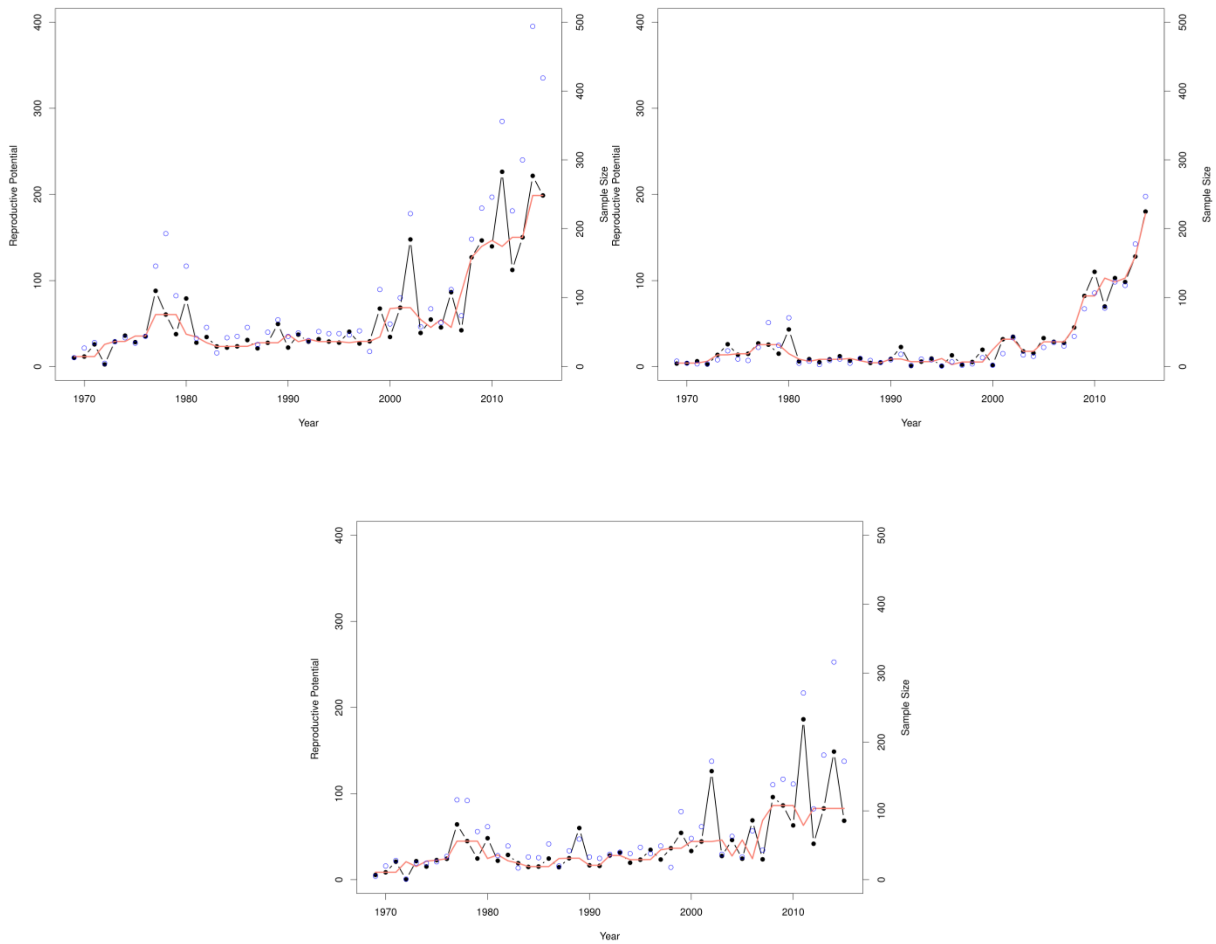


Figure A35. NEFSC Fall survey American Lobster reproductive potential for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Annual sample sizes are shown as blue points.

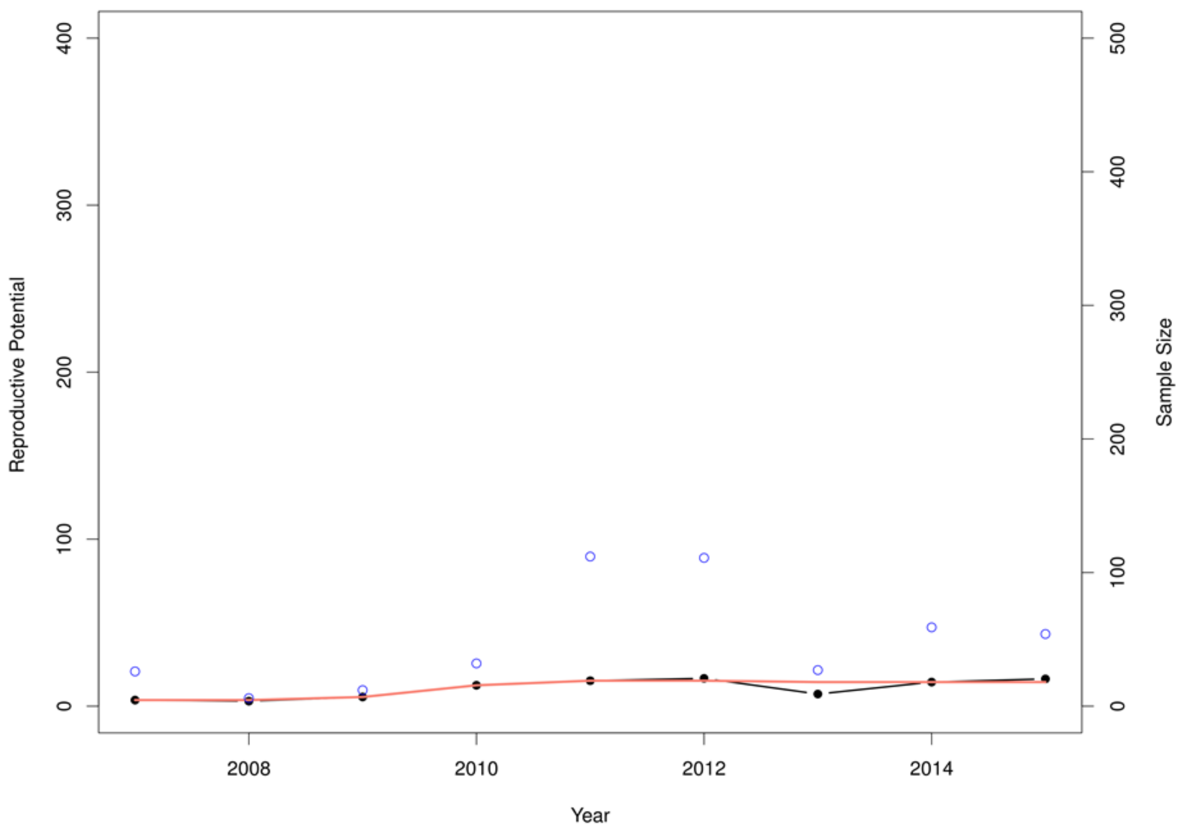


Figure A36. DFO RV Georges Bank survey American Lobster reproductive potential for the Canadian portion of the survey from 2007 to 2015. Red line represents a three year running median. Annual sample sizes are shown as blue points.

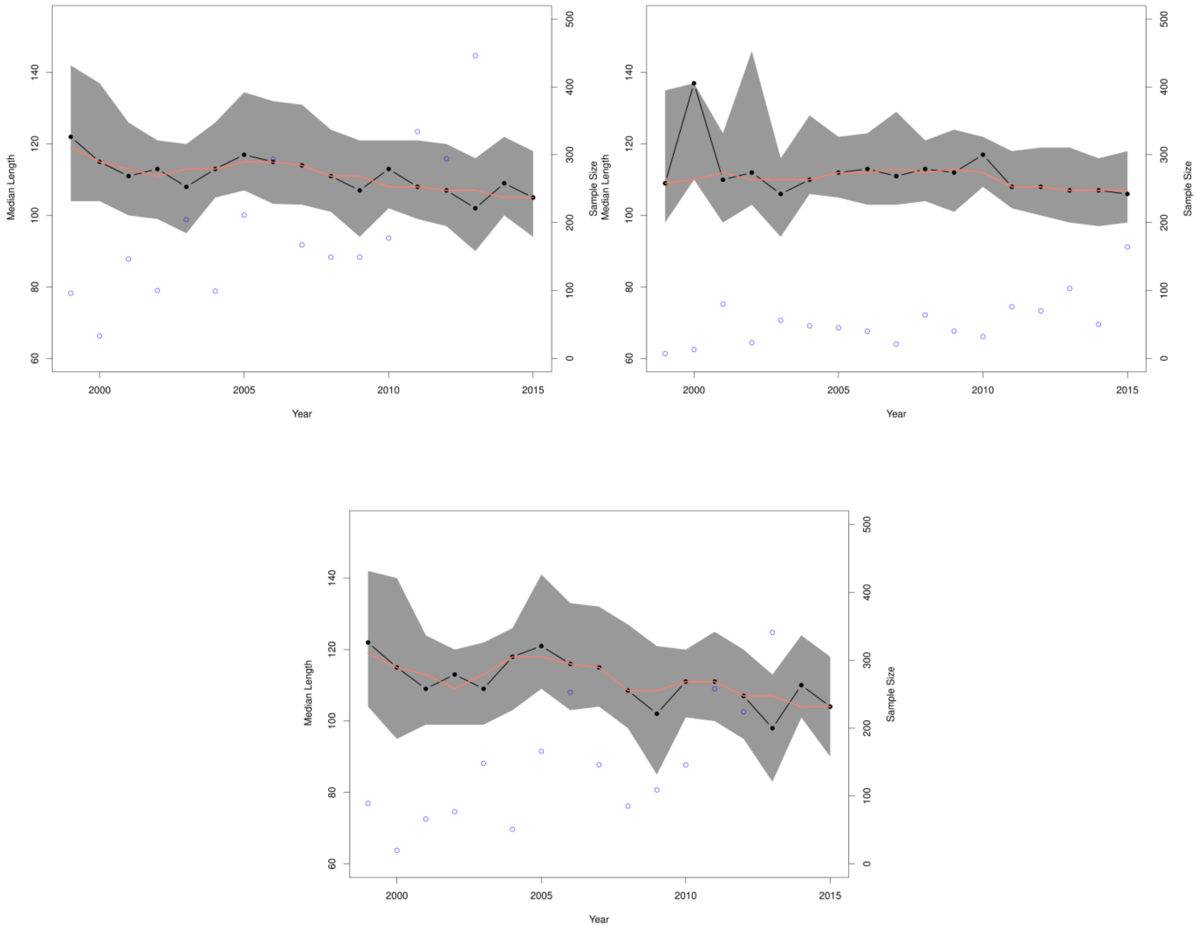


Figure A37. DFO Summer RV survey American Lobster population weighted median length (solid line and points) with accompanying first and third quartiles (shaded polygon) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1999 to 2015. Red line represents a three year running median. Within each plot the blue points represent the sample size of observed Lobster within that year and area.

