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2019 Framework Assessment of American Lobster (*Homarus americanus*) in LFA 34–38

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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 inshore commercial fishery for American Lobster (*Homarus americanus)* has been active for over 150 years in Lobster Fishing Areas (LFAs) 34–38. These areas cumulatively cover 34,000 km^2 from southwestern Nova Scotia, north to the Bay of Fundy and along the New Brunswick coast to the Canadian—United States border. The fishery is active throughout the LFAs with both inshore and offshore components.

Lobster stocks in LFAs 34–38 have a long history of assessments which are conducted almost annually. The last framework for assessing Lobster in LFAs 34–38 occurred in 2013 with separate assessment documents for LFA 34 and LFAs 35–38. The most recent stock assessments for LFA 34 use landings, the Inshore Lobster Trawl Survey (ILTS) catch rate index, and raw commercial catch rates as primary indicators of stock status.

LFAs 35–38 were assessed as one unit with a single set of primary stock status indicators. These indicators include landings, raw commercial catch rates, and total abundance from the Fisheries and Oceans Canada (DFO) summer Research Vessel (RV) survey.

In this stock assessment framework the stock status indicators were re-examined and their methodologies for estimation evaluated. Background on the available data sources and analyses were described. The code to perform all analyses is available on a GitHub repository. This framework will provide information on ecological and environmental indicators, incrementally moving toward applying an ecosystem approach to stock assessments. Indicators will be estimated for each LFA separately. It was recognized that there are likely connections between LFAs and similar processes impacting production; however, each LFA is managed separately with unique conservation measures adopted.

There are three groups of indicators in this document, primary, secondary, and contextual. The primary indicators will be used to define stock status, and reference points will be developed. Secondary indicators are those in which time-series trends will be updated and displayed in subsequent stock status reports; however, no reference points will be developed for these indicators. The contextual indicators will be included in stock assessments, and will be infrequently updated.

The data used in this stock assessment represent a mixture of both fisheries dependent and fisheries independent data. The fisheries independent data come from a number of mobile sampling methods. Each of these surveys cover a portion of the overall stock area. The longest time series of data on the Lobster within these LFAs comes from the fisheries dependent data.

LFA 34

In LFA 34, the time-series trends in abundance (or biomass) of several size classes of Lobster were examined across multiple surveys. From each of these surveys, two time trends were often identified using Dynamic Factor Analysis (DFA), showing a dramatic increase in recent years. This increase was also observed in the commercial catch rates as well as the total landings. Given relatively constant effort in this fishery, it has long been presumed that landings are proportional to total abundance. There was supporting evidence from the indicators of distribution and patchiness which suggest that the LFA 34 Lobster are more evenly distributed across a much broader range of habitats than previously reported.

The commercial biomass index and the relative fishing mortality (relF) indicators from the bottom trawl surveys were suggested as **Primary Indicators** with reference points developed based on changes in productivity. **Secondary Indicators** include landings, commercial catch rates, and recruitment indices.

LFA 35–38

Although LFAs 35, 36, and 38 were assessed separately, a common approach to providing stock assessment advice was proposed. Each LFA has fishery independent data collections, however none have a sufficient data density (or spatial coverage) to be used as a primary indicator of abundance. The combined LFAs 35–38 DFO summer survey series will provide **Secondary Indicators** to the overall Bay of Fundy area. The fisheries dependent commercial catch rate model was selected as the **Primary Indicator** of stock status as it provides information on the effort corrected catches in each LFA. The reference points developed for each LFA were based on the productivity changes within each area. Total landings is the longest time series of data within the LFA and as such it will remain a **Secondary Indicator**.

HARVEST CONTROL RULES

A simulation model was developed to explore the biological implications of different Harvest Control Rules (HCR). Simulations were conducted only for LFA 34 in this framework. This simulation model represents the first steps in developing a useful tool to describe some of the population processes across LFAs. The basis for the simulation is moult process model where moult frequency is dependent on degree days (temperature x time), as determined from an analysis of tagging data. Other inputs include area specific size of maturity, and available estimates of fishing mortality or exploitation. The simulation model tracks a Lobster cohort from late juvenile to adult stages through moulting, reproduction, fishing, and natural mortality. The outputs include total landings (numbers and weight) and egg production, and are used to determine the biological impacts of the type and relative magnitude of the HCRs such as changes in Minimum Legal Size (MLS), change in the duration of the fishing season, protection of a window size of Lobsters, and protection of Lobsters above a maximum size.

INTRODUCTION

BACKGROUND

The inshore commercial fishery for American Lobster (*Homarus americanus)* has been active for over 150 years in Lobster Fishing Areas (LFAs) 34–38. These areas cumulatively cover 34,000 km^2 from southwestern Nova Scotia, north to the Bay of Fundy and along the New Brunswick coast to the Canadian—United States border (Figure 1). The fishery is prosecuted throughout the LFAs with both inshore and offshore components.

LFAs 34–38 account for 40% of Canadian Lobster landings and 20% of North American Lobster landings in each of the last several years, annually producing approximately 35–40,000 tons of landed Lobster. These Lobster fisheries are effort controlled, with general restrictions on the season length, number of licenses, number of traps per license, Minimum Legal Size (MLS), and non-retention of berried females (Table 1).

SPECIES BIOLOGY

The American Lobster (*Homarus americanus*) is a crustacean species that has been commercially fished since the early 1800's. This decapod has a complex life cycle characterized by several phases from eggs, larvae, juvenile, and adults, and relies on moulting its exoskeleton for an increase in size. Typically, the mature females mate after moulting in late summer, and extrude eggs the following summer. The eggs are attached to the underside of the tail to form a clutch and are carried for another 10–12 months hatching in June–August. The eggs hatch into a pre-larvae or prezoea, and through a series of moults become motile larvae. These larvae spend 30–60 days feeding and moulting in the upper water column before the post-larvae settle to the ocean floor seeking shelter. For the first few years of life, juvenile Lobsters remain in or near this sheltered environment 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). Moulting frequency begins to decrease from 1 moult per year (at about 0.45 kg individual weight) to moulting 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 of 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 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 93 mm CL for Northeast Georges and Browns Bank (Cook et al. 2017). In LFAs 34–38, the SoM has been estimated through several studies (e.g., Gaudette et al. 2014), with the general consensus that SoM is larger in the Bay of Fundy than other regions.

In LFAs 34–38 the MLS is below the SoM indicating only a small proportion of females have had the opportunity to carry eggs prior to entering the fishery (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 moult (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 moult 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. Intermoult mating has also been observed in laboratory conditions (Waddy and Aiken 1990).This consecutive spawning strategy enables large Lobsters to spawn more frequently than their smaller conspecifics. This, combined with the exponential relationship between body size and numbers of eggs produced (Campbell and Robinson 1983, Estrella and Cadrin 1995), means that very large Lobsters have a much greater relative fecundity and are thus an important component to conservation. In the Gulf of Maine, the management plan and past assessments have looked at maintaining the high reproductive potential in this area by preserving its size structure dominated by mature animals, which has been a key component of stock assessments (Pezzack and Duggan 1987, Pezzack and Duggan 1995).

DISTRIBUTION AND STOCK STRUCTURE

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

The currently defined LFAs do not represent biological units. They 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 increasing densities 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 (Uzmann et al. 1977, Pezzack and Duggan 1986). Whether these findings are indicative of the present day movement of Lobster 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 LFA 34–38 has not been fully described. The current hypothesis is that the 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, and Quinn 2014). However, self-seeding has been identified as an important source of juvenile Lobsters in most LFAs (Quinn 2014).

In this framework, all LFAs were examined separately, despite suggestions of linkages between LFAs through direct movement and similarity of population processes. This choice was made as each LFA is managed separately and several possess unique conservation measures which may impact observed trends in indicators.

PREDATORS

The predators of Lobsters include Cunner, sculpin, skate species, Cod, Spiny Dogfish, Sea Raven, wolfish species, Haddock, hake, and various crab species (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 RV survey on the Scotian Shelf, has suggested that predation rates on Lobster is relatively low (36 stomachs containing Lobster of the 160,580 stomach examined between the 1960s and 2009 (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 as this survey is only conducted at depths greater than 50 m.

ENVIRONMENTAL IMPACTS

American Lobsters exist in a variety of habitats from mud, cobble, bedrock, and eelgrass beds to depressions in the sand depending on the stage of their lifecycle and / or the need for refuge (Lavalli and Lawton 1996). The American Lobster begins its life as a pelagic larva before settling to the bottom during the post larval stage. As newly settled juveniles, a complex rocky bottom with seaweed is the preferred habitat as it provides crevices for protection from predation. Juveniles remain in their crevices during the day, foraging mainly at night on the substrate near their burrows (Johns and Mann 1987, Lawton 1986). During this stage juveniles are exposed to a high risk of predation until they develop more robust defense mechanisms as an adult (Lawton 1986). As adults, American Lobster require crevices in their habitat for moulting and mating, but can use a broader range of habitat types than juveniles, as their risk of predation is reduced (Lawton and Lavalli 1995).

One of the primary environmental factors impacting American Lobster is temperature. Fluctuations in temperature affect all stages of the Lobster's lifecycle differently, influencing growth, reproduction, and movement (McMahan et al. 2016 and Laufer et al. 2013).

A further environmental factor that is known to impact the survival and productivity of Lobster is salinity. Performance (survival, swimming, foraging) of American Lobster larvae begins to decline when salinities drop below 19–20 ppt, and they tend to avoid areas with a salinity of 21–22 ppt (Aiken and Waddy 1986). Larvae and post larval Lobster can osmoregulate in a broad range of salinities but salinity gradients can influence the vertical distribution of larvae in the water column (Ennis 1995). Though adult Lobsters typically occupy areas where salinities are > 25 ppt, they can move to estuarine locations during seasonal movement to find optimal salinity and temperature conditions (Lawton and Lavalli 1996).

STOCK ASSESSMENT HISTORY AND CURRENT FRAMEWORK

Lobster stocks in LFAs 34–38 have a history of assessments which are conducted periodically through the Regional Assessment Process (RAP) and coordinated by the Canadian Science Advisory Secretariat (CSAS) (Table 2). LFAs in the Maritimes have a target frequency for assessments every 5 years, with stock status updates provided in the intervening years. The last framework for assessing Lobster in LFAs 34–38 occurred in 2013 with separate assessment documents for LFA 34 from LFAs 35–38. Stock status updates for LFAs 34–38 occurred annually from 2014 to 2018, with separate documents for LFA 34 and LFAs 35–38.

The most recent stock assessments for LFA 34 use landings, the Inshore Lobster Trawl Survey (ILTS) catch rate index, and raw commercial catch rates as primary indicators of stock status. For each primary indicator an Upper Stock Reference (USR) was defined based on the historic trends. A Limit Reference Point (LRP) was only defined for the landings index. There was no guidance provided on the interpretation of divergent signals between indicators and what would constitute a change in stock status.

LFAs 35–38 are currently assessed as one unit with a single set of primary stock status indicators. These indicators include landings, raw commercial catch rates and total abundance from the DFO summer RV survey. Each indicator has a USR defined based on historic trends in the time series. Only the landings indicator has an LRP. Similar to LFA 34 assessments, there was no guidance provided on the interpretation of divergent signals between indicators and what would constitute a change in stock status.

In this stock assessment framework the stock status indicators will be re-examined and their methodologies for estimation evaluated. Background on the available data sources will be supplied as well as detailed descriptions of the methods for estimating each indicator. The code to perform all analyses is available on a GitHub repository. This framework will provide information on ecological and environmental indicators, incrementally moving toward applying an ecosystem approach to stock assessments.

Indicators and reference points will be estimated for each LFA separately. It was recognized that there are likely connections between LFAs and similar processes impacting production, however, each LFA is managed separately. It is considered more precautionary to provide indicators at the single LFA level as patterns in indicators may be masked by trends in adjacent LFAs if data sets are combined.

As this document serves as the framework for multiple LFAs, details on data sources, general analyses, and reference points will be provided in the introductory section to avoid repetition.

This document will serve as the reference for the ensuing stock assessments and science responses which will follow the accepted indicators and reference points provided within.

DATA SOURCES

The data used in this stock assessment represent a mixture of both fisheries dependent and fisheries independent data. The fisheries independent data come from a number of mobile sampling programs involving bottom trawls, dredges and SCUBA transects. Each of these surveys cover a portion of the overall stock area. The longest time series of data on the Lobster within these LFAs comes from fisheries dependent data. There are a number of caveats associated with relying on fishery dependent data to provide stock status advice as time series may be influenced by factors outside of changes in abundance or stock structure. For example, changes in management measures, fishing practices, market preference or market demand, will all influence the perceived patterns in trends. In the Lobster fisheries in LFAs 34–38, the consistency of the effort controls over the last 30–40 years (number of licences, number of traps per licence, etc.) reduces some of the concerns over using fishery dependent data to describe stock status.

For this stock assessment framework, the most up to date time series for some data sources were not used. As this is a stock assessment framework, the goal of this document was to provide a description of the methods for assessing stock status which do not necessarily rely on the most up to date data. There are a number of sampling programs that provide components of data to assist our understanding of the Lobster stocks in LFAs 34–38. In the following sections we will describe these data coverage, present results, and provide rationale for their inclusion / omission from future stock assessments. Following the framework, a stock assessment will be conducted using current data to provide stock status.

FISHERY INDEPENDENT

Bottom Trawl / Dredge Surveys

Bottom trawl/dredge surveys have been conducted throughout the region for most of the past 50 years. Originally, several of these surveys were designed (both statistically and by gear type) to obtain abundance and biomass indices for specific species. Throughout their duration, however, Lobster abundance, biomass, and in some instances, size and sex frequency information have been collected. In other surveys, size and sex information have only been collected in more recent years (details below).

It is important to note that bottom trawls/dredges will not sample all habitats equally. Rocky and complex habitats will not be well sampled with bottom trawls as they may lose contact with the substrate. Gear limitations with dredges, such as gear saturation and height off the bottom will affect Lobster catches. Given Lobster's affinity for complex habitats (Lawton and Lavalli 1995), the probability of detection in trawls is lower in these areas. We therefore consider the abundance, biomass, and distributional indices generated from trawl survey series to be conservative estimates. That said, the indicators generated from these surveys are assumed to be affected by the same gear and sampling limitations throughout their respective time series and therefore provide relevant indicators of population status and trends.

DFO Maritimes Summer Research Vessel Trawl Survey

The DFO Maritimes Region Summer Trawl Survey (herein RV survey) covers the offshore portions on the Scotian Shelf (Figure 2 and 4). This survey has been conducted annually since 1970 and has used the same depth stratified survey design for its duration. Set allocation is approximately proportional to stratum area. The survey was originally designed to provide abundance trends for groundfish at depths from about 50 m to 400 m, but has provided total numbers of Lobsters captured throughout its duration. 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 these years. Beginning in 1999, all Lobsters were measured to the nearest millimeter CL and were sexed.

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

The distribution of Lobster catches and relative abundance of the catch by time period is shown in Figure 3. The strata considered to represent the LFA 34 stock area were 476, 481, 484, 485, 490, 491, 492, and 495. The intersection of the total strata area and LFA 34 boundaries from this survey represents 65.5% of the total LFA.

The strata considered in the LFA 35 stock were 490, 491, 494, and 495. The intersection of the total strata area and the LFA 35 boundaries from this survey represents 42.7% of the total LFA.

The strata considered in the LFA 36 stock were 490, 491, 493, 494, and 495. The intersection of the total strata area and the LFA 36 boundaries from this survey represents 69.9% of the total LFA.

The strata considered in the LFA 38 stock were 484, 491, 492, and 493. The intersection of the total strata area and the LFA 38 boundaries from this survey represents 69.3% of the total LFA.

Despite strata boundaries having significant overlap with LFAs 35–38, there were few (< 20 per year; Tables 3–6) stations within each LFA suggesting that the value of indicators derived from this data was limited. Indicators on the combined LFAs 35–38 will be presented as potential secondary indicators (see below). This survey series will be referred to as the DFO series.

NEFSC Bottom Trawl Surveys

The Northeast Fisheries Science Center (NEFSC) bottom trawl surveys are conducted in spring (March–May) and autumn (September–November). These surveys were initiated in the late 1960's though only data from 1969 onward will be used.

Both NEFSC (spring and autumn) 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 4–6). Most strata are further subdivided into sampling units to achieve a more even sampling distribution across the area covered by the survey. Station allocation is proportional to stratum area. Lobster size (CL) and sex were determined throughout the survey time series.

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

From 2009–present, the RV *Bigelow* conducted both spring and autumn surveys. Accompanying this change in vessel, a new trawl and fishing protocols were adopted. The new trawl is a four-seam bottom trawl (NEST), 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 change 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 distribution of Lobster catches and relative abundance of the catch by time period is shown in Figure 5 and 6, representing spring and fall respectively.

The strata considered as part of the LFA 34 stock included 1,340,1,330,1,360,1,351 and 1,352. Strata 1,310 was originally included in NEFSC surveys, however, it has not been regularly sampled in the last 10 years and has therefore been excluded from all years' estimates (Figure 5 and 6). The total strata area within LFA 34 from this survey represents 65.2% of the total area of LFA 34.

LFAs 35 and 36 were not sampled by the NEFSC surveys, and very few stations were completed annually in LFA 38 (Table 3–6). These surveys will not be used to generate indicators in these LFAs. These surveys for LFA 34 will be referred to as NSpr, NFal for the spring and fall surveys respectively.

Inshore Lobster Trawl Survey

The Inshore Lobster Trawl Survey (ILTS) began as the Individual Transferable Quota (ITQ) survey in 1995 to obtain information on the abundance of Cod, Haddock and Winter Flounder in inshore areas not sampled by the annual RV trawl survey. Since its beginning, the ITQ survey has consistently captured Lobsters, particularly in LFA 34. The ITQ survey has recorded Lobster numbers since 1996 and, beginning in 2005, more detailed data on Lobster (size, sex) were collected as part of the sampling protocol. The ITQ survey was a fixed station survey that began in July of each year. Prior to the initiation of the survey, a fixed grid of polygons were defined and industry participants selected a station location in each of the polygons (Figure 7). These stations were then meant to be trawled in future surveys. There were 180 stations in Northwest Atlantic Fisheries Organization (NAFO) Division 4X; 50–60 of these were sampled in LFA 34 in each year from 1995–2012. The gear was a 280-balloon trawl (14-inch cookie rock hopper footgear, 1 ¼-inch cod end liner) with a wingspread of approximately 17 m (55’). Tows were one nautical mile (1.85 km) in length and generally 20 minutes in duration. As such, the approximate area swept per tow was 31,450 m^2 .

In 2016, gear trials were performed to assess the potential effectiveness of the National Marine Fisheries Service Ecosystem Survey Trawl (NEST) for the ILTS. The NEST is currently used in the NEFSC surveys and will likely be adopted for future DFO RV surveys as well. Correction factors for converting the 280 balloon trawl catches to NEST equivalents, were estimated using a zero inflated beta binomial model. The current set allocation for LFA 34 are provided in Table 3. Length frequencies of Lobsters caught in this survey can be found in Appendix A, for the period where the balloon trawl was used (Figure A1) and since the NEST trawl has been adopted (Figure A2).

Scallop Dredge Surveys

Surveys for sea scallops were conducted annually from the early 1980s to the present to assess abundance (Sameoto et al. 2012, Smith et al. 2012). These surveys started in the Bay of Fundy in 1981 and were extended into the area off southwest Nova Scotia in 1991. Surveys in Scallop Fishing Area (SFA) 29 began in 2001. The survey gear is multiple dredges or drags (“Digby drags”); a comparison of two types of scallop drags found no difference in catch rate, standardized by area swept (Smith et al. 2013). Tows are 8 minutes in duration at 2.5–3.5 knots. Catches of scallops and other species are standardized to an 800 m tow length and a tow width of 17.5 feet (5.334 m) for an area swept of 4,267 m^2 . Although the scallop tows have a much smaller swept area than the RV and ILTS tows, they are much more numerous. For example from 2006–2018 there were 4,574 scallop tows in LFA 34 (Table 3–6). Lobsters are caught as a bycatch at a subset of the stations and are measured prior to being returned to the ocean. Scallops are typically found on gravel sea bottoms, a habitat not favored by Lobsters (Tremblay et al. 2009), but the two species do overlap in some areas. Scallop surveys occur in each LFA from 34–38, but they don’t cover the entire LFAs (Figure 9). The timing of scallop surveys has changed over time. They are conducted primarily in June for Scallop Production Area (SPA) 3 (found within the northern portion of LFA 34), primarily in July for the Bay of Fundy (LFAs 35 and 36), August around Grand Manan Island (LFA 38), and in September for SFA 29 (found within the southern portion of LFA 34; Figure 9). Scallop surveys that occurred prior to July can be considered pre-moult; those in July and August overlap the Lobster moulting period. This is evident when comparing size frequency data from scallop surveys in SPA 3 conducted in June with surveys in SFA 29 conducted in September (Figure A3 and A4). June surveys in

LFA 34 are post-fishery and pre-moult and show the bulk of the size distribution just below the legal size, while surveys conducted in September in LFA 34 show that many Lobsters have recently moulted and are now legal size. Size frequencies of Lobsters captured in scallop surveys in LFAs 35–38 are also presented in Figures A5–A7.

Results from these surveys will be referred to as SPA3, SFA29, BoF35, BoF36 and GM38.

Recruitment Trap Survey

The Fishermen and Scientist Research Society (FSRS) is a partnership organization concerned with long-term sustainability of marine fisheries in Atlantic Canada. They coordinate a recruitment trap project involving volunteer fishermen who track Lobsters that are captured in project traps. Participants of the project are located along the Atlantic coast of Nova Scotia with trap locations shown in Figure 9. The number of participants has varied through time, but as of 2018, 18 participants were active in LFA 34 and 2 in LFA 35 (Table 8). LFA 36 is currently piloting the FSRS recruitment trap project, but this project has not been implemented in LFA 38. Data recorded includes carapace size, sex, and the presence of external eggs for all Lobsters captured in standard traps every day during the commercial fishery. Soak times are typically one day, except during the winter. The FSRS wire traps have modifications that lead to a higher retention of pre-recruit Lobster than the commercial traps, including a smaller mesh size (2.5 cm), smaller entrance rings (12.5 cm), and no escape vents. Hence these modified traps provide a better indication of the abundance of pre-recruit Lobster than the commercial traps. The FSRS trap design is the same throughout the study area to allow for standardized comparison between areas that may fish with different designs of commercial traps. Traps are set in the same location throughout the season by fishers; however, in some areas, fishers will move commercial traps substantial distances during the fishing season, and will sometimes also move the FSRS traps. When this occurs, the location changes are noted and recorded in the database. Traps are equipped with temperature recorders that provide data on nearshore bottom temperatures (Tremblay et al. 2007). Measurements of the Lobster carapace are made with the FSRS gauge. Size groups as measured on gauges from 1996 to 2003, and 2003 to current day, are provided in Table 7. Size groups 8 and 9 are in 5 mm increments to give a clear indication of the number of Lobsters just under the legal size limit. The relative size frequencies of Lobsters captured in FSRS traps are presented for LFA 34 and 35 in Figures A.8 and A.9.

The FSRS recruitment traps have had consistent spatial coverage in LFA 34 throughout the duration of the project, but coverage in LFA 35 has been very low in recent years.

Flagg Cove Dive Study

A dive survey for Lobster was conducted in Flagg Cove, NB between 1989 and 2015 with the intent to provide a fishery-independent index of Lobster and berried female densities. The Grand Manan Fishermen's Association (GMFA) were heavily involved in this program and supplied the data from this survey. The area is recognized as a major aggregative ground for berried Lobster based on knowledge from trapping and diving surveys from 1982 (Campbell 1990). The dive transects are deployed perpendicular to the shoreline starting at the low water mark and extending outwards with maximum depths up to 20 m. Divers recorded CL and sex on all Lobsters found within a 1 m reach of either side of the transect (Robichaud and Pezzack 2007). For this report, data from 1989 to 2015 was included but no data was available for 1996, 2009, 2010, 2012, and 2013.

FISHERY DEPENDENT

Landings and Effort Data

The landings data presented here represent a combination of data sets. LFA 34–38 landings data reported here were derived from multiple sources as outlined in Tremblay et al. (2013), and wherever possible standardizations were implemented. From 1892 to 1946, landings were tabulated by calendar year and county (Williamson 1992). Yarmouth and Digby counties were used for LFA 34 (Figure 10), recognizing that some landings for LFA 34 would have been allocated to Shelburne. The counties did not align well with LFAs 35–38 and therefore historic landings were not allocated to these LFAs.

From 1947 to 1974, landings were tabulated by statistical district and calendar year. Beginning in 1975 landings were available both on the basis of calendar year and fishing season (which spans two calendar years Autumn of year 1 to Spring/Summer of year 2). In 1995, a change in the mandatory catch reporting system was implemented from dealer sales slips being submitted to individual fishermen sending in monthly catch settlement reports. These catch settlement reports provided information on daily catch by port and date of landing.

At the beginning of the 1998 fishing season, LFA 34 fishermen adopted an expanded reporting system, called the Lobster Catch and Settlement Report which required them to provide estimates of daily catch and effort by reference to a 10 minute x 10 minute grid system. The measured weight of Lobsters landed was reported in the weigh-out slip portion of these logs. The grid-referenced catch and effort on these logs provided the first georeferenced landings and effort distribution within LFA 34. The gridded system was later implemented in LFAs 35–38 and was in full use by 2005.

For this framework, all landings data prior to 1975 were obtained from a manuscript report (Williamson 1992). The data from 1975 to 1996 were obtained from Legacy Data Oracle tables by port and Lobster District. Data from 1997–2001 was obtained from the Zonal Interchange File Format (ZIFF) weigh-out slip and estimate Oracle tables by Lobster District. From 2002 to present, landings reported by LFA were taken from the Slip portion of the Maritime Fishery Information System (MARFIS) database representing the actual amount of Lobsters sold on a particular date. Where effort or locations are included, the data has been taken from the log portion of the MARFIS database. These are the data that the fisherman report on each day fished and landings from this portion are estimates. In most cases, the difference between the total slip data and log data are minimal. There are several factors that might account for these differences between the slip and log reporting. These include illegal landings, unreported landings, general misreporting, non-reporting of nil fishing activity, etc.

Current inshore logbooks provided information on date, location (by grid), effort, soak days, and estimated catch. The logbooks also provide information on the fishery footprint expressed in terms of commercial catch rates, Catch Per Unit Effort (CPUE) (Figure 11), effort (Figure 12) and landings (Figure 13) for each grid reported.

Changes in reporting systems in 1996 and 1998–2005 may influence accuracy and completeness of landings. Landings prior to 1996, based on sales slips, may have missed a portion of the catch sold directly to consumers or sold directly in the USA. The size of the underestimate is not known. Post 1996 landings, reported by fishermen directly, should be more complete; however, no analysis has been done to determine completeness or accuracy reports. Thus, changes observed since 1996 must be viewed in light of the change in reporting methods.

Removals of Lobster by means other than the commercial fishery are partially documented or undocumented, but are thought to be low relative to the commercial fishery. The reported landings by the commercial fishery in LFAs 34–38 were all at, or near, all-time highs between 2015 and 2018 (Figure 14).

DFO currently issues Food, Social, and Ceremonial (FSC) Lobster access to 17 Indigenous groups in the Maritimes Region. Each of these licences contain reporting requirements to DFO. The FSC catch data provided through this reporting process varies from community to community and the data received is not provided in a consistent format. We are working with our Indigenous partners to improve the quality and consistency of the data we receive.

At-Sea Observations

At-sea samples collect information from the catch during normal commercial fishing operations. This data source also provides information of the non-retained bycatch (herein bycatch) in the Lobster fishery. For Lobster 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.

Frequency and distribution of sampling has varied over the history of the fisheries in LFAs 34-38. These LFAs have been sporadically sampled through strategic projects, specifically a Species at Risk Act (SARA) project was initiated to cover many of the LFAs and characterize the bycatch in the Lobster fishery. In 2018 a standardized at-sea data collection project was piloted in LFAs 33–35. Size frequencies from the available data in LFAs 34–38 are presented in Figures A10–A15.

For the current framework we will not be evaluating, nor developing, indicators from the at-sea sampled data as very few samples have been collected since the last framework, except for this new pilot project. Further analyses will be conducted following the completion of this pilot project.

ANALYSES

FISHERIES INDEPENDENT INDICATORS

Stratified Random Surveys

For each Stratified Random Survey (STRS), abundance, biomass and size based indices were estimated, accounting for the strata weighting scheme following the traditional methods of Cochran (1982), with confidence intervals estimated through bootstrapping with replacement (Smith 1997). Indicators where more specific details were necessary are provided below.

For each survey, strata boundaries were intersected with the polygon of the specific LFA, or LFA grouping and only stations that fall within the LFA were used. As part of the stratified analyses, annual sample sizes used for estimating the specific indicator (i.e., total numbers of observed Lobsters) were provided.

Survey Efficiencies

The appropriateness of survey strata for defining Lobster abundance trends has routinely been raised (Pezzack et al. 2015). An analysis was conducted to determine the effectiveness of the stratification scheme for DFO and NEFSC spring and fall surveys for each LFA. Generally, STRSs 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 an 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 an STRS compared to that estimated if the survey were analyzed as an 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 variance 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 1999–2018 to ensure catch rates were sufficiently high for developing reasonable variance estimates on which to perform these analyses.

Design Weighted Area Occupied

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 Weighted Area Occupied (DWAO):

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

where n was the number of tows within the survey year, y_i is the number of Lobster caught in tow i, and a_i is the area of the stratum fished for in tow i divided by the number of sets fished in that stratum (Smedbol et al. 2002). DWAO was expressed as km^2 for each survey. It is important to note, that due to the differences in total area of each survey, the estimates of DWAO will only be comparable within a survey.

Patchiness

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.

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), 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 ($p_a = \frac{\sum_{h=1}^{N} A_h}{\sum A_h}$) 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.

ILTS Spatial Analysis of Survey Data – LFA 34

Despite being a fixed station survey, spatial coverage and allocation of stations in the ILTS have varied in some years. This was the result of shifting priorities with respect to Lobster sampling, but it presents a problem when using the time series of Lobster abundance as an indicator of stock status. In the past, index stations were used to account for adding and dropping stations to the fixed design (Pezzack et al. 2015). Taking this approach does not make the most use of the data that has been collected. A geospatial approach was used to account for variability in the spatial coverage while still including all the stations that were sampled in a given year. Several Generalized Additive Models (GAM) were evaluated for predicting abundance and biomass from the ILTS. Due to the zero inflated and continuous nature of the Lobster density from the trawl survey, two distributions were tested. First, a two-phase model approach, often call a hurdle or delta model, was employed whereby a binomial model is fit to the presence-absence data and a lognormal model was fit to the positive catch data. The second used the Tweedie distribution, which assumes the observed density follows a Compound Poisson-Gamma (CPG) distribution with densities of Lobsters resulting from specific biomass following a gamma distribution and the probability of catching the aggregations follows a poisson distribution. The CPG approach allows for the possibility of zero-catches and very high catches within the same model. Both models have been frequently used for fisheries data (Lecomte et al. 2013, Jannot and Holland 2013).

The influence of temporal, spatial and depth covariates were explored for both distributions. In each model, *Year* was included as a factor, allowing free estimation of annual effects rather than implying temporal autocorrelation. *Depth* was included as a thin plate spline and spatial effects were modelled in planar coordinates as a thin plate spline with a penalty on null space. The spatial spline was constrained to 100 knots. Model diagnostics were performed for each model run. Each model's predictive ability was explored using Monte Carlo cross validation with Root Mean Squared Error (RMSE) as the summarizing statistic.

For all indicators, the CPG model including *Year, Depth,* and *Space* had the lowest Akaike Information Criterion corrected (AICc) for number of parameters and the best predictive ability as described by the lowest cross validated RMSE (results only shown for total abundance model; Table 9) with smooth fits shown in Figure 15. This common model structure was be used to develop the ILTS survey indices.

FISHERIES DEPENDENT INDICATORS

Commercial Catch Rates

Catch rates are a preferred indicator over landings data as they are standardized to account for the level of fishing effort, especially important in effort controlled fisheries. Landings may follow the trend in overall biomass when effort is constant over time. In situations where effort is altered through direct management measures or other factors such as major storm events, total landings may decrease simply due to the reduction in effort, not through decreases in biomass available to the fishery.

Catch rates however, may vary during the fishing season due to changes in biomass and catchability, which can be incorporated into catch rate models. Biomass, the underlying process behind this indicator, changes over time as Lobsters recruit to the fishery (usually between seasons when moulting occurs) and during the season as Lobsters are removed from the population through fishing. Catchability can vary as a result of behaviour due to changing temperature during the season.

Data for assessing catch rates primarily comes from mandatory logs that were not put in place until the mid 2000’s. The time series of mandatory logs was supplemented wherever possible with voluntary logs. Additional catch rate information was collected from historic studies. Background on the data collections for the historic data was lacking in some instances; however, daily records of total landings and effort (trap hauls) were typically available from several boats across several ports within the LFA. For LFA 34, Paloheimo (1963) provides a description of the data collections. Within LFA 34, landings and effort data were available for Port Maitland, Clarks Harbour, Abbots Harbour, Little River and Seal Island. LFA 38 had historic data from Seal Cove, North Head and Ingalls Island. Only years where greater than 30 daily catch and effort records were recorded were included in the figures (Figure 16).

Bottom temperature data was not available in the logs so it was predicted from the temperature model described below in the simulation modelling section. The temperature predictions were based on the date fished, depth of fishing, and LFA. Depth data were not available from the logs. Location data which could be used to assign depth were only provided by grid, which tend to be large and encompass a variety of depths. Depths were assigned to log book records using the average depth within each grid where it was reported.

Commercial catch rates were modelled separately for each LFA with generalized linear models where the weight reported in each log record was log-transformed and offset by the log of the trap hauls with factors of day of season, predicted bottom temperature, and year. The *Year* term was treated as a factor to allow free estimation of inter-annual variability rather than forcing annual signals toward the mean. This was done as there can be substantial variability in annual Lobster recruitment.

The data density in the logbook records made the consideration of vessel as a random effect computationally intractable. Different formulations of temperature and day of season were tested and the formulation with the lowest AIC included both temperature and day of season and their interaction (Table 10). This model formulation was applied to each LFA individually and the annual index was the predicted CPUE on the first day of the season at the average temperature typically experienced on that day.

The daily predicted CPUE, assuming average temperature for that day, can be seen overlaid on the individual records of CPUE in Figure 17. The red line, which indicates predicted daily CPUE can be seen to start off high in each LFA and drop exponentially as the season heads into the winter. Also in each LFA the predicted daily CPUE begins to increase again in the spring as the water temperatures begin to increase. The blue dots in this plot represent the annual index, predicted at an average temperature for the time series on day one of the season instead of the average temperature for that year. In years where the temperature on the first day of the season was warmer than average the red line starts higher than the blue dot and when the temperature on the first day of the season was cooler than average the blue dot is higher. Since water temperatures have tended to be warmer in recent years this is an important correction to make to ensure the index isn’t overly optimistic. The time series of modelled CPUE for each LFA was shown in Figure 18 and Tables 11–14.

FSRS Catch Rates

The FSRS recruitment trap survey provides information on the abundance of under sized Lobsters. The recruit abundance index were defined as sublegal Lobsters 71 mm - MLS (FSRS size code 8, 9, 10, and indicated short Lobster). As with the commercial CPUE data there are other factors that can affect the catch of Lobsters in traps other than abundance such as temperature and depletion for legal size Lobsters. The catch rate of sublegal Lobsters is also affected by behavioural interactions with larger Lobsters. Small Lobsters are less likely to enter a trap where larger Lobsters are already present. Temperature data are available directly from the temperature loggers on the traps; therefore, there is no need to rely on the temperature model for that information.

Models were developed to standardize FSRS catch rates. A Bayesian approach was implemented using the R package rstanarm (Stan Development Team 2016) in order to characterize the credible intervals of the predicted time series that would be used as the indicator. Three models were fit in each LFA for numbers of recruits. The responses were assumed to follow a negative binomial distribution with the log number of traps used as an offset. For sublegal and recruit size-classes, the predictors tested included temperature, the number of legal size Lobsters caught, and year. For legal sized Lobsters the predictors were temperature, the day of the season, and year as a factor. The resultant models were used to predict the number of Lobsters (for each size class) per trap for each area and year in the middle of the season with the temperature set to 5 ºC. For the sublegal size class models, the number of legal Lobsters included in predictions was three.

Exploitation Indicators

Continuous Change In Ratio

Change In Ratio (CIR) methods provide estimates of population parameters based on the changes in observed proportions of components within the population. Estimating exploitation using CIR relies on defining and monitoring two (or more) components of the population, consisting of a reference (non-exploited) component and an exploited component. The premise of this method is the proportion of reference individuals within the population will increase with the cumulative removals from the exploitable component. Traditional CIR methods use discrete monitoring programs at the start and end of the harvesting seasons to estimate removal rates by describing the changes in proportions of these components (Paulik and Robson 1969). Recognizing the inherent sensitivity of this method to the quality of information gathered at these two time points, Claytor and Allard (2003) developed a Continuous CIR (CCIR) method, which uses samples obtained throughout the harvesting season to update exploitation estimates as new information is obtained.

The estimates of exploitation using CCIR do not consider the harvest rate on the entire population, as only components of the population are compared. Although the size categories chosen for the exploitable component represents a large component of the fisheries landings, the exploitation rates estimated here will be considered indices of exploitation rather than absolute estimates.

The implicit assumptions of the CCIR include 1) the population is closed, 2) the ratio of catchability of the two components is constant throughout the sampling period, 3) the ratio of the catchability of the monitoring traps and the commercial traps is constant over the season, and 4) the monitoring effort is directly proportional to harvesting effort.

Assumption 1, that the population is closed may be violated in this data set, depending on level of data density and spatial representativity. Studies from elsewhere suggest the second assumption of constant catchability between the reference class and exploitable may be violated as negative interactions between size classes within a trap have been documented (Ziegler et al. 2002). However, Tremblay et al. (2011) suggested that small differences in CL between the size groups may reduce the negative interactions, thereby validating this assumption. The sensitivity of exploitation indices to the third assumption of constant catchability between monitoring and commercial fishing traps was examined by Claytor and Allard (2003) and was determined to be insignificant. The final assumption was examined in Cook et al. (2020a) by comparing the estimated exploitation indices using either the monitoring effort or fishing effort as the predictor variable, and was determined to be insignificant.

Here we rely on the FSRS recruitment trap catch data to relate the changes in pre-exploitable reference group (*r*) to exploitable group (*y*). Following the recommendations of Claytor and Allard (2003) and Tremblay et al. (2011) the size class definitions were chosen to 1) minimize the size differences between groups and 2) maximize the sample sizes for the analyses. The size class definitions for LFA 34 were size group 9 (76–81 mm) for the reference group and 10 (82–90 mm) for the exploitable group.

After exploring several modelling options, the CCIR model of Claytor and Allard (2003) was cast in a Bayesian binomial setting to allow for the estimation of credible intervals of exploitation. Under this formulation the probability distribution of *y* was

$$p(\mathrm{y}) = \binom{n}{y}\theta^{y}(1-\theta)^{n-y}$$

where *n* was the combined *y* + *r* and *θ* was the estimable parameter *y*/*n*. Estimates of $\hat{\theta}$ for each sampling trip *k* were defined as:

$$\widehat{\theta_k} = \frac{1}{1+\frac{1}{(A+Bg_k)}}$$

with A and B as constants and g_k representing $\sum_{i=1}^{k} n_i$. The resulting $\widehat{\theta_k}$ were related to the set (*n, y*) as:

$$y \sim binomial(n, \theta_k)$$

Parameter estimates of A and B as well as the estimates of $\widehat{\theta_k}$ were obtained using a No-U-Turn Sampler (NUTS) with Markov chain Monte Carlo (MCMC) method implemented in Stan (Hoffman and Gelman 2014). Normally distributed priors were chosen for A and B such that coefficients of variation were greater than five. Four chains were run for 35,000 iterations, following a burn-in of 2,000, every 20th sample was maintained for posterior analyses. The number of iterations and thinning were examined to ensure mixing of chains, and the removal of autocorrelation as is typical with MCMC methods. The number of iterations required was less than typically used in Bayesian inference Using Gibbs Sampling (BUGS) as NUTS is a more efficient sampler of parameter space.

The posterior samples of $\widehat{\theta_k}$ were used to obtain the distributions of exploitation for each interval u_k as:

$$u_k = 1 - \frac{\hat{\theta}_k / 1-\hat{\theta}_k}{\hat{\theta}_0 / 1-\hat{\theta}_0}$$

CCIR estimates of exploitation were determined for each year (2001–2018) for LFA 34. Berried females contained in either group were removed prior to analyses. Monitoring samples with less than ten Lobsters measured were not included in the analyses, nor were years with less than ten sampling intervals.

Simulation testing methods were developed to ensure predictive ability of the model. In all, 100 simulations were performed using parameter estimates covering the range observed in previous CCIR model runs. Overall, the medians of posterior distributions were within 3% of the generating parameters.

The CCIR exploitation indices are relevant for the newly recruited proportion of the Lobster stock, and do not account for the decreased exploitation from the protection of berried Lobsters, or other non-MLS related conservation measures as many of these occur at larger body sizes or life stages that are not considered in this analysis. These exploitation rates are not to be treated as absolute rather indices of exploitation.

The CCIR provided a more robust measure of exploitation, when compared to the cohort analysis (Cook et al. 2020a). Previous work showed exploitation indices estimated through cohort analysis are sensitive to variable recruitment, which given the evidence of increased Lobster production in recent years, invalidates this method. Although suggestions have been made that cohort analyses can be augmented by combining several consecutive years to include variable recruitment, temporal autocorrelation will generally lead to overestimation of exploitation. Years where landings are high and the proportion of new recruits is high, exploitation will also be increased, irrespective of the population abundance. This issue can be overcome with a fully integrative model, where growth and size compositions are directly accounted for in the model; however, this type of analysis is beyond the scope of this framework.

The CCIR exploitation index, despite not representing the entire fishable population, provides an index of exploitation for newly recruited Lobster and is independent of the specific size frequency data. The continuous aspect to the CIR implemented by Claytor and Allard (2003) provides robustness to this analysis, as the change in proportions of each size category were tracked throughout the season with continuous sampling. Through this intensive sampling, anomalous data points become down weighted and the overall estimates are improved. CCIR exploitation rates were only estimable from LFA 34 due to the lack of sampling in LFAs 36–38 and the limited numbers of samples in LFA 35.

Relative Fishing Mortality

Relative fishing mortality (relF) uses both survey data and landings to show the changes in removals (C_t) relative to the j survey indices (I_{jt}) 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. For the spring and summer surveys, that occur after the fishery is complete, the estimation of relF was adjusted by the landings as:

$$relF_{jt} = \frac{C_t}{(I_{jt} + C_t)}$$

Patchiness of Commercial Catches

Patchiness was estimated through the use of the Gini Index, which has been used as an index of dispersion for catches (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). In this case, the patchiness as it relates to the commercial landings across grid cells within an LFA.

The commercial catches of Lobster across the time series of mandatory logs were used to develop Lorenz curves and estimate the Gini indices. Estimating the Gini index per year and LFA involved estimating the within grid total landings of Lobster (x_h). The x_h were then ordered such that $x_1 \leq x_2 \leq x_3 \leq \ldots \leq x_{N.}$, with N representing the total number of grids within the LFA. The corresponding A_h were ordered based on the indices of the ordered x_h. The Lorenz curve was the line joining the cumulative sum of the ordered area ($p_a = \frac{\sum_{h=1}^{N} A_h}{\sum A_h}$) on the x-axis and the cumulative proportion of total abundance ($p_x = \frac{\sum_{h=1}^{N} x_h}{\sum x_h}$) on the y-axis (Myers and Cadigan 1995). The Gini index was defined as twice the area between the identity function and the Lorenz curve, with higher values representing patchy distributions.

ECOSYSTEM INDICATORS

Predator Index

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 (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 (Hanson 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, American 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 RV survey, represents a relative index of the predators in the area. Although not specific to the small Lobster habitat, this index yields information on the area, as distributions of species expand with increasing abundance; therefore, the RV survey should reflect the overall pattern of abundance for the region.

Bottom Temperature

Lobster behavior and phenology are influenced by water temperatures (Campbell and Stasko 1986). Processes such as moulting, 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 have their own assumptions, the trends in bottom temperature obtained during the same surveys where Lobster are being sampled were presented here.

OVERALL ANALYSES

General Smoothing

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

Trend Comparison of Indicators

In some LFAs multiple indicators were estimated from the available fisheries independent and fisheries dependent information. Each survey may cover only a portion of the total LFA or contain some indication of the time series trends within an LFA. Understanding the dominant trends in the time series was important to describe the status of the stock and the value of the surveys. If, for example, all surveys showed different trends for the same indicator, then the 'true' trend would be highly uncertain.

DFA was used to decompose the time series trends. It is a multivariate method specifically designed for time series data and allows the estimation of common time series trends (Zuur et al. 2003). The DFA was set in a state space framework:

$$\boldsymbol{x_t} = \boldsymbol{x_{t-1}} + \boldsymbol{w_t} \ where \ \boldsymbol{w_t} \sim MVN(0, \boldsymbol{Q_t})$$

$$\boldsymbol{y_t} = \boldsymbol{Z}\boldsymbol{x_{t-1}} + \boldsymbol{v_t} \ where \ \boldsymbol{v_t} \sim MVN(0, \boldsymbol{R_t})$$

$$\boldsymbol{x_0} \sim MVN(\boldsymbol{\pi}, \boldsymbol{\tau})$$

where the n time series of observations (**y**) were represented as a linear combination of m hidden trends (**x**) and factor loadings (**Z**). The **x** equation is the state process whereas the **y** represents the observation process.

x was a m x T matrix of states,

y was a n x T matrix of observations

w was a m x T matrix of process errors, with the process errors at time, t, are multivariate normal with mean 0 and covariance $\boldsymbol{Q_t}$

$\boldsymbol{v}$ was a n x T matrix of the observation errors which, at time t, are multivariate normal with mean 0 and covariance matrix $\boldsymbol{R_t}$

$\boldsymbol{\pi}$ is a parameter vector of length m

τ is a m x m covariance matrix, which following Zuur et al. (2003) was set to a diagonal matrix with large variances. Models were fit using the MARSS R-package (Holmes et al. 2012).

Prior to analyses individual time series were natural log and z-score transformed. During model selection a sequence of m trends from 1: n-1 were modelled; these represented the suite from one shared state for all-time series to n-1 trends across the n time series. Additionally, several covariance structures for both $\mathbf{Q_t}$ and $\mathbf{R_t}$ including diagonal and equal, diagonal and unequal, equal variance and covariance and unconstrained were examined.. Model selection was performed using AICc's following the suggestion by Zuur et al. (2003) and Holmes et al. (2012).

It is important to note both the shape of the trend and the direction of the factor loading for that trend, as an increasing trend over the time series only directly relates to the trend in the surveys that are positively loaded. Only time series factor loadings with absolute values above 0.05 were included in loadings plots.

STOCK ASSESSMENT AND DEVELOPMENT OF REFERENCE POINTS

The underlying theory of reference points 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 maximum level of removals which can be routinely taken from a stock without long-term depletion, along with the biomass at which MSY can be sustained (B_{MSY}) and the fishing mortality to maintain MSY (F_{MSY}) are estimated. Typically, reference points rely on the development of a stock recruitment relationship, however, other approaches using yield and spawner per recruit analyses (Sissenwine and Shepard 1987), or biomass dynamic modelling (Hilborn and Walters 1992) are often explored.

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 PA will be applied in practice to Canadian stocks and fisheries (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 an LRP, which delineates the critical (red) and cautious (yellow) stock status zones, and an USR which is the boundary between the cautious and healthy (green) zones (Figure 19). Within each zone, a Removal Reference (RR) establishes the maximum removal rate.

The LRP defines the boundary below which serious harm is occurring to the stock and is defined on the basis of biological criteria through Science Review Process (DFO 2009). The USR is the upper stock limit below which 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).

USR and LRP are usually defined in terms of biomass or Spawning Stock 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 MYS (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 was 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.

Part of the context for the DFO 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.

To date there have been no modelled estimates of biomass or MSY reference points developed for the Lobster stocks in LFA 34, 35, 36 or 38. Despite substantial efforts leading up to this framework, quantitative models are currently not satisfactory to describe stock status nor define reference points.

Exploring alternative measures of determining stock status, biomass, and RR 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., Cook et al. 2017, Cook et al. 2020a), where stock status zones were defined based on survey indices or commercial catch rates. These will be described in LFA specific sections below.

One further consideration in defining stock status zones and reference points from both data driven approaches and quantitative models was the determination of shifts in productivity. 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 2013a); 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 15–20 years in almost all LFA's (Cook et al. 2020b). 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).

Determining changing productivity 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 which 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 was 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 the hyperprior was set to 0.05. Across multiple types of indicators, 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).

INDICATORS

In the following sections, time series of stock status indicators will be either developed or updated for each LFA. Some indicators developed here are directly linked to stock health and status (i.e., survey trends), whereas others describe the characteristics of the population captured by the fishery (i.e., distribution) or ecosystem considerations (i.e., temperature). These indicators provide a snapshot of the Lobster stock and are derived from both fishery dependent and fishery independent data.

Indicators will be estimated for each LFA separately. It was recognized that there are likely connections between LFAs and the similar / shared processes impacting production, however, each LFA is managed separately with unique conservation measures adopted.

There are three groups of indicators in this section, primary, secondary and contextual. The primary indicators will be used to define stock status, and reference points will be developed. Secondary indicators are those in which time series trends will be updated and displayed in subsequent stock status reports; however no reference points will be developed for these indicators. The contextual indicators will be included in stock assessments, and will be infrequently updated. The indicators in each category will be identified within each section.

LFA 34

INDICATOR RESULTS

The depth stratification used in both the DFO and NEFSC spring and fall surveys were effective in reducing the overall variance in stratified estimates across all LFAs (figures not shown). The allocations across strata were suboptimal for decreasing Lobster variance, however, as these are both multispecies surveys, trade-offs in set allocation across strata are necessary.

Survey Total Abundance

This indicator represents the longest time series of data from multiple surveys as not all surveys recorded individual measurements, although, total abundance and biomass were typically monitored. Three time series (NSpr, NFal, and DFO) provide abundance indices from greater than 45 years within LFA 34. The ILTS, SFA29 and SPA3 surveys provide indices for 23, 20, and 15 years respectively. There was some variation in the patterns in abundance trends observed throughout the time series across surveys (Figure 20). DFA was used to describe the common trends across surveys. Comparing 1 to 5 potential time series trends, across different covariance structures yielded a model with two trends, and diagonal and unequal covariance structure with the lowest AICc (Table 15). Both trends show a general increasing pattern since the mid-1990s (Figure 20). Time trend 1 shows a strong cyclic pattern in abundance. The NFal, NSpr, DFO and ILTS surveys were all positively loaded on trend 1 and the cyclic patterns are evident in the three long running surveys (Figure 21, 22). This pattern will be a focus of future study.

ILTS, SPA3 and SFA29 were all positively loaded on trend 2, which shows a general decreasing pattern until the mid-1990s with a rapid increase thereafter. These three surveys only have data during the increasing period of trend 2, suggesting the earlier downward trend was from the negative loadings in Nspr and Nfal. Neither of the trends identified captured the decrease through the early 2000s present in the SFA29 survey which was characterized by a period of rapid growth in all other surveys. Perhaps this was due to catchability of the survey gear, as the scallop dredge is more size selective toward smaller Lobsters than any other gear observed here. It is therefore suggested that the scallop surveys not be used for further examination of total abundance and maybe used for the pre-recruit sized Lobsters which are better selected by this gear. Despite being a long running index, parsing this index into size components will a more descriptive basis for stock advice. Survey total abundance should be updated as a **Contextual Indicator**.

Recruit Abundance

Recruits were defined as individuals between 70 and 82 mm, which assumed these individuals would moult into the fishable component of the stock at next moult. The abundance of recruits from spring and summer surveys were considered in a pre-moult stage and therefore would be entering the fishery in the fall of the same year. The recruits from the fall surveys were considered post moult (i.e., just moulted into this size class) and would be entering the fishery in the following year. The fall surveys were lagged by one year in order to make trends comparable. As > 80% of landings in many inshore Lobster fisheries consists of newly recruited

Lobsters and exploitation rates of this stock component are very high (Cook et al. 2020a), this indicator constitutes an important component of the Lobster stock and associated fishery.

DFA was conducted on the recruit abundance from the DFO, NSpr, NFal, SFA29, SPA3, FSRS recruitment traps and the ILTS (Figure 23). The time series was constrained to 1996 to 2017 as it represents a time block with significant overlap between surveys. Model comparisons were shown in Table 16, with two time trends (states) and diagonal and unequal variance-covariance matrices on both process and observation error matrices yielding the lowest AICc. Only model comparisons from the observation error matrices were shown.

Of the two trends, the first which showed a decrease from 1996 to 2005 and an increase thereafter was positively related to the SFA29 and DFO surveys and negatively related to the NFal, NSpr and ILTS survey. The NFal and NSpr surveys do show a similar trend of decreasing recruitment in recent years, which is the inverse of most other surveys which show an increase (Figure 24, 25).

The second trend was described by a slow increase from 1996 to 2008, followed by a dramatic increase to 2016 (Figure 24, 25). The DFO, FSRS and ILTS were positively related to this trend. The scallop in SPA3 does not fit well into any of the time trends and will therefore not be used in future analyses discussed further.

By relating the two time trends to observed landings trends gives some insight into how well the recruitment trends can be used as an indicator of landings in the following season. Time trend 2 and landings had a correlation of 0.88 ($p < 0.0001$; Figure 26) whereas time trend 1 was not significantly related to the observed landings trends. These recruit survey trends are related to commercial landings in the following year and should be used as a **Secondary Indicator** of stock status in future assessments.

Survey Commercial Biomass

Commercial biomass were defined as individuals available to the fishable component > 82.5 mm CL and excluded berried females. The commercial biomass from spring and summer surveys represent the individuals remaining following the commercial fishery. The commercial biomass from the fall survey were considered post moult (i.e., just moulted into this size class) and would be part of the fishery during the current year. In LFA 34, the size at 50% maturity (SoM) is greater than the MLS for the fishery (Gaudette et al. 2014), indicating significant proportions of the overall stock have not matured or spawned prior to being becoming available to the fishery. The commercial sized survey indices in spring and summer represent the individuals that would to moult to the mature size class and become part of the spawning stock. Ensuring sufficient biomass of spawners is key to population persistence.

DFA was conducted on the commercial biomass indices from the DFO, NSpr, NFal and the ILTS (Figure 27). The scallop surveys were not included in this analysis as their selectivity for commercial sized Lobsters was low. The time series for the DFO series used the proportion of commercial to total biomass between 1999 and 2018 (0.71) to split the total biomass from the pre-1999 time series to generate a longer commercial biomass time series.

DFA model comparisons were shown in Table 17, with two time trends (states) and diagonal and unequal variance-covariance matrices on both process and observation error matrices yielding the lowest AICc. Only model comparisons from the observation error matrices were shown.

The first trend was described by an increase from 1969 to 1978, and a stable, cyclic cycle from 1978 to 1994, followed by an increase to 2018 (Figure 28 and 29). The DFO, Nspr and Nfal survey indices were positively loaded to this trend.

The second trend showed a decrease during the 1969–1996 period, was not indicative of any time series as only the ILTS had a factor loading > 0.05 and that time series does not start until 1996. From 1996 to 2016 a strong positive trend was evident, since 2016, there has been a levelling off or slight decrease.

The commercial biomass survey trends should be used as a **Primary Indicator** of stock status in future assessments. It relates to both the fishable biomass and those commercial sized individuals remaining in the spring and summer surveys and reflects those that will likely be entering the spawning component during their summer moult. Reference point development from this index will be discussed below.

Landings

The landings in LFA 34 between 1897 and 1980 had a median of 3,266 t with a range of 857 to 7,563 t (excluding the anomalous year in 1898; Figure 14). Since 1980, using spectral analyses on the detrended data (Figure 30) landings have increased on a 12 year cycle with 8–9 years of increase followed by 3–4 years of stabilization. There has been nearly a 600% increase in landings since 1980, which in the last 10 years has a median landings of 23,043 t with a range of 17,262 to 29,133 t. Landings provides the longest time series of data available for Lobsters in the region. The nominal effort (number of licences x trap limit x days fished) has largely been consistent through out much of the past 40 years. Due to the long term data available for landings, and the relatively consistent effort it comprises a useful index of stock status and the recommendation is to provide landings trends in the stock assessments as a **Secondary Indicator**.

Fishery CPUE

Fishery CPUE was modelled to account for the effect of temperature and day of season in the catch rates observed from the logs. The indicator value was the predicted catch rate on the first day of the season assuming the average temperature for the time series on that day (Figure 16–18).

The CPUE index indicates increasing abundance in recent years but is somewhat less pronounced than uncorrected values would be because temperature has been higher in recent years. Notably, on the first day of the season in years 2010 to 2014 the bottom temperature was warmer than average and the index value is lower than the predicted CPUE for those days. Still the CPUE index value for 2018 (3.31 kg/Trap Haul) is the third highest in the time series and the values for the last five years are also the five highest values in the time series. Fishery CPUE in LFA 34 will be included as a **Secondary Indicator.**

CCIR Exploitation and relF

CCIR exploitation was estimable from 2001 to 2018 using the FSRS recruitment traps. This method suggests a stable exploitation for most of the time series presented. Decreases were evident in 2013–2015 when landings were near their highest (Figure 31).

Relative fishing mortality was estimated from the DFO, ILTS, Nfal and NSpr surveys as they cover a significant proportion of the total area of LFA 34 (Figure 32). Similar to other sections a DFA was explored to determine if common trends in relative F. For comparison, the CCIR estimates of exploitation described above were included in the analyses. Results suggest a single trend was evident across the five time series (Figure 33) with diagonal and equal variance-covariance structure in the observation errors (Table 18). Each of the trawl surveys were positively loaded to the same trend, whereas the CCIR exploitation index was not

(Figure 33 and 34). This may be due to the different scope of measure of exploitation where the CCIR is reliant on the FSRS traps and the localized depletion in the areas adjacent to traps. By comparison the relF from the survey data encompasses large portions of the LFA which may be more representative. RelF was recommended as a **Primary Indicator** with reference points developed in later sections. The CCIR exploitation index should be continued as a **Contextual Indicator**.

Spatial Extent and Patchiness

The area occupied by Lobsters captured within the surveys provides an index of the distribution of the stock. Typically, as abundance increases, optimal habitat becomes fully utilized and the stock becomes more widely distributed. Regions of high localized biomass may remain as the stock is increasing or decreasing or within species with strong affinity to specific habitats. These localized patches will be characterized by patchy distributions. It is important to consider both area occupied (total distribution) as well as the patchiness of the distribution in order to better understand the stock dynamics.

For the area based indicators, only the surveys with broad coverage, the ILTS, DFO, NSpr and NFal will be considered as the two scallop surveys only cover small proportions of the overall stock area. For the patchiness indicators, the modelled results from the ILTS will not be considered as the indices of spatial variability are less directly comparable.

Across the three surveys beginning in 1970, an increasing trend is apparent in the area occupied suggesting Lobsters are found in more habitats than in earlier periods. In the DFO survey, the trend has been steadily increasing since the early 1990s. In the ILTS, although it is a slightly different metric, resulting from modelled output which represents the proportion of area with > 5 Lobsters per km^2, the area occupied by Lobsters in LFA 34 has been high since the mid-2000s (Figure 35)

Along with the increasing area occupied, the Gini index of patchiness has been decreasing in recent years suggesting more even distributed Lobster stock (Figure 36). The lower Gini index in the mid-1980s observed in the DFO survey results from the overall low abundance and the sets containing Lobsters had very few. Spatial extent and patchiness will be included as a **Contextual Indicator**.

Fishery Patchiness

Fishery patchiness represent the evenness of landings throughout the LFA. In LFA 34, since 2010, the distribution of Lobster landings has become more even across the LFA (Figure 37). This information coupled with the increased overall landings suggest that they are not only increasing in abundance in localized areas, but are broadening their habitat usage. This metric also suggests a decreased likelihood of localized depletion. Though this indicator provides an interesting snapshot of the fishing distribution, it is best suited to the infrequent updates of the **Contextual Indicators**.

Bottom Temperature

Bottom temperature trends examined from the longest time series trends of observed data in LFA 34 show strong levels of interannual variability (Figure 38). The three time series used here represent spring, summer and autumn surveys and therefore provide a broader picture of the within year trends than any survey alone. DFA was applied to these indicators, which suggested a single trend was apparent across all three (Table 19; Figure 39) and that all surveys were positively loaded to this trend. The indication of a pulse of warm temperatures during the early

1980s, which declined during the early 1990s and a consistent strong increasing trend in temperature since the mid 1990s (Figure 39 and 40). Preliminary analyses of the DFA temperature trend with trend 2 of total abundance DFA using cross correlations suggests a relationship with a seven year lag. Future work will further explore this relationship. Until the work relating temperature to production is complete bottom temperature will remain as a **Contextual Indicator**.

Predation Pressure

Predator abundance and biomass was estimated using the DFO survey series. The biomass of predators has decreased since the early 1990s in LFA 34, whereas the numerical abundance has shown less of an overall trend (Figure 41). The pulses of incoming recruitment to various predator species at small sizes as well as the overall decreases in body size of groundfish in the area contributed to the differences observed in metrics. This indicator would be strengthened by weighting the predator species and size groups using relative consumption estimates if these become available. This indicator will be included as a **Contextual indicator** due to the limited work linking predation pressure to Lobster production from this time series.

OVERALL INDICATORS FOR LFA 34

Throughout the LFA 34 section, indicators are available for both fisheries independent and fisheries dependent data. It is important to recognize that bottom contacting mobile gear do not effectively sample all habitats where Lobster reside. This is evident in the years (1970's) where the surveys did not report the capture of any Lobster, despite significant landings in the commercial fishery. The trawl survey data has the advantage that it does not rely on individual behaviour or other external factors in order to attract and capture Lobster. Furthermore, considering the sampled area of a trawl is on the order of thousands of square meters when compared to trapping or other methods that may sample 10's of meters, the representatively of trawls, in the areas they sample cannot be discounted. In LFA 34, multiple trawl surveys are conducted by several agencies using different trawl gear types, providing the opportunity to examine the temporal patterns across the different time series. By employing DFA, it was evident that several of the surveys were showing similar patterns of abundance, biomass and distributional changes which provides confidence in selecting this type of data with which to base the stock assessment.

The time series trends in abundance or biomass of several size classes of Lobster were examined across the multiple surveys, from each of these surveys two time trends were often identified, each showing a dramatic increase in recent years. This increase was also seen in the commercial catch rate data as well as the total landings. Given the relatively constant effort in this fishery it has long been presumed that landings are proportional to total abundance. There was supporting evidence from the indicators of distribution and patchiness which suggest that the LFA 34 Lobster are more evenly distributed across a much broader range of habitats than previously reported.

In terms of the ecosystem indices that were examined, bottom water temperatures have been increasing in recent years which have been related to increasing Lobster production in other areas. Similarly there was a reduction in the relative abundance and biomass of predators in the region, which was suggested to have played a role in the increased Lobster productivity (Boudreau and Worm 2010). Future studies will continue to explore the relationships between environment, species interactions and Lobster production.

The commercial biomass index and the relF indicators will be further examined as **Primary Indicators** with reference points developed in the following section. **Secondary Indicators** include landings, commercial catch rates and recruitment indices. The spatial indicators, bottom temperature, total abundance, predator abundance and biomass and CCIR exploitation will be considered **Contextual Indicators**.

REFERENCE POINTS

Survey commercial biomass trends in combination with landings information were explored for defining stock status zones and reference levels. As multiple surveys are available, and they have not been combined to create a single integrated commercial biomass trend, the methods employed in Cook et al. (2017) were used to define reference indicators and reference points. The notation used for describing the USR and LRP for each survey index will be Upper Stock Indicator (USI) and Limit Reference Indicator (LRI). Removal references for each survey will also be estimated and use the similar Removal Indicator (RI) notation. Stock status will be a combined result across survey indices relative to their respective LRI, USI and RI. The proposed definition to change between stock states is outlined in Table 20. Using this multiple survey method allows for any uncertainties or changes that may occur specific to one survey to be independently explored. Further, the change in stock status zones are based on strength of evidence from multiple data sources which increases rigor and decreases potential biases.

The applicability of survey results to define stock productivity relies on the assumption that the trends observed in the survey are characteristic of the stock and are proxies of the stock productivity and carrying capacity. For each survey examined in this framework several options were explored for defining biomass and RR indicators. The first were based on DFO (2013b) 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 levels in each time series.

Alternative reference points were proposed based on productivity periods such that the LRI_l was defined based the median biomass during lower productivity period. Similarly, USI_h was defined using the median biomass during the high productivity period as a proxy for carrying capacity *K*. Following theory based on a logistic production model, B_{msy} = K/2 and applying a $0.8B_{MSY}$, 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 a more precautionary option as a longer time series of data informs the level further dampening 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.

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

Methods

Each of the four survey time series in LFA 34 cover a different season or proportion of the area, however, each was considered as an index of biomass within the entire LFA. In order to use the entire time series of survey data from DFO surveys, the estimated proportion of commercial biomass to total biomass for years where data was available (0.71) was applied to all other years. Commercial biomass from the NEFSC surveys was estimated for the entire time series using available information.

Survey biomass trends were examined for the indication of a productivity period following methods outlined in the Development of Reference Points section above.

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 proposed 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.

Results

The BCP for the DFO survey indicated change points occurring in 1994 and 2000, moving from a relatively stable and low biomass from 1970 to 1994 moderate increases to 2000 then rapidly increasing to 2018 (Figure 42). Defining the transition from a low productivity period to a high productivity period from 2000–2018 yielded a USI_h indicated by the green line. Similarly the LRI_l was defined using the 1970–1999 period indicated by the blue line (Figure 42). The $LRI_{recover}$ and USR_f were indicated by the orange and purple lines respectively. There was little difference between the two LRI reference indicators as both were estimated from the lower productivity period, whereas the two USR reference indicators were taken from the full and high productivity periods. There was substantial differences in the productivity of the commercial Lobster biomass through this time series. RelF during the lower productivity period (RI_l) was higher than relF on the full time series (RI_f) due to the low biomasses from the survey indices. However, the survey index increased faster than the landings, which can be seen in decreasing relF estimates during recent years.

The NEFSC spring commercial biomass index showed several change points through the early low productivity phase, a substantial increase between 1999 to 2006 and a levelling off since (Figure 43). The variability during the early phases of the survey index yielded substantial differences between the LRI_l and the $LRI_{recover}$. Similarly, the transition between the lower and higher productivity periods was not as dramatic in this survey index when compared to some of the others, which yielded similar values for the USI_h and USI_f (Figure 43). The RI_l was higher than the RI_f as the survey index was substantially lower during the low productivity period. In recent years, the relF is close to the long term median, despite productivity being high.

The NEFSC fall commercial biomass index was similar to the NEFSC spring index in that there was much more variability during the 1969–2000 years when compared to the DFO survey (Figure 44). This pattern again yielded substantial differences between the two LRI indicators with $LRI_{recover}$ being lower. As with the other surveys there was a clear change point detected, however this change was in 1998. The transition from a low to a higher productivity period was evident with the post 1998 period being substantially higher, yielding the differences between the two USR reference points. The relF estimates for the fall survey were scaled differently from those in the other surveys as this was a pre-fishery biomass rather than a post fishery. Similar to the NEFSC spring relF estimates, recent years are close to the long term median (RR_f). The RI_l was lower than the RI_f for this survey index.

The ILTS survey had a shorter time series than the other surveys, however it samples much more of the Lobster habitat than any of the others. The survey begins in 1996, which was prior to the change point detected in the other surveys, however without a long time series of lower productivity. This shortened time series led to the overlap in LRI_l and $LRI_{recover}$ as the five lowest non-zero biomasses coincided with the survey data points prior to the first change point detected in 1999. Two other changes points were detected in 2005 and 2009, however these appear along the continuum of increasing productivity, and therefore the high productivity period was considered 1999–2018 (Figure 45). In the other series, the USI_f was below the USI_h due to the long period of low productivity, this was not the case for the ILTS as most of the time series was in the high productivity period, and USI_f would likely approximate K rather than 0.8 B_{MSY}. The gap between the RI_f and the RI_l was similar for the ILTS and the other surveys. Although the long term low productivity period (pre-1998) was not surveyed in this data set, the estimates of RI_l still provide a valuable reference as the survey has the most comprehensive coverage in this LFA.

Overall Reference Points

The proposed USI, LRI and RI for these commercial biomass survey indices would be the USI_h from the high productivity period, the $LRI_{recover}$ and the RR_l as they best represent the suite of potential production of the Lobster in the area. Trawl survey data do not sample all habitats inhabited by Lobster as can be clearly seen in the years where biomass estimates were zero, despite continued landings, albeit at low levels compared to current levels. The $LRI_{recover}$ gives an index of biomass from the surveys from which the stock was able to expand to current levels. Similarly, the RI_l, representing the derived RR from the low productivity period, would be an appropriate choice as the stock reached the current biomasses with removals at this rate. Using the USI_h reflects the current high production potential of Lobster in the region. The current Lobster stocks in many areas along the east coast of North America are at the highest biomasses ever observed. Assuming that the current population is approaching or at carrying capacity and these survey indices provide a true index of biomass, then the B_{MSY} proxy of 0.8 as an upper stock indicator would be an appropriate reference level.

Applying the proposed reference indicators to the running medians of the survey and relF trends can be seen in the phase plots (Figure 46). Combining these reference indicators to define the stock status can be done through the examination of these plots. As the current points for commercial survey biomass is well within the healthy zone for all 4 of the surveys. Furthermore as the relF is below the RI in all four surveys indices then the stock would not be considered overfished. Through these phase plots it can be inferred that the stock was in the cautious zone between 1970 and 1999, relative to current productivity, as all 4 surveys fell below respective USIs. LFA 34 has never been in the critical zone, and has only been considered overfished during several short periods during the 1970s and 1980s.

COMBINED LFA 35–38

The depth stratification used in the DFO survey was effective in reducing the overall variance in stratified estimates across all LFA 35–38. The set allocations across strata were suboptimal for decreasing Lobster variance, however, as this is a multispecies surveys, tradeoffs in set allocation across strata are necessary.

Survey Total Abundance

The total abundance of Lobster from the DFO survey in LFA 35–38 showed a strong increasing trend since 2010 (Figure 47). There were slight increases in Lobster abundance in the early 2000s, however there rapid increase in 2010 to 2013 and variability around a higher production level was evident. As with the total abundance trend in LFA 34, this indicator will be considered a **Contextual Indicator**, as partitioning this index into recruiting and commercial size classes will provide a better picture of the Lobster stock across these LFAs.

Survey Recruit Abundance

Survey recruit abundance (70–82 mm CL) has followed a similar pattern to the total abundance, with increases from 2010 to 2013, and then variable catch rates at a substantially higher level than had been observed in the time series (Figure 48). This indicator will be considered a **Secondary Indicator** as it provides information on the incoming recruitment to the fishery in the following year.

Survey Commercial Biomass

Extending the commercial survey biomass index to years prior to 1999 when size information was not collected was performed using the ratio of commercial to total biomass estimated between 1999 and 2018 (0.746). The time series of commercial biomasses showed a pulsed increase in 2000–2004 which subsequently declined to 2010 and increased to 2013 where biomass has remained high and variable since (Figure 49). As with LFA 34, the SoM for the Bay of Fundy is substantially greater than the MLS, and as such, the commercial biomass available post fishery will constitute those individuals entering the spawning population in the upcoming year. This commercial biomass index closely follows the landings index for the combined area (see below). This index will be considered a **Secondary Indicator** as it represents an important component of the Bay of Fundy stock, and although we cannot estimate trends for each LFA due to low sample sizes, the combined fisheries independent indicator should be continue to be monitored.

Landings

Landings in the combined LFA 35–38 showed a strong increasing trend since the mid-1990s to 2000, a levelling off between 2001 and 2009 and rapid increases to 2016 (Figure 50). There was more variability across the specific LFAs in this combined indicator, however this represents landings within the entire Bay of Fundy. Landings will be separated by LFA for the indicator trends, however, as relF is estimated below for the combined area, using the combined landings was determined valuable.

Relative Fishing Mortality

The estimates of relF have been following a similar pattern to the commercial biomass index with decreases between the late 1990s and early 2000s, increases to 2010 then decreases to 2013 with variable but low estimates of relF since (Figure 51). Tracking the relF for the Bay of Fundy provides a depiction of the patterns observed across the larger area and should be include as a **Secondary Indicator**.

Spatial extent and patchiness

The area occupied has been increasing since the mid-1990s and is currently high and stable (Figure 52). Further, the Gini index of patchiness decreased in the late 1990's early 2000's and has been low and variable since (Figure 53). These indicators suggest that Lobster are increasing their overall habitat usage. The difference between time periods in the area occupied was more pronounced than the change in the Gini index, which suggests that there remain more variability in the Lobster catch rates, however they are overall found in more habitats. These indicators will be included as **Contextual Indicators** as the long term patterns are valuable to track.

Bottom Temperature

The summer bottom temperature in the Bay of Fundy increased dramatically between 2010 and 2011 (Figure 54). The median temperature prior to 2010 was 7.75 ºC which increased to a median of 9.05 ºC thereafter. The dramatic increase in landings and survey abundance within the Bay of Fundy occurred at the same time as summer temperatures increased. Further research should be focussed on expanding previous work on the relationship between temperature, Lobster productivity and bioenergetics. Bay of Fundy bottom temperatures should be included as a **Contextual Indicator** in stock assessments until such time the functional relationships between temperature and production are understood.

Predation Pressure

Predator abundance and biomass was estimated using the DFO survey series. The biomass of predators has decreased since the late 1980s in LFA 35–38, whereas the numerical abundance has shown less of an overall trend (Figure 55). The pulses of incoming recruitment to various predator species at small sizes as well as the overall decreases in body size of groundfish in the area contributed to the differences observed in metrics. The upward increase in 2015 and 2016 was largely due to several strong year-classes of haddock. This indicator would be strengthened by weighting the predator species and size groups using relative consumption estimates if these become available. This indicator will be included as a **Contextual indicator** due to the limited work linking predation pressure to Lobster production from this time series.

OVERALL INDICATORS LFA 35–38

The DFO survey indicators provide information for the overall patterns in the Bay of Fundy, LFAs 35–38. There were insufficient numbers of tows to estimate robust indicators for any individual LFA, however the combined data allows for estimation that can be considered as secondary and contextual indicators for the LFA specific stock assessments.

Across these LFAs, there has been an increase in total, commercial and recruit abundance since the early 2000s, and particularly since 2010. These increases in relative abundance coincide with dramatically increasing bottom water temperatures in the area. The increasing water temperatures may influence the availability of Lobster in these LFAs to the survey, as the DFO survey does not sample in depths shallower than 50m, which are important Lobster habitats.

Lobster directed fisheries independent surveys in each of the Bay of Fundy LFAs with sufficient sampling intensity would be a valuable addition to the stock assessments for these areas.

LFA 35

SCALLOP SURVEY RECRUIT ABUNDANCE

The abundance of Lobster recruits from scallop survey tows within LFA35 have been increasing in recent years (Figure 56). Prior to and post 2008, there are marked differences in the median abundance of Lobster going from 14 Lobsters per drag to 35.4 Lobsters/km^2. The coverage of this scallop survey provides information on the Lobster recruitment through large portions of the LFA, as such this survey should be considered a **Secondary Indicator** in future Lobster stock assessments.

FISHERY CPUE

Fishery CPUE was modelled to account for the effect of temperature and day of season in the catch rates observed from the logs. The indicator value is the predicted catch rate on the first day of the season assuming the average temperature for the time series on that day (Figure 16–18)

The CPUE index indicates increasing abundance in recent years but is somewhat less pronounced than uncorrected values would be because temperature has been higher in recent years. Notably on the first day of the season in the middle of Oct 2010–2014 the bottom temperature was warmer than average and the index value is lower than the predicted CPUE for those days. Still the CPUE index values for this period (3.9–4.4 kg/Trap Haul) were the highest in the time series, while the index has been declined slightly in the last three years and was 3.84 kg/TH in 2018. Fishery CPUE is the most comprehensive data set for providing stock status advice in LFA 35 and will be included as a **Primary Indicator** with reference points developed below.

RECRUITMENT TRAP RECRUIT ABUNDANCE

The modelled recruitment trap abundance trend in LFA 35 varied without trend for the period 2006–2018 (Figure 57). There has been variable participation in this recruitment trap monitoring throughout the time series (Table 8), which decreases the value of this indicator. Recruitment trap abundance will be considered a **Contextual Indicator** given these data constraints.

LANDINGS

The landings in LFA 35 between 1947 and 1984 had a median of 134 t with a range of 75 to 184 t (Figure 3). Between 1984 and 1994 there was a marginal increase to a median of 250.5 t (range 226–330 t), from 1994 to 2010 there was a steady increase in landings to 1,898 t. In the most recent years, LFA 35 landings have more than doubled to a record high in 2014 of 3941t. Landings provides the longest time series of data available for Lobsters in the region. The nominal effort (number of licences x trap limit x days fished) has largely been consistent through out much of the past 40 years. Due to the long term data available for landings, and the relatively consistent effort it comprises a useful index of stock status and the recommendation is to provide landings trends in the stock assessments as a **Secondary Indicator**.

FISHERY PATCHINESS

Fishery patchiness represent the evenness of landings throughout the LFA. There was no trend evident in the In LFA 35 (Figure 58) as the majority of landings result from only a few grids (Figure 14) which have been relatively consistent over time. Despite this, it will be updated in future frameworks as a **Contextual Indicator.**

OVERALL INDICATORS FOR LFA 35

Throughout the LFA 35 as well as the 35–38 combined sections, indicators are available for both fisheries independent and fisheries dependent data. LFA 35 lacks the fisheries independent information for the development of primary indicators and reference points as only a single survey with between 10 and 15 stations are performed annually. Developing **Secondary Indicators** based on the combined data from LFA 35–38 provides some context to the overall area. The scallop survey data provides some indication of recruit abundance within the LFA, however, the gear selectivity may not provide a robust primary indicator of abundance and thus will remain a **Secondary Indicator** of stock status. The FSRS recruitment trap abundance series has few participants, and shows little trend despite the dramatic changes in the fishery, it will therefore only be included as a **Contextual Indicator**. The fisheries dependent commercial catch rate model was selected as the **Primary Indicator** of stock status as it provides information on the effort correct catches in the area. Total landings is the longest time series of data within the LFA and as such it will remain a **Secondary Indicator**.

REFERENCE POINTS

Prior to this framework the stock status of the Bay of Fundy LFAs (LFA 35–38) were assessed annually using combined data sets for both fisheries dependent and fisheries independent data. Although the LFAs may share a common Lobster resource, identifying trends and references points within the specific LFAs is a more precautionary approach. The longest time series of data for LFA 35 is landings data, however, without effort corrections the usefulness of landings as a primary indicator of abundance is tenuous, particularly given that this is an effort controlled fishery. Any changes in management controls (i.e., if the fishery entered the cautious zone) would affect the relationship between landings and reference points.

Commercial catch rates have the advantage over total landings as an indicator of abundance or biomass as changes in the level of effort are directly accounted for in their estimation. Specifically, if changes in management structure occur which directly impact the level of effort in the fishery, these will be reflected in the estimated catch rates.

Catch rates have been used elsewhere as indices of abundance or biomass (Cook et al. 2018), however, as mentioned above, other factors have been shown to influence the strength of the relationship. In Lobster, catch rates are known to be influenced by environmental conditions (wind, temperature; Drinkwater et al. 2006), moult stage, and reproductive state. Additionally, time series of catch rates can be influenced by either hyperstability or hyperdepletion, whereby catch rates change slower (or faster) than abundance changes (Hilborn and Walters 1992). Although neither pattern has been documented for American Lobsters, the South Australian Rock Lobster showed hyperdepletion in catch rates as the fishery expanded and catch rates decreased faster than overall abundance due to localized depletion of high density areas (Lewis 1981, 1983). Using the standardized CPUE model where temperature is included as an explanatory factor makes this index more robust.

The time series of commercial catch rates for LFA 35 is short, 2006–2018, which covers the current high productivity period and a lower productivity period from 2006–2010 (Figure 59). Using the median modelled CPUE during the 2011–2018 high productivity period as a proxy for carrying capacity (K), and applying the 80% and 40% of the B_{MSY} proxy, yields USR and LRP values shown in Figure 59. The current CPUE index is well above the USR and has been above for the duration of the time series. The three-year running median will remain the CPUE indicator to compared to the reference points. As in the CPUE models, year was treated as a factor which reduces the constraint of adjacent years possessing similar estimates as interannual variability in recruitment of Lobster stocks can be high. By using the temperature adjusted catch rate model, the impact of interannual climate variability was directly included in the reference point estimation, improving the robustness of the stock assessment results and statements on stock status into the future.

There are currently no analyses which have provided suitable estimates of exploitation within LFA 35, as such a RR cannot be identified at this time.

LFA 36

SCALLOP SURVEY RECRUIT ABUNDANCE

The abundance of Lobster recruits from scallop survey tows within LFA36 was very low between 1999 and 2005 at a median of 4.6 Lobsters/km^2, increased to 2010 and then has been high and stable since with a median of 49.3 Lobsters/km^2 (Figure 60). The coverage of this scallop survey provides information on the Lobster recruitment through large portions of the LFA, as such this survey should be considered a **Secondary Indicator** in future Lobster stock assessments.