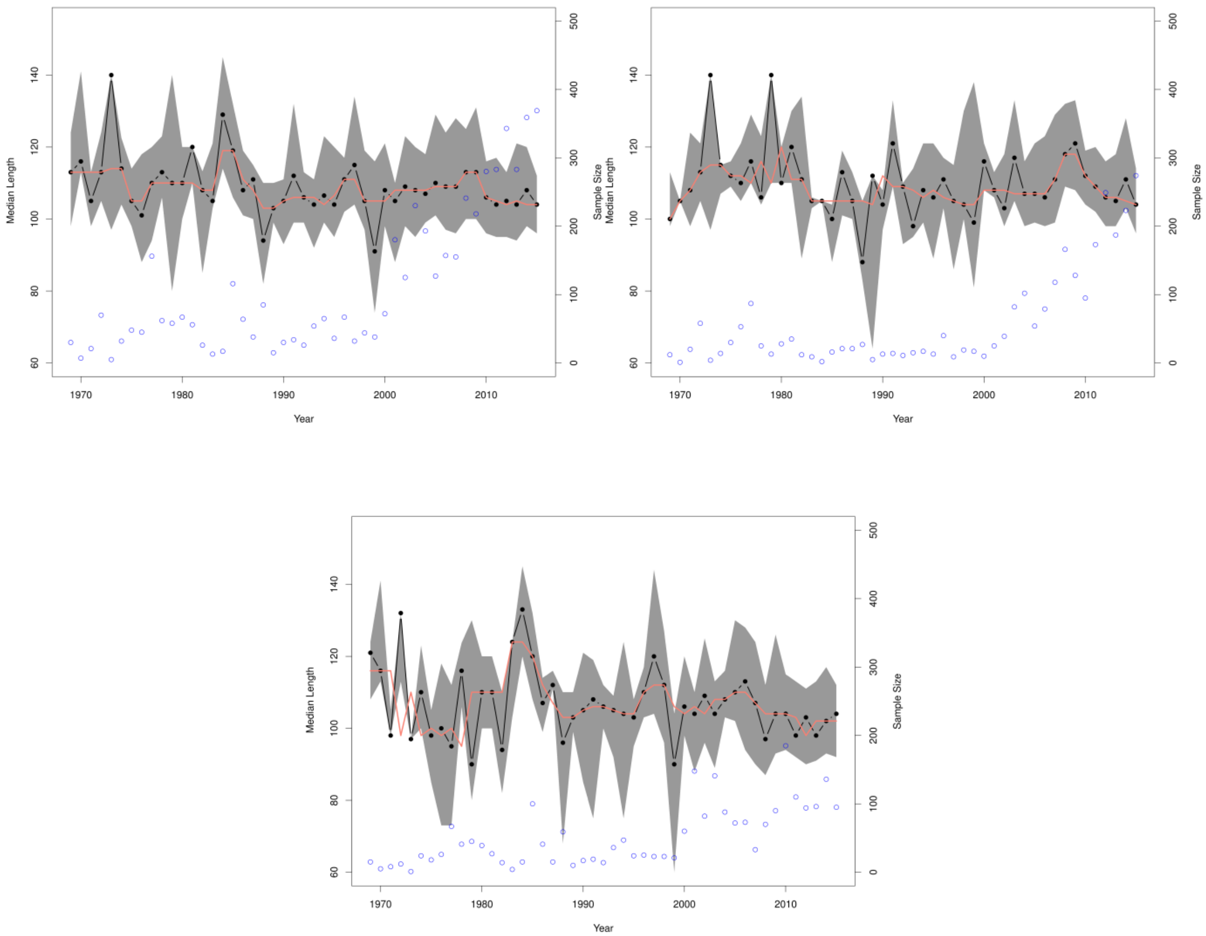


Figure A38. NEFSC spring survey American Lobster population weighted median length (solid line and points) with accompanying first and third quartiles (shaded polygon) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Within each plot the blue points represent the sample size of observed Lobster within that year and area.

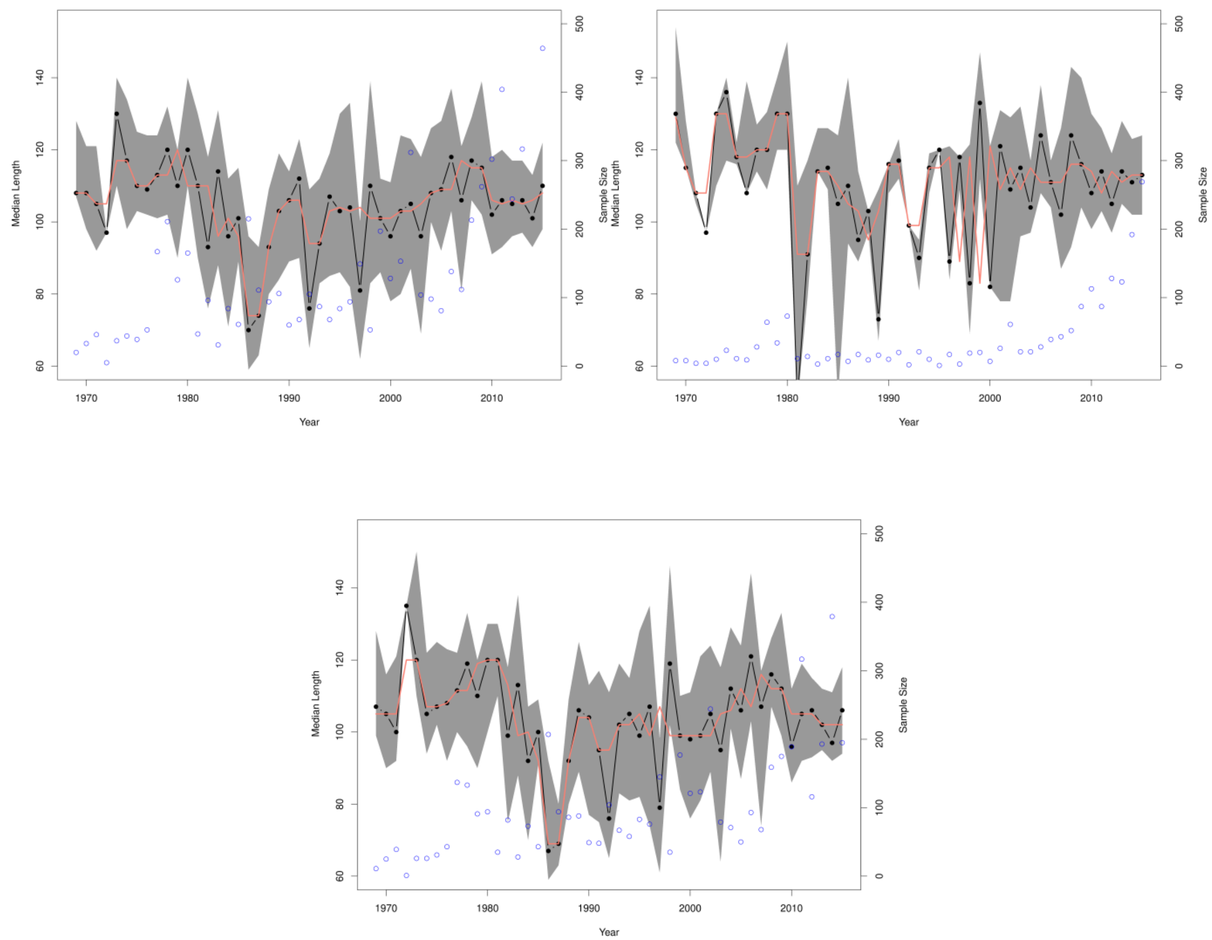


Figure A39. NEFSC Fall survey American Lobster population weighted median length (solid line and points) with accompanying first and third quartiles (shaded polygon) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median. Within each plot the blue points represent the sample size of observed Lobster within that year and area.

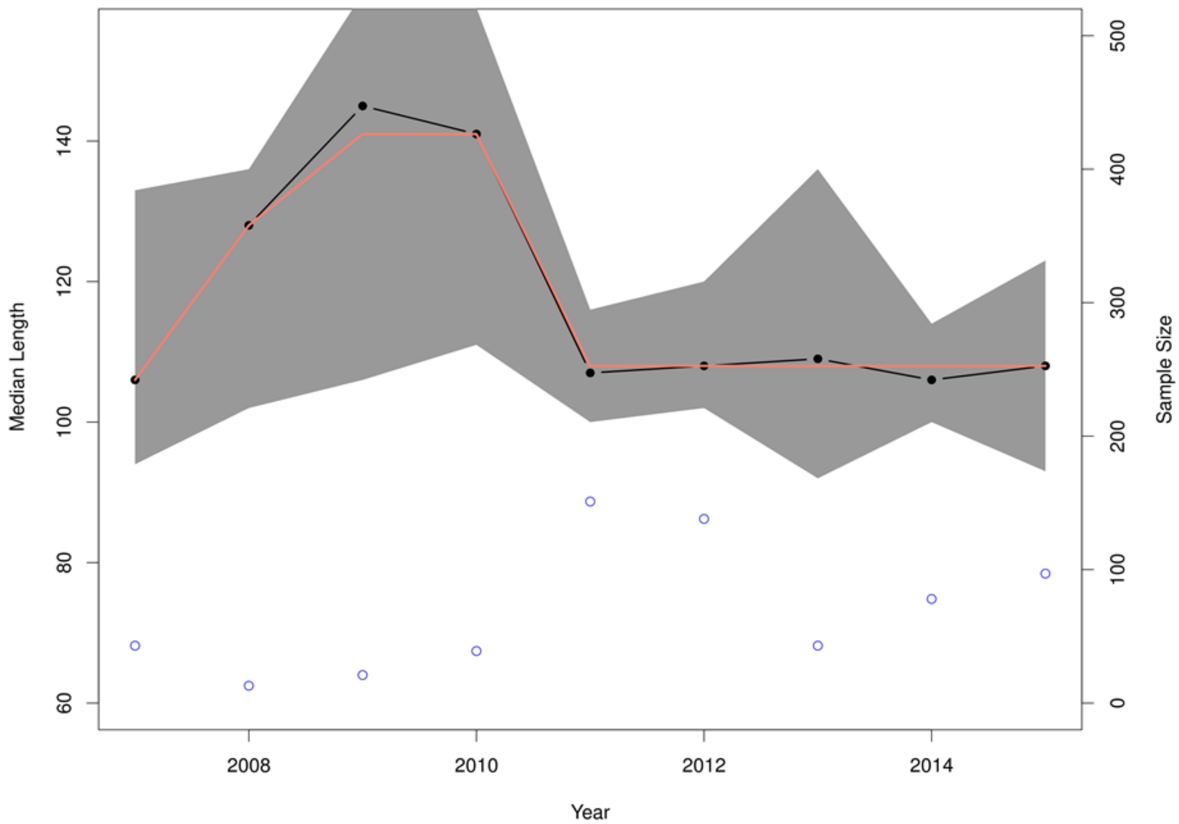


Figure A40. DFO RV Georges Bank survey American Lobster population weighted median length (solid line and points) with accompanying first and third quartiles (shaded polygon) for the Canadian portion of the survey from 2007 to 2015. Red line represents a three year running median. Blue points represent the sample size of observed Lobster within that year and area.

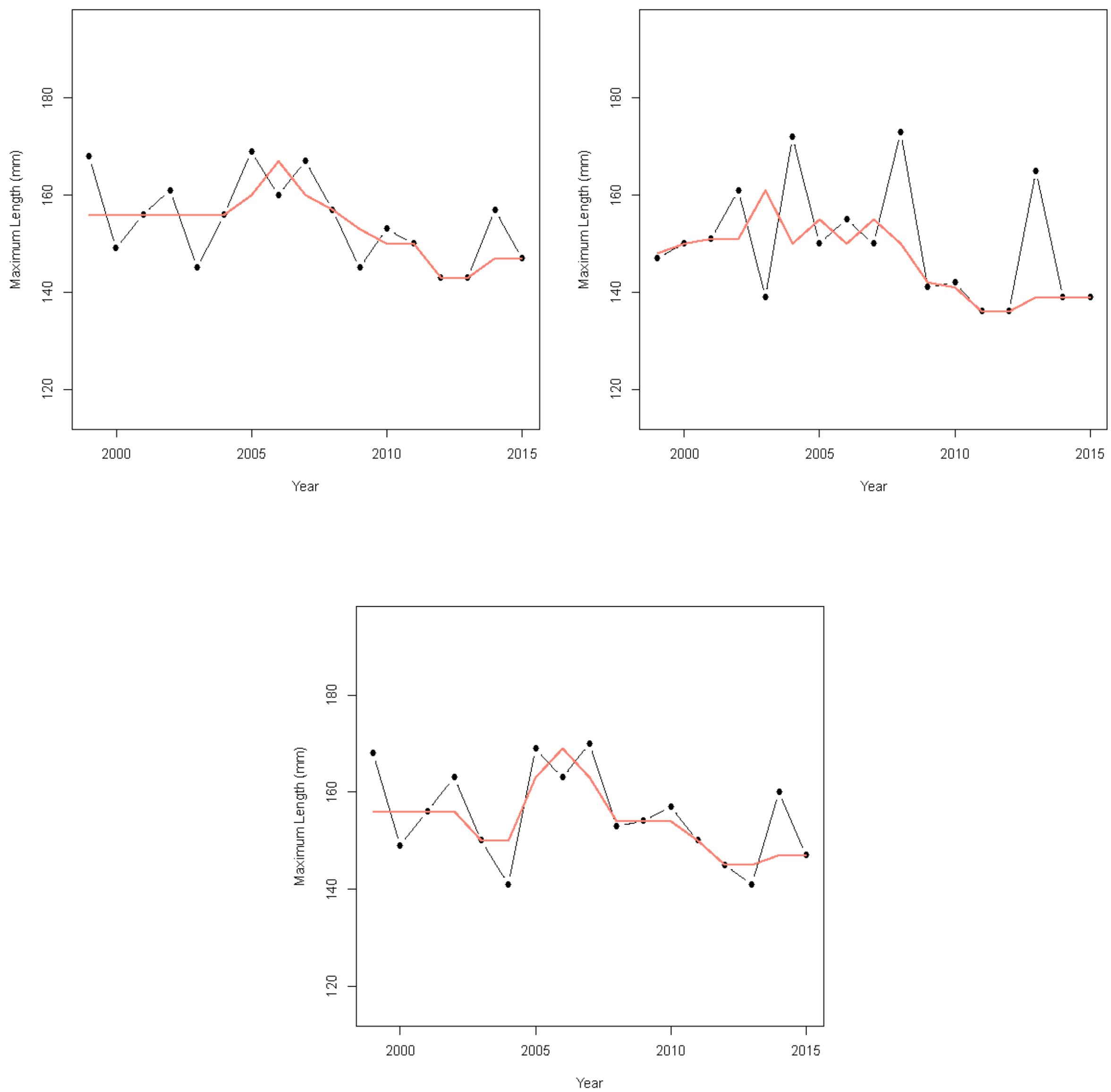


Figure A41. DFO Summer RV survey American Lobster population weighted upper 95% length (solid line and points) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1999 to 2015. Red line represents a three year running median.

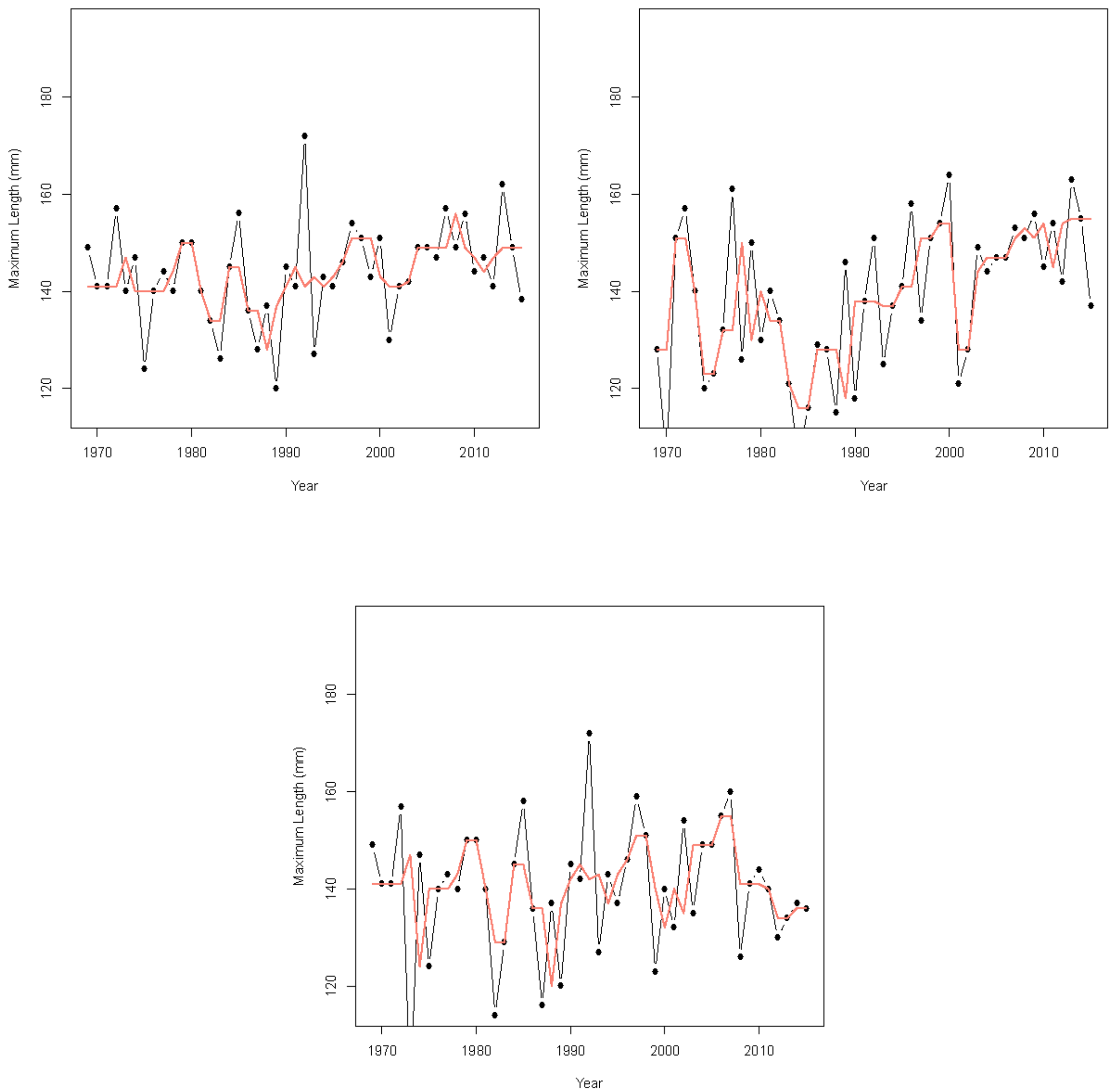


Figure A42. NEFSC spring survey American Lobster population weighted upper 95% length (solid line and points) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median.