LANDINGS

The landings in LFA 36 between 1947 and 1980 had a median of 227 t with a range of 47 to 338 t (Figure 3). Between 1981 and 1996 there was a marginal increase to a median of 268.5 t (range 156–427 t), from 1997 to 2010 there was a steady increase in landings to 1,594 t. In the most recent years, LFA 36 landings have more than doubled to a record high in 2018 of 4,022 t. Landings provides the longest time series of data available for Lobsters in the region. The nominal effort (number of licences x trap limit x days fished) has largely been consistent through out much of the past 40 years. Due to the long term data available for landings, and the relatively consistent effort it comprises a useful index of stock status and the recommendation is to provide landings trends in the stock assessments as a **Secondary Indicator**.

FISHERY CPUE

Fishery CPUE was modelled to account for the effect of temperature and day of season in the catch rates observed from the logs. The indicator value is the predicted catch rate on the first day of the season assuming the average temperature for the time series on that day.

The CPUE index indicates increasing abundance in recent years (2013–2018; Figure 16–18). It is somewhat less pronounced than uncorrected values would be because temperature has been higher in recent years but this effect is not as pronounced in LFA 36 as it was in the other LFAs. The CPUE index values for the 2013–2018 period range from 3.29–3.92 kg/TH were higher than the previous 6 years (2007–2012) which ranged from 2.21–2.71 kg/TH. The index value for 2018 was 3.86 kg/TH, which is slightly higher than the model predicted value for 2017-11-15 because the water temperature was actually cooler than average on that day. Fishery CPUE is the most comprehensive data set for providing stock status advice in LFA 36 and will be included as a **Primary Indicator** with reference points developed below.

FISHERY PATCHINESS

Fishery patchiness represent the evenness of landings throughout the LFA. There was no trend evident in the In LFA 36 (Figure 61) as the majority of landings result from only a few grids (Figure 14) which have been relatively consistent over time. Despite this, it will be updated in future frameworks as a **Contextual Indicators.**

OVERALL INDICATORS FOR LFA 36

Throughout the LFA 36 as well as the 35–38 combined sections, indicators are available for both fisheries independent and fisheries dependent data. LFA 36 lacks the fisheries independent information for the development of primary indicators and reference points as only a single survey with between 10 and 15 stations are performed annually. Developing

Secondary Indicators based on the combined data from LFA 35–38 provides some context to the overall area. The scallop survey data provides some indication of recruit abundance within the LFA, however, the gear selectivity may not provide a robust primary indicator of abundance and thus will remain a **Secondary Indicator** of stock status. The fisheries dependent commercial catch rate model was selected as the **Primary Indicator** of stock status as it provides information on the effort correct catches in the area. Total landings is the longest time series of data within the LFA and as such it will remain a **Secondary Indicator**.

REFERENCE POINTS

Prior to this framework the stock status of the Bay of Fundy LFAs (LFA 35–38) were assessed annually using combined data sets for both fisheries dependent and fisheries independent data. Although the LFAs may share a common Lobster resource, identifying trends and references points within the specific LFAs is a more precautionary approach. The longest time series of data for LFA 36 is the landings data, however, without effort corrections the usefulness of landings as a primary indicator of abundance is tenuous, particularly given that this is an effort controlled fishery. Any changes in management controls (i.e., if the fishery entered the cautious zone) would affect the relationship between landings and reference points.

Commercial catch rates have the advantage over total landings as an indicator of abundance or biomass as changes in the level of effort are directly accounted for in their estimation. Specifically, if changes in management structure occur which directly impact the level of effort in the fishery, these will be reflected in the estimated catch rates.

Catch rates have been used elsewhere as indices of abundance or biomass (Cook et al. 2018), however, as mentioned above, other factors have been shown to influence the strength of the relationship. In Lobster, catch rates are known to be influenced by environmental conditions (wind, temperature Drinkwater et al. 2006), moult stage, and reproductive state. Additionally, time series of catch rates can be influenced by either hyperstability or hyperdepletion, whereby catch rates change slower (or faster) than abundance changes (Hilborn and Walters 1992). Although neither pattern has been documented for American Lobsters, the South Australian Rock Lobster showed hyperdepletion in catch rates as the fishery expanded and catch rates decreased faster than overall abundance due to localized depletion of high density areas (Lewis 1981, 1983). Using the standardized CPUE model where temperature is included as an explanatory factor will make this index more robust.

The time series of commercial catch rates for LFA 36 is short, 2005–2018, which covers the current high productivity period and a lower productivity period from 2005–2012 (Figure 62). Using the median modelled CPUE during the 2013–2018 high productivity period as a proxy for carrying capacity (K), and applying the 80% and 40% of the B_{MSY} proxy, yields USR and LRP shown in Figure 62. The current CPUE index is well above the USR and has been above for the duration of the time series. The three-year running median will remain the CPUE indicator which will be compared to the reference points, as in the CPUE models, year was treated as a factor which reduces the constraint of adjacent years possessing similar estimates as interannual variability in recruitment of Lobster stocks can be high. By using the temperature adjusted catch rate model, the impact of interannual climate variability was directly included in the reference point estimation, improving the robustness of the stock assessment results and statements on stock status into the future.

There are currently no analyses which have provided suitable estimates of exploitation within LFA 36, as such a RR cannot be identified at this time.

LFA 38

SCALLOP SURVEY RECRUIT ABUNDANCE

The abundance of Lobster recruits from scallop survey tows within LFA38 was very low between 1999 and 2008 at a median of 160 Lobsters/km^2, four years of high density (median 480 Lobsters/km^2) followed by four years of a low density (median 239 Lobsters/km^2) with the last two years having high abundance (median 444 Lobsters/km^2; Figure 63). The coverage of this scallop survey provides information on the Lobster recruitment through large portions of the LFA, however, the changes in recruitment do not match with changes in commercial catch rates or landings. As such this survey should be considered a **Contextual Indicator** for future Lobster stock assessments.

LANDINGS

The landings in LFA 38 between 1947 and 1988 had a median of 325 t with a range of 170 to 450 t (Figure 3). Between 1989 and 1997 there was a marked increase to a median of 512 t (range 467–661 t), from 1997 to 2013 there was a steady increase in landings to 2,682 t. In the most recent years, LFA 38 landings have more than doubled to a record high in 2016 of 5,711 t. Landings provides the longest time series of data available for Lobsters in the region. The nominal effort (number of licences x trap limit x days fished) has largely been consistent through out much of the past 40 years. Due to the long term data available for landings, and the relatively consistent effort it comprises a useful index of stock status and the recommendation is to provide landings trends in the stock assessments as a **Secondary Indicator**.

FISHERY CPUE

Fishery CPUE was modelled to account for the effect of temperature and day of season in the catch rates observed from the logs. The indicator value is the predicted catch rate on the first day of the season assuming the average temperature for the time series on that day (Figure 17, 18).

The CPUE index indicates increasing abundance in recent years (2014–2018). It is somewhat less pronounced than uncorrected values would be because temperature has been higher in many recent years. Notably on the first day of the season in the middle of Nov 2011, 2014, 2015 and 2016 the bottom temperature was warmer than average and the index value is lower than the predicted CPUE for those days. The CPUE index values for the 2014–2018 period range from 4.69–5.57 kg/TH were higher than the previous 5 year (2009–2013) which ranged from 2.40–3.32 kg/TH. The index value for 2018 was 4.81 kg/TH, which is slightly higher than the model predicted value for 2017-11-15 because the water temperature was actually cooler than average on that day. Fishery CPUE is the most comprehensive data set for providing stock status advice in LFA 38 and will be included as a **Primary Indicator** with reference points developed below.

FISHERY PATCHINESS

Fishery patchiness represent the evenness of landings throughout the LFA. There was a slight decrease in the patchiness of landings between 2010 and 2012 in LFA 38, and has been low and stable since (Figure 64). This indicator will be updated in future frameworks as a **Contextual Indicators.**

FLAGG COVE DIVE SURVEY

The Flagg Cove dive transect survey was conducted for many of the years between 1989–2015. The index of Lobster density derived from this data was shown in Figure 65. This survey has consistently found high proportions of berried females in the area (Figure 65). However, the overall density of Lobster observed during the survey was quite variable, and did not follow similar trends to the commercial catch rates or total landings, nor did it follow the trends evident in the scallop survey, suggesting the factors affecting the indicator of abundance from this survey was not reflective of the overall population.

OVERALL INDICATORS FOR LFA 38

Throughout the LFA 38 as well as the 35–38 combined sections, indicators are available for both fisheries independent and fisheries dependent data. LFA 38 lacks the fisheries independent information for the development of primary indicators and reference points as only a single survey with between 10 and 15 stations are performed annually. Developing **Secondary Indicators** based on the combined data from LFA 35–38 provides some context to the overall area. The fisheries dependent commercial catch rate model was selected as the **Primary Indicator** of stock status as it provides information on the effort correct catches in the area. Total landings is the longest time series of data within the LFA and as such it will remain a **Secondary Indicator**.

REFERENCE POINTS

Prior to this framework the stock status of the Bay of Fundy LFAs (LFA 35–38) were assessed annually using combined data sets for both fisheries dependent and fisheries independent data. Although the LFAs may share a common Lobster resource, identifying trends and references points within the specific LFAs is a more precautionary approach. The longest time series of data for LFA 38 is the landings data, however, without effort corrections the usefulness of landings as a primary indicator of abundance is tenuous, particularly given that this is an effort controlled fishery. Any changes in management controls (i.e., if the fishery entered the cautious zone) would affect the relationship between landings and reference points.

Commercial catch rates have the advantage over total landings as an indicator of abundance or biomass as changes in the level of effort are directly accounted for in their estimation. Specifically, if changes in management structure occur which directly impact the level of effort in the fishery, these will be reflected in the estimated catch rates.

Catch rates have been used elsewhere as indices of abundance or biomass (Cook et al. 2018), however, as mentioned above, other factors have been shown to influence the strength of the relationship. In Lobster, catch rates are known to be influenced by environmental conditions (wind, temperature; Drinkwater et al. 2006), moult stage, and reproductive state. Additionally, time series of catch rates can be influenced by either hyperstability or hyperdepletion, whereby catch rates change slower (or faster) than abundance changes (Hilborn and Walters 1992). Although neither pattern has been documented for American Lobsters, the South Australian Rock Lobster showed hyperdepletion in catch rates as the fishery expanded and catch rates decreased faster than overall abundance due to localized depletion of high density areas (Lewis 1981, 1983). Using the standardized CPUE model where temperature is included as an explanatory factor will make this index more robust.

The time series of commercial catch rates for LFA 38 is short, 2005–2018, which covers the current high productivity period and a lower productivity period from 2005–2013 (Figure 66). Using the median modelled CPUE during the 2014–2018 high productivity period as a proxy for carrying capacity (K), and applying the 80% and 40% of the B_{MSY} proxy, yields USR and LRP shown in Figure 66.

The current CPUE index is well above the USR and has been above for the duration of the time series. The three-year running median will remain the CPUE indicator which will be compared to the reference points, as in the CPUE models, year was treated as a factor which reduces the constraint of adjacent years possessing similar estimates as interannual variability in recruitment of Lobster stocks can be high. By using the temperature adjusted catch rate model, the impact of interannual climate variability was directly included in the reference point estimation, improving the robustness of the stock assessment results and statements on stock status into the future.

There are currently no analyses which have provided suitable estimates of exploitation within LFA 38, as such a RR cannot be identified at this time.

OVERALL DISCUSSION OF INDICATORS AND PROPOSED PRIMARY, SECONDARY AND CONTEXTUAL CATEGORIES

Prior to 2018, landings was used as one of the primary stock status indicators for all LFAs across DFO Maritimes region (Tremblay et al. 2012), as well as in other regions (DFO 2013). In recent stock assessments other LFAs are moving toward commercial catch rates and other indices to define stock status (Cook et al. 2017, Cook et al. 2018). Landings, commercial catch rates and survey indices were all used to assess stock status in LFA 34 and LFA 35–38 combined. Despite having multiple indicators, there were no recommendations on how to define stock status if indices diverged. In this framework the primary stock status indicator was moved to survey indices for LFA 34 and modelled commercial catch rates with reference points defined based on productivity regimes.

In the current framework, the proposal would be to define stock status on an LFA by LFA basis, as the fisheries are managed separately, and by combining indicators across regions may mask changes within each LFA, thereby making results less precautionary.

In LFA 34 there are multiple, long term fisheries dependent and fisheries independent data sets to examine the patterns of relative abundance and productivity. Using DFA, it was suggested that many of these time series had similar trends and are likely reflective of the overall changes in population productivity. Using the fisheries independent bottom trawls as the primary stock status indicators provides information that is not influenced by fisheries behaviour or market changes. Having the information from multiple trawl surveys performed at different times of year using different gear types allows for increased confidence in the results provided. Identifying productivity periods and setting reference points based on the best available information which assume that the current population has approached carrying capacity provides precautionary reference points for the fishery. Removal references based on the relF for each survey index were also proposed based on the different productivity periods. By only combining the surveys in a qualitative manner after identifying the survey status relative to USIs, LRIs and RIs allows for the strength of evidence to be fully utilized. Secondary indicators of landings, temperature corrected commercial catch rates, FSRS recruit catch rates all provide extra information on the current status of the stock and the fishery.

In LFA 35–38 a common approach was applied to each LFA. The time series of temperature adjusted commercial catch rates were used as the primary indicator of stock status for each LFA. Using the 13 and 14 years of commercial catch rates with which to develop reference points, an analysis was conducted to identify the high productivity period. This time period was applied as a proxy for carrying capacity, K, with 0.8 and 0.4 B_{msy} used as USR's and LRP's respectively. Using the modelled commercial catch rates which include temperature adjustments improves the robustness of this index as the interannual variation in catch rates due to temperature changes were accounted for in the index and are integrated directly into the currently proposed reference points. The DFO trawl survey data provides information on LFAs 35–38 but there are insufficient numbers of tows within each LFA to provide robust indices of status. Secondary indicators from this trawl survey for the combined sets from LFA 35–38 will be included in stock assessments. In addition, total landings, and in LFA 35 and 36, recruit abundance indices from the scallop directed dredge surveys will be included as secondary indicators.

BIOLOGICAL GUIDANCE ON HARVEST CONTROL RULES

Harvest Control Rules (HCR) refer to the management actions that come into effect when the stock status enters the cautious zone and are intended to facilitate the stocks' rebuilding back into the healthy zone. In output controlled fisheries HCRs result in some level of quota reduction. In input controlled fisheries, such as the Lobster fishery, appropriate HCR are less obvious. Therefore the process for defining effective HCRs requires careful thought, analysis and consultation with industry. Various input control mechanisms have been proposed including: trap limit reduction, season length reduction, increase in MLS, window size prohibition. One of the goals for this stock assessment framework was placing these conservation measures in a biological context that will allow industry and resource managers to make informed decisions from a biological productivity prospective. To accomplish this, a simulation model was developed to track a Lobster cohort from late juvenile to adult stages through moulting, reproduction, fishing, and natural mortality. The model incorporates regionally specific parameters to evaluate potential HCRs. The outputs of the simulation models include total landings and egg production and are the metrics used to determine the biological impacts of the type and relative magnitude of the HCRs.

MOULTING

Growth is a major component of the biological guidance provided by the simulation analysis. Lobsters undergo a punctuated growth process whereby growth occurs with each moult. Growth is therefore described by the combination of moult probability and moult increment. In Lobster, moult probability decreases with an increase in carapace size, and is sexually dimorphic whereby females' moult probability decreases faster with size than males. The growth increments between moults are variable and increase with carapace size but at a higher rate in males than females. In general, Lobster from 60–80 mm moult approximately once a year, 140 mm–160 mm every second year and Lobster between 180–200 mm likely moult every 3 to 4 years (Campbell 1983). Two moults during a single season can occur and has been reported in Lobster over 60 mm in the Southern Gulf of St. Lawrence (Comeau and Savoie 2001). Within regions the length increment per moult is relatively consistent across years, but is spatially variable (Aiken and Waddy 1986). The most influential external factor that has been identified to influence moult timing and frequency is temperature. Lobster in areas with warm late-spring temperatures grow faster as high temperatures allow Lobsters double moult and often have larger growth increments than those Lobster in regions characterized by colder temperatures (Comeau and Savoie 2001). Given the influence of temperature on the moulting process a relationship based on cumulative degree days above 0 ºC will inform the growth component in the simulation model for each LFA.

SIMULATION METHODS

Each simulation run tracks 1,000 individual Lobsters from CL 50 mm to 200 mm in 5 mm bins as they moult, mature, produce young, and die naturally or are captured in the fishery. Total landings and reproductive potential of the cohort are used to evaluate the effect of various HCRs. The basis of the simulation is a moult process model:

$$N_{t+1,\, l,\, i,\, j+1} = N_{t,\, l,\, i,\, j} * (1 - pM)$$

$$N_{t+1,\, l+iM,\, i+1,\, 1} = N_{t,\, l,\, i,\, j} * pM$$

where $N_{t,l,i,j}$ is the number of Lobsters in time step t, of CL l, that have moulted i times and j time steps have passed since their last moult. The probability of Lobsters moulting (pM) is a function of the CL (l) and the sum of the daily bottom temperatures (*degree days*) since the last moult (j). The moulting increment (iM) is a function of the CL (l) which differs for males and females.

Bottom Temperature

Area specific growth rates incorporate temperature profiles characteristic of the area, which are integrated into the moult probability model. Lobsters in areas that have warmer bottom temperatures have an increased moult frequency at a particular carapace size compared to areas with cooler bottom temperatures. The specific relationship was described by the number of degree days since the last moult. Therefore the simulation model required regional specific estimates of average daily bottom temperature in the Lobster habitat.

The FSRS temperature data is a good representation of bottom temperature of Lobster habitat during the fishing season, but it is important to know bottom temperature for the remainder of the year as it affects biological processes such as growth and reproduction. A deterministic temperature model was developed to predict the daily bottom temperatures for each LFA, in order to calculate accumulated degree days to inform the moult process. The FSRS data was the primary data source for the temperature model which also included a time series of observed bottom temperature data from a variety of sources both inshore and offshore (Figure 67). Depth was taken into consideration but a fully spatial-temporal temperature model, though desirable, was not attempted due to its high computational demands and the low data density in inshore areas.

The temperature model was developed as a GAM estimated through the “mgcv” R package (Wood 2016) to predict temperature based on area, depth and a continuous time variable y in decimal years. Harmonics of decimal year ($sin(2\pi y)$, $cos(2\pi y)$) were used to account for the annual cycle and seasonal cycles in temperature. Depth relationships were only significant in its impact on the seasonal components. Smoothing functions (s) were based on nonparametric cubic splines.

$$\text{Temperature} \sim \text{Area} + s(y) + s(y, by=\text{Area}) + \sin.y + \cos.y + s(\text{Depth}, \sin.y, \cos.y)$$

The inter-annual variability for each area can be more clearly visualized when predicting at a 25 m depth on June 1 of each year (Figure 68).

Daily bottom temperature predictions were used to calculate degree days for input into the simulation model.

Tagging Data

Mark-recapture tagging data with complete size information at mark and recapture were used to define the moulting process. Lobster growth through the moulting process was a characterized as a function size, time and temperature. The available tagging data come from studies that were conducted in the 1980s and 1990s in the Bay of Fundy, Southwestern Nova Scotia and Cape Breton (Campbell and Stasko 1986, Campbell 1989, Tremblay and Drinkwater 1997; Figure 69). Using the complete data set allowed sufficient contrast in the growth temperature relationship allowing for better characterization of the potential variability and assuming that the area differences can be largely explained by the effect of temperature.

Moult probability

The tagging data was used to estimate the relationship between moult probability and CL and degree days since last moult. Recaptured Lobsters that increased their CL by more than 4% since release were assumed to have moulted. The temperature model was used to calculate the number of degree days between release and recapture dates with the location of recapture used as the area to define temperature trends. A binomial generalized linear model of the occurrence of moulting was fit to the tagging data where degree days and CL were the linear predictors. The resulting predicted probabilities for moulting were used in the simulation model to determine the number of Lobsters moulting for a given length bin and number of degree days since last moult (Figure 70).

Moult Increment

Moult increment was estimated from the tagging data. In order to select Lobsters that presumably have moulted only once, Lobsters which had increased in size by at least 4% between recapture and release were included in the analysis. The size difference at various initial carapace sizes were modelled separately for each sex using the R package rstanarm (Stan Development Team 2016) in order to characterize the variability in moult increment (Figure 71)

Size of maturity

A variety of studies using a suite of methods have been used to assess size of maturity (Reeves et al. 2011). Due to challenges assimilating the various data sources, a comprehensive analysis that integrates size of maturity data across the Maritimes region has not been done. Until this analysis is completed the static SoM model for LFA 34 was used (Figure 72).

Fecundity

The fecundity-CL relationship of Campbell and Robinson (1983) was used to quantify the total reproductive potential of a given cohort under specific environmental and fishery pressures.

$$\text{Fecundity} = 0.00256 * CL^{3.409}$$

Natural mortality

Natural mortality is an important parameter that influences the results of the simulation analysis yet there is very little information available to inform it. For this analysis natural mortality was assumed to be 0.15 constant across all sizes and areas.

Exploitation

For LFA 34 two exploitation scenarios were tested. A high exploitation scenario using the average exploitation estimates from the CCIR analysis and a lower exploitation scenario using the average relative exploitation from the survey. They were both converted to annual fishing mortality rates,

$$F = \frac{-\log(1 - E)}{t}$$

where E is the CCIR exploitation or relF and t is the length of the season. Fishing mortality was applied to the simulated population in each commercial sized length bin and time step as

$$N_{t+1,l} = N_{t,l} \cdot e^{F_l \cdot s}$$

where F_l is the fishing mortality for a given length bin and s is the duration (in decimal years) of the fishing season within a given time step. This approach allows for the examination of small changes in the timing and duration of the fishing season.

Reproduction

The simulation was run separately for males and females with berried females treated as a separate population component within the female run. The Size of Maturity parameters are used to determine the proportion of berried females in each length bin. Mature females were assumed to have mated at the same time as moulting with gestation and brooding requiring 320 and 360 days respectively (Talbot and Helluy 1995). Variability in gestation and brooding times were not included in the simulation. Once the brooding period is complete the eggs are released and are included in the cumulative total of egg production and the females return to the exploitable population where are susceptible to fishing mortality. The berried female component of the population is only susceptible to natural mortality.

Scenarios

The different HCRs tested using the simulation method included *changes in MLS*, *change in the duration of the fishing season*, *protection of Lobsters above MLS, and protection of a window size of Lobsters*. Simulations of trap limits and v-notching were suggested as potential HCRs, but these were not tested using the currently developed simulation model as the relationship between trap hauls and exploitation is not well defined and the implementation of v-notching requires substantial expansion in model development respectively.

For the *change in the duration of the fishing season* HCR, reductions to 90%, 80%, 70%, 60%, and 50% of the original duration of the season were tested for each LFA. These reductions in season length were implemented as delayed starts to the season; however since temperature effects on catchability were not included, the results would have been similar if the reduction was at the end of the season. With this approach catch rates will be high at the beginning of the season regardless of the actual start date, which may not accurately reflect reality in LFA 34 where catch rates drop off significantly due to cooling water temperatures in January. For the *change in MLS* HCR increases to 85, 87.5, and 90 mm were tested.

Window size restrictions were evaluated using a small window (115–125 mm) and large window (105–125 mm) applied either the full population (males + females) or females only. *Maximum size* scenarios of 125, 130, and 135 mm were also tested and applied to both sexes and females only.

Results and Discussion

Outputs for LFA 34 with both relF and CCIR exploitation were displayed as bubble plots for males, females and berried females from the simulated cohort under the various management scenarios (Figures 73–82). These plots show the total number of Lobsters in each size bin at each quarter-year ($N_{t,l}$) as the generation progresses over 15 years from an initial cohort at 50 mm CL. Also shown were simulated removals due to the fishery, the numbers of Lobsters moulting, and the numbers of eggs released by the berried females. Only one example of each management scenario is shown in the plots, i.e., MLS 90, 50% Season, Window Size 115–125 and Max Size 125. The results in terms of the evaluation metrics (numbers landed, weight landed, and eggs produced), are shown for all levels of management scenarios tested in Table 16 for CCIR exploitation and Table 17 for relF exploitation.

Generally, males tend to grow faster than females due to higher moult frequency and increment. The effect of different inputs on the simulation results was discussed in Cook et al. (2018) by examining differences between different areas. All variations between LFAs were due to the differences in temperature effects on moult frequency, size-at-maturity effects, and exploitation impacts on the rate at which Lobsters are removed from the cohort. LFA 34 has the characteristics of high size-at-maturity and fast growth due to warmer temperatures when compared to other LFAs. This means that Lobsters tend to recruit to the fishery faster but the number of eggs per recruit is lower because females enter the exploitable population prior to maturity. This results in in fewer berried females from the initial 1,000 females.

In increasing MLS scenarios, the average size of Lobsters in the landings were larger which resulted in fewer Lobster being landed to reach the same total landings (Figures 75 and 76). Increasing MLS gives smaller females a chance to spawn before becoming susceptible to fishing and it increases the overall number of females carrying eggs (Figure 75 and 76). Due to the exponential nature of the fecundity-size relationship large females contribute significantly more eggs than smaller females.

Through *shortening season length* scenarios by 50% (Figures 77–78) exploitation was reduced for all legal sizes which yielded increased median size of the catch and biomass per Lobster landed. Reduced exploitation increased landings over time by allowing continued growth, particularly in areas with warmer bottom temperatures. It also increased egg production by increasing survivability of all females.

Implementing *windows and maximum size as* HCRs is similar to increasing the MLS in that it protects a certain size class of Lobsters from harvesting but selects larger Lobsters for protection that are capable of carrying more eggs. (Figures 79–82) Implementing window or maximum size for females only retains the benefits for egg production but is less effective at reducing exploitation.

Comparing the outputs from each of the simulation runs from the high exploitation scenario (CCIR) versus the lower exploitation scenario (relF) reveals significant differences (Figures 73–74). Substantially more eggs are produced under the low exploitation scenario because there are more female Lobsters surviving to larger sizes that produce more eggs. The exploitation estimates from the CCIR analysis are so high that relatively few Lobsters remain after 5 years of simulation and this has implications on the effectiveness of the various management scenarios.

For previous areas tested (LFAs 27–33) a 50% season reduction was found to be more beneficial than an increase in MLS to 90 mm (Cook et al. 2018). However in the high exploitation scenario for LFA 34, this was reversed; an increase in MLS was more effective at increasing the number of eggs produced, decreasing the number of Lobsters landed and increasing the overall weight of the landings (Table 16). This is the case because under very high exploitation rates the vast majority of Lobsters are removed from the population in the first half of the season, meaning that closing the second half actually saves relatively few Lobsters from being removed from the population. However under the high exploitation scenario, size protections such as MLS, maximum or window size are still effective as those size Lobsters are protected no matter what. In fact window size and maximum size restrictions were actually more effective at increasing egg production in the high exploitation run than either increasing MLS or season reduction. It should also be noted that the evaluation criteria in Table 16 represents percent change in egg production and in the high exploitation scenario coupled with LFA 34 high size of maturity relatively few eggs were resulting from the simulated cohort and any management measure that protects a portion of the population is likely to have a significant effect in terms of percent change.

In the lower exploitation scenario, a season reduction was more effective at increasing the number of eggs produced, decreasing the number of Lobsters landed and increasing the overall weight of the landings (Table 17). It should be noted that a season reduction is analogous with any measure that reduces the overall effort in the fishery. A reduction in season is also a more efficient measure as a reduction in effort means a reduction in costs associated with fishing and overall higher catch rates. However, it is necessary to exercise caution when interpreting these results as there are many assumptions that are made in the simulation. For example the simulation assumes there is no change in catchability during the season and only depletion will effect changes in catch rates. The effect of temperature on catchability has not been included. It also assumes the exploitation estimates, which were estimated for Lobsters newly recruited to the fishery are the same for all sizes of Lobster.

Overall the summary of the results suggested that under current levels of exploitation estimated, either from the CCIR analysis or relF from the survey, growth overfishing is likely occurring. Growth overfishing was suggested from these simulation models as decreased exploitation or increased MLS led to increased yield per recruit as the landings indicated. This conclusion is predicated on very high levels of exploitation in combination with high growth rates in males estimated from the analysis of moult increment data. It suggests that in any scenario reduced exploitation will likely have positive effects on the harvestable biomass and egg production

This analysis was not intended to recommend changes to the current management of the fishery. It was only intended to present a method for determining what types of management changes would be most effective at promoting recovery if stock status entered the cautious zone.

SOURCES OF UNCERTAINTY

The primary data sources available for assessing the Lobster stocks in LFA 35–38 are from Lobster traps. Due to the passive nature of traps, the inferences on population processes are limited to the component of the stock retained by the traps. Catchability describes the relationship between total landings and the fishable biomass, and is comprised of the availability of the species to the fishing gear and the selectivity of the gear. For Lobster traps, availability is dependent not only on the proximity of the animal to the gear, but also the behaviour of individuals and their desired to enter traps. Numerous studies have suggested that not all Lobster are available to traps at all times with factors such as water temperature, mating and moult status being influential. Relying solely on trap data to assess stock status leads to uncertainties in trends over time. Obtaining a region wide fisheries independent data source would improve our confidence in describing stock status.

The assumption that the Lobster populations have been at or near carrying capacity during the monitoring period underlies the definition of reference points and stock status. Most time series suggest that the Lobster in LFA 34–38 have been more productive over the last 15 years than previously recorded. It is uncertain if this level of productivity is sustainable into the future or if production will decrease. Regardless, applying the productivity based reference points, as was done here, make the definition of stock status more precautionary.

The impacts of predation pressure on Lobster is unknown, however was suspected to be a larger component of mortality when groundfish were abundant. The influence of recovering groundfish, or the range expansion of other predator species into Lobster habitat, on future Lobster productivity is not known.

The impact of changing climate on Lobster biology, physiology and phenology have been studied, but the long terms effects are not known. Work from elsewhere suggests climate may be an important driver of population process in Lobster.

RESEARCH RECOMMENDATIONS

Implementing intensive fishery independent data collections in LFAs 35–38 would provide a valuable new source of information which would bolster our understanding of stock dynamics and Lobster production. In LFA 34, bottom trawl surveys have provided a reliable and useful sampling tool (Cook et al. 2017). Although some Lobster habitats are not fully available to this type of sampling gear, Lobsters in higher densities will use a broader range of substrate types, including those areas more amenable to bottom trawling. The advantage of a bottom trawl over trapping study lies in the active nature of the sampling. In trap studies, catch rates and the biological sampling of animals relies on the attraction of Lobster to traps. The active sampling offered by a bottom trawl avoids this potential bias and allows for improved understanding of population processes as a larger size range of Lobster can be captured. Other options for obtaining fisheries independent data would include video or scuba-diver transect surveys, either of which would provide a valuable source of active sampling information.

Regional tagging studies have been conducted in the past. These studies were designed to improve understanding of Lobster movements, catchability, growth and regional connectivity. Several of these studies were conducted on a small spatial scale, thereby limiting the portability of their results. Applying the same tagging protocols and expanding the scope of the studies would improve the understanding of the spatial and temporal variability in Lobster growth and production as well as their connectivity between regions.

The impacts of climate change on Lobster stock productivity has been studied in some regions. At the southern extent of the Lobster’s biogeographic range, results have suggested there have been negative consequences of changing climates on Lobster stocks, including decreased production and increased prevalence of disease. The Nova Scotian current which flows south and westward from the Gulf of St Lawrence along the coast of Nova Scotia, provides cool waters through the nearshore in the region. That said, the impact of warming temperature trends in other regions and the potential impacts of ocean acidification should be examined in more detail.

Improving the integration of the various data streams into a single integrated model would improve our understanding of the stock dynamics throughout the region. This type of analysis requires high quality data on the size structure and trends in stock abundance through time, but would allow for increased understanding of the stock dynamics.

SCHEDULE AND TRIGGERS

Following the approval of methods from this stock assessment framework, stock assessments for LFA 34 and LFAs 35–38 will be conducted in Autumn 2019 using data to the end of 2019. Following that stock assessment, a Stock Status update will be conducted. Stock assessment updates will continue annually until the next stock assessment framework in 5–7 years. An earlier than expected framework would be triggered if the primary indicators were approaching the Cautious stock status zones. Given the current healthy and productive state of these fisheries, nearing the Cautious zone would indicate a dramatic shift in production which should be further examined and a more fulsome examination of the contextual indicators would be warranted.

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TABLES

Table 1. Numbers (No.) of licenses and management measures in LFAs 34–38 as of 2018.

LFA	Season	Total No. of licenses	Trap Limit[1]	MLS (mm)	Other Measures
34	Last Monday in November to May 31st	979	375	82.5	Escape vents and biodegradable trap mechanisms
35	October 14th to December 31st and February 28th – July 31st	95	300	82.5	Escape vents and biodegradable trap mechanisms
36	2nd Tuesday in November to January 14th and March 31st to June 29th	177	300	82.5	Escape vents and biodegradable trap mechanisms
38	2nd Tuesday in November to June 29th	136	300	82.5	Escape vents and biodegradable trap mechanisms

[1] Trap limit is for category "A" licence holder.

Table 2. List of Lobster assessments in the Maritimes Region for LFAs 34–38 from 1991–2016. (-- = no data).

LFA	Publication	1996	1998	1999	2001	2006	2007	2013	2014	2015	2016	2017	2018
34	Stock Status Update	96/118E	98/C3-62	--	01/C3-62	--	--	--	2014/036	2015/029	2016/037	2017/038	2018/044
	Research Document	--	--	99/032	2001/156	2006/010	2007/041	2013/078	--	--	--	--	--
	Stock Advisory Report	--	--	--	--	2006/024	--	2013/024	--	--	--	--	--
35	Stock Status Update	96/119E	98/C3-61		01/C3-61	--	--	--	2014/047	2015/030	2017/022	2017/039	2018/049
	Research Document	--	--	99/031	--	--	--	2013/078	--	--	--	--	--
	Stock Advisory Report	--	--		--	--	2007/037	2013/023	--	--	--	--	--
36	Stock Status Update	96/119E	98/C3-61	--	01/C3-61	--	--	--	2014/047	2015/030	2017/022	2017/039	2018/049
	Research Document	--	--	99/031	--	--	--	2013/078	--	--	--	--	--
	Stock Advisory Report	--	--	--	--	--	2007/037	2013/023	--	--	--	--	--
38	Stock Status Update	96/119E	98/C3-61	--	01/C3-61	--	--	--	2014/047	2015/030	2017/022	2017/039	2018/049
	Research Document	--	--	99/031	--	--	--	2013/078	--	--	--	--	--
	Stock Advisory Report	--	--	--	--	--	2007/037	2013/023	--	--	--	--	--

Table 3. Summary of the multiple survey information used for indicator estimation in LFA 34. (-- = no data).

Year Block	Survey	N Sets	NSets With Lobster	Total Lobster	Median Nsets per year
1970–1980	DFO	230	29	107	22
	NEFSC Spring	128	24	42	12
	NEFSC Fall	118	47	130	10
	ILTS	--	--	--	--
	Scallop	--	--	--	--
1981–1990	DFO	269	61	134	24
	NEFSC Spring	101	22	105	11
	NEFSC Fall	106	54	267	11
	ILTS	--	--	--	--
	Scallop	484	--	--	48
1991–1998	DFO	242	55	348	31
	NEFSC Spring	76	44	218	10
	NEFSC Fall	76	40	360	10
	ILTS	239	77	2,731	60
	Scallop	1,308	69	142	153
1999–2009	DFO	364	210	1,976	31
	NEFSC Spring	101	87	1,170	10
	NEFSC Fall	110	76	2,747	10
	ILTS	642	367	16,952	58
	Scallop	3,871	1,059	3,994	357
2010–2018	DFO	346	304	5,617	39
	NEFSC Spring	64	53	441	6
	NEFSC Fall	68	56	1,074	7
	ILTS	778	646	54,656	64
	Scallop	3,089	1,642	8,796	342

Table 4. Summary of the multiple survey information used for indicator estimation in LFA 35. (-- = no data).

Year Block	Survey	N Sets	NSets With Lobster	Total Lobster	Median Nsets per year
1970–1980	DFO	101	17	40	9
1970–1980	Scallop	--	--	--	--
1981–1990	DFO	107	28	65	10
1981–1990	Scallop	571	--	--	61
1991–1998	DFO	89	26	49	11
1991–1998	Scallop	674	14	16	66
1999–2009	DFO	141	118	1,224	12
1999–2009	Scallop	2,307	266	529	214
2010–2018	DFO	130	127	6,215	15
2010–2018	Scallop	1,867	586	1,556	201

Table 5. Summary of the multiple survey information used for indicator estimation in LFA 36. (-- = no data).

Year Block	Survey	N Sets	NSets With Lobster	Total Lobster	Median Nsets per year
1970–1980	DFO	133	25	51	12
1970–1980	Scallop	--	--	--	--
1981–1990	DFO	134	26	58	13
1981–1990	Scallop	20	--	--	3
1991–1998	DFO	102	32	85	13
1991–1998	Scallop	210	5	5	61
1999–2009	DFO	175	131	1,407	15
1999–2009	Scallop	1,315	193	496	124
2010–2018	DFO	169	165	10,577	20
2010–2018	Scallop	989	448	1,531	101

Table 6. Summary of the multiple survey information used for indicator estimation in LFA 38. (-- = no data).

Year Block	Survey	N Sets	NSets With Lobster	Total Lobster	Median N Sets per year
1970–1980	DFO	116	21	35	11
	NEFSC Spring	19	4	21	2
	NEFSC Fall	23	5	6	2
	Scallop	--	--	--	--
1981–1990	DFO	125	25	49	12
	NEFSC Spring	12	3	4	2
	NEFSC Fall	18	6	17	3
	Scallop	--	--	--	--
1991–1998	DFO	92	24	85	12
	NEFSC Spring	11	6	16	2
	NEFSC Fall	14	3	4	2
	Scallop	160	31	71	62
1999–2009	DFO	148	100	1,004	13
	NEFSC Spring	23	19	112	2
	NEFSC Fall	18	11	20	2
	Scallop	782	441	1,574	77
2010–2018	DFO	151	145	7,536	17
	NEFSC Spring	32	30	745	3
	NEFSC Fall	20	17	276	3
	Scallop	691	561	4,218	77

Table 7. Size groups of gauges used in the Fishermen and Scientist Research Society (FSRS) recruitment and commercial trap projects.

1996–2003		2003–2019	
Size Bin	Carapace Length (mm)	Size Bin	Carapace Length (mm)
1	< 51	1	< 11
2	51 ≤ x > 61	2	11 ≤ x > 21
3	61 ≤ x > 71	3	21 ≤ x > 31
4	71 ≤ x > 76 & x < MLS	4 ≤	31 ≤ x > 41
4.1	71 ≤ x > 76 & x ≤ MLS	5	41 ≤ x > 51
5	76 ≤ x > 81	6	51 ≤ x > 61
6	81 ≤ x > 91 & x < MLS	7	61 ≤ x > 71
6.1	81 ≤ x > 91 & x ≤ MLS	8	71 ≤ x > 76
7	91 ≤ x > 101	9	76 ≤ x > 81
8	101 ≤ x	10	81 ≤ x > 91
		11	91 ≤ x > 101
		12	101 ≤ x > 111
		13	111 ≤ x > 121
		14	121 ≤≤ x > 131
		15	131 ≤ x

Table 8. Summary of Fishermen and Scientist Research Society (FSRS) recruitment trap samples by year indicating the number of participants, grids, Lobsters and traps sampled by year and LFA.

Year	LFA	N Participants	N_Grids	Total Lobsters	Total Trap Hauls	LFA	N Participants	N_Grids	Total Lobsters	Total Traps
1998–1999	34	3	2	452	136					
1999–2000	34	24	14	11,066	2,498					
2000–2001	34	37	24	22,614	4,415					
2001–2002	34	38	27	29,386	4,320					
2002–2003	34	42	38	27,106	4,776					
2003–2004	34	40	40	19,557	3,722					
2004–2005	34	46	36	26,387	5,303					
2005–2006	34	49	43	33,555	5,677	35	6	4	2,399	502
2006–2007	34	39	41	21,048	4,304	35	6	5	2,513	742
2007–2008	34	34	33	17,238	3,837	35	13	8	7,036	1,085
2008–2009	34	32	29	16,839	3,607	35	13	9	10,575	2,014
2009–2010	34	31	33	18,772	3,275	35	14	9	9,530	1,876
2010–2011	34	30	36	16,251	3,036	35	13	10	11,301	1,909
2011–2012	34	25	25	18,766	2,808	35	13	7	11,227	2,078
2012–2013	34	25	25	17,937	2,370	35	10	6	4,873	1,320
2013–2014	34	23	27	15,280	2,321	35	6	4	2,546	615
2014–2015	34	20	24	11,809	1,729	35	2	3	1,699	393
2015–2016	34	20	24	15,525	2,163	35	1	1	1,145	355
2016–2017	34	21	26	12,825	2,091	35	3	4	2,336	583

Table 9. Summary statistics of Generalized Additive Models (GAM) used to predict the spatial distribution and abundance of Lobster within LFA 34 using data collected during the ILTS.