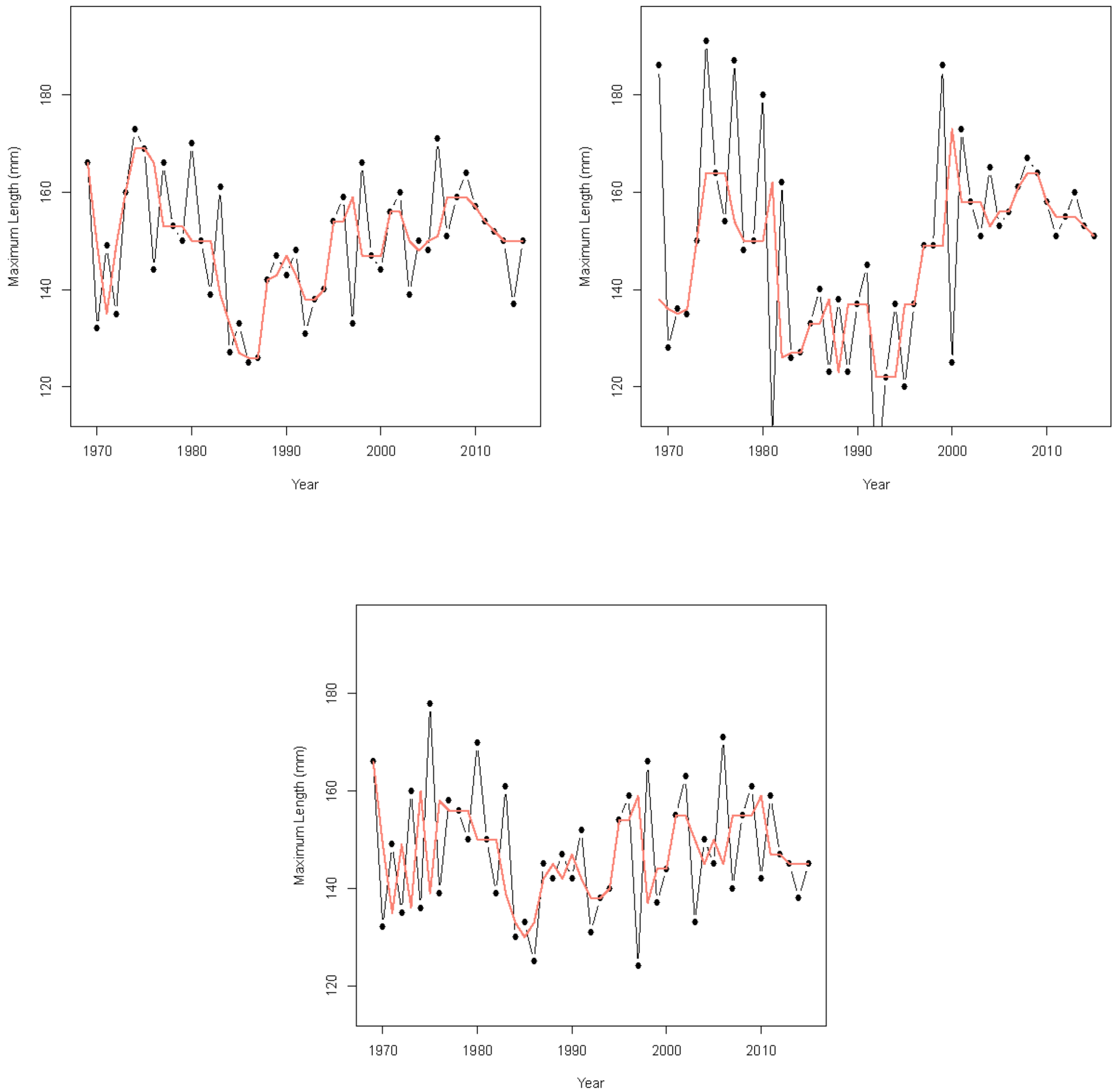


Figure A43. NEFSC Fall survey American Lobster population weighted upper 95% length (solid line and points) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 1969 to 2015. Red line represents a three year running median.

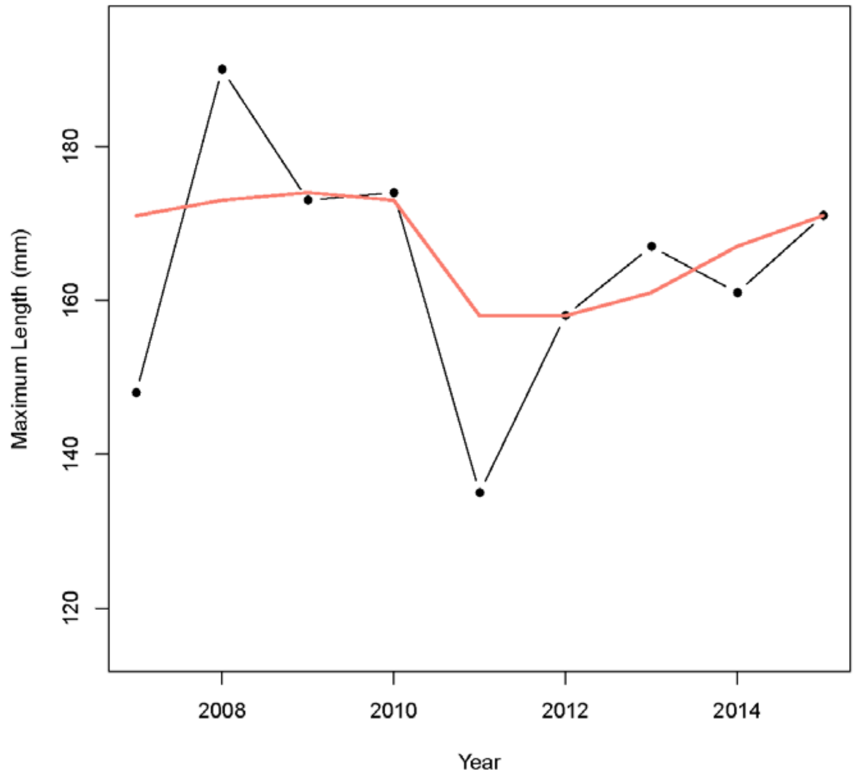


Figure A44. DFO RV Georges Bank survey American Lobster population weighted upper 95% length (solid line and points) for the base survey (top left), pruned survey (top right) pruned to adjacent areas (bottom) from 2007 to 2015. Red line represents a three year running median.

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

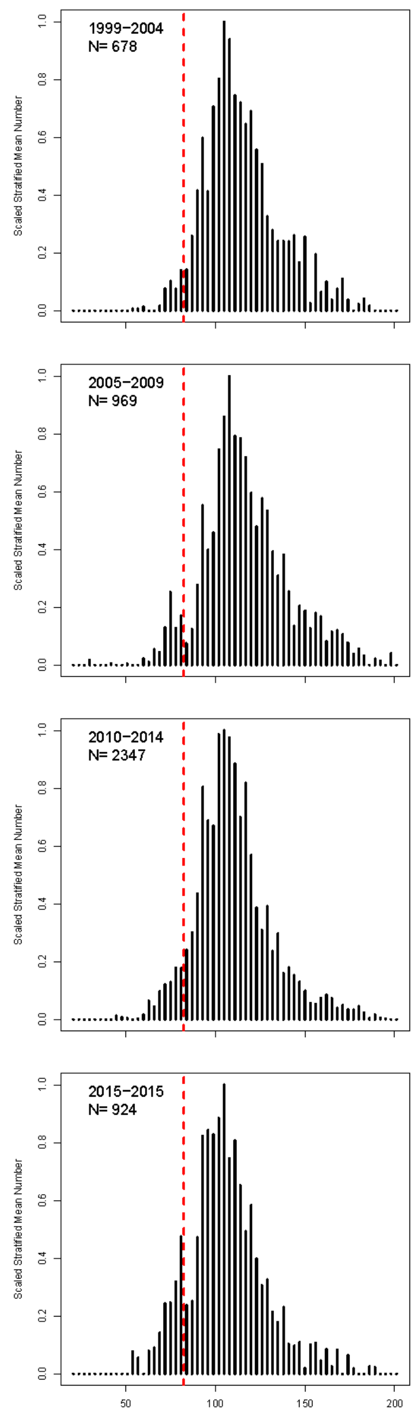


Figure B1. Carapace length frequencies of American Lobster captured during the Summer RV survey with the base strata for LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

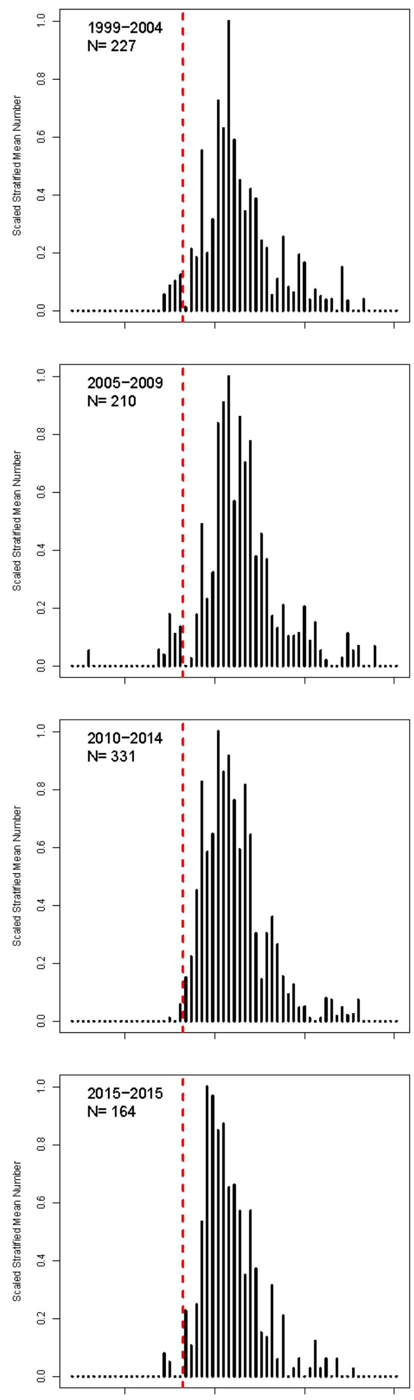


Figure B2. Carapace length frequencies of American Lobster captured during the Summer RV survey with following the restratification strategy to areas within LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates the minimum legal size.

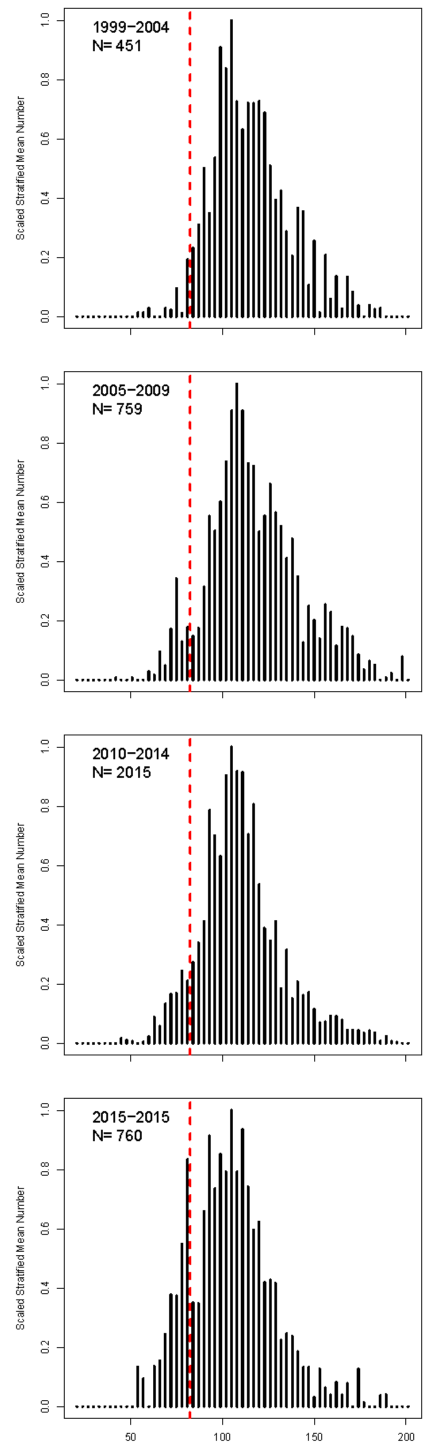


Figure B3. Carapace length frequencies of American Lobster captured during the Summer RV survey with following the restratification strategy to areas adjacent to LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates the minimum legal size.

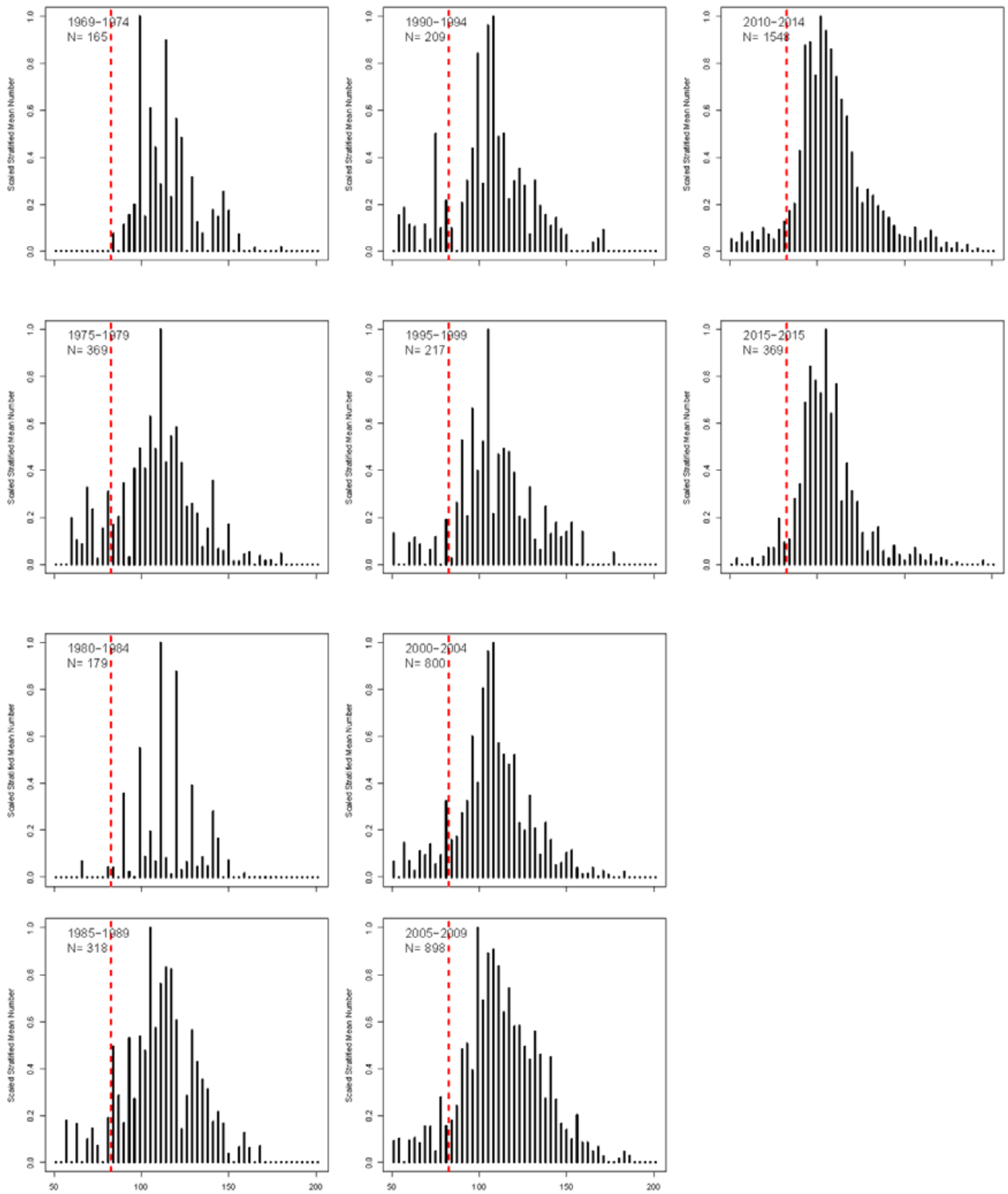


Figure B4. Carapace length frequencies of American Lobster captured during the Spring NEFSC survey with the base strata for LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

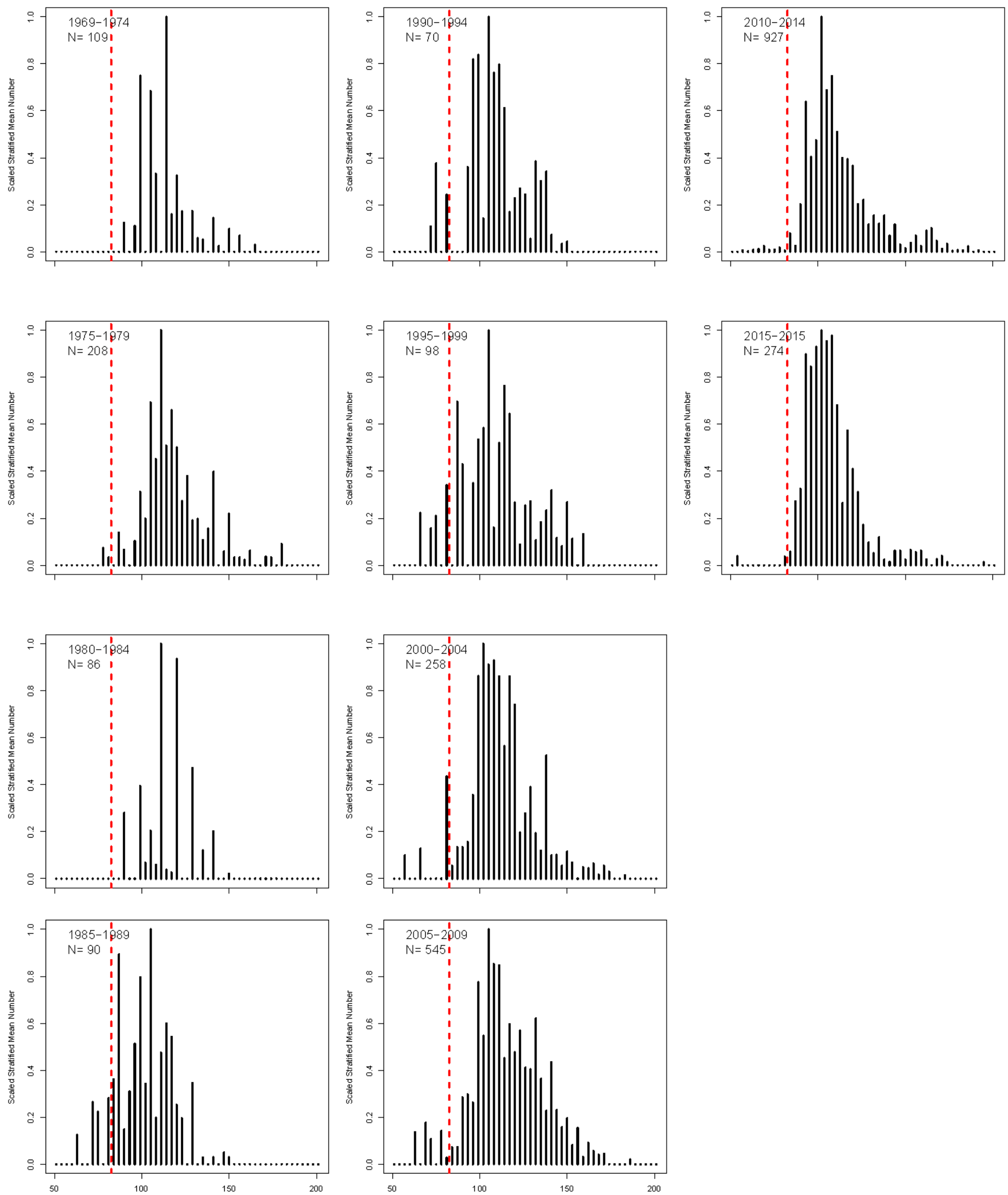


Figure B5. Carapace length frequencies of American Lobster captured during the Spring NEFSC survey with the restratified strata for LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