Model	Distribution	N of Parameters	Log Likelihood	AIC_C	RMSE (CV)
$Year + s(Depth) + s(longitude, latitude)$	CPG	101	−8,992	18,202	1.81
$Year + s(longitude, latitude)$	CPG	99	−8,996	18,204	1.85
$Year + s(Depth)$	CPG	28	−11,055	22,054	2.46
$Year$	CPG	24	−13,951	27,951	3.03
$Year + s(Depth) + s(longitude, latitude)$	Hurdle	99	−1,602	−2,992	3.3
$Year + s(longitude, latitude)$	Hurdle	97	−1,606	−3,003	3.25
$Year + s(Depth)$	Hurdle	28	−2,203	−4,348	3.36
$Year$	Hurdle	24	−2,720	−5,391	3.21

Table 10. Delta-AICc values for various formulations of the CPUE model. Values are the difference between the AIC of the indicated model and the lowest AICc within each LFA.

Model	LFA 34	LFA 35	LFA 36	LFA 38
Year + DoS + Temp + DoS x Temp	0	0	0	0
Year + DoS + Temp	52,958	810	3,314	4,686
Year + DoS	543,668	13,054	33,010	23,118
Year + Temp	436,519	29,085	26,490	36,000

Table 11. CPUE index for LFA 34 predicted on the first day of the season using average temperature. Also shown is the CPUE uncorrected for temperature.

LFA	Year	Start Date	Temp	Avg. Temp	CPUE index	CPUE uncorrected
34	2005	2004-11-30	7.78	8.54	2.68	2.09
34	2006	2005-11-28	7.89	8.54	2.57	2.17
34	2007	2006-11-27	7.99	8.54	2.04	1.86
34	2008	2007-11-29	8.11	8.54	2.63	2.41
34	2009	2008-11-24	8.82	8.54	2.50	3.06
34	2010	2009-11-30	8.55	8.54	2.75	2.87
34	2011	2010-11-29	9.06	8.54	2.63	3.20
34	2012	2011-11-29	9.19	8.54	2.89	3.67
34	2013	2012-11-27	9.25	8.54	2.82	3.87
34	2014	2013-11-30	9.32	8.54	3.66	4.37
34	2015	2014-11-29	9.12	8.54	2.92	3.48
34	2016	2015-11-30	8.80	8.54	3.59	3.94
34	2017	2016-11-29	8.83	8.54	3.04	3.32
34	2018	2017-11-28	9.19	8.54	3.31	3.64

Table 12. CPUE index for LFA 35 predicted on the first day of the season using average temperature. Also shown is the CPUE uncorrected for temperature.

LFA	Year	Start Date	Temp	Avg. Temp	CPUE index	CPUE uncorrected
35	2006	2005-10-14	12.93	13.37	2.27	2.16
35	2007	2006-10-14	12.85	13.37	2.20	2.13
35	2008	2007-10-14	13.19	13.37	2.50	2.50
35	2009	2008-10-14	13.34	13.37	2.74	2.87
35	2010	2009-10-14	13.43	13.37	3.12	3.44
35	2011	2010-10-14	13.88	13.37	3.92	4.50
35	2012	2011-10-14	13.73	13.37	4.24	4.97
35	2013	2012-10-14	13.91	13.37	4.15	4.88
35	2014	2013-10-14	13.92	13.37	4.39	5.11
35	2015	2014-10-14	13.33	13.37	4.06	4.64
35	2016	2015-10-14	13.13	13.37	3.83	4.28
35	2017	2016-10-14	13.12	13.37	3.68	4.03
35	2018	2017-10-14	13.12	13.37	3.85	4.16

Table 13. CPUE index for LFA 36 predicted on the first day of the season using average temperature. Also shown is the CPUE uncorrected for temperature.

LFA	Year	Start Date	Temp	Avg. Temp	CPUE index	CPUE uncorrected
36	2005	2004-11-09	9.90	10.50	2.30	1.95
36	2006	2005-11-09	9.97	10.50	2.34	1.97
36	2007	2006-11-15	9.57	10.50	2.27	1.69
36	2008	2007-11-13	9.91	10.50	2.54	2.12
36	2009	2008-11-11	10.48	10.50	2.51	2.38
36	2010	2009-11-10	10.89	10.50	2.21	2.33
36	2011	2010-11-12	10.91	10.50	2.42	2.58
36	2012	2011-11-08	11.33	10.50	2.71	3.32
36	2013	2012-11-16	10.63	10.50	3.38	3.37
36	2014	2013-11-13	10.80	10.50	3.92	4.15
36	2015	2014-11-11	10.96	10.50	3.29	3.56
36	2016	2015-11-10	10.76	10.50	3.58	3.84
36	2017	2016-11-08	10.73	10.50	3.25	3.53
36	2018	2017-11-15	10.14	10.50	3.87	3.44

Table 14. CPUE index for LFA 38 predicted on the first day of the season using average temperature. Also shown is the CPUE uncorrected for temperature.

LFA	Year	Start Date	Temp	Avg. Temp	CPUE index	CPUE uncorrected
38	2005	2004-11-09	9.05	10.04	2.83	2.53
38	2006	2005-11-09	9.74	10.04	2.56	2.34
38	2007	2006-11-15	9.14	10.04	2.60	2.09
38	2008	2007-11-13	9.66	10.04	2.74	2.46
38	2009	2008-11-11	10.07	10.04	2.41	2.45
38	2010	2009-11-10	10.64	10.04	2.61	2.94
38	2011	2010-11-12	10.39	10.04	3.02	3.43
38	2012	2011-11-08	10.98	10.04	3.01	3.90
38	2013	2012-11-16	10.20	10.04	3.32	3.49
38	2014	2013-11-15	10.08	10.04	5.22	5.55
38	2015	2014-11-11	10.53	10.04	4.95	5.69
38	2016	2015-11-10	10.35	10.04	5.57	6.36
38	2017	2016-11-08	10.15	10.04	4.69	5.46
38	2018	2017-11-15	9.59	10.04	4.81	4.57

Table 15. Model selection from DFA of time series trends of total abundance indices in LFA 34. R refers to the observation error covariance structure, m the number of time trends, logLik is the log likelihood, K the number of parameters and AICc the Akaike Information Criteria corrected for number of parameters.

R	m	logLik	K	AICc
diagonal and equal	1	−260.388	7	535.3409
diagonal and equal	2	−245.117	12	515.8505
diagonal and equal	3	−242.675	16	520.2282
diagonal and equal	4	−242.692	19	527.4694
diagonal and equal	5	−242.692	21	532.4051
diagonal and unequal	1	−260.085	12	545.7857
diagonal and unequal	2	−239.014	17	515.2827
diagonal and unequal	3	−234.605	21	516.2325
diagonal and unequal	4	−234.535	24	523.6996
diagonal and unequal	5	−238.458	26	536.7604
equalvarcov	1	−259.981	8	536.6931
equalvarcov	2	−244.999	13	517.8932
equalvarcov	3	−242.466	17	522.187
equalvarcov	4	−242.317	20	529.1749
equalvarcov	5	−242.318	22	534.1654
unconstrained	1	−236.249	27	534.9919
unconstrained	2	−235.108	32	546.4238
unconstrained	3	−228.32	36	544.4038
unconstrained	4	−228.02	39	552.8342
unconstrained	5	−233.936	41	570.871

Table 16. Model selection from DFA of time series trends of recruit abundance indices in LFA 34. R refers to the observation error covariance structure, m the number of time trends, logLik is the log likelihood, K the number of parameters and AICc the Akaike Information Criteria corrected for number of parameters.

R	m	logLik	K	AICc
diagonal and equal	1	−172.4	8	362.0
diagonal and equal	2	−162.6	14	356.7
diagonal and equal	3	−158.0	19	360.6
diagonal and equal	4	−157.8	23	371.7
diagonal and equal	5	−157.8	26	380.8
diagonal and equal	6	−157.3	28	386.0
diagonal and unequal	1	−162.3	14	356.2
diagonal and unequal	2	−149.6	20	346.6
diagonal and unequal	3	−148.1	25	358.3
diagonal and unequal	4	−146.7	29	368.2
diagonal and unequal	5	−146.7	32	378.4
diagonal and unequal	6	−146.7	34	385.5
Equalvarcov	1	−172.1	9	363.7
Equalvarcov	2	−165.8	15	365.6
Equalvarcov	3	−161.3	20	370.0
Equalvarcov	4	−156.9	24	372.9
Equalvarcov	5	−156.8	27	381.9
Equalvarcov	6	−157.9	29	390.5
Unconstrained	1	−146.5	35	388.7
Unconstrained	2	−143.5	41	406.4
Unconstrained	3	−137.5	46	416.7
Unconstrained	4	−136.7	50	434.9
Unconstrained	5	−136.4	53	450.3
Unconstrained	6	−138.8	55	466.6

Table 17. Model selection from DFA of time series trends of commercial biomass in LFA 34. R refers to the observation error covariance structure, m the number of time trends, logLik is the log likelihood, K the number of parameters and AICc the Akaike Information Criteria corrected for number of parameters.

R	m	logLik	K	AICc
diagonal and equal	1	−209.223	5	428.8091
diagonal and equal	2	−200.298	8	417.4855
diagonal and equal	3	−200.299	10	421.9729
diagonal and unequal	1	−207.905	8	432.6985
diagonal and unequal	2	−197.748	11	419.1567
diagonal and unequal	3	−201.539	13	431.3974
equalvarcov	1	−207.634	6	427.7811
equalvarcov	2	−199.178	9	417.4738
equalvarcov	3	−199.179	11	422.0176
unconstrained	1	−197.262	14	425.2155
unconstrained	2	−190.896	17	419.791
unconstrained	3	−190.897	19	424.8265

Table 18. Model selection from DFA of time series trends of relative fishing mortality (relF) in LFA 34. R refers to the observation error covariance structure, m the number of time trends, logLik is the log likelihood, K the number of parameters and AICc the Akaike Information Criteria corrected for number of parameters.

R	m	logLik	K	AICc
diagonal and equal	1	−243.353	6	499.1776
diagonal and equal	2	−240.209	10	501.6827
diagonal and equal	3	−240.209	13	508.547
diagonal and equal	4	−240.209	15	513.2585
diagonal and unequal	1	−239.055	10	499.3743
diagonal and unequal	2	−235.575	14	501.6204
diagonal and unequal	3	−235.575	17	508.8145
diagonal and unequal	4	−235.575	19	513.7559
equalvarcov	1	−243.347	7	501.3274
equalvarcov	2	−240.209	11	503.9432
equalvarcov	3	−240.209	14	510.8878
equalvarcov	4	−240.209	16	515.6553
unconstrained	1	−232.4	20	509.9221
unconstrained	2	−227.105	24	509.7094
unconstrained	3	−228.716	27	521.0628
unconstrained	4	−233.017	29	535.2599

Table 19. Model selection from DFA of time series trends of bottom temperature time series in LFA 34. R refers to the observation error covariance structure, m the number of time trends, logLik is the log likelihood, K the number of parameters and AICc the Akaike Information Criteria corrected for number of parameters.

R	m	logLik	K	AICc
diagonal and equal	1	−192.326	4	392.934
diagonal and equal	2	−191.672	6	395.9448
diagonal and unequal	1	−191.645	6	395.8893
diagonal and unequal	2	−189.895	8	396.8338
equalvarcov	1	−182.364	5	375.1541
equalvarcov	2	−183.04	7	380.8863
unconstrained	1	−178.203	9	375.7199
unconstrained	2	−178.197	11	380.3488

Table 20. Description of the Upper Stock Reference (USR) and Limit Reference Point (LRP) for LFA 34.

<table>
<tr><th>Zone</th><th colspan="2">Reference Points</th></tr>
<tr><td>Healthy</td><td>USR</td><td>2 or more survey biomasses are above their respective USIs</td></tr>
<tr><td rowspan="3">Cautious</td><td rowspan="3">-</td><td>3 or more survey biomasses are below their respective USI and above their respective LRI; or</td></tr>
<tr><td>2 survey biomasses are above their respective USIs and 2 survey biomass are below their respective LRIs; or</td></tr>
<tr><td>1 survey biomass above its respective USI, 1 survey biomass below its respective LRI, and 2 survey biomasses between their respective USIs and LRIs</td></tr>
<tr><td>Critical</td><td>LRP</td><td>2 or more survey biomasses are below their respective LRIs</td></tr>
</table>

Table 21. Percent change in egg production, numbers and weight of Lobsters landed with various harvest controls for LFA 34 using the CCIR exploitation rate.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase minimum legal size	90 mm	115	−9	20
	87.5 mm	58	−5	12
	85 mm	33	−4	8
Shorter season	50%	47	−1	2
	60%	22	0	1
	70%	10	0	0
	80%	4	0	0
	90%	1	0	0
Window size	105–125 mm	461	−2	8
	115–125 mm	88	0	2
Females only	105–125 mm	461	−1	1
	115–125 mm	88	0	0
Maximum legal size	135 mm	37	−1	−2
	130 mm	79	−1	−3
	125 mm	160	−2	−5
Females only	135 mm	37	0	0
	130 mm	79	0	−1
	125 mm	160	0	−1

Table 22. Percent change in egg production, numbers and weight of Lobsters landed with various harvest controls for LFA 34 with exploitation from survey relF.

Harvest Control		**Eggs produced**	**Numbers landed**	**Weight landed**
Increase minimum legal size	90 mm	62	−6	17
	87.5 mm	35	−3	10
	85 mm	19	−2	6
Shorter season	50%	374	−10	25
	60%	233	−7	18
	70%	139	−4	12
	80%	74	−2	7
	90%	130	−1	3
Window size	105–125 mm	246	−4	12
	115–125 mm	67	−1	4
Females only	105–125 mm	246	−3	2
	115–125 mm	67	−1	0
Maximum legal size	135 mm	51	−3	−9
	130 mm	90	−4	−12
	125 mm	152	−5	−15
Females only	135 mm	51	−1	−1
	130 mm	90	−1	−2
	125 mm	152	−2	−4

FIGURES

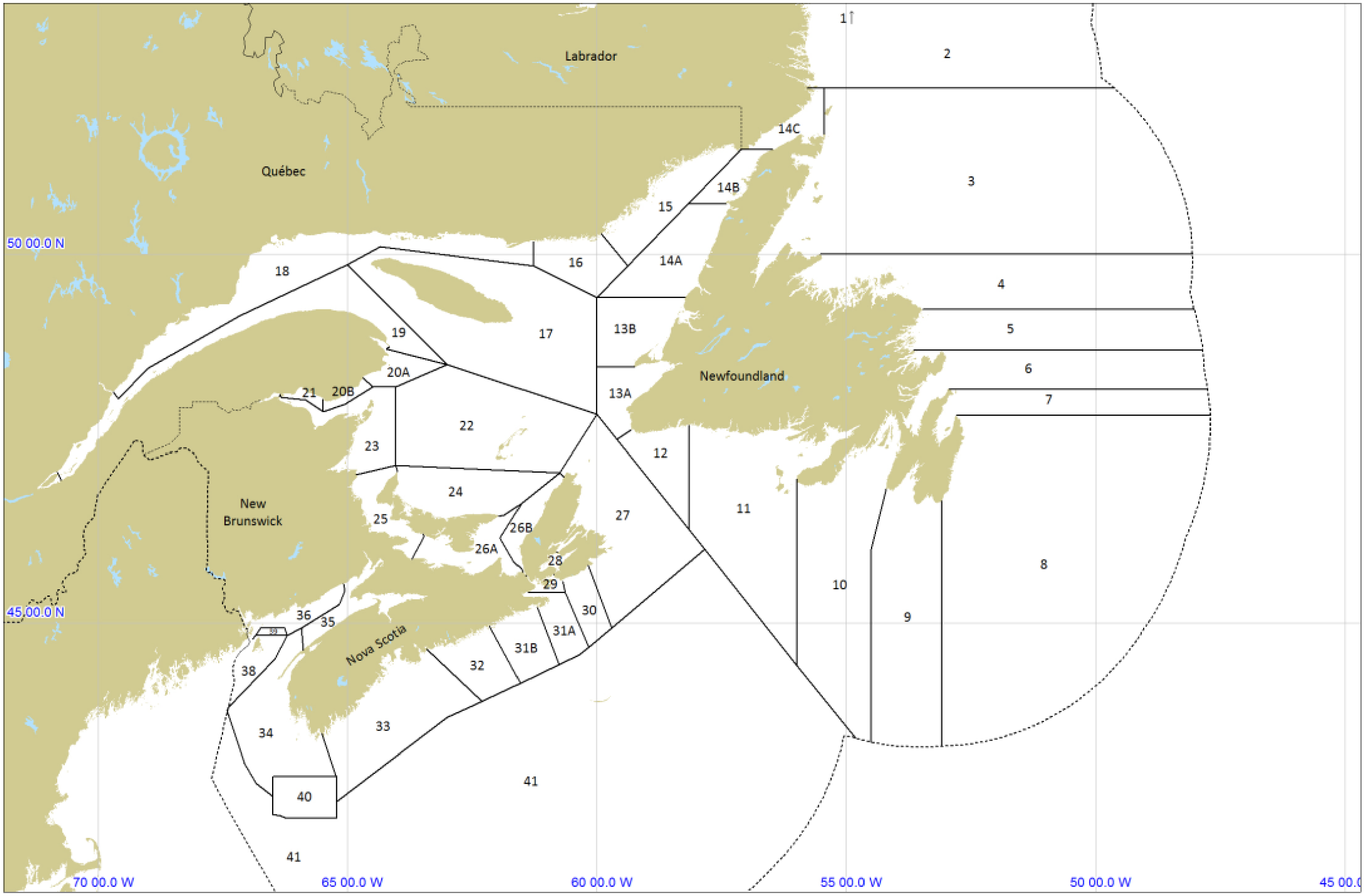

Figure 1. Map of the Lobster Fishing Areas in Atlantic Canada using the boundaries identified in the Atlantic fishery regulations.

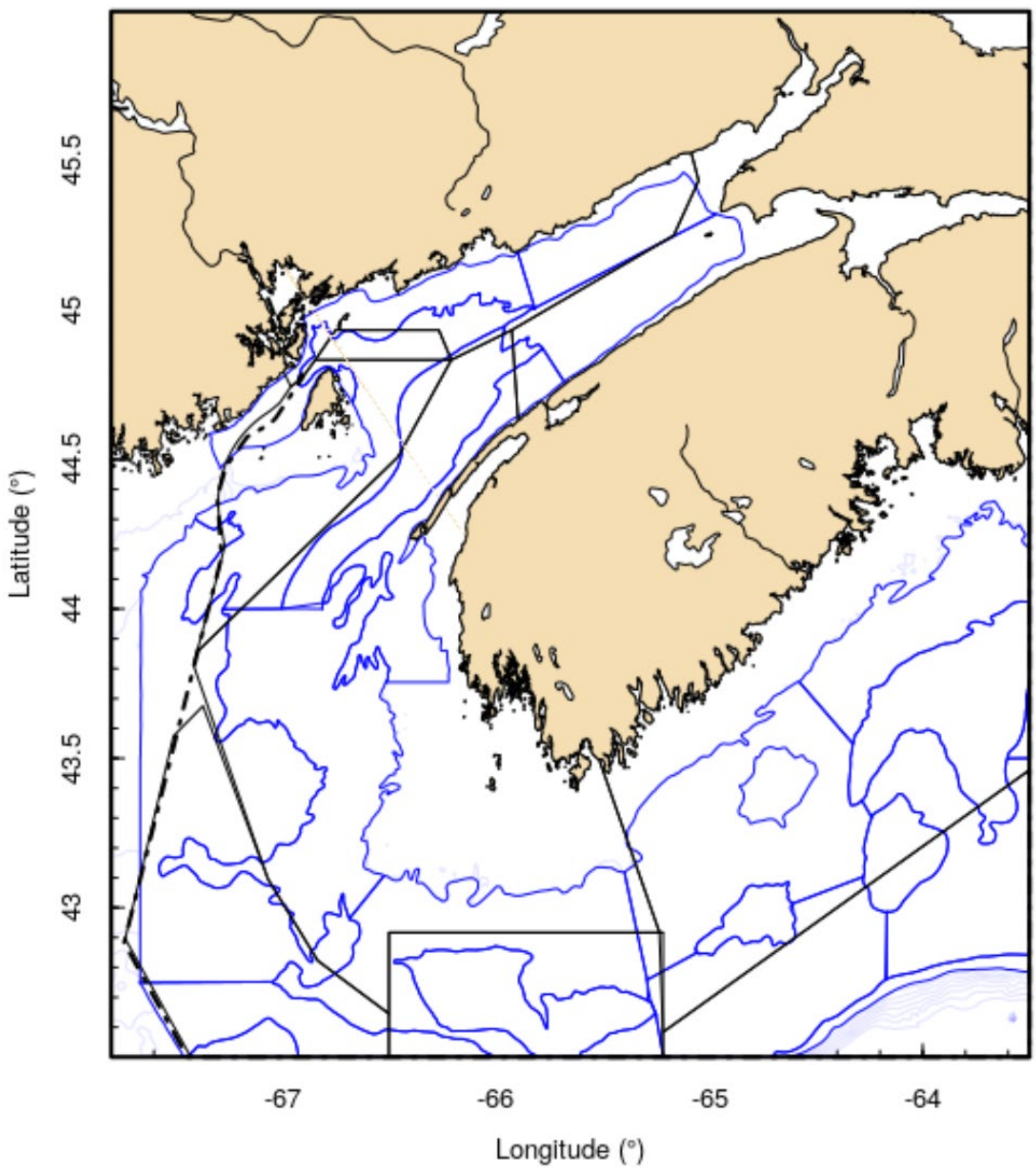

Figure 2. Strata map (blue lines) for DFO summer Research Vessel (RV) surveys in LFAs 34–38 (black lines).

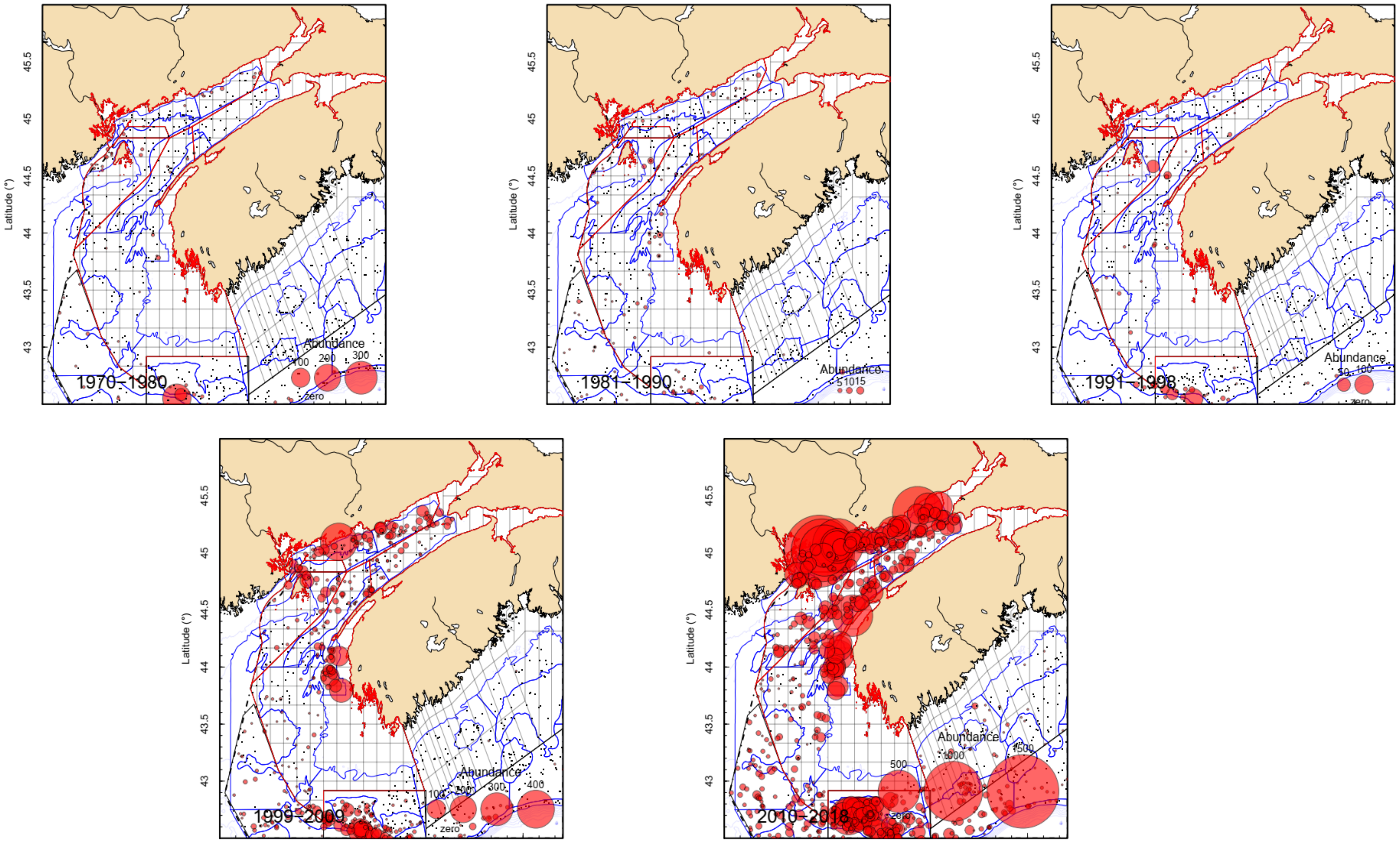

Figure 3. Map of the abundance of Lobster captured during DFO's summer RV survey of the Scotian Shelf. Strata boundaries are outlined in blue and LFA boundaries are outlined in black. Size of the symbols are scaled to the number observed within each tow. Years; top row left to right - 1970–1980, 1981–1990, 1991–1998. Bottom row, left to right - 1999–2009, 2010–2018.

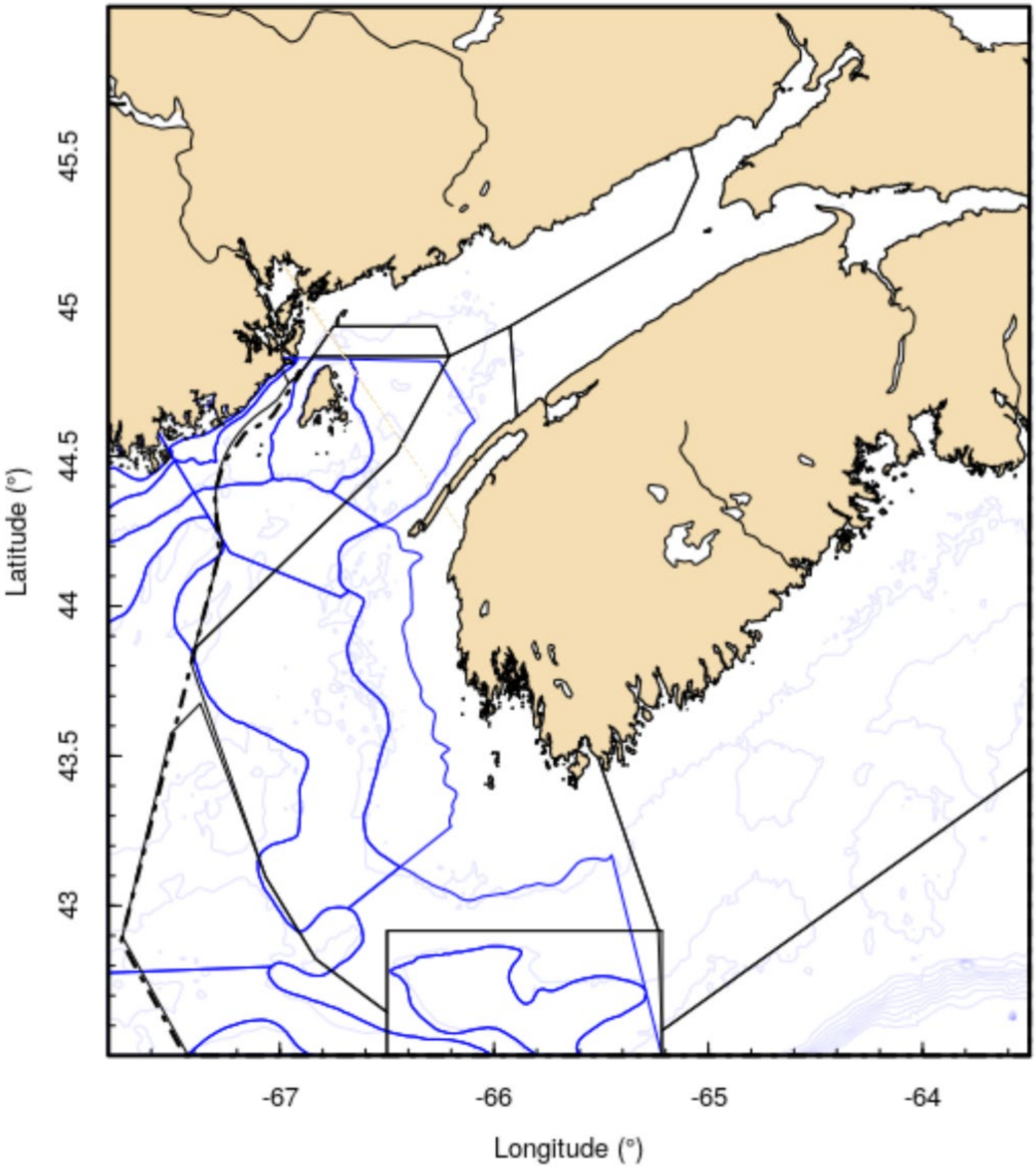

Figure 4. Strata map (blue lines) for NEFSC spring and fall RV surveys in LFAs 34–38 (black lines).

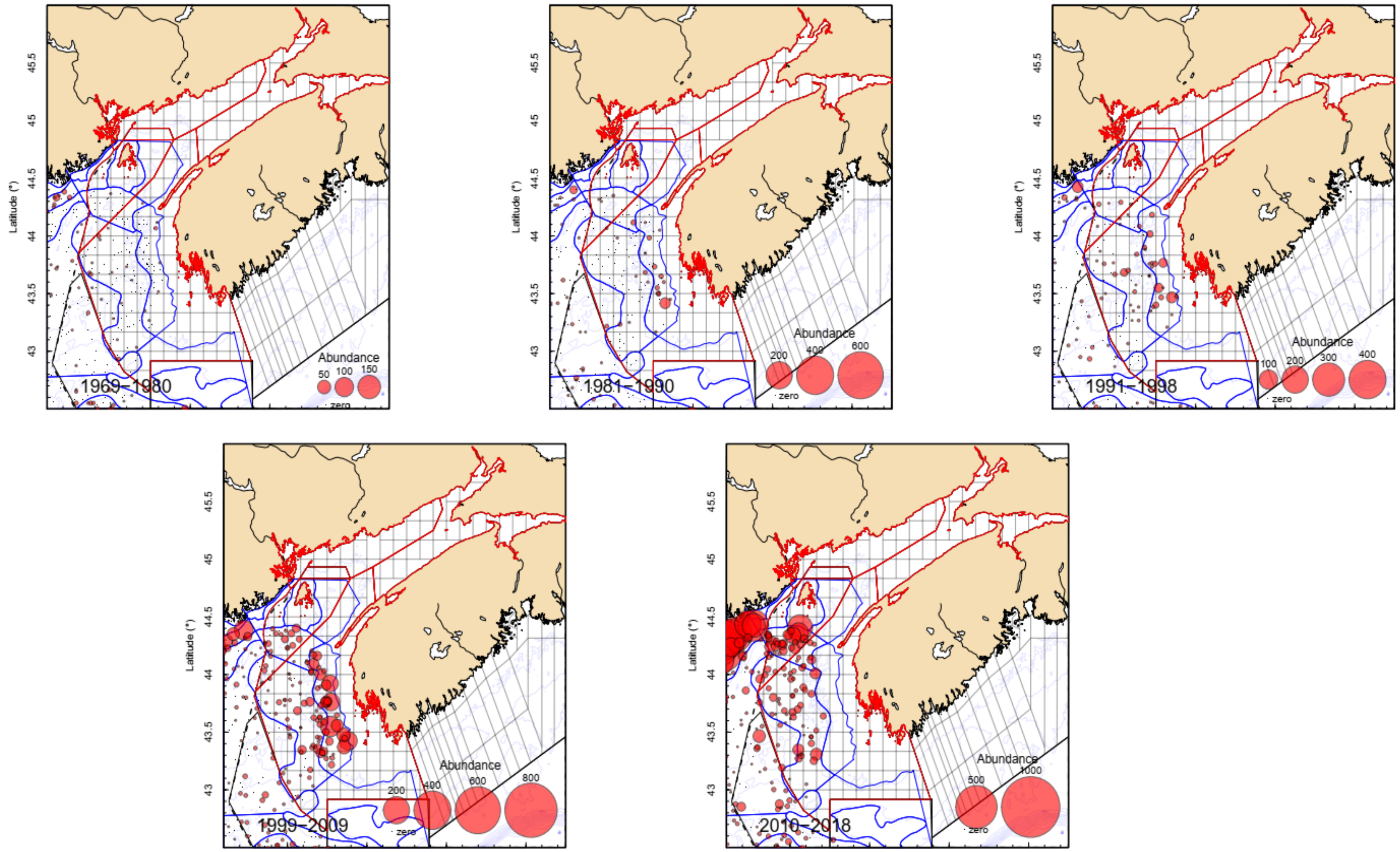

Figure 5. Map of the abundance of Lobster captured during NEFSC spring RV survey of the Scotian Shelf. Strata boundaries are outlined in blue and LFA boundaries are outlined in black. Size of the symbols are scaled to the number observed within each tow. Years; top row left to right - 1969–1980, 1981–1990, 1991–1998. Bottom row, left to right - 1999–2009, 2010–2018.

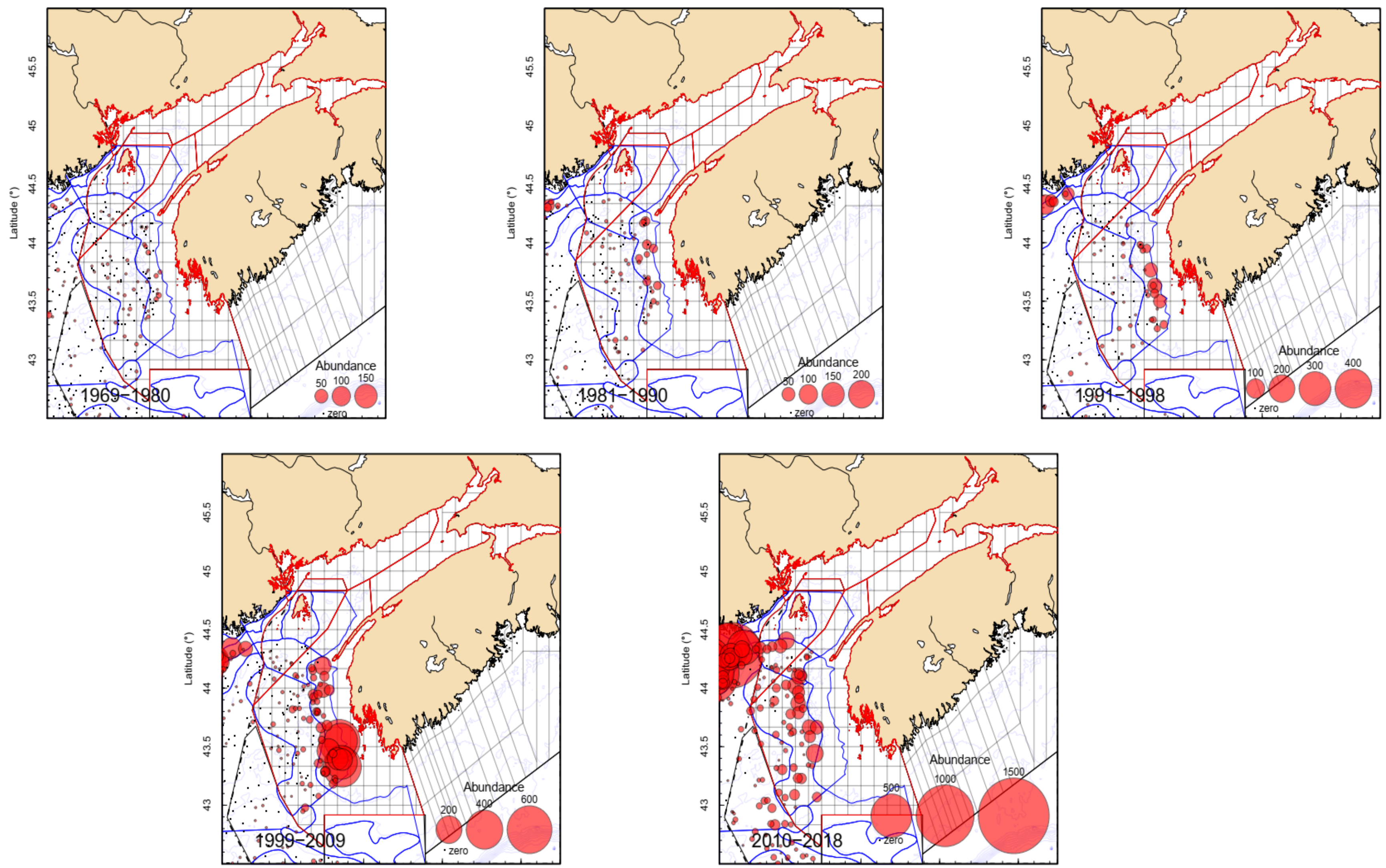

Figure 6. Map of the abundance of Lobster captured during NEFSC fall RV survey of the Scotian Shelf. Strata boundaries are outlined in blue and LFA boundaries are outlined in black. Size of the symbols are scaled to the number observed within each tow. Years; top row left to right - 1969–1980, 1981–1990, 1991–1998. Bottom row, left to right - 1999–2009, 2010–2018.

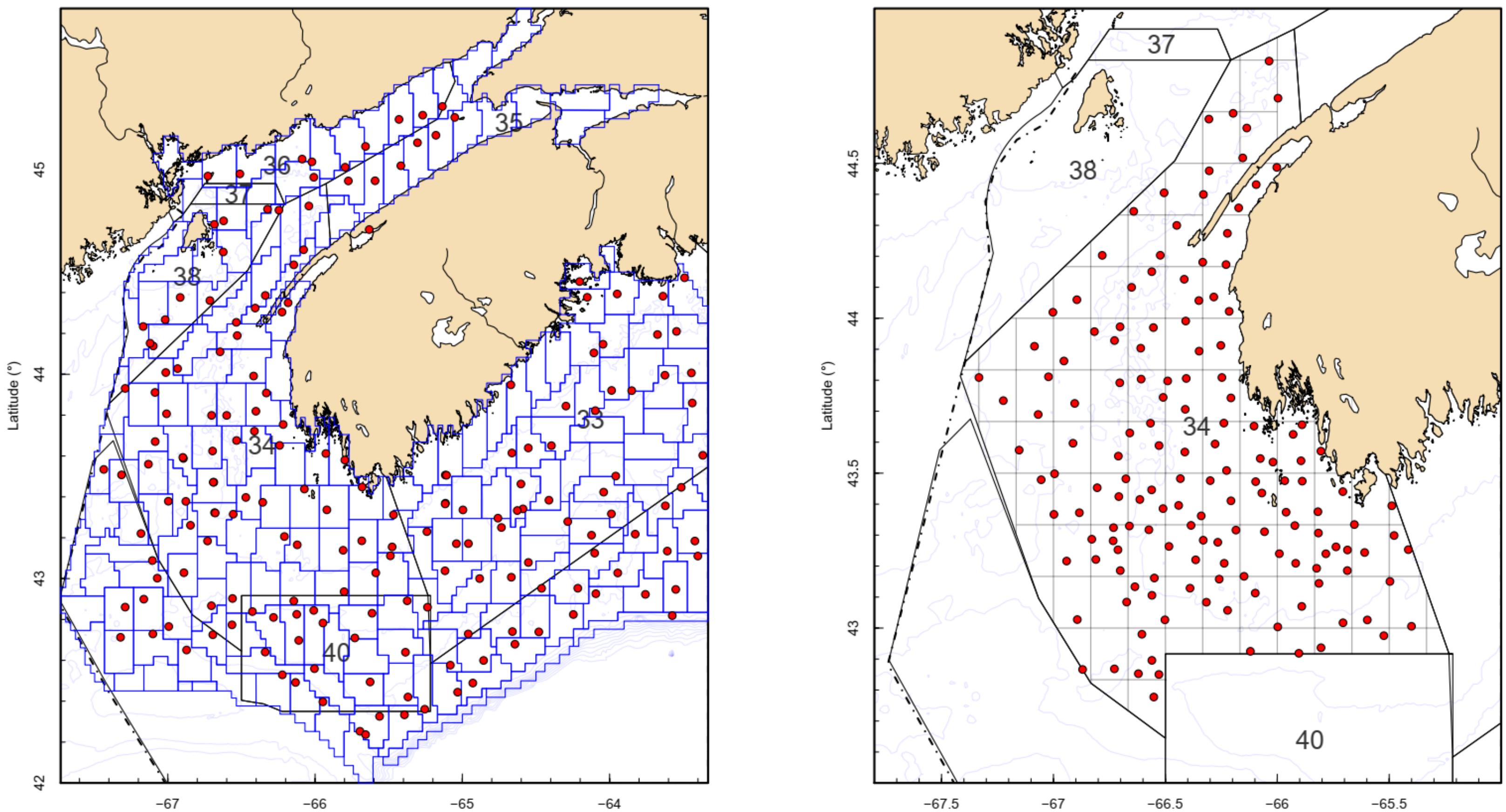

Figure 7. Maps of the fixed gear survey stations from the ITQ survey (left) and the ILTS survey (right).