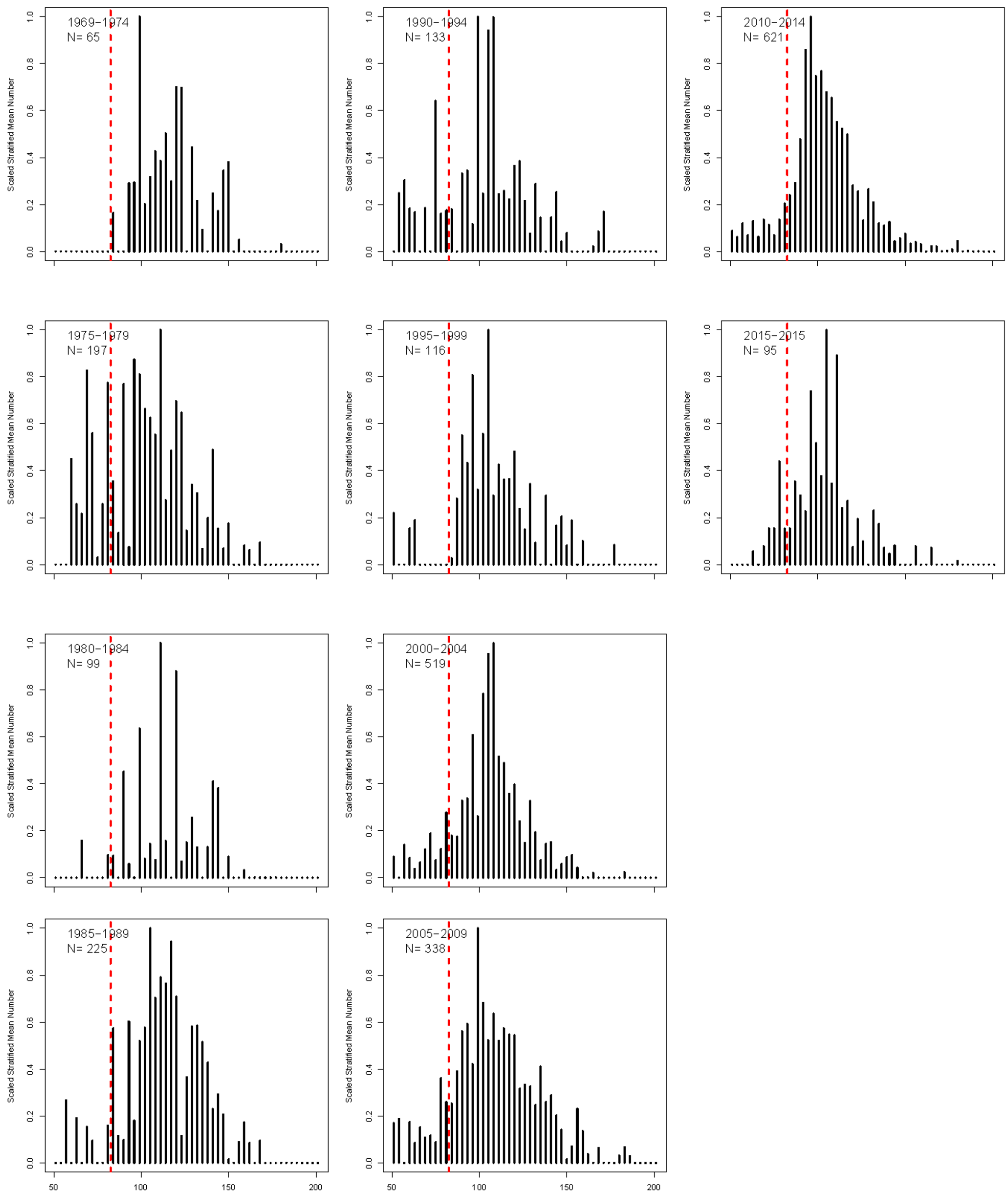


Figure B6. Carapace length frequencies of American Lobster captured during the Spring NEFSC survey with the restratified strata adjacent to LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

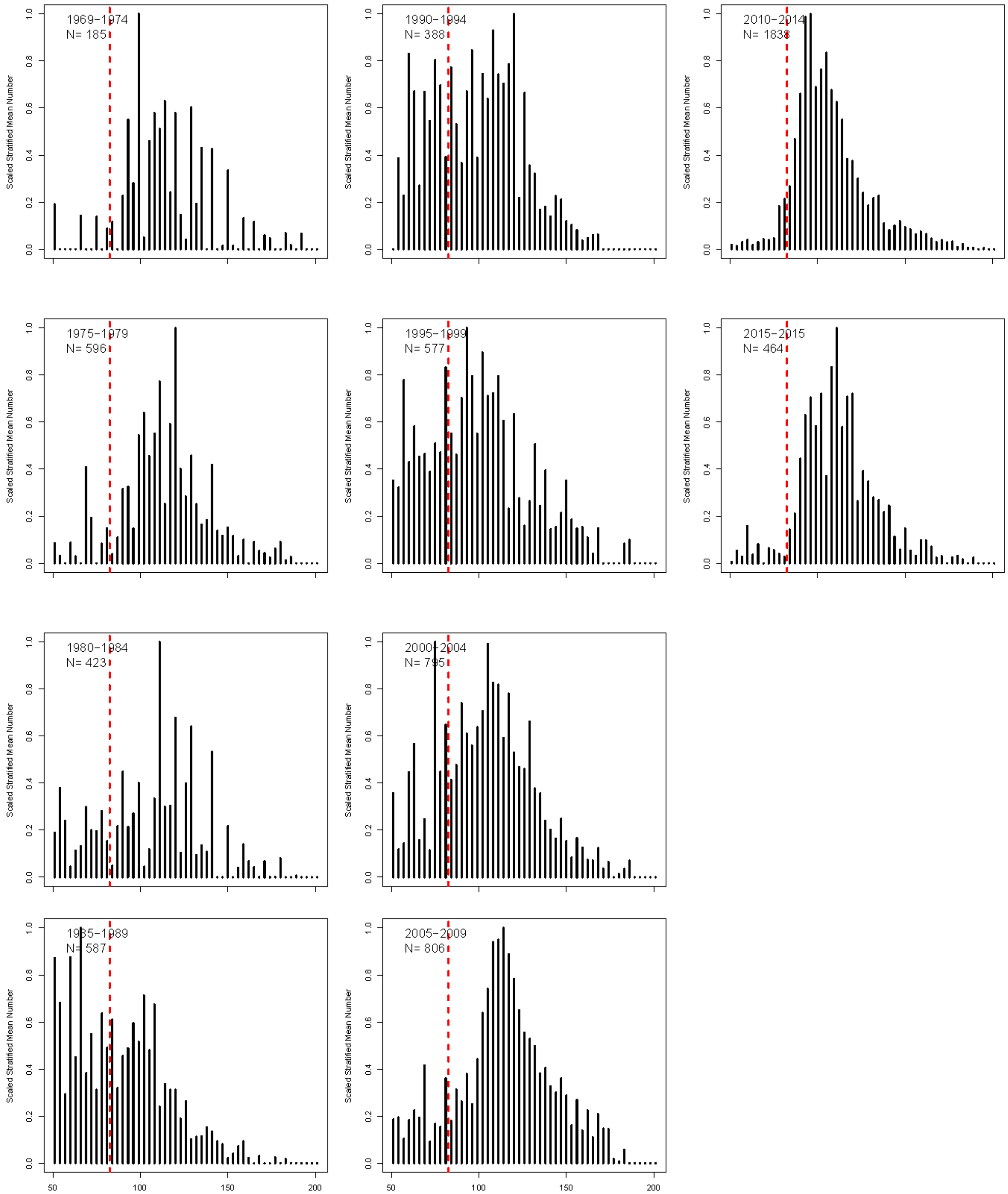


Figure B7. Carapace length frequencies of American Lobster captured during the fall NEFSC survey with the base strata for LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

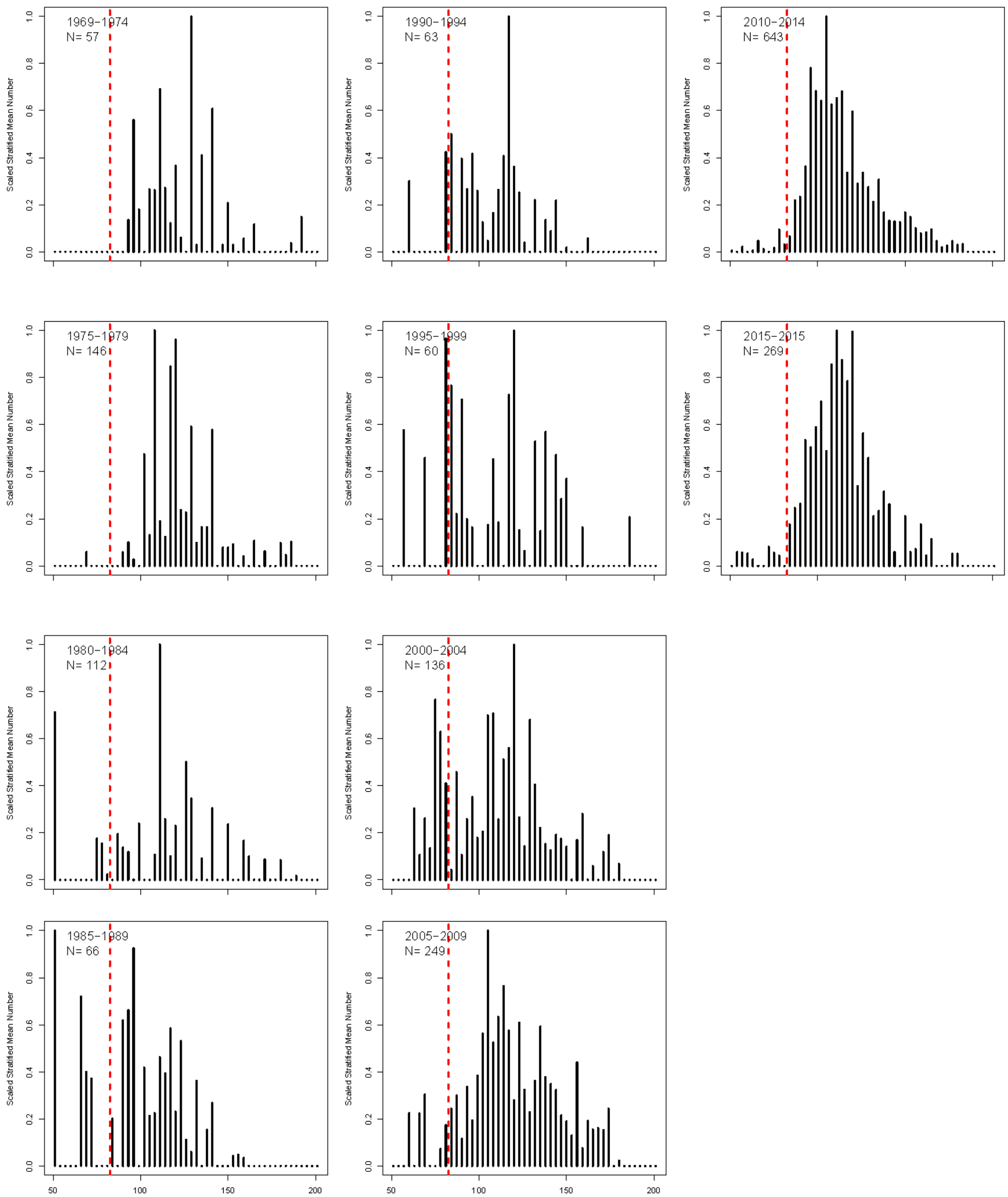


Figure B8. Carapace length frequencies of American Lobster captured during the fall NEFSC survey with the restratified strata for LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

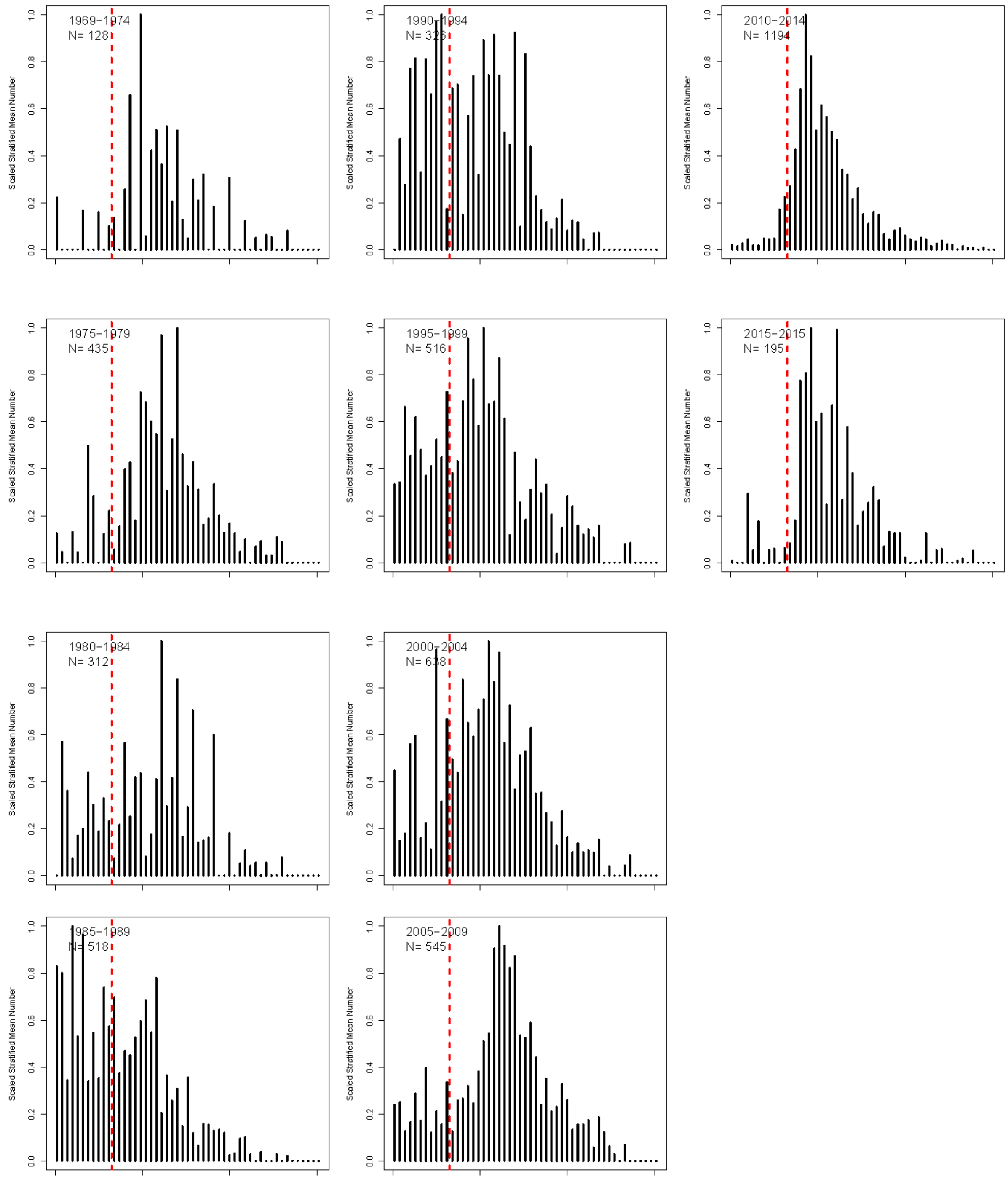


Figure B9. Carapace length frequencies of American Lobster captured during the fall NEFSC survey with the restratified strata adjacent to LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

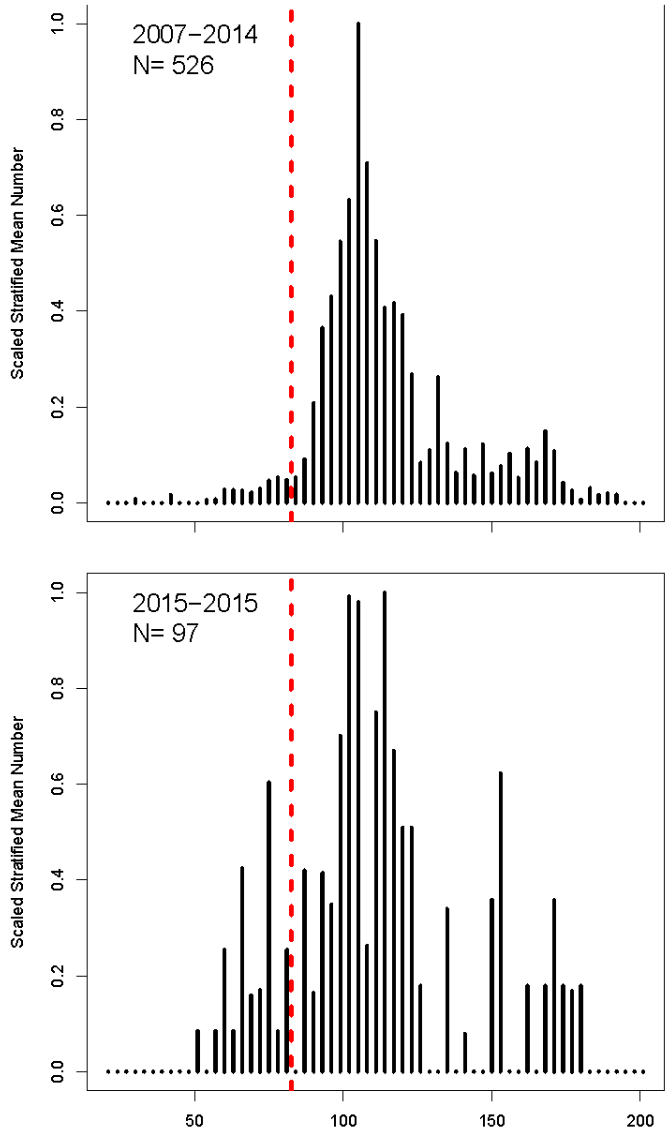


Figure B10. Carapace length frequencies of American Lobster captured during the Georges Bank survey within LFA 41. Bars represents the mean number per tow for each length bin scaled to the maximum numbers per tow. For plots with multiple years bars represent the average over respective time spans. Dashed red line indicates minimum legal size.

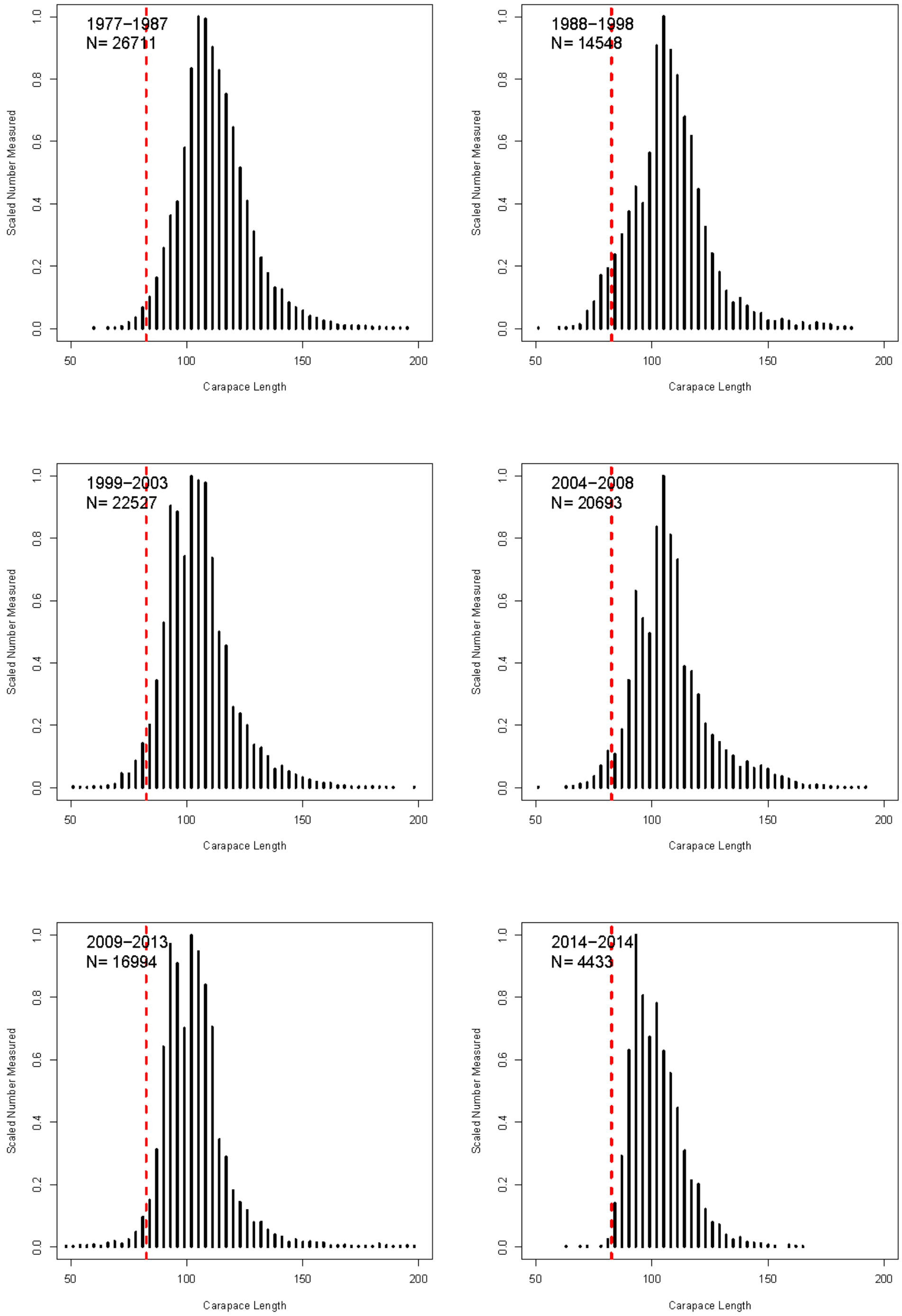


Figure B11. Southwestern Browns Bank carapace length frequency histograms binned into 3 m groups. Red dashed line represents minimum legal size of 82.5 mm. Total sample sizes are shown in the legend.