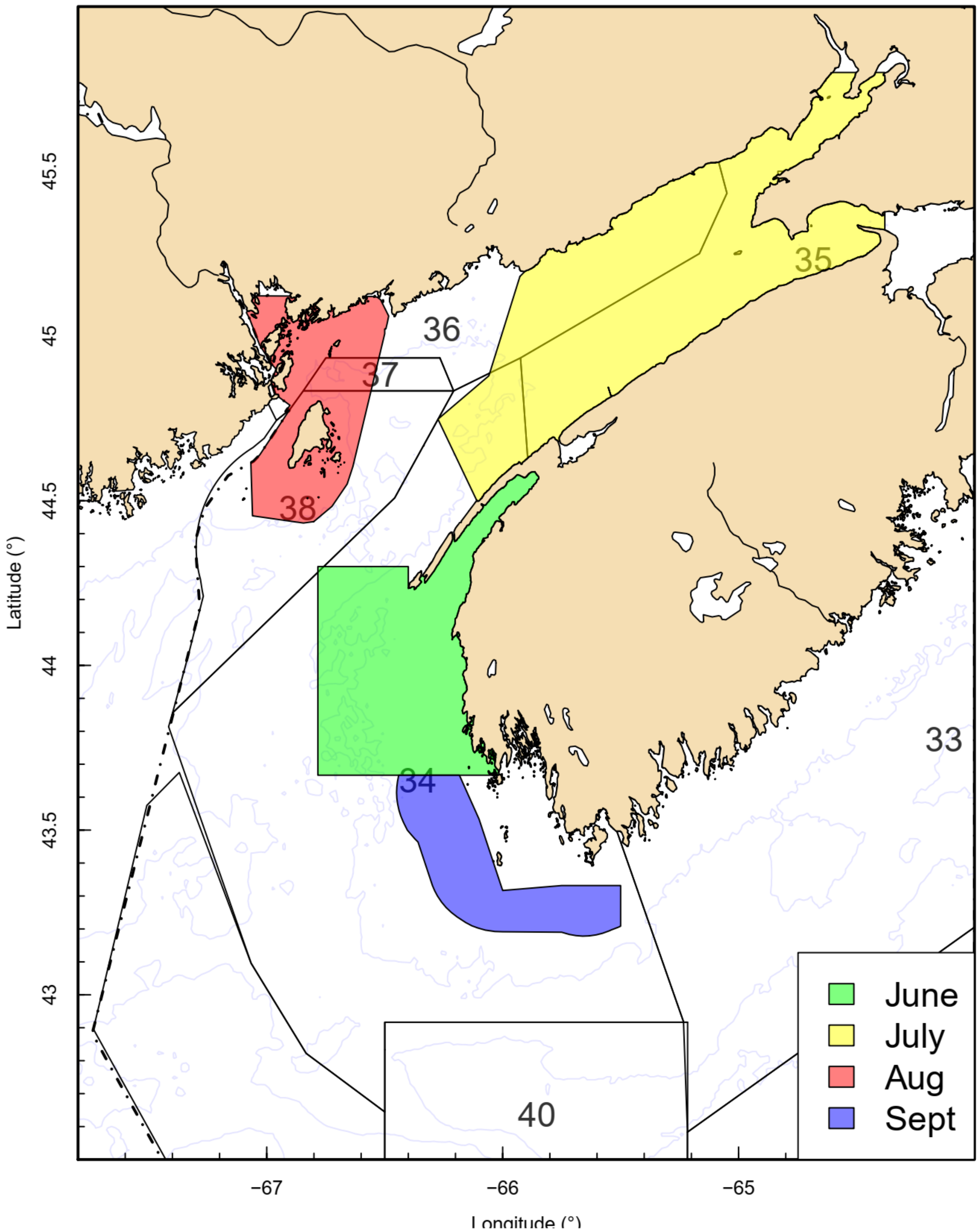

Figure 8. Map of the outer boundaries for the inshore scallop surveys with the month of year that the survey is conducted.

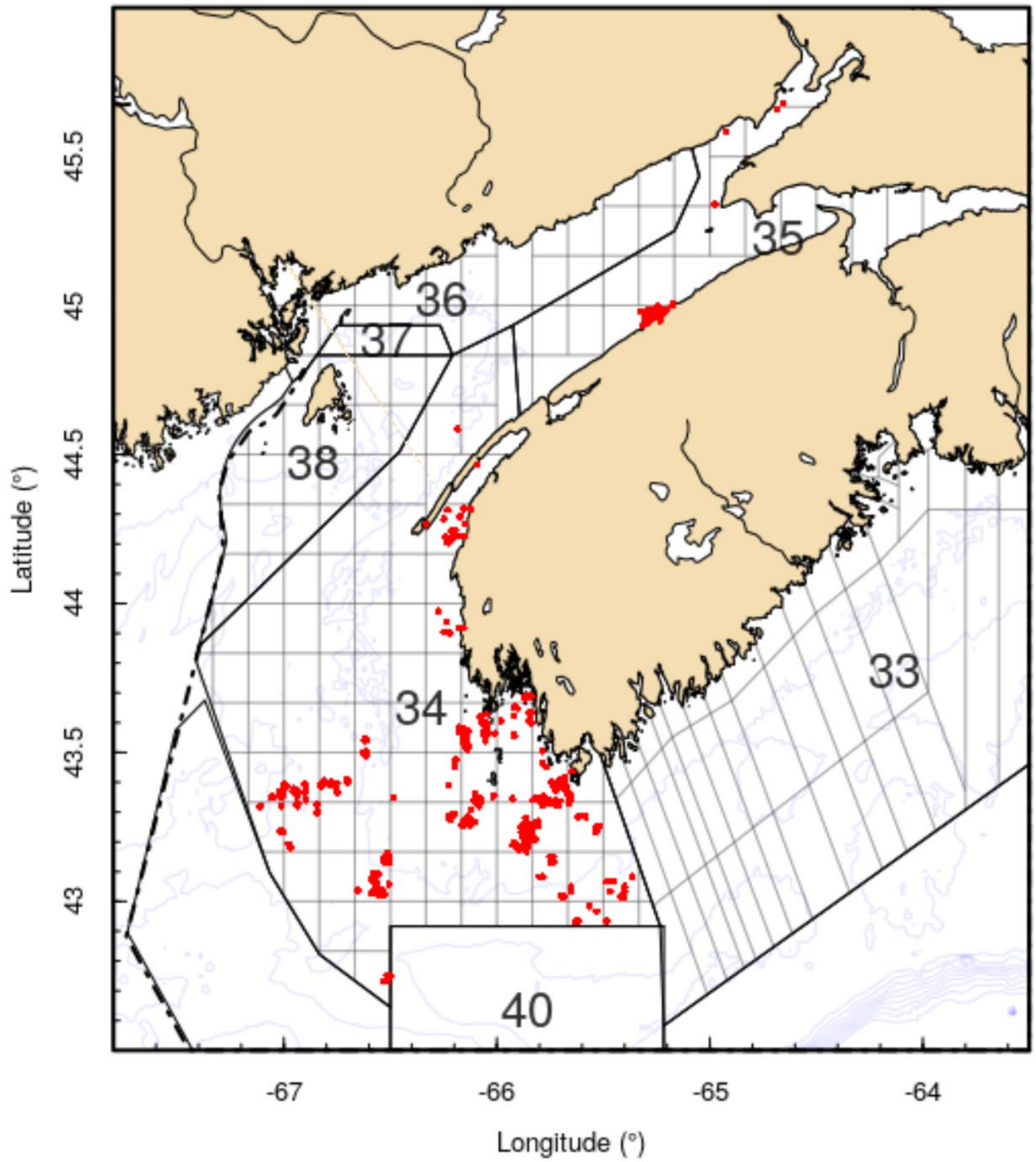

Figure 9. Trap sampling locations for Fishermen and Scientist Research Society (FSRS) recruitment traps between 2015 and 2018 in LFA 34–38.

Figure 10. Map of the counties in Nova Scotia used for splitting the historic landings information for LFA 34 (Yarmouth and Digby county).

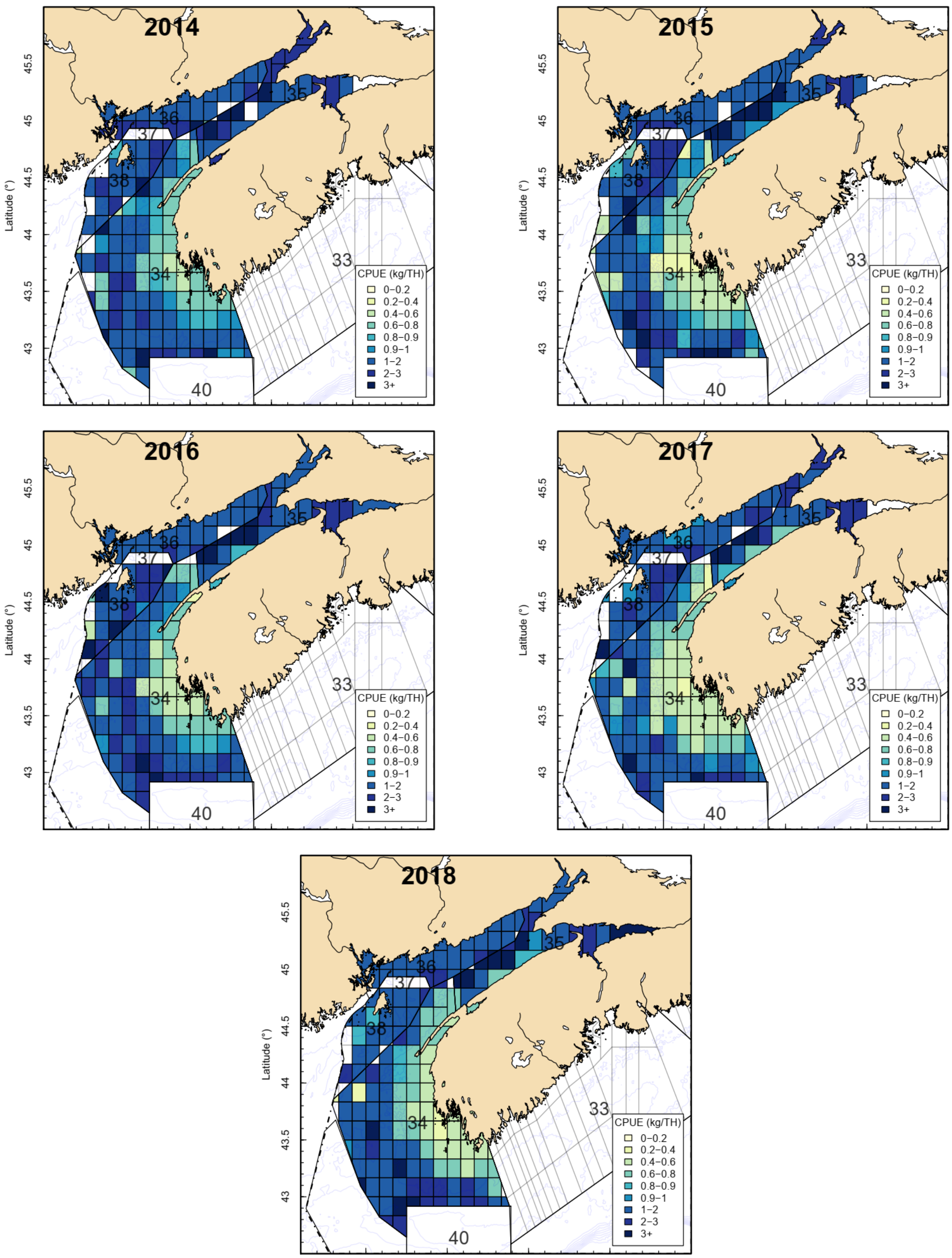

Figure 11. Map of the fishery footprint expressed as the commercial catch rates in each grid of LFAs 34–38 from 2014–2018.

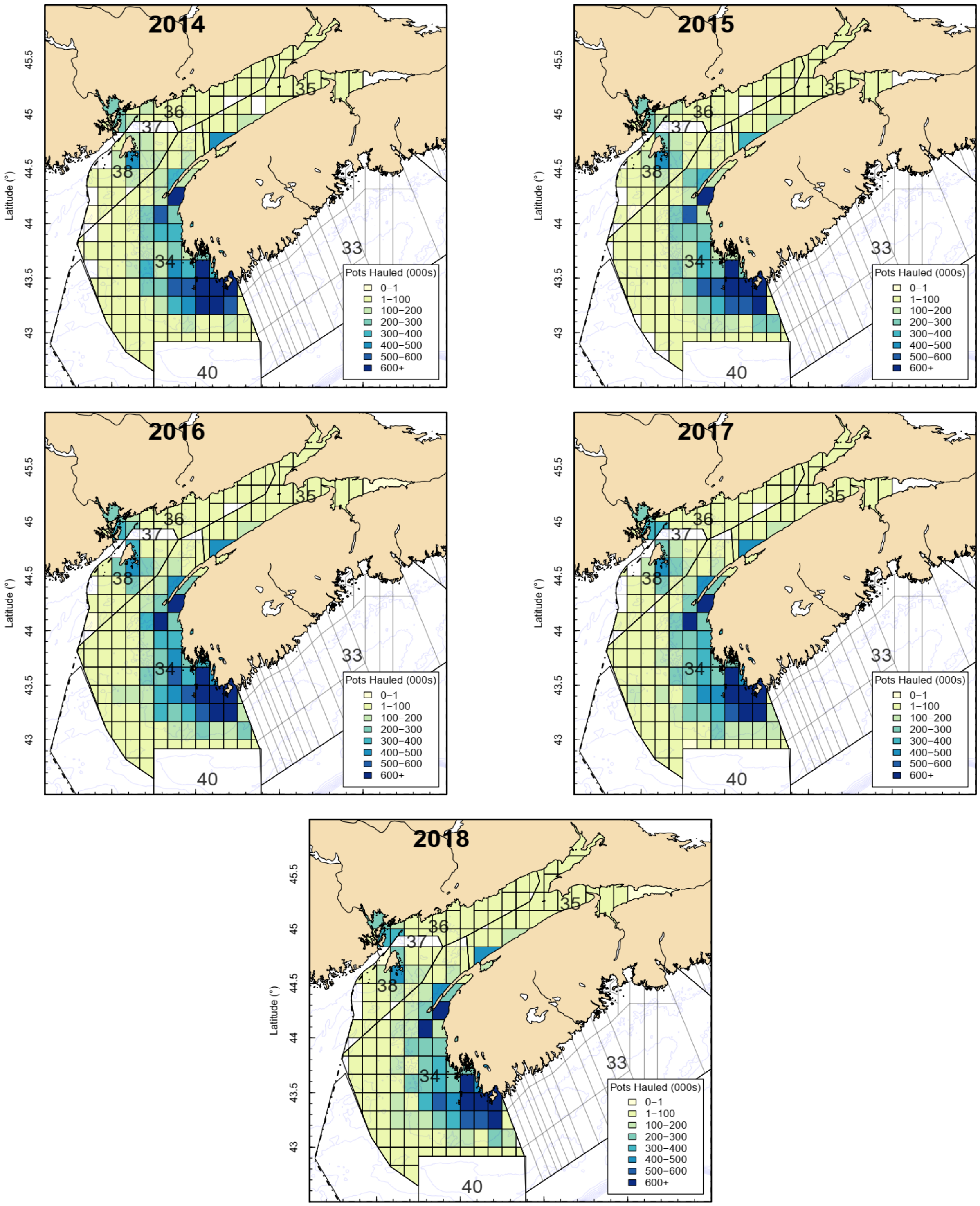

Figure 12. Map of the fishery footprint expressed as the numbers of trap hauls in each grid of LFAs 34–38 from 2014–2018.

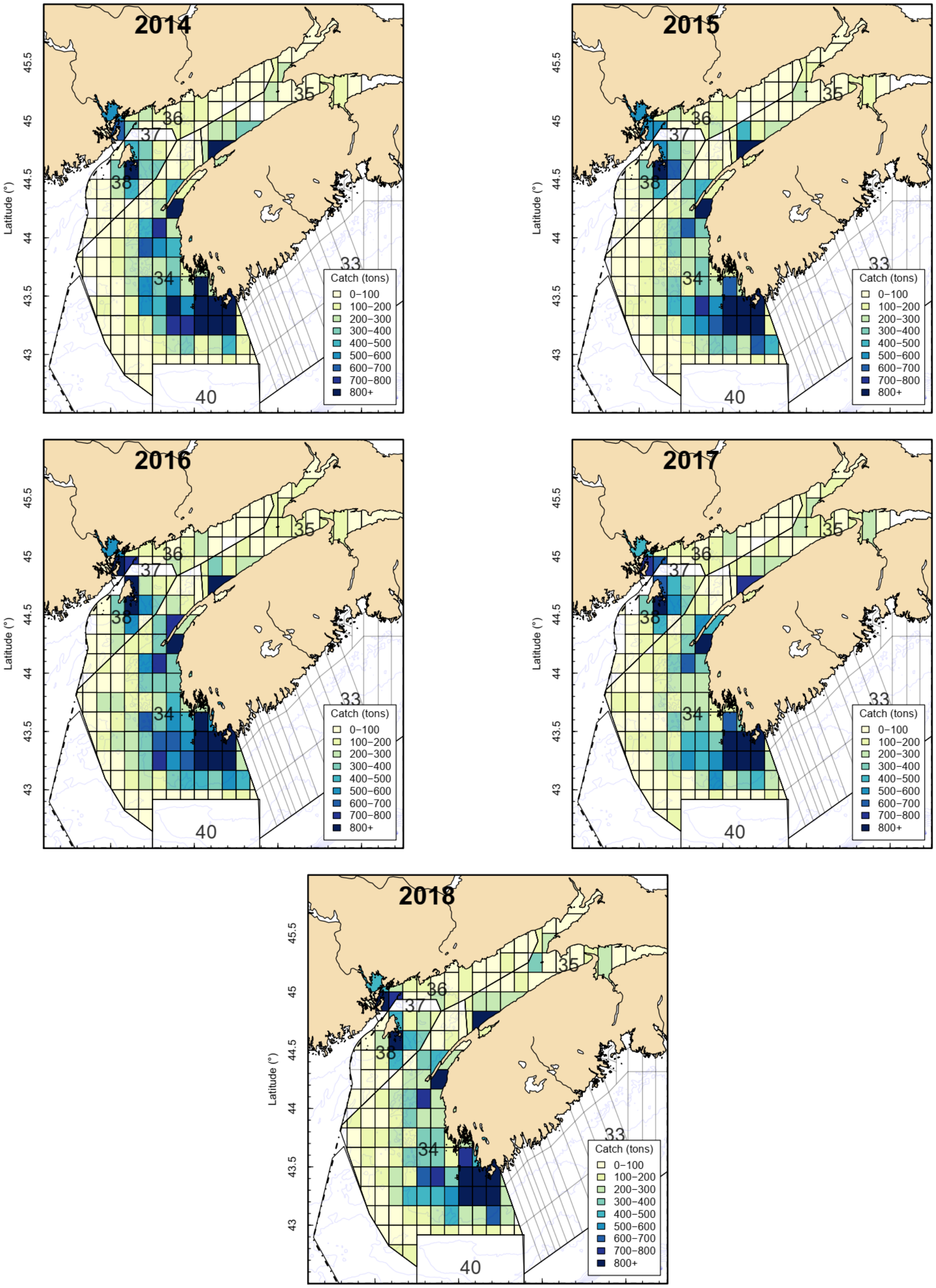

Figure 13. Map of the fishery footprint expressed as the weight of landings in each grid of LFAs 34–38 from 2014–2018.

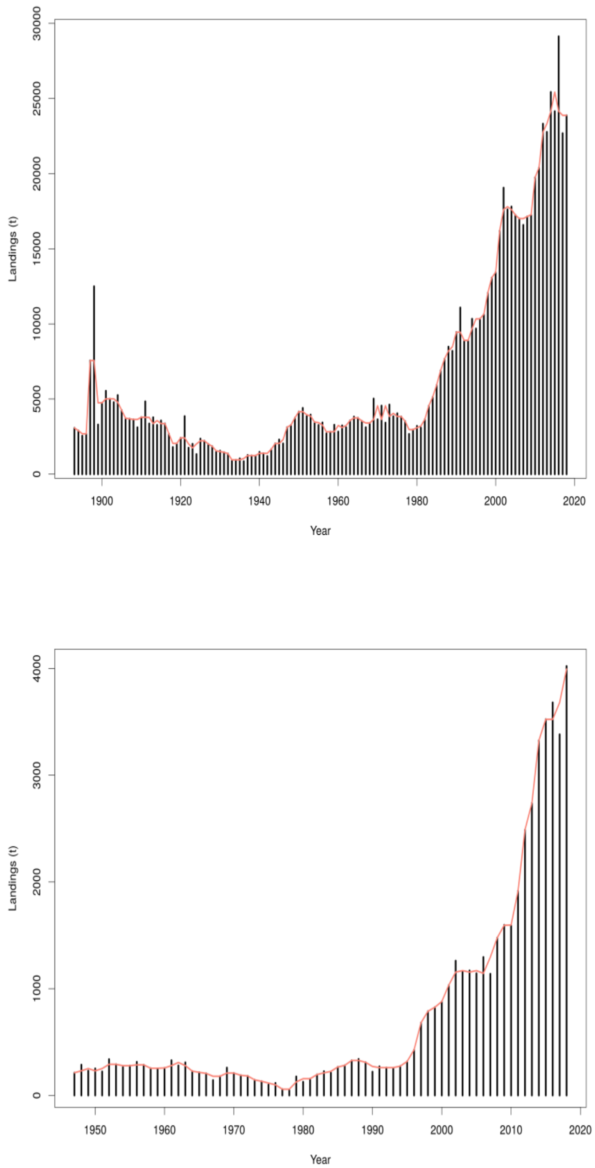

Figure 14. Landings trends by LFA, clockwise from top left, LFA 34, LFA 35, LFA 38, LFA 36. Red lines represent the three-year running medians within each plot. In LFA 34 landings prior to 1947 were split into LFAs by county as indicated in Figure 10.

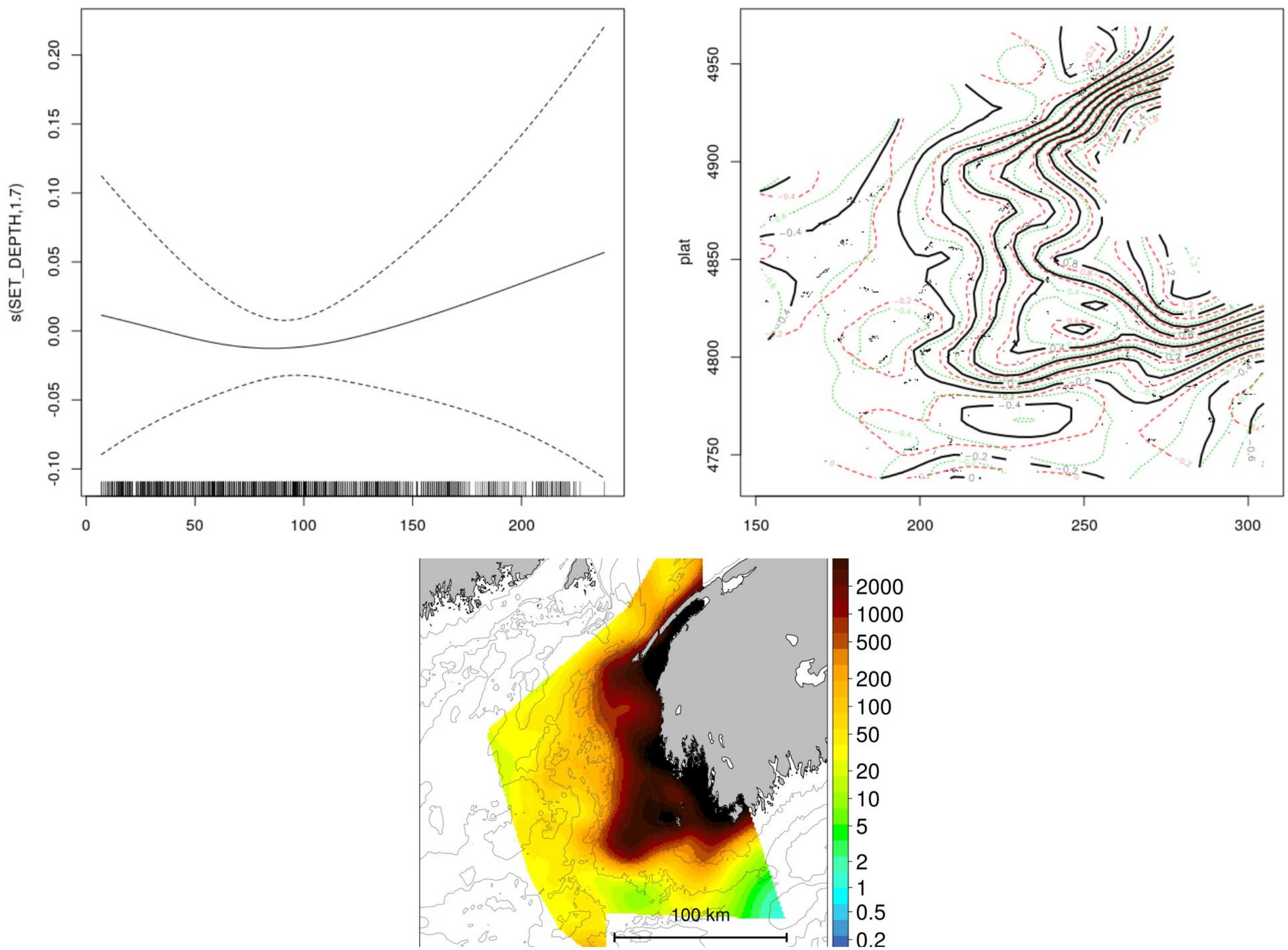

Figure 15. Plots of the smooth depth and spatial terms of the total abundance Generalized Additive Model (GAM) for the Inshore Lobster Trawl Survey (ILTS) (top). Predicted surface of Lobster abundance within LFA 34 from the selected GAM model for 2018 (bottom).

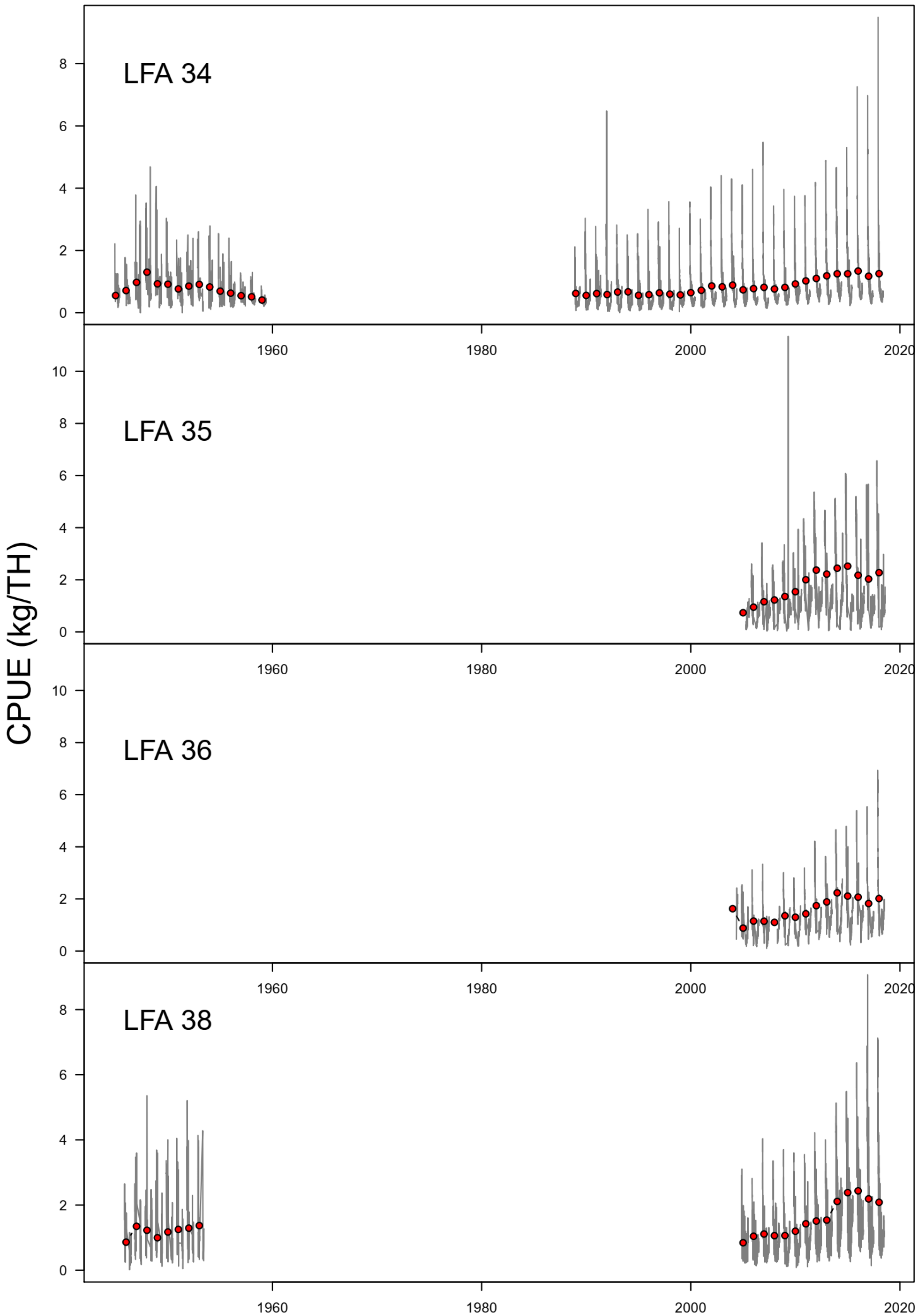

Figure 16. Daily (grey line) and Annual (red dot) mean Catch Per Unit Effort (CPUE) (kg/Trap Haul) for each LFA.

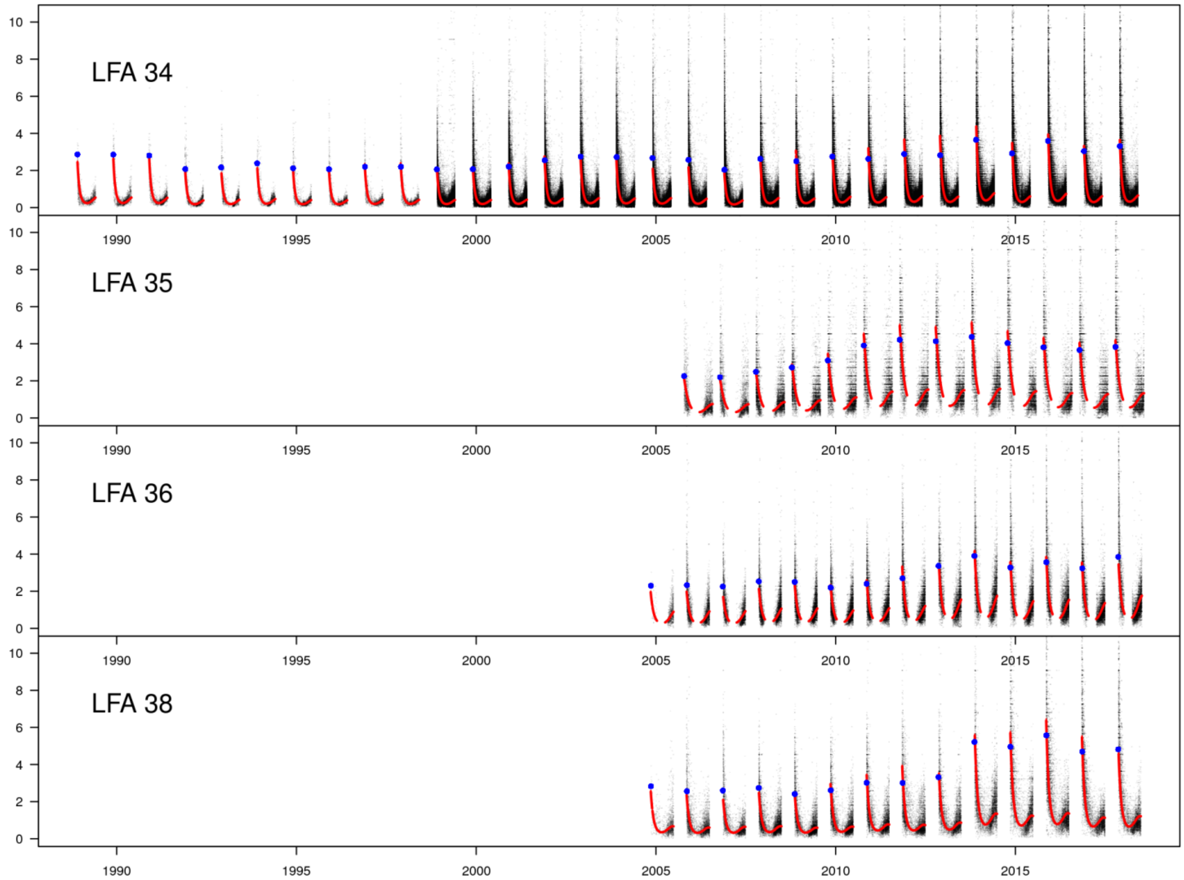

Figure 17. Predictions of Catch Per Unit Effort (CPUE) (kg/Trap Haul) from the model for each day (red line), overlaid on the raw data for LFAs 34–38.

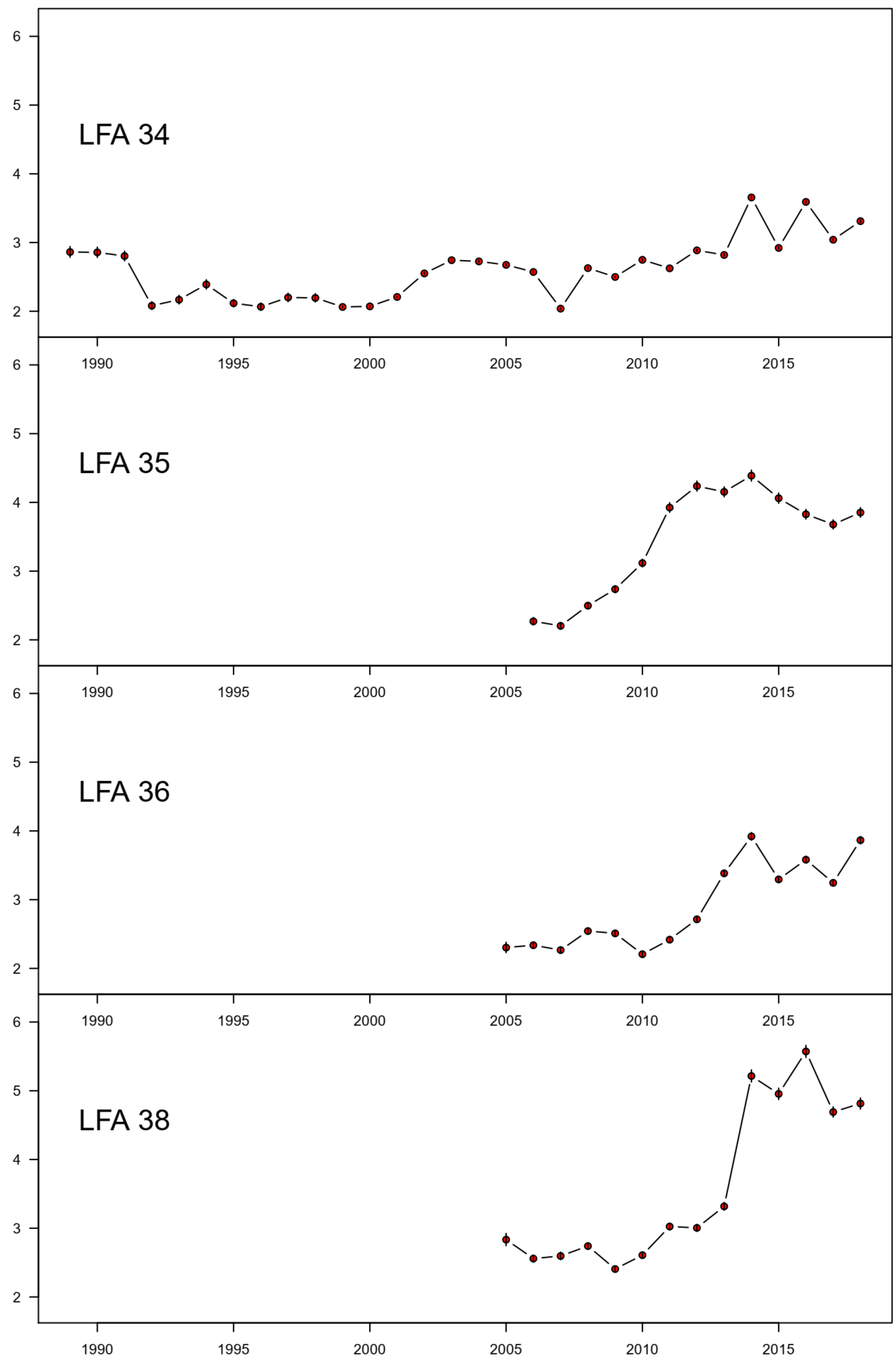

Figure 18. The model predicted mean and standard deviation (covered by points) Catch Per Unit Effort (CPUE) indices for each LFA.

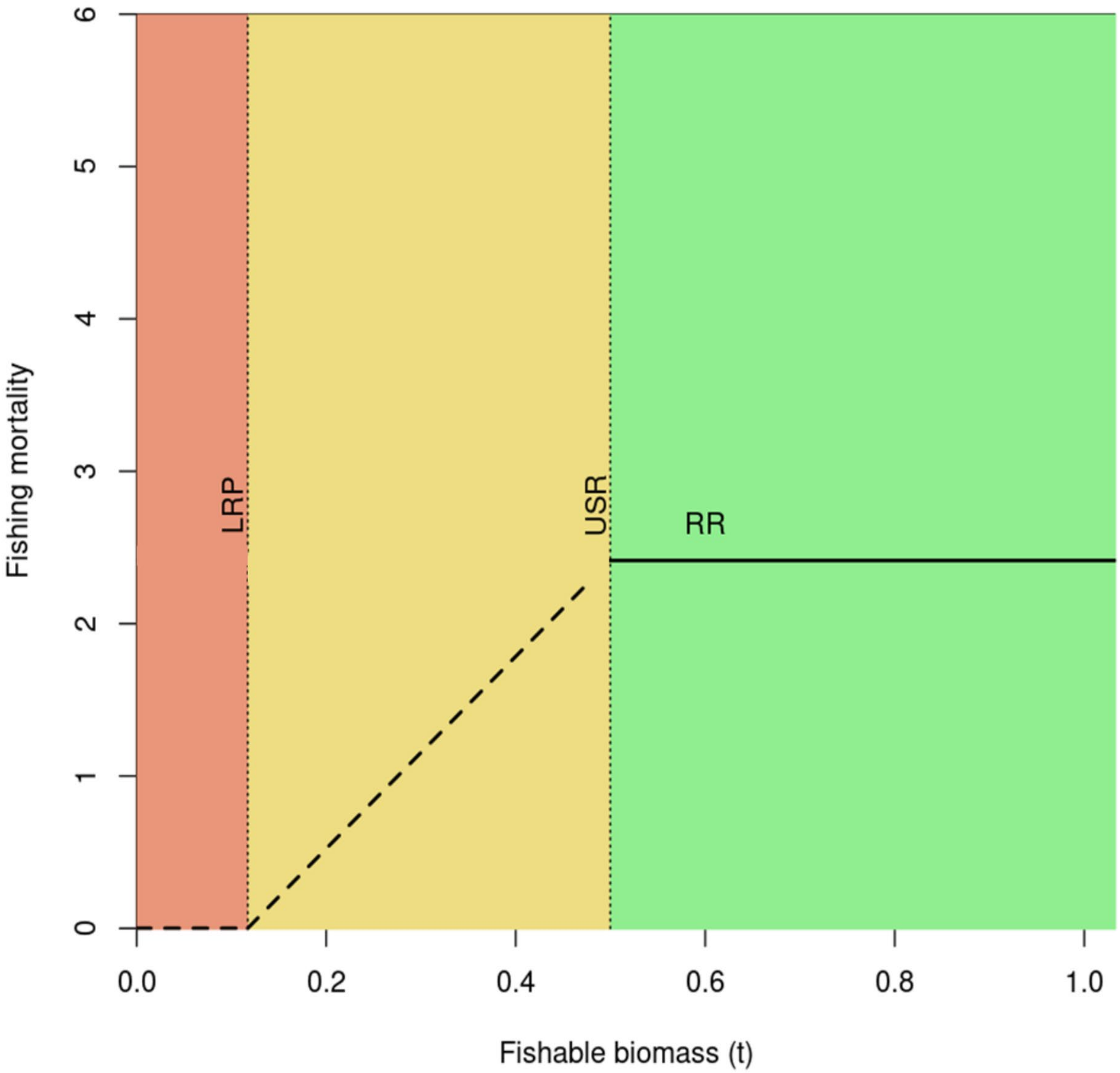

Figure 19. Example precautionary approach phase plot delimiting the healthy zone (green), Upper Stock Reference (USR) the cautious zone (yellow) (between the USR and the Limit Reference Point (LRP)), and critical zone (red) (below the LRP). The Removal Reference (RR) is shown as a solid black line in the healthy zone and progressively decreasing through the cautious zone, the shape and rate of decrease was shown as an example.