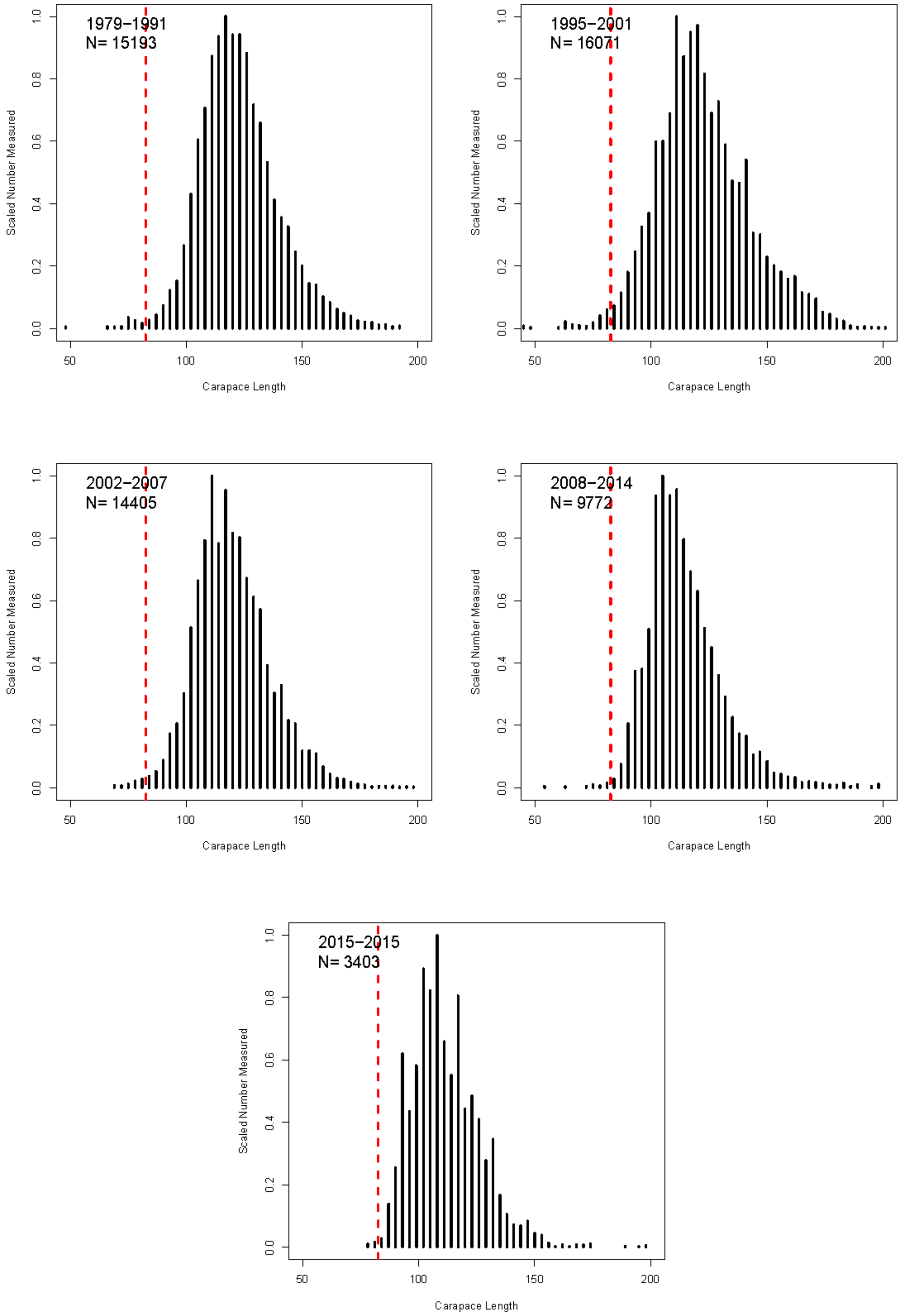


Figure B12. Southeastern Browns Bank carapace length frequency histograms binned into 3 mm groups. Red dashed line represents minimum legal size of 82.5 mm. Total sample sizes are shown in the legend.

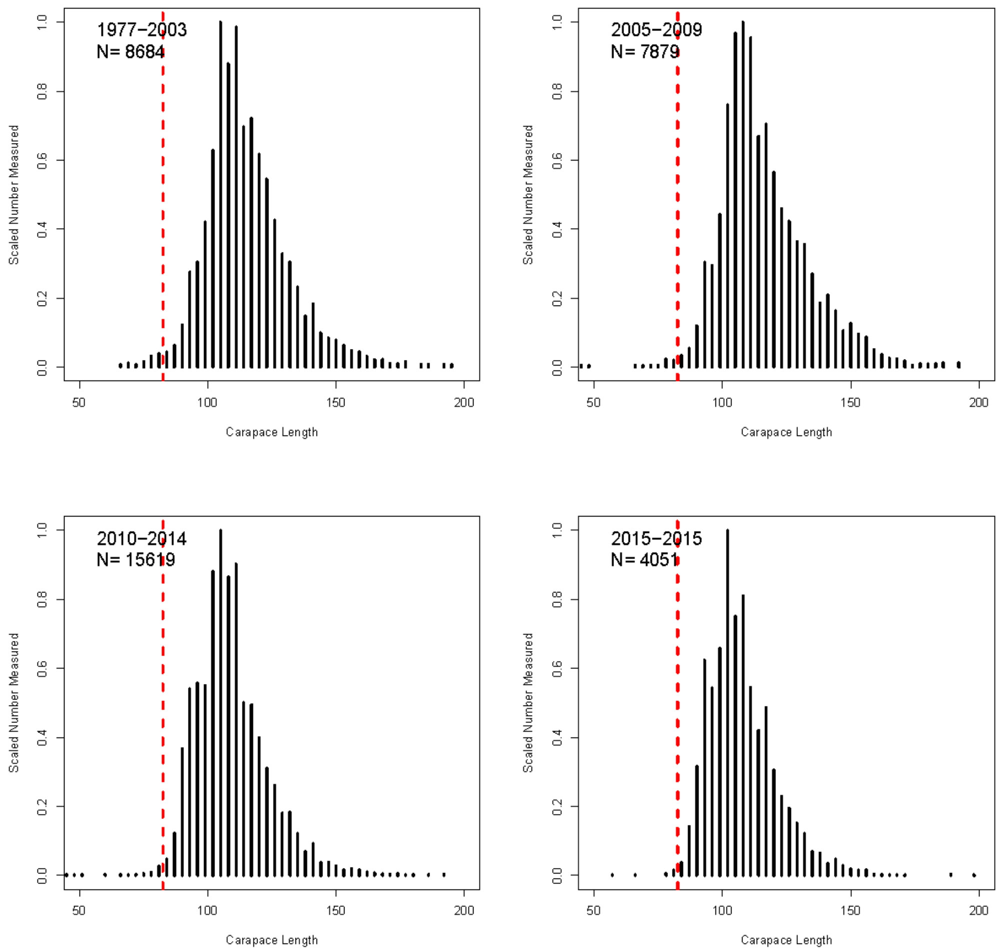


Figure B13. Georges Basin carapace length frequency histograms binned into 3 mm groups. Red dashed line represents minimum legal size of 82.5 mm. Total sample sizes are shown in the legend.

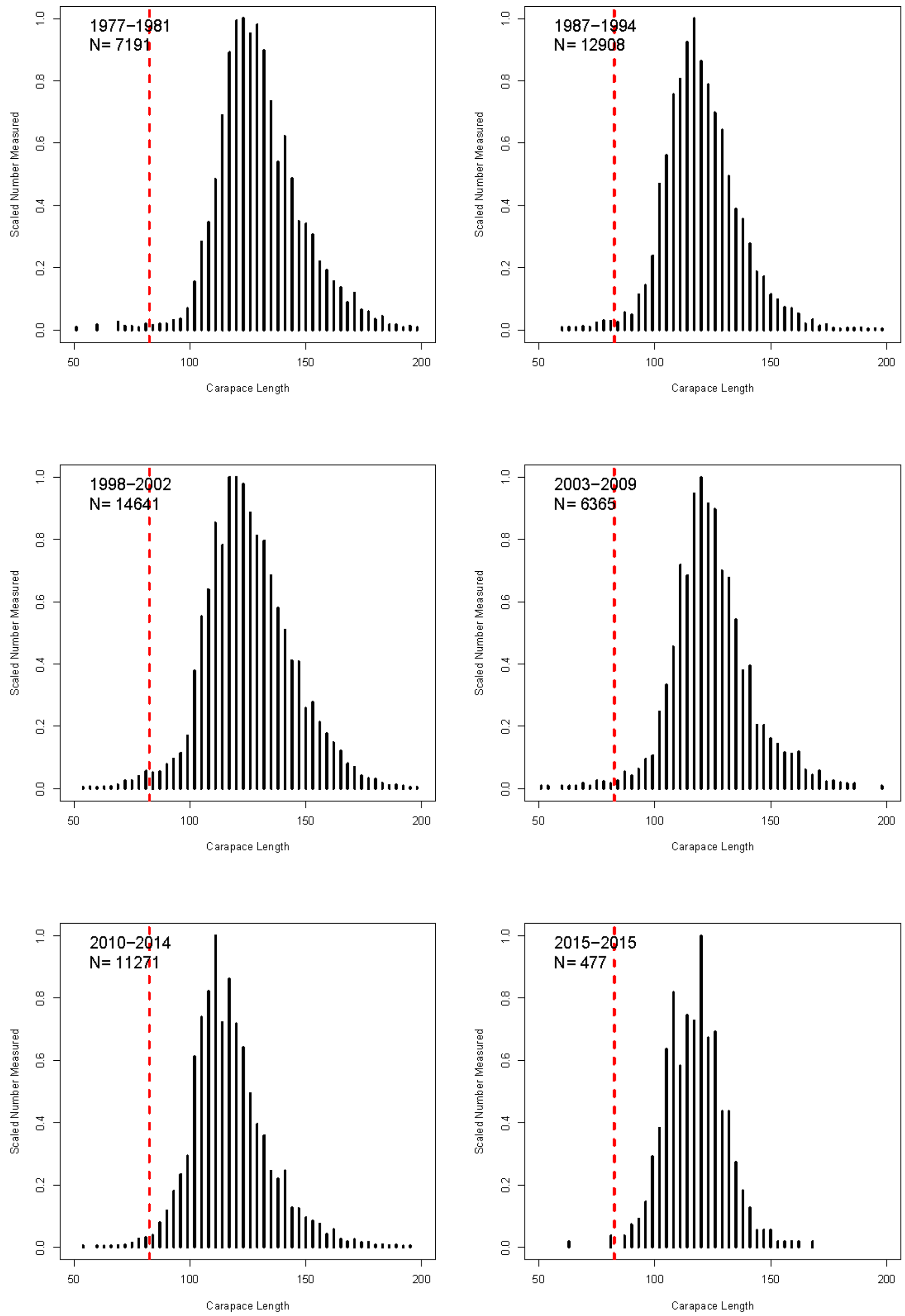


Figure B14. Georges Bank carapace length frequency histograms binned into 3 mm groups. Red dashed line represents minimum legal size of 82.5 mm. Total sample sizes are shown in the legend.