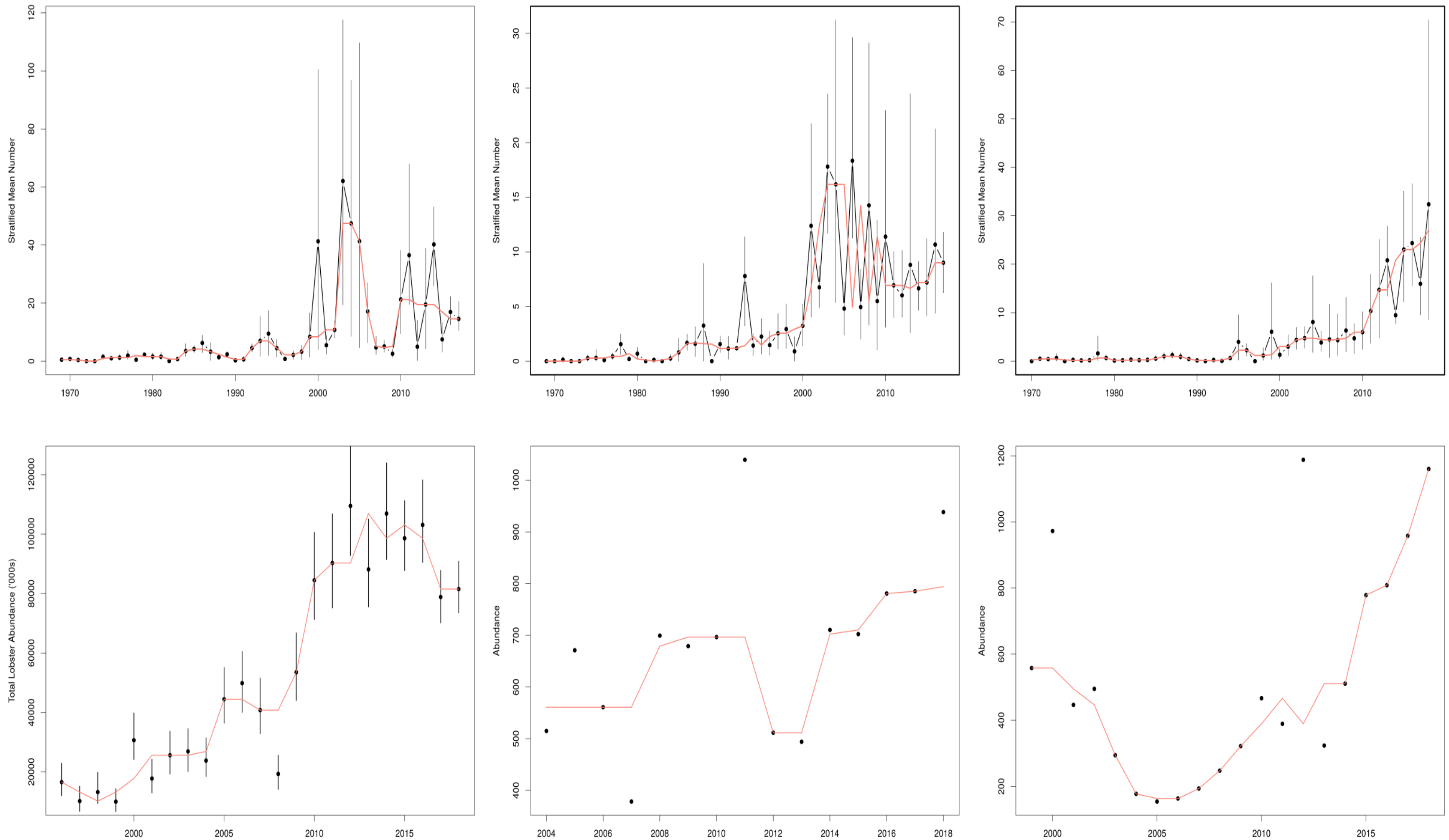

Figure 20. Plot of the total abundance indices of Lobsters in LFA 34. Clockwise from top left, NFall, NSpr, DFO, SFA29, SPA3, and ILTS. Orange lines represent three-year running medians. Indices were stratified abundances for the STratified Random Surveys (STRS) and for the ILTS generalized additive model predictive surface.

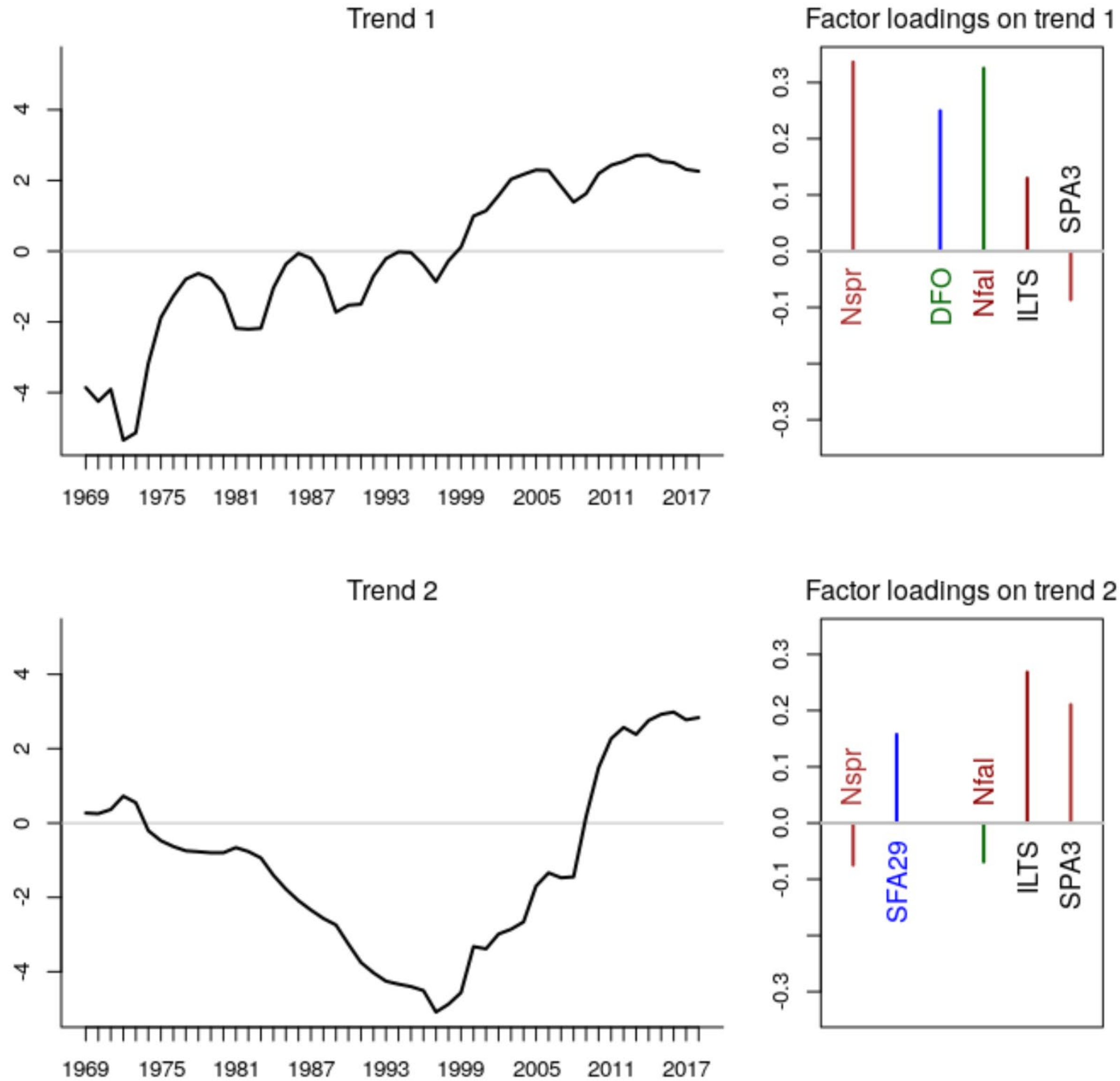

Figure 21. Time series states in LFA 34 total Lobsters estimated from Dynamic Factor Analysls (DFA) of the six abundance trends.

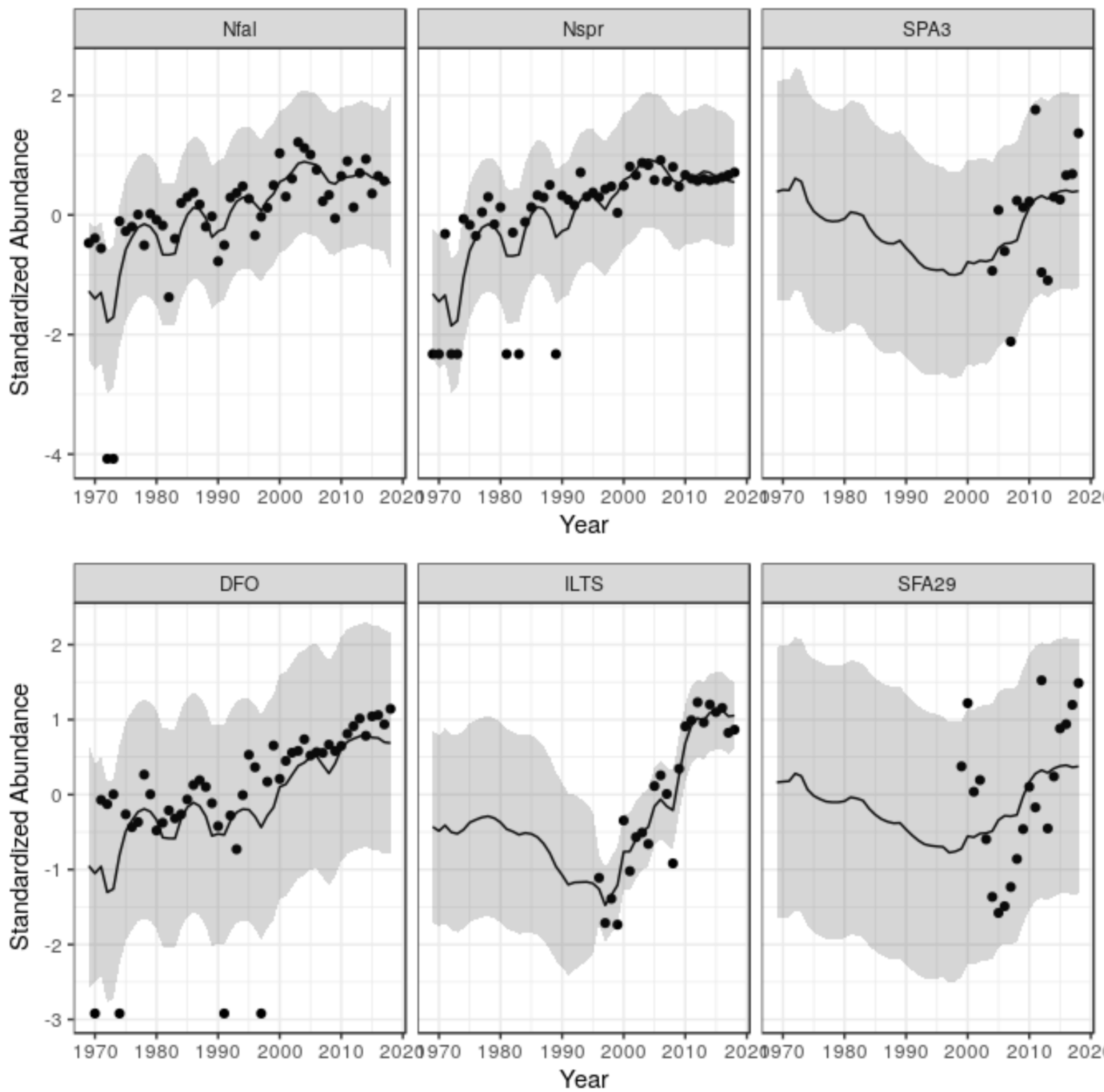

Figure 22. Time series trend fits with confidence intervals from Dynamic Factor Analysis (DFA) of the six abundance trends.

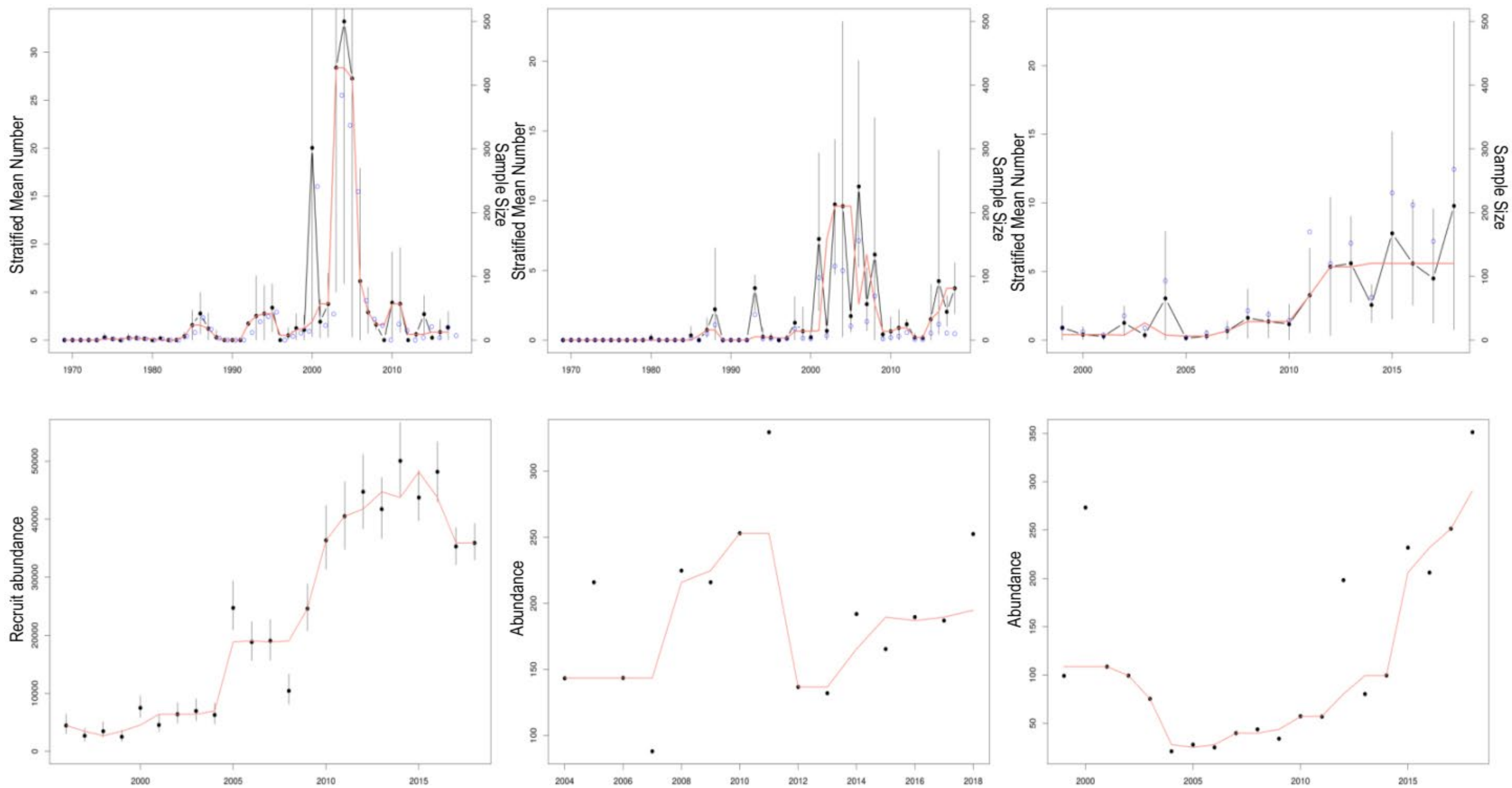

Figure 23. Plot of the recruit abundance indices of Lobsters in LFA 34. Clockwise from top left, NFall, NSpr, DFO, SFA29, SPA3, and ILTS. Orange lines represent three-year running medians. Indices were stratified abundances for the STratified Random Survey's (STRS's) and for the ILTS generalized additive model predictive surface.

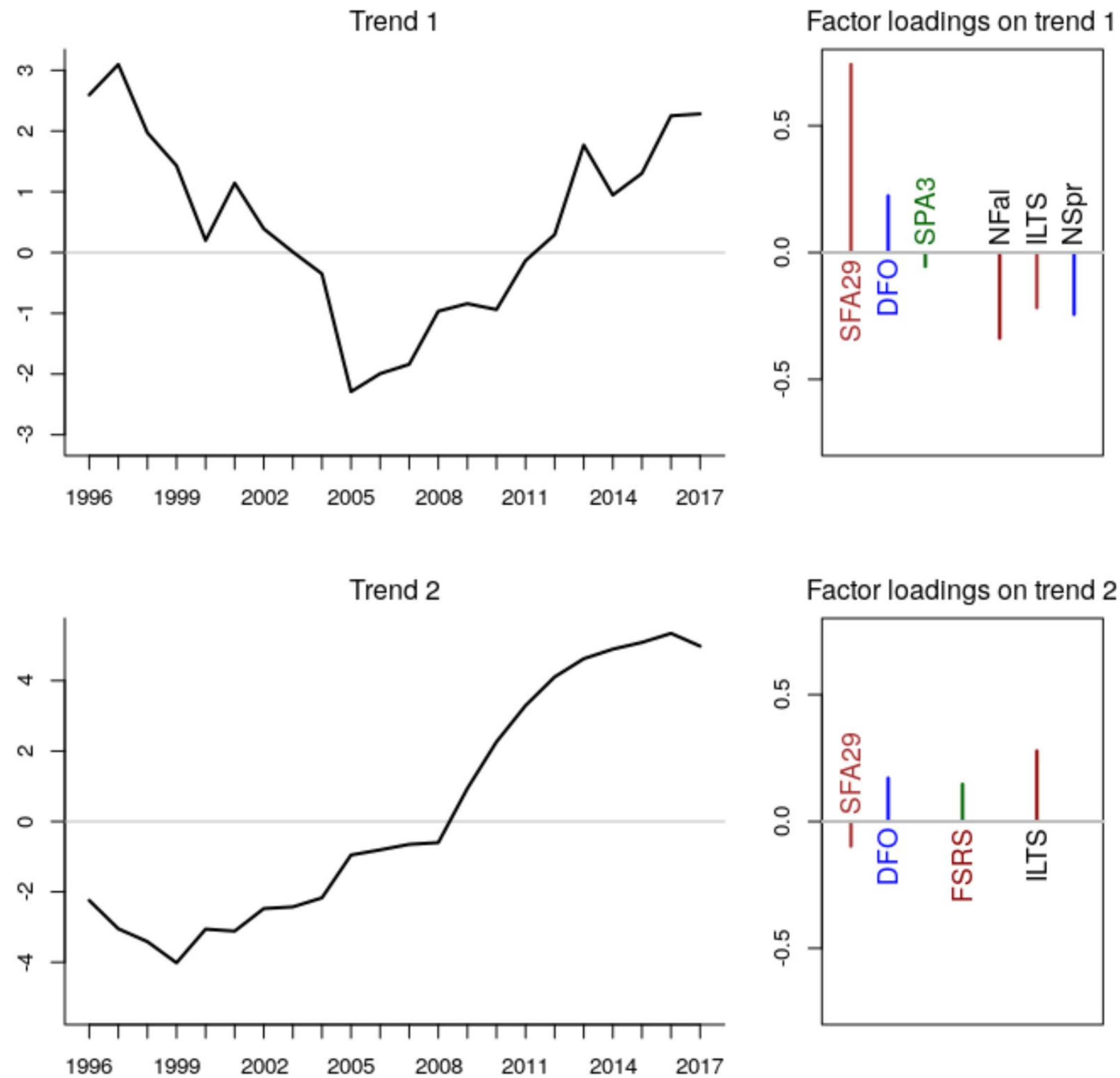

Figure 24. Time series states in LFA 34 recruiting Lobsters estimated from Dynamic Factor Analysis (DFA) of the seven abundance trends.

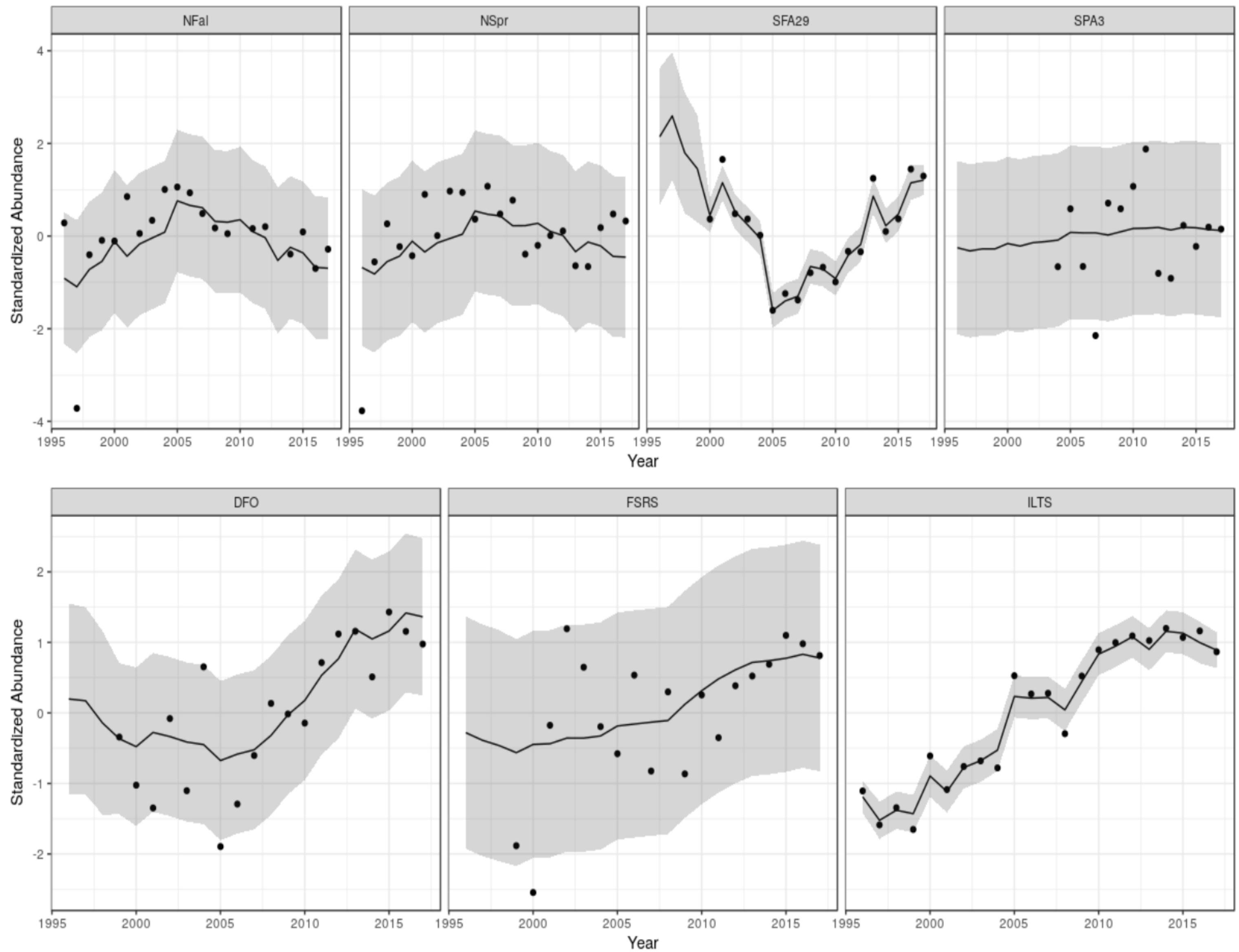

Figure 25. Time series trend fits with confidence intervals from Dynamic Factor Analysis of the seven abundance trends.

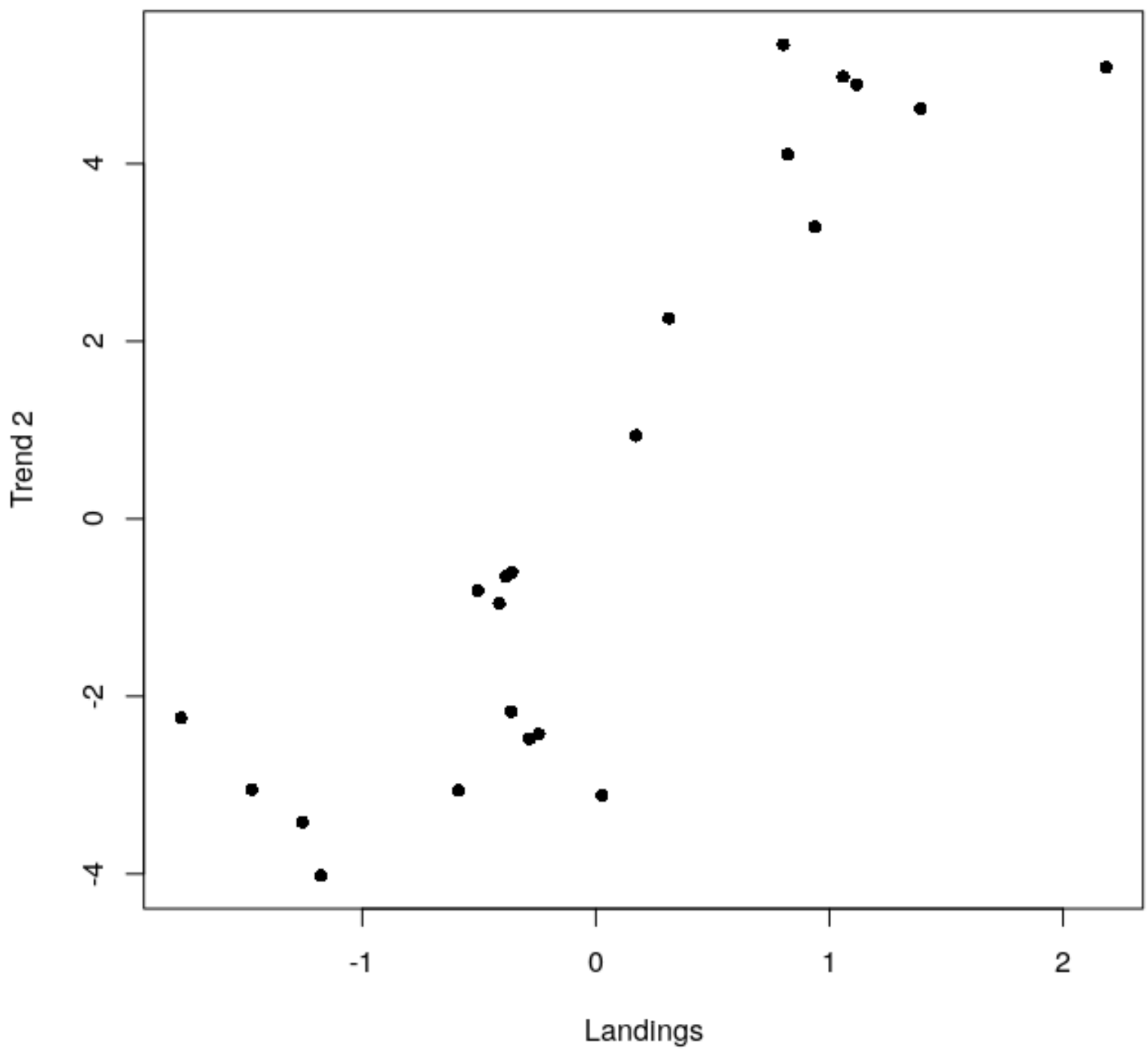

Figure 26. Plot of Dynamic Factor Analysis (DFA) time trend 2 of recruit abundance in LFA 34 to landings in the following year.

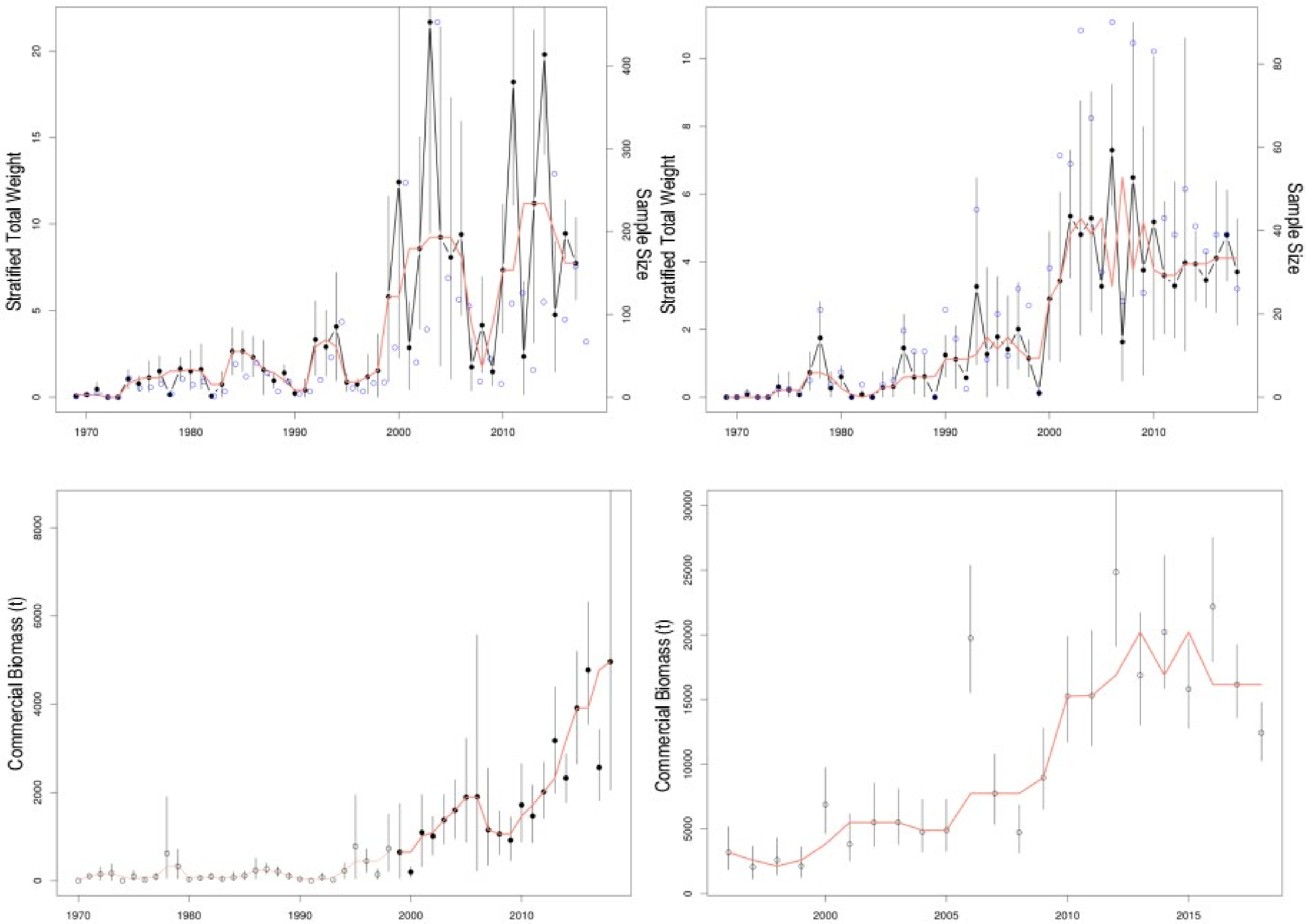

Figure 27. Time series trends in commercial biomass for Lobsters within LFA 34 captured in trawl surveys. Clockwise from top left, NFall, NSpr, ILTS and DFO. Orange lines represent three-year running medians. The commercial biomass in the DFO time series from 1970–1998 was estimated using the proportion of commercial biomass to total biomass in the trawl survey between 1999 and 2018.

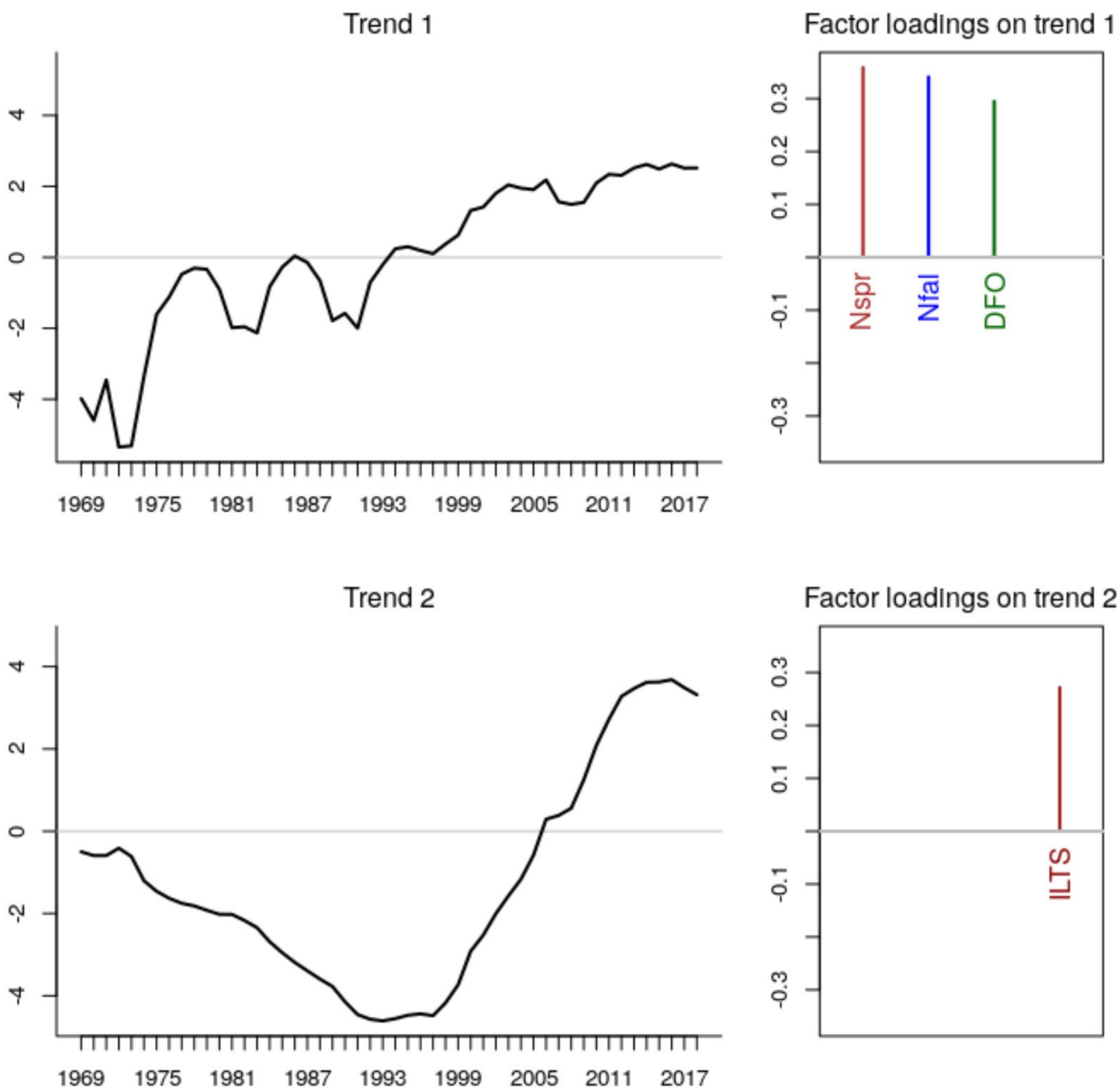

Figure 28. Time series states in LFA 34 commercial biomass trends estimated from Dynamic Factor Analyses (DFA).

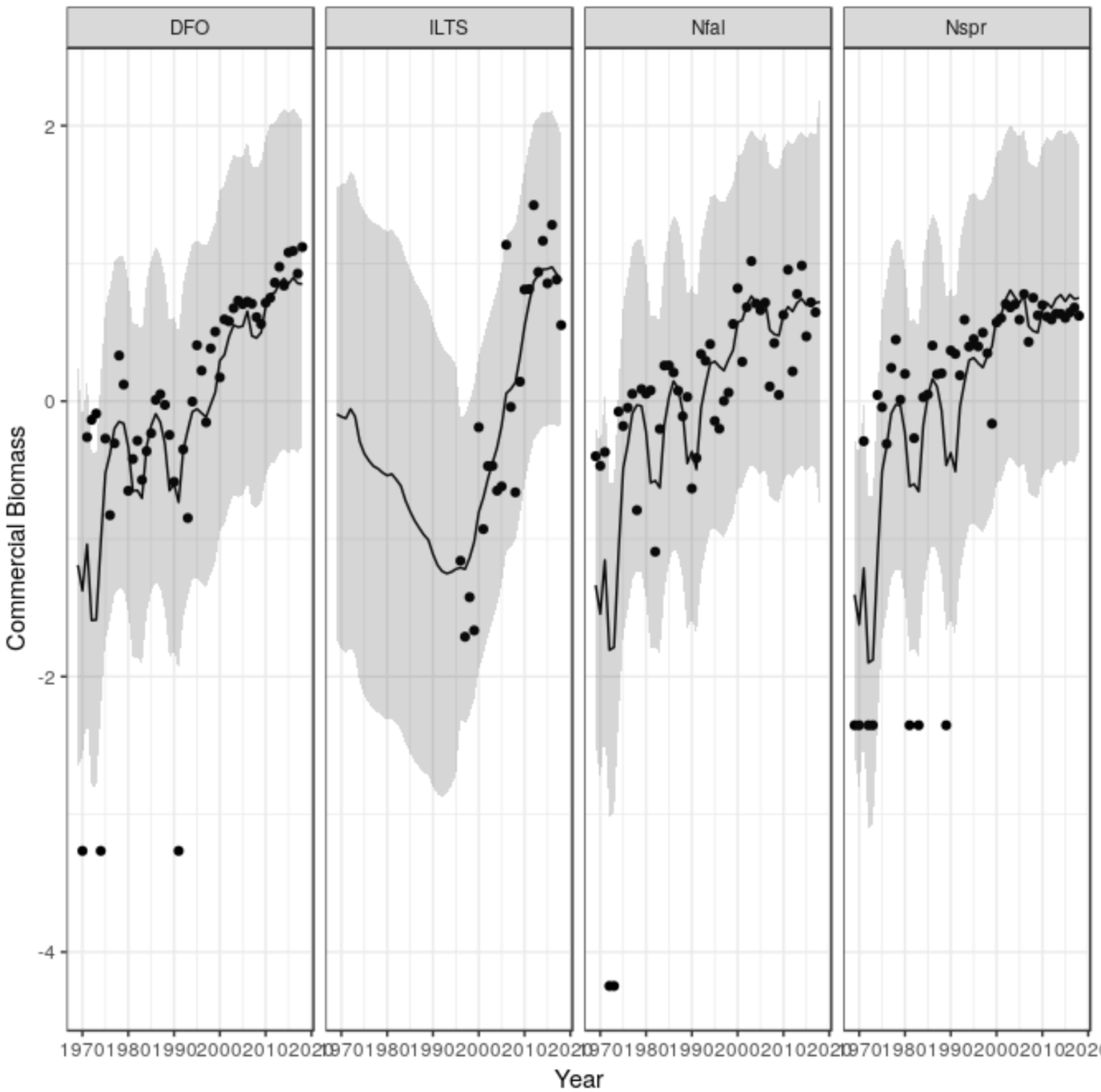

Figure 29. Time series trend fits with confidence intervals from Dynamic Factor Analysis of the commercial biomass trends.

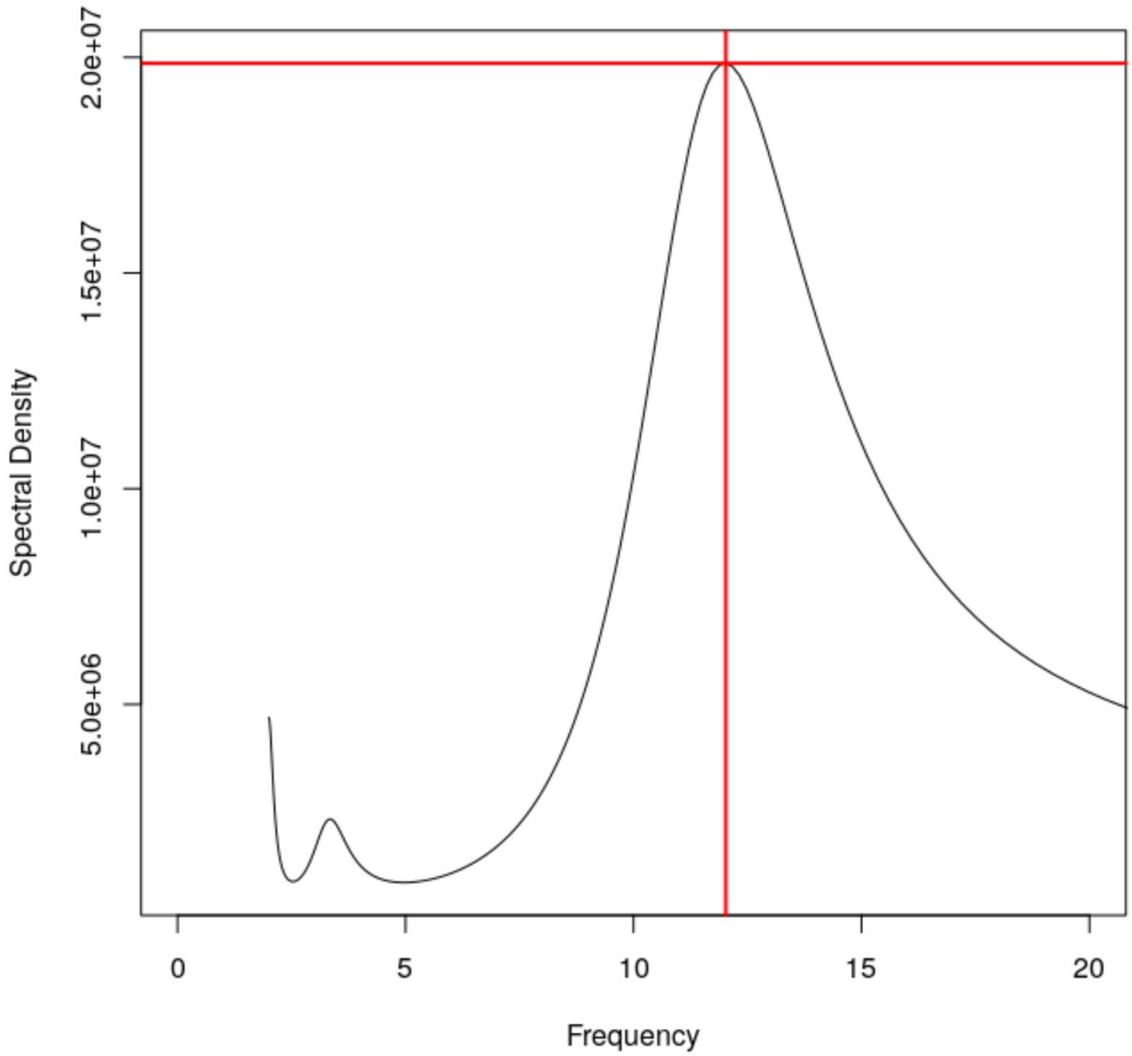

Figure 30. Spectral density of de-trended landings data from LFA 34 to determine the frequency of the cyclic pattern observed in the data.

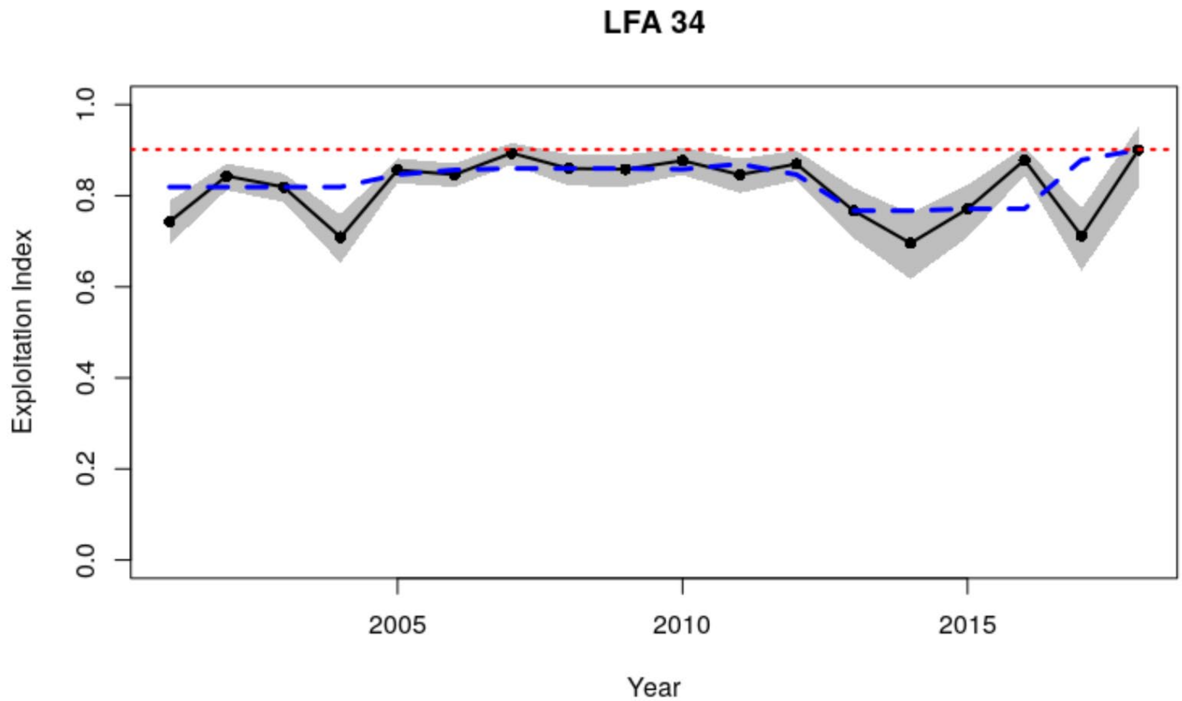

Figure 31. Exploitation index for LFA 34 derived using the Continuous Change In Ratio (CCIR) method on the Fishermen and Scientist Research Society (FSRS) recruitment trap data.

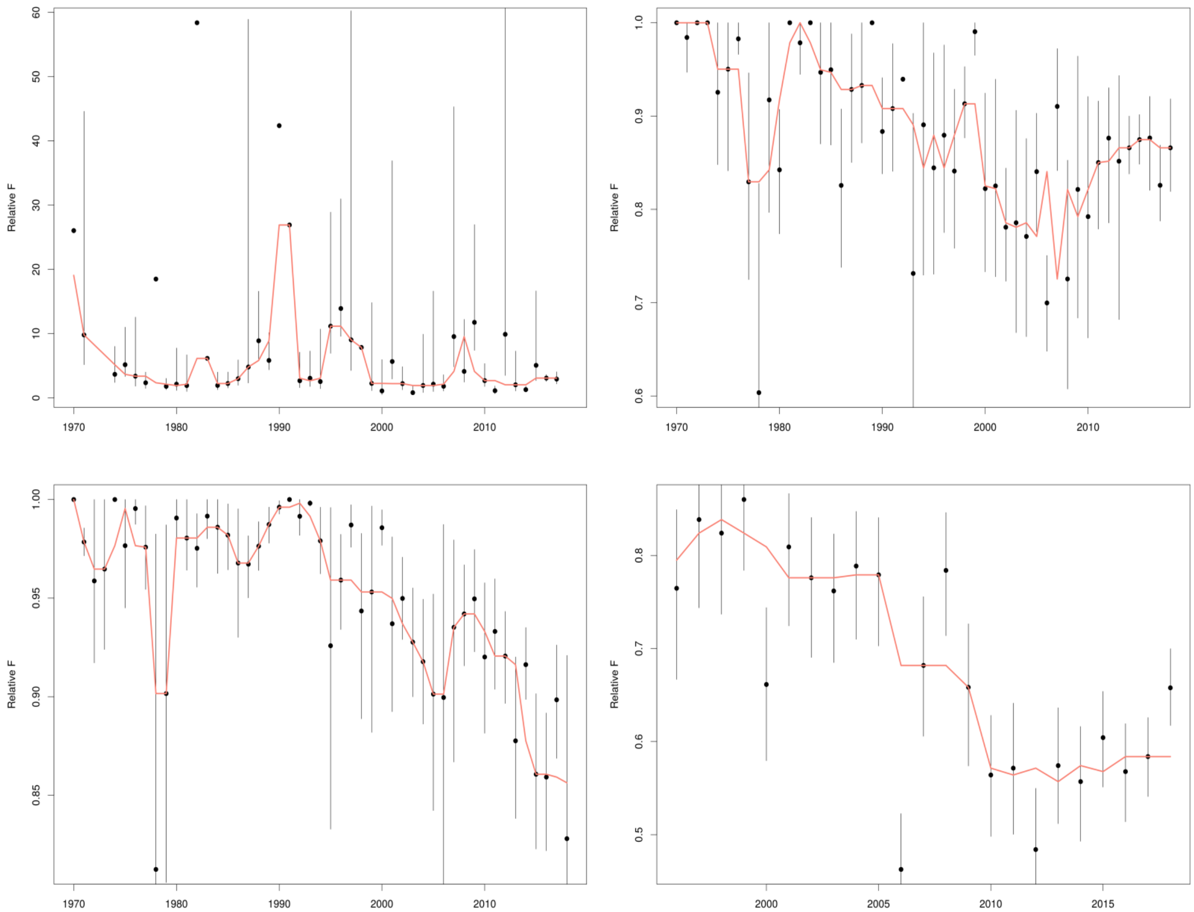

Figure 32. Time series trends of relative fishing mortality (relF) using observed landings and survey estimated commercial biomass for Lobsters within LFA 34. Clockwise from top left, NFall, NSpr, ILTS and DFO. Orange lines represent three-year running medians.

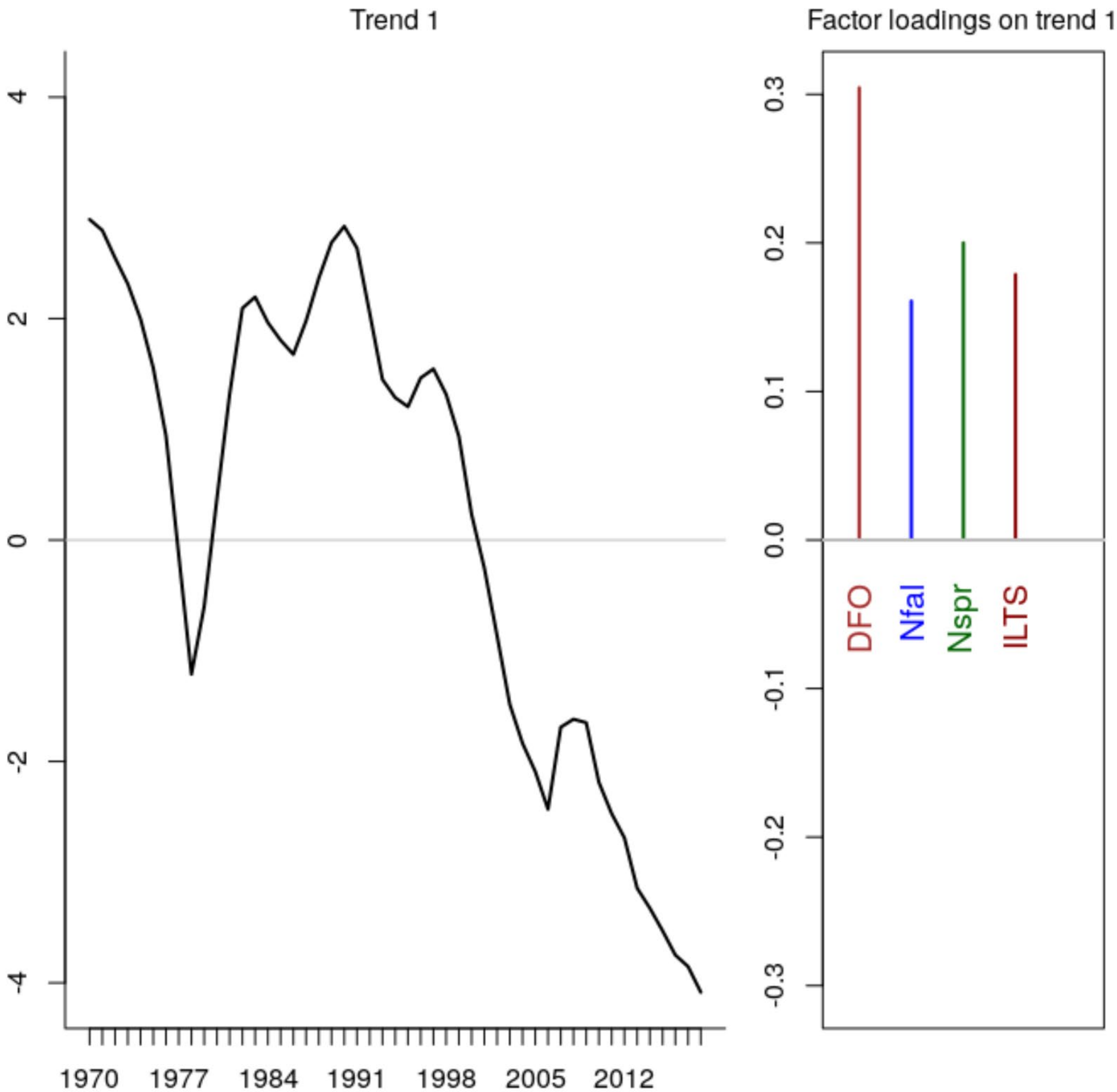

Figure 33. Time series states in LFA 34 relative fishing mortality (relF) and Continuous Change In Ratio (CCIR) exploitation from Dynamic Factor Analysis (DFA).

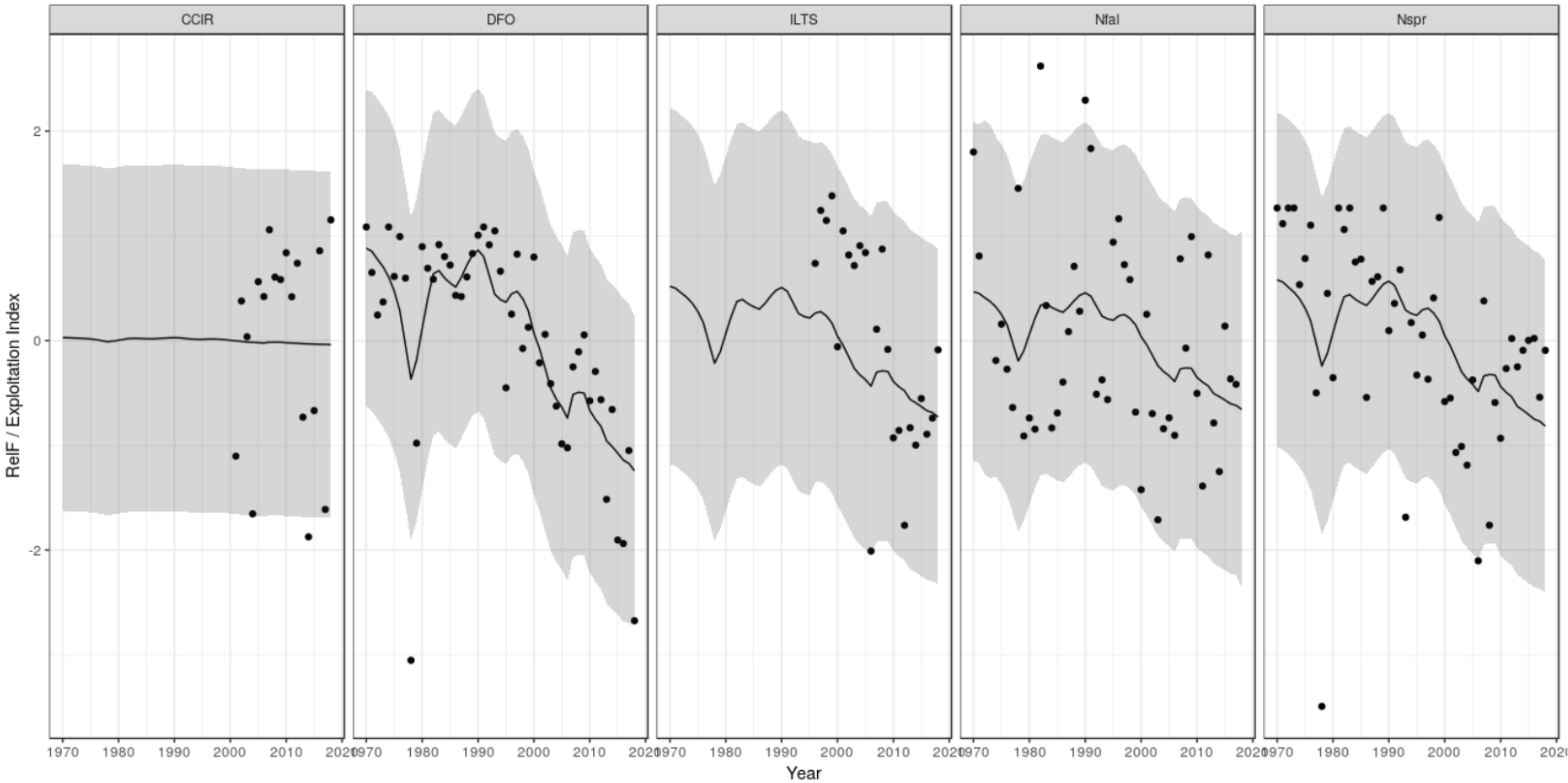

Figure 34. Time series trend fits with confidence intervals from Dynamic Factor Analysis of the relative fishing mortality (relF) and Continuous Change In Ratio (CCIR) exploitation indices in LFA 34.

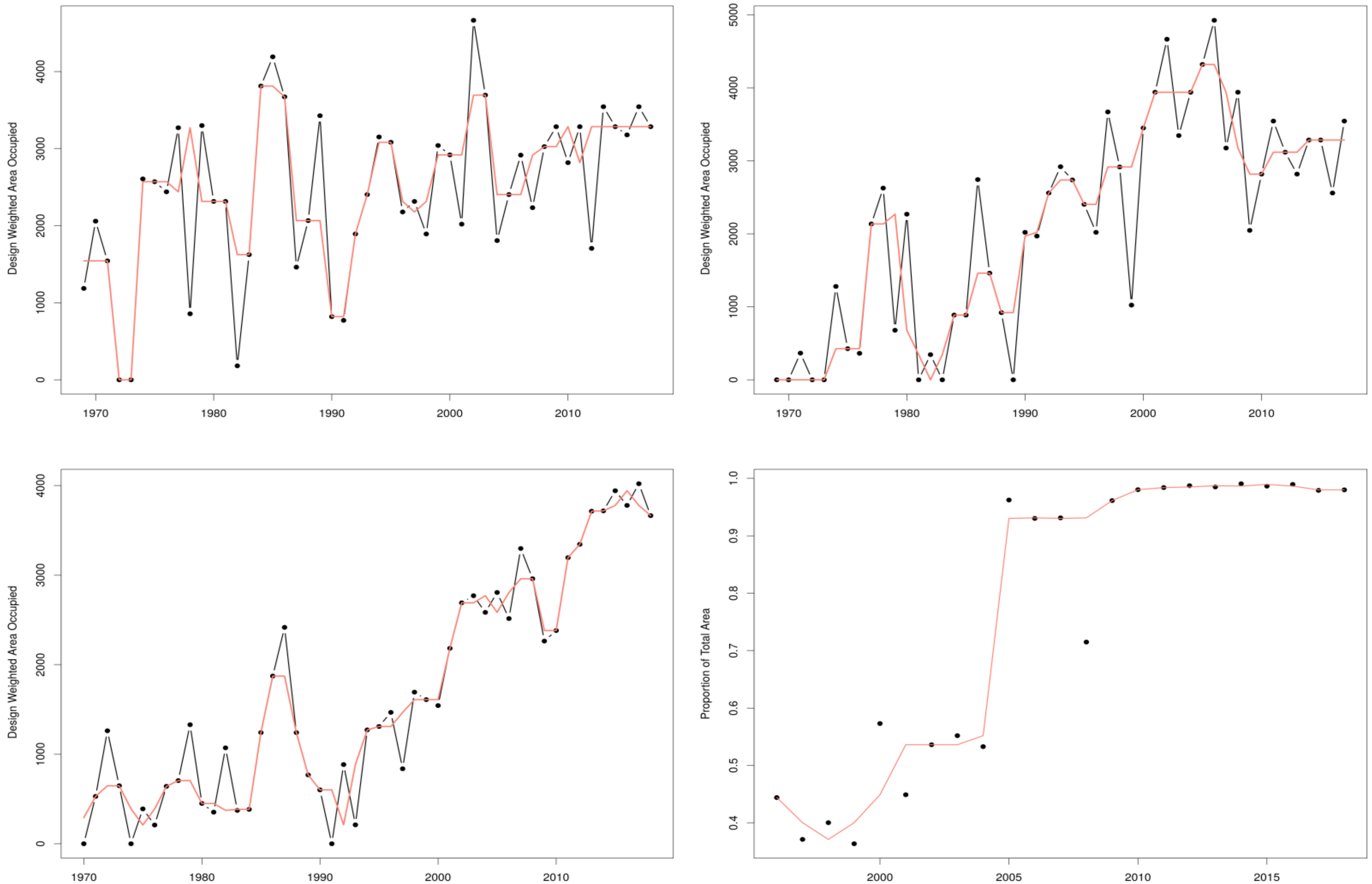

Figure 35. Plot of the area occupied of Lobsters within LFA 34 captured during surveys. Clockwise from top left, NFall, NSpr, ILTS, DFO. Orange lines represent three-year running medians. Indices were Design Weighted Area Occupied (DWAO) for the STratified Random Survey's (STRS's) and for the ILTS proportion of total area with > 5 recruits per km^2.

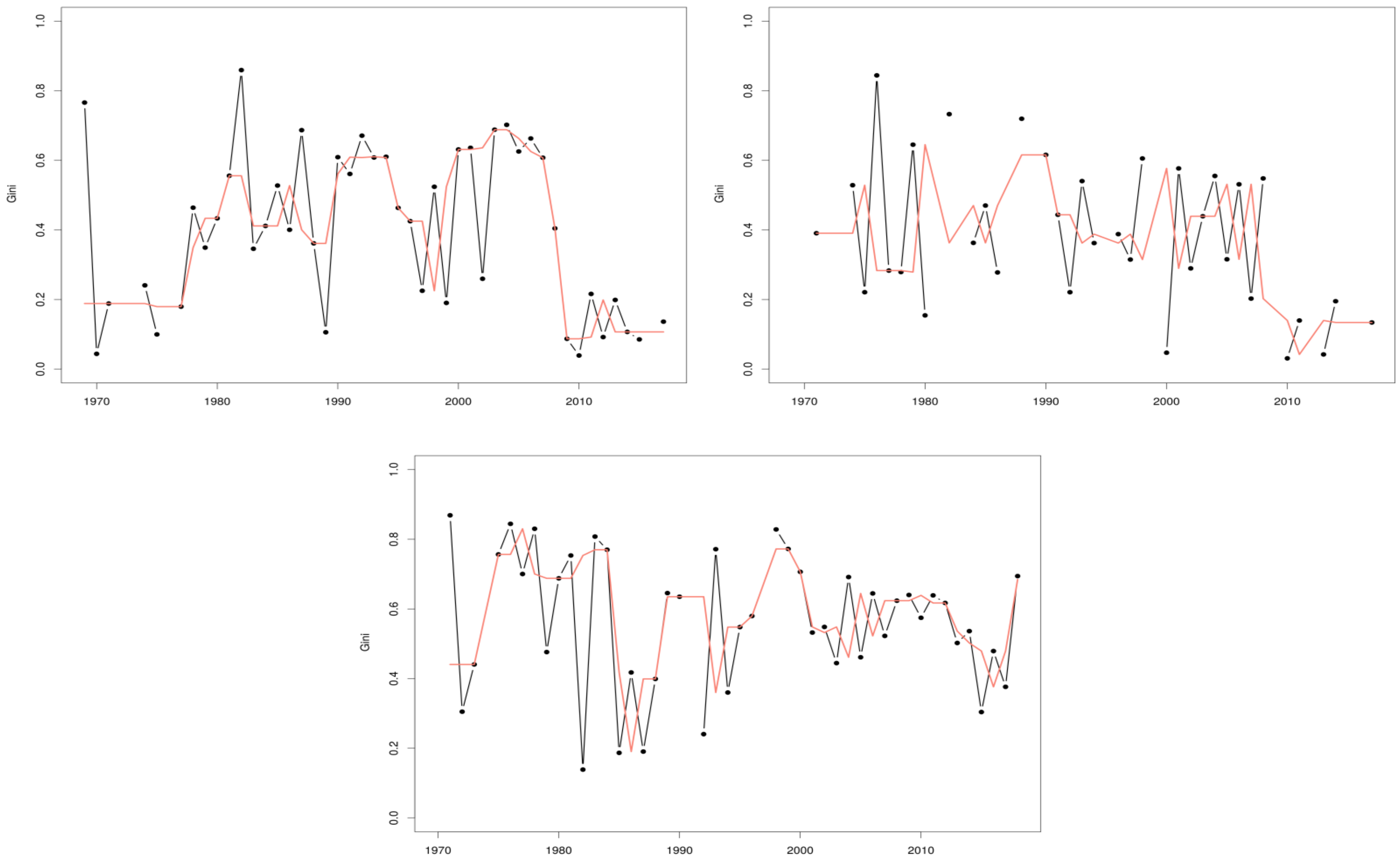

Figure 36. Plot of the level of patchiness of survey catch rates for Lobsters within LFA 34. Clockwise from top left, NFall, NSpr and DFO. Orange lines represent three-year running medians Indices were generated using the Gini index where low numbers represent even distribution and high numbers patchy distributions.

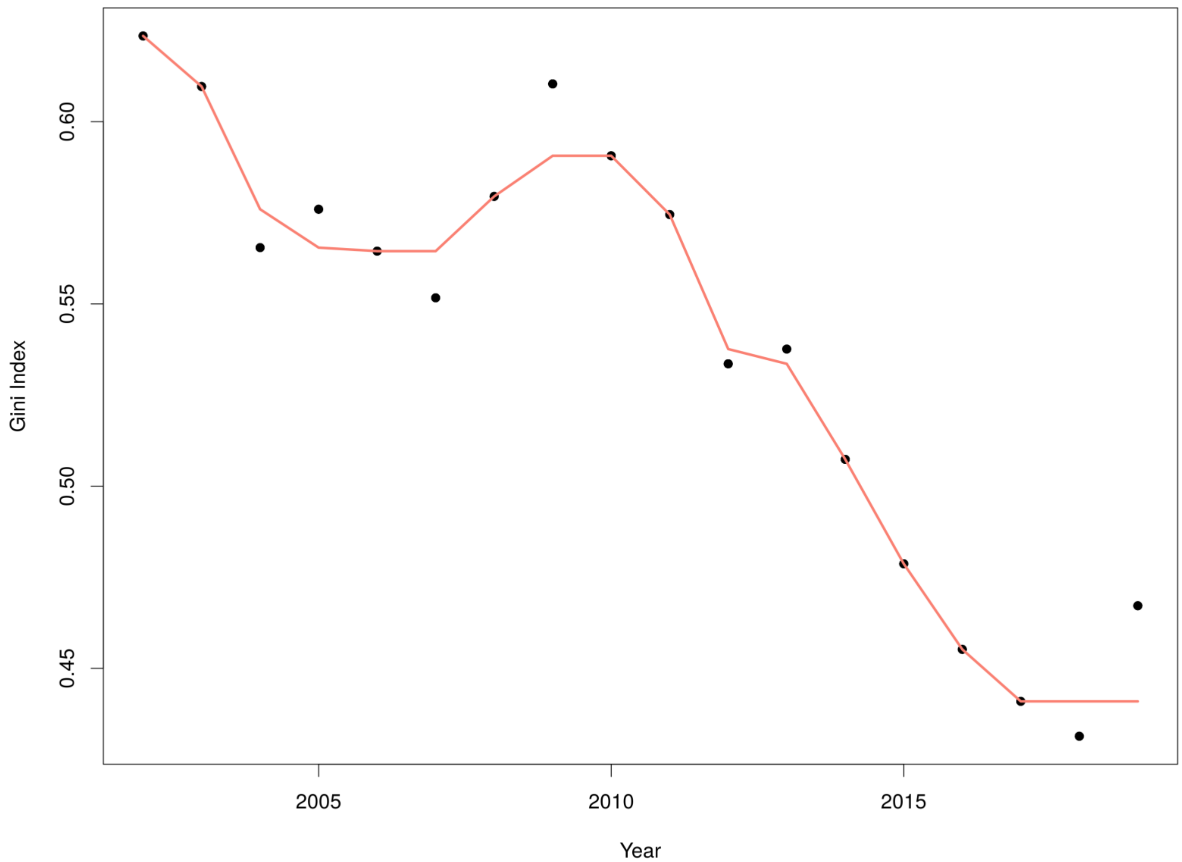

Figure 37. Plot of level of patchiness of landings of Lobsters within LFA 34. Patchiness was estimated by the Gini index.

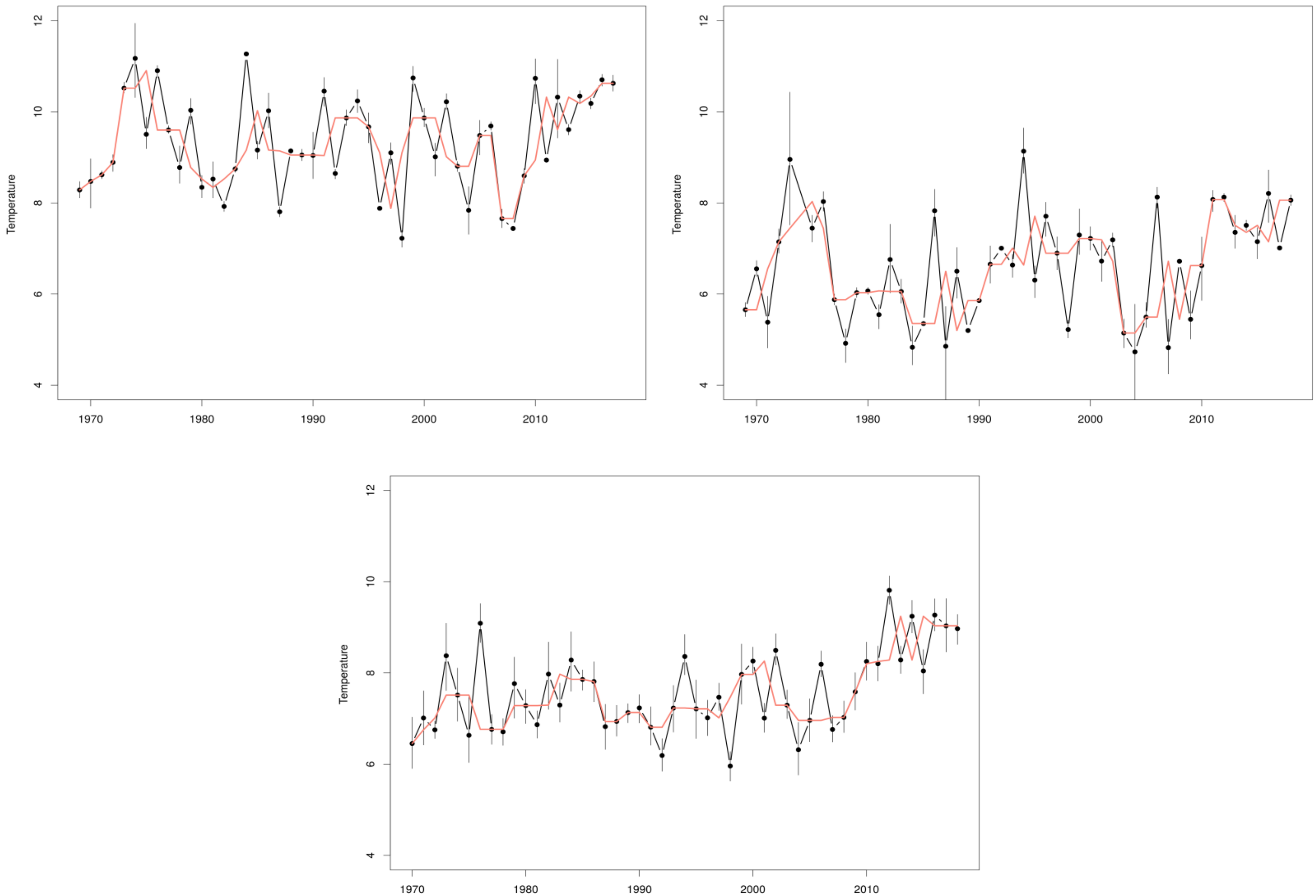

Figure 38. Plot of the mean bottom temperatures from long running surveys within LFA 34. Clockwise from top left, NFall, NSpr, and DFO. Orange lines represent three-year running medians.

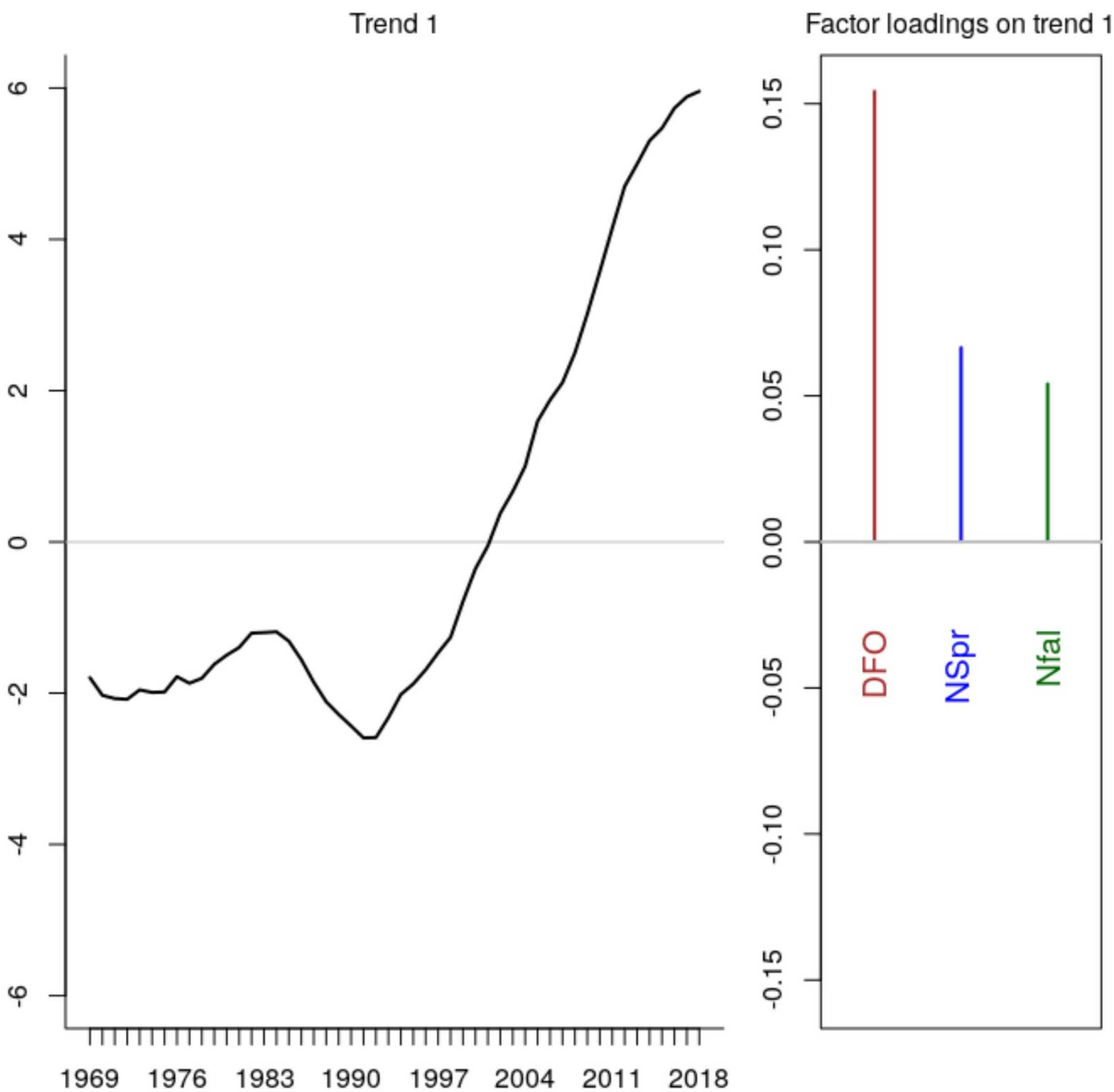

Figure 39. Time series states in LFA 34 bottom temperatures estimated from Dynamic Factor Analyses (DFA) of three survey trends.

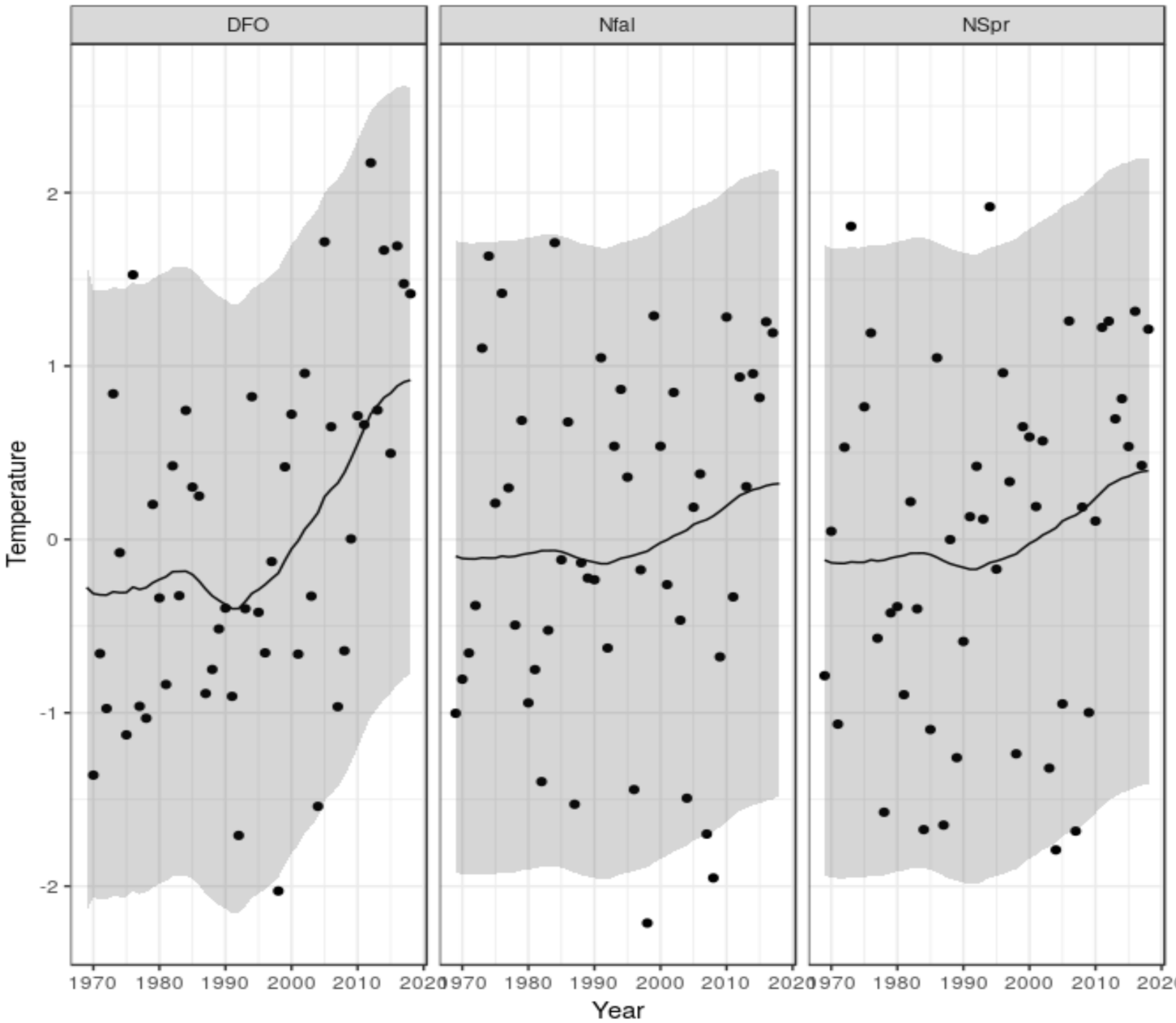

Figure 40. Time series trend fits with confidence intervals from Dynamic Factor Analysis (DFA) of the bottom temperature time series.

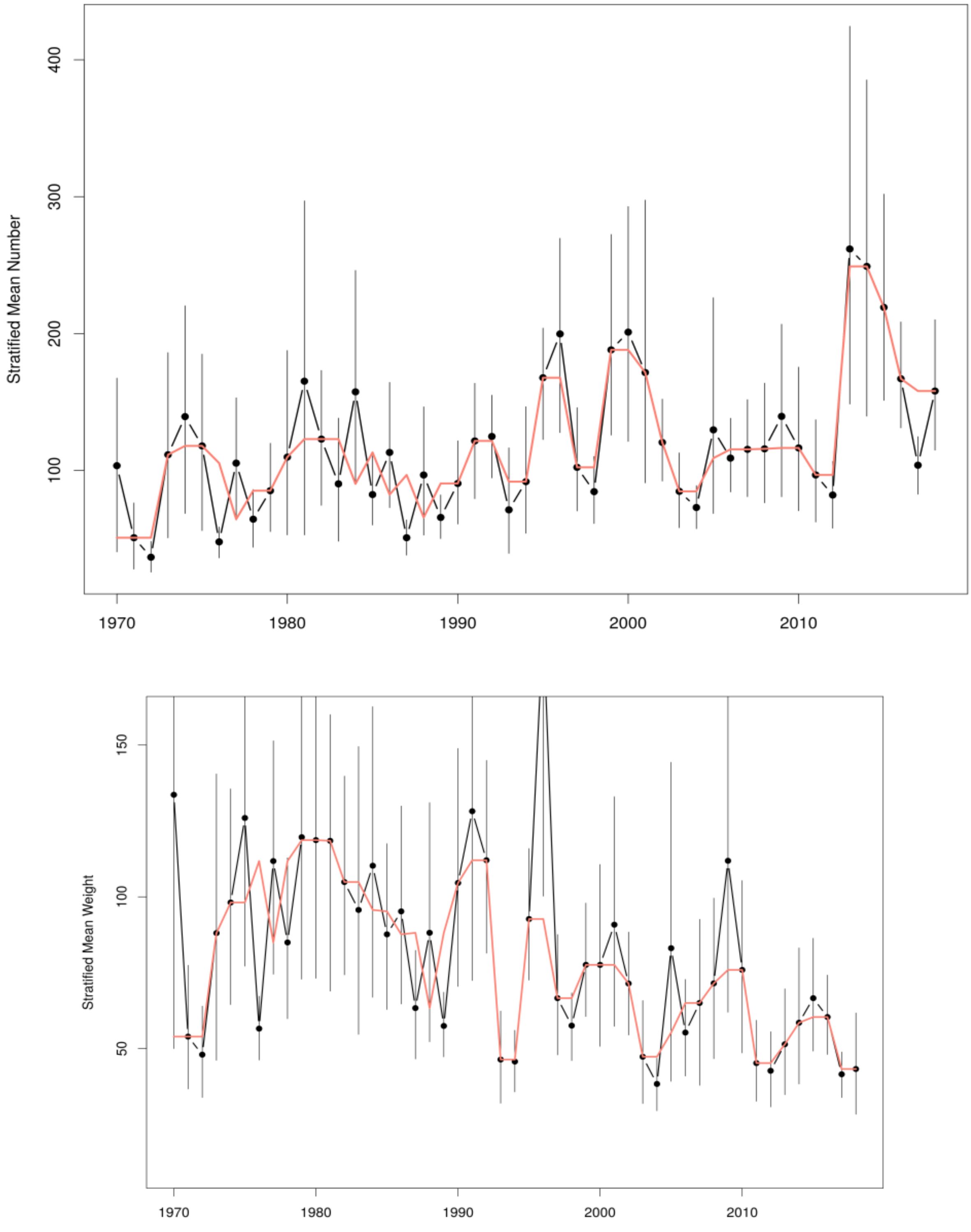

Figure 41. Plot of the stratified abundance and biomass estimates of Lobster predators from the DFO bottom trawl survey. Red line represents three-year running medians.

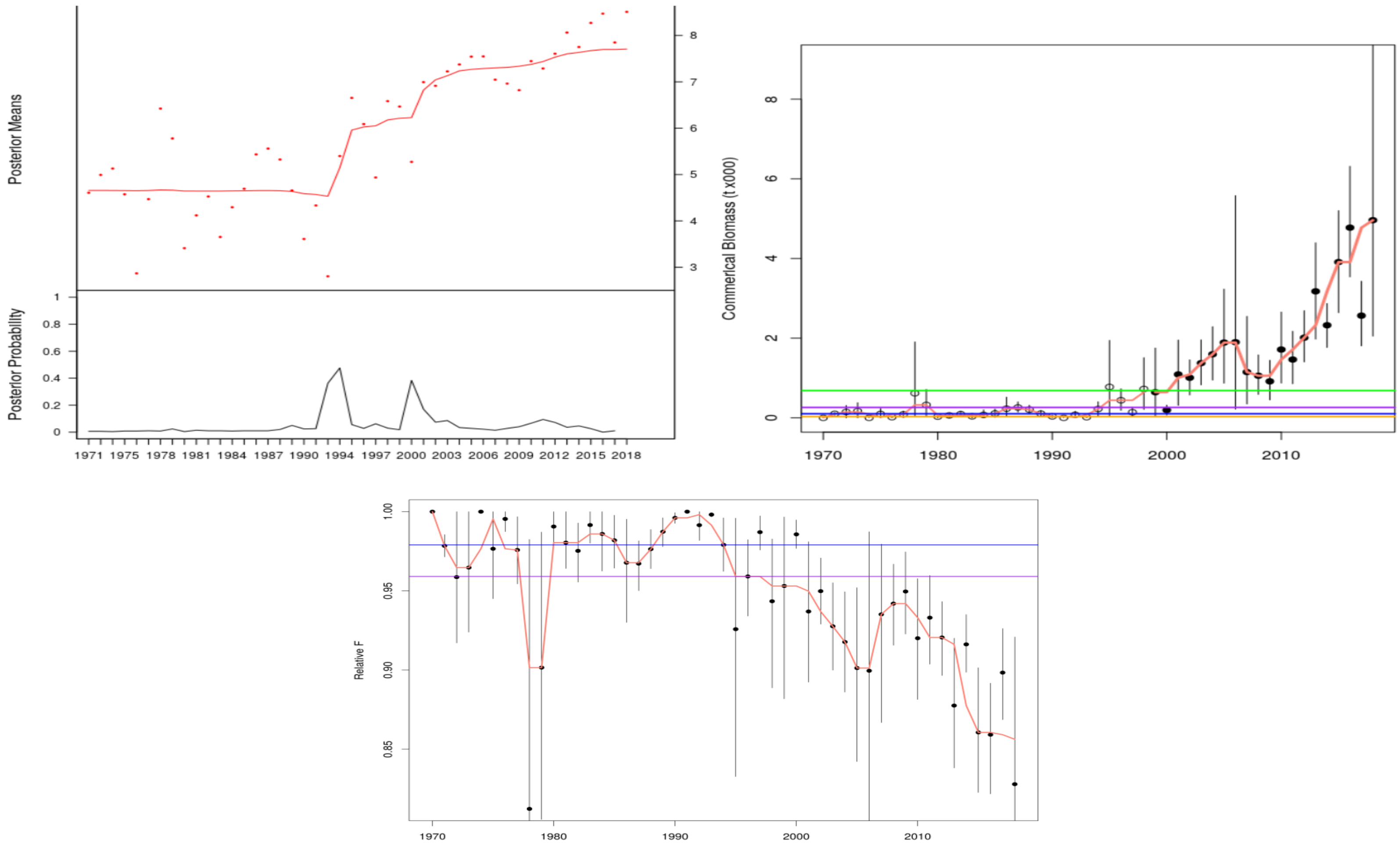

Figure 42. Plot of the Bayesian change point analyses on the DFO commercial biomass survey index (top left). Plot of the commercial biomass index in thousands of tons with reference points from the DFO survey (top right) : Green line represents USI_h, purple line was the USI_f, blue line was the LRI_l and orange was the $LRI_{recover}$. Time series of relative fishing mortality (relF) with long term median relF (purple) and median of low productivity relF (blue) (bottom). In each plot red line represents three-year running medians.

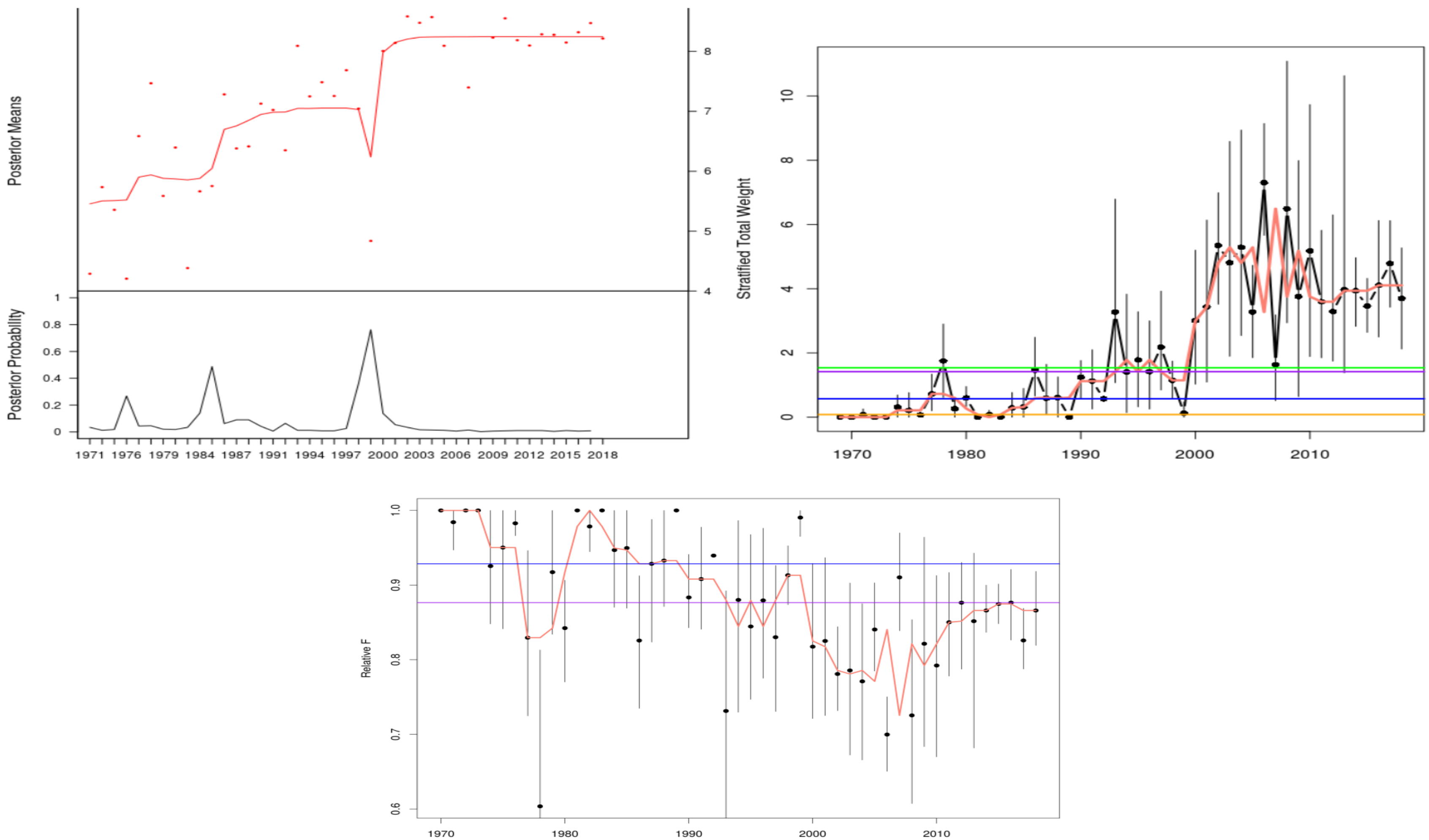

Figure 43. Plot of the Bayesian change point analyses on the NEFSC spring commercial biomass survey index (top left). Plot of the commercial biomass index in thousands of tons with reference points from the NEFSC spring survey (top right): Green line represents USIh, purple line was the USIf, blue line was the LRII and orange was the LRIrecover. Time series of relative fishing mortality (relF) with long term median relF (purple) and median of low productivity relF (blue) (bottom). In each plot red line represents three-year running medians.

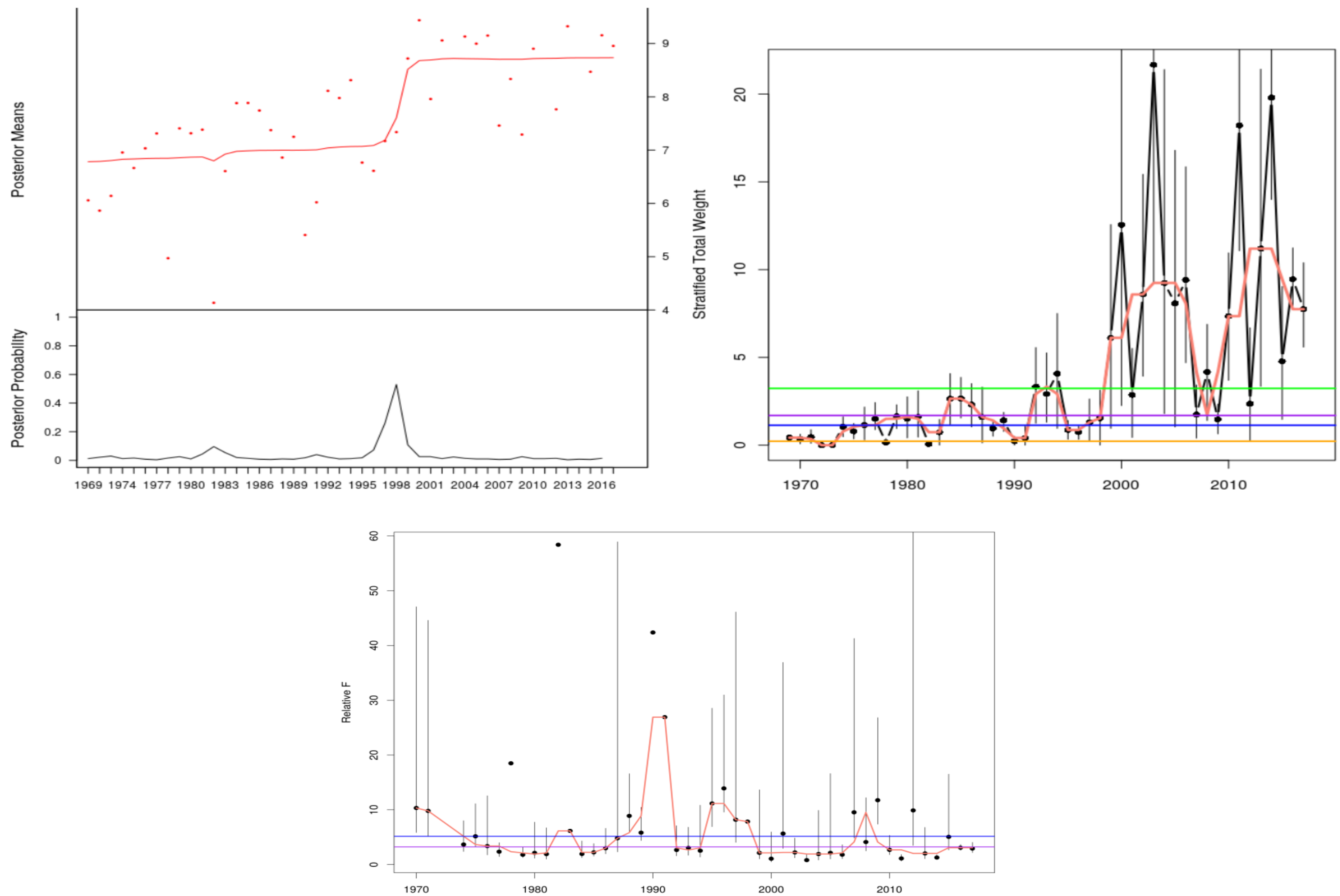

Figure 44. Plot of the Bayesian change point analyses on the NEFSC Fall commercial biomass survey index (top left). Plot of the commercial biomass index in thousands of tons with reference points from the NEFSC Fall survey (top right) : Green line represents USI_h, purple line was the USI_f, blue line was the LRI_l, and orange was the $LRI_{recover}$. Time series of relative fishing mortality (relF) with long term median relF (purple) and median of low productivity relF (blue) (bottom). In each plot red line represents three-year running medians.

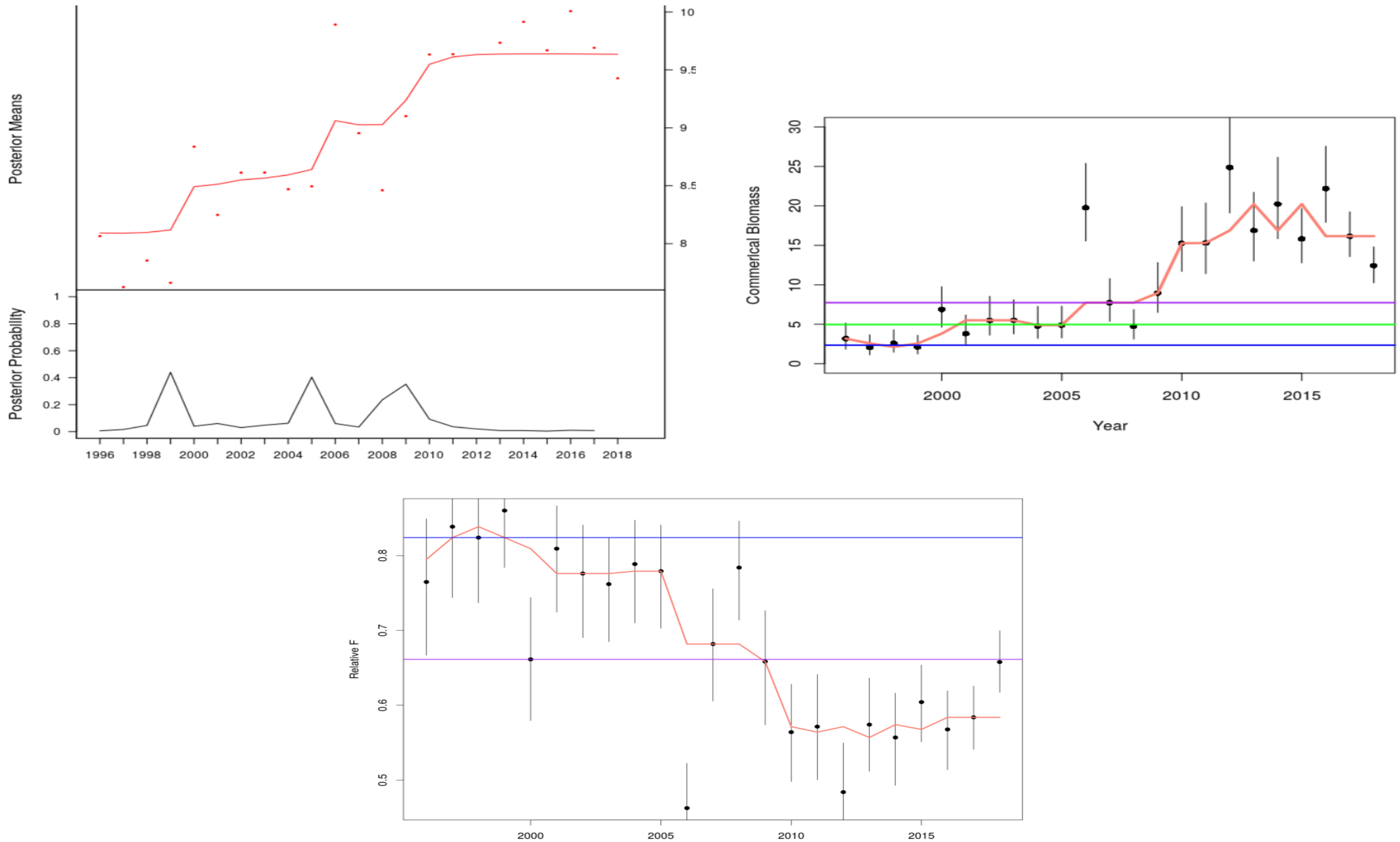

Figure 45. Plot of the Bayesian change point analyses on the ILTS commercial biomass survey index (top left). Plot of the commercial biomass index in thousands of tons with reference points from the ILTS survey (top right): green line represents USI_h, purple line was the USI_f, blue line was the LRI_l and orange was the $LRI_{recover}$. There was complete overlap between LRI_l and LRIrecover. Time series of relative fishing mortality (relF) (bottom), with long term median relF (purple) and median of low productivity relF (blue). In each plot red line represents three-year running medians.

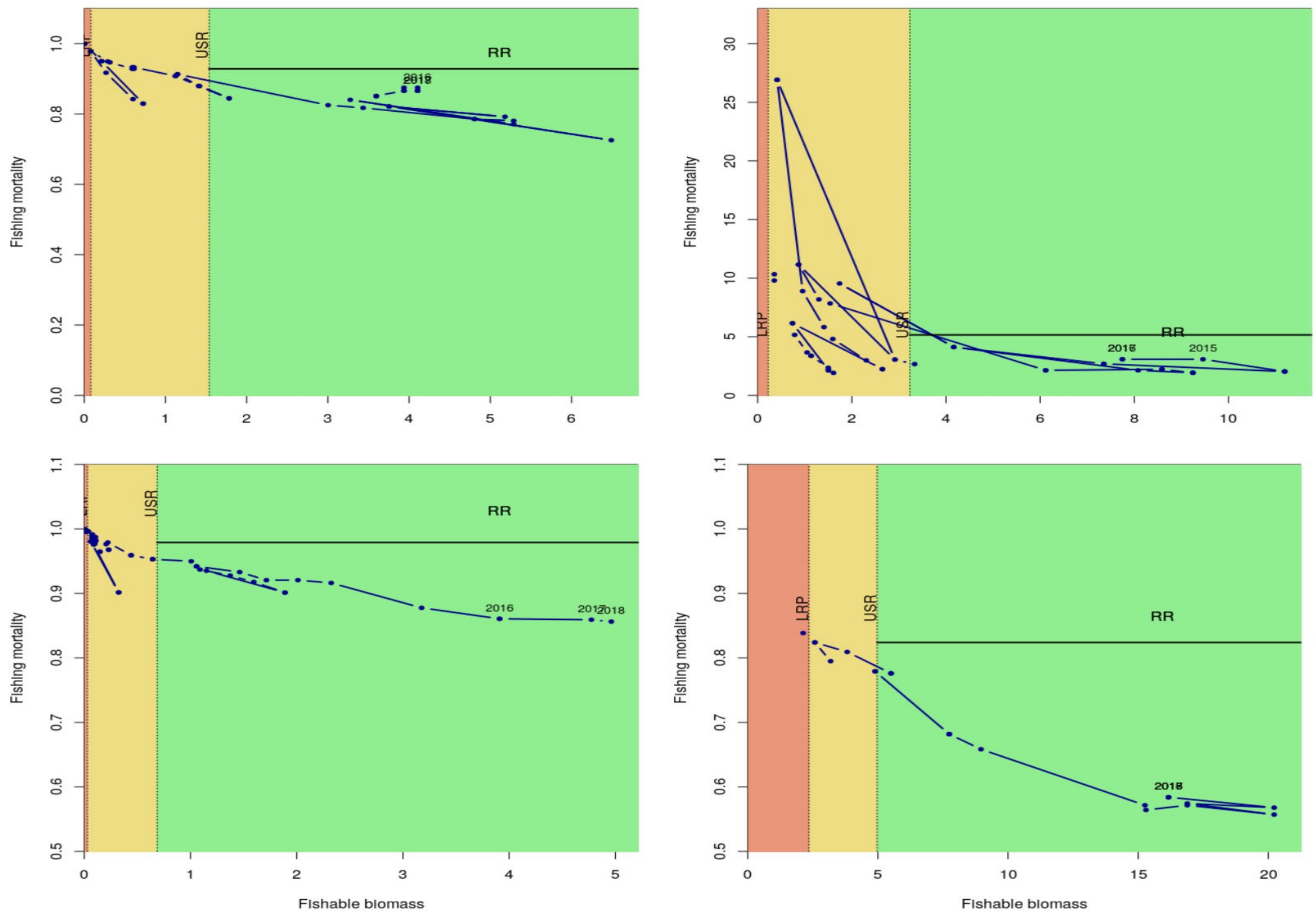

Figure 46. Phase plots of running medians of commercial biomass and relative fishing mortality (relF) from each of (clockwise from top left) NEFSC spring, NEFSC fall, ILTS and DFO surveys using proposed reference point indicators (USIh, LRIrecover). Green shaded areas represent healthy stock status zones, whereas yellow and red represent cautious and critical respectively. Removal References (RR) are only shown in the healthy stock status zone, but would apply in the cautious and critical zones, however the rate of decay through these zones will be discussed at future advisory meetings.

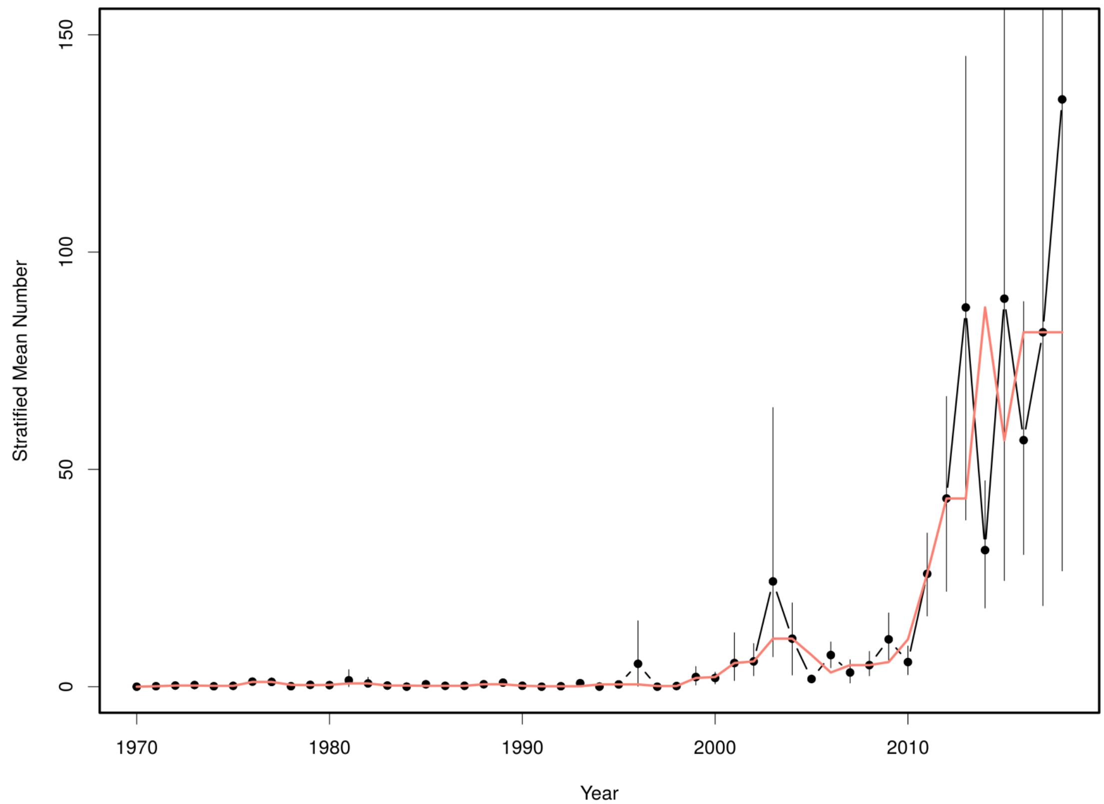

Figure 47. Time series of DFO survey trends for LFA 35–38 total abundance.

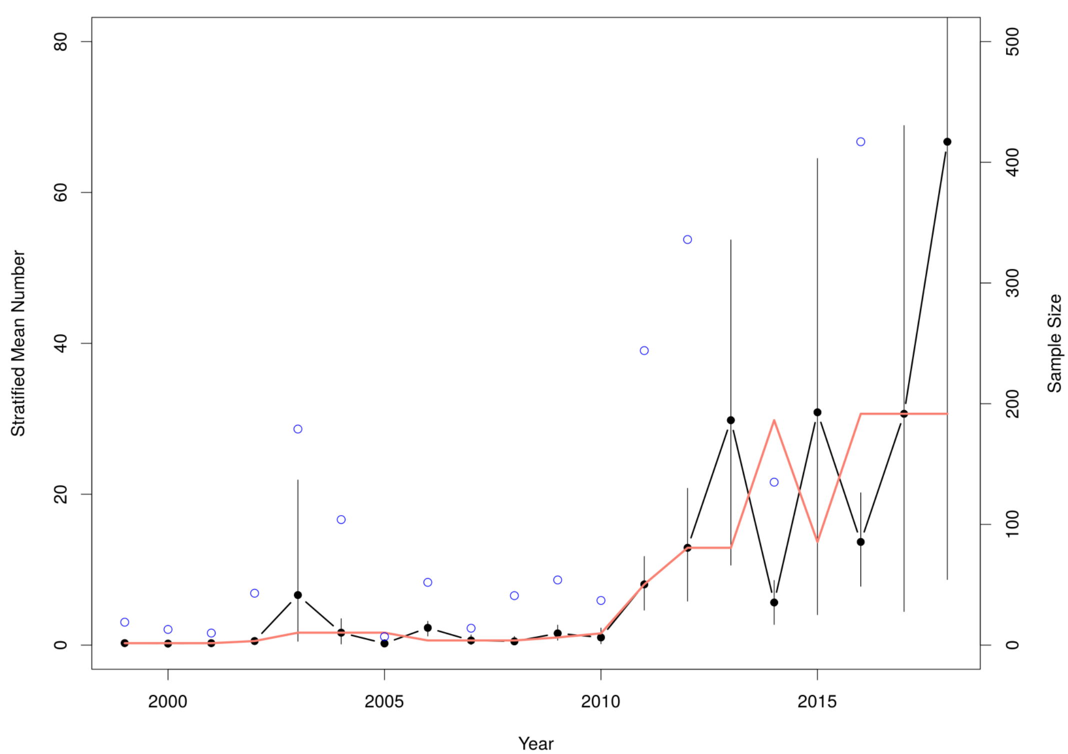

Figure 48. Time series of DFO survey trends for LFA 35–38 recruit abundance.

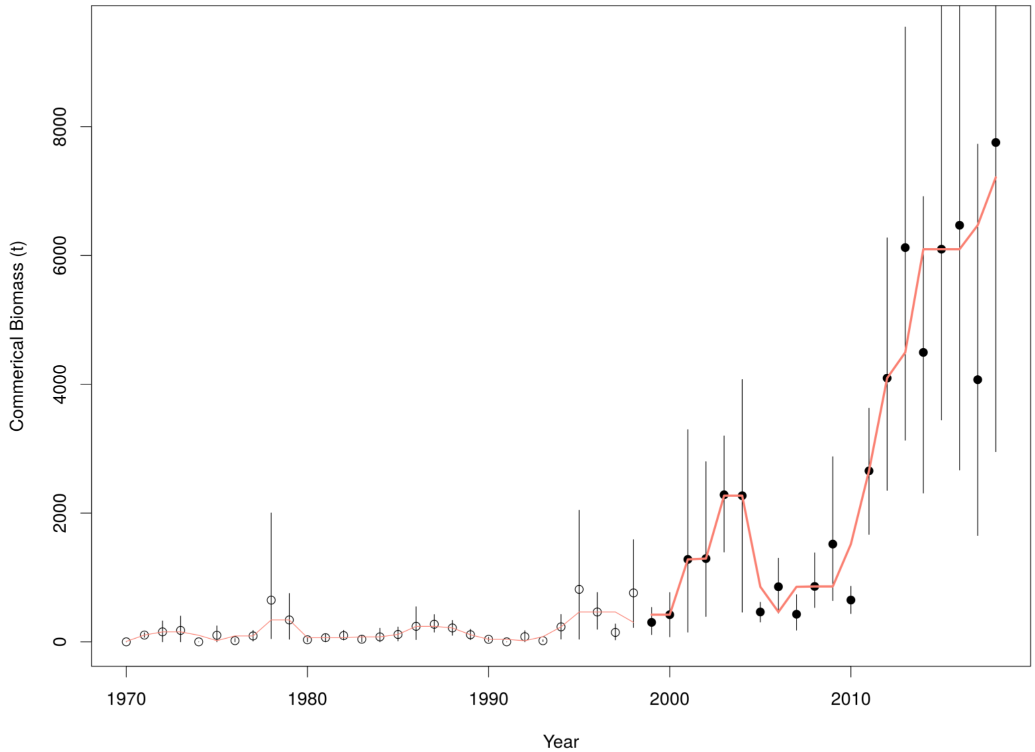

Figure 49. Time series of DFO survey trends for LFA 35–38 commercial biomass. Values prior to 1999 were derived using the mean proportion of commercial to total biomass between 1999 and 2018 (0.746).

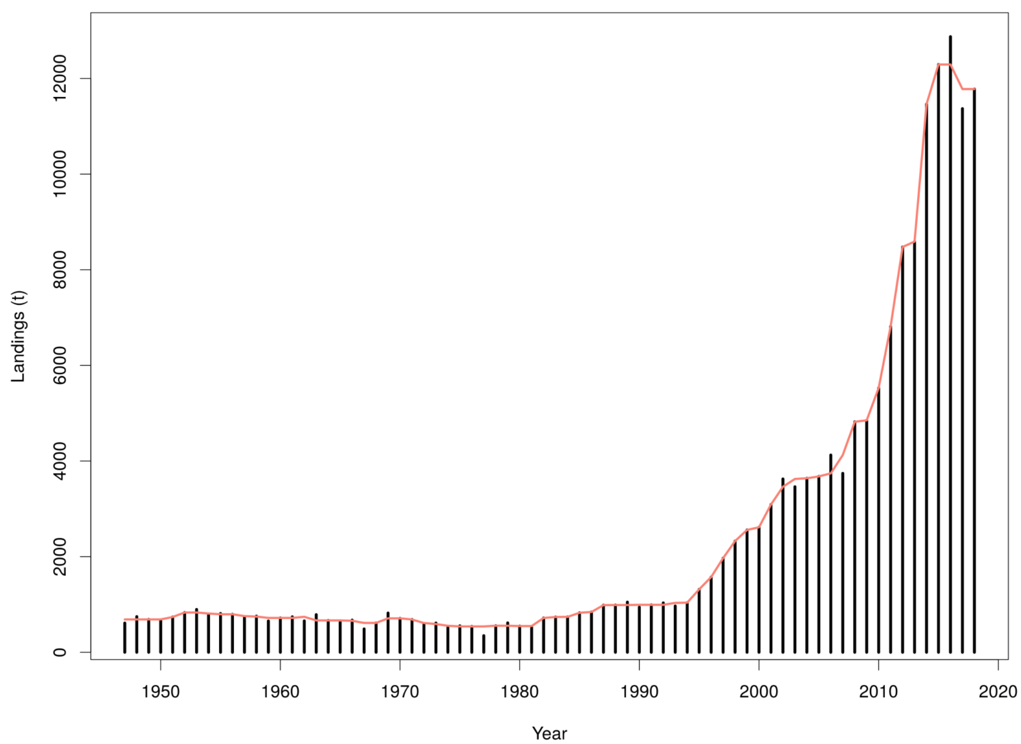

Figure 50. Landings of Lobster in the combined LFA 35 to LFA 38. Red line represents the three-year running median.

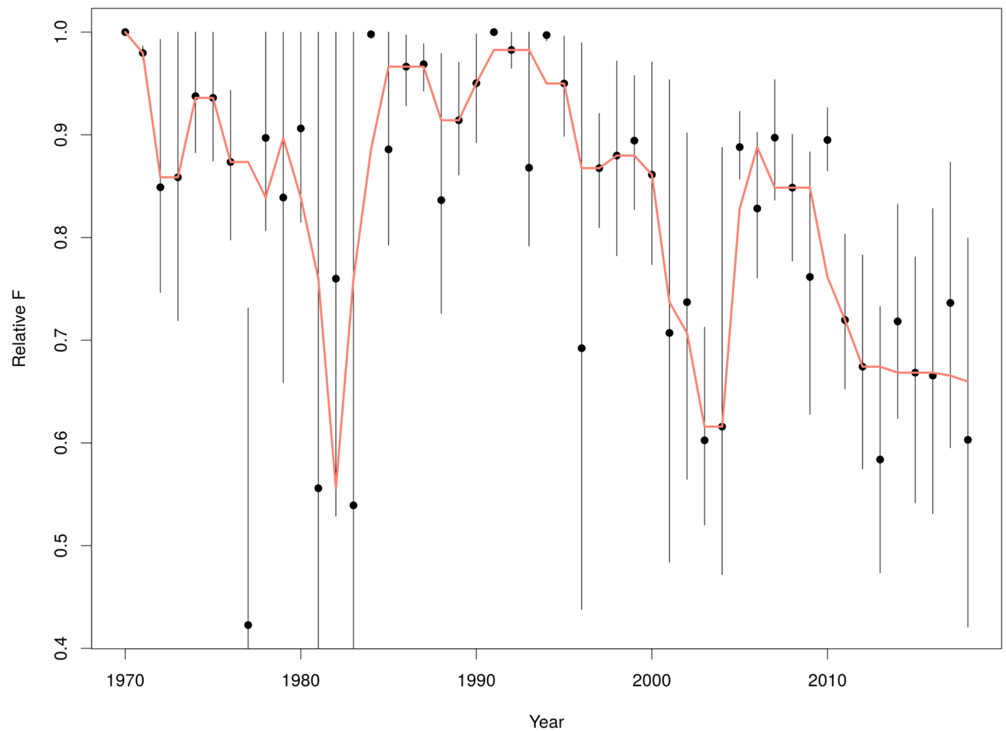

Figure 51. Time series of DFO survey trends for LFA 35–38 commercial biomass. Values prior to 1999 were derived using the mean proportion of commercial to total biomass between 1999 and 2018 (0.746).

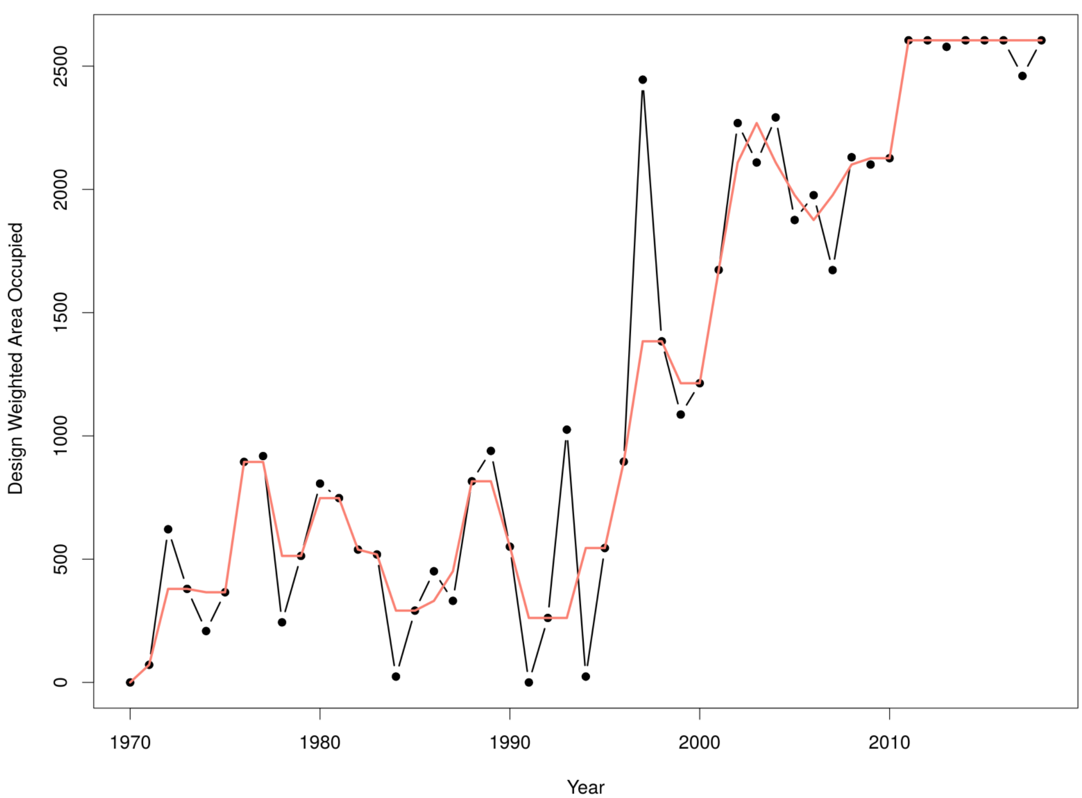

Figure 52. Time series of DFO survey trends for LFA 35–38 area occupied.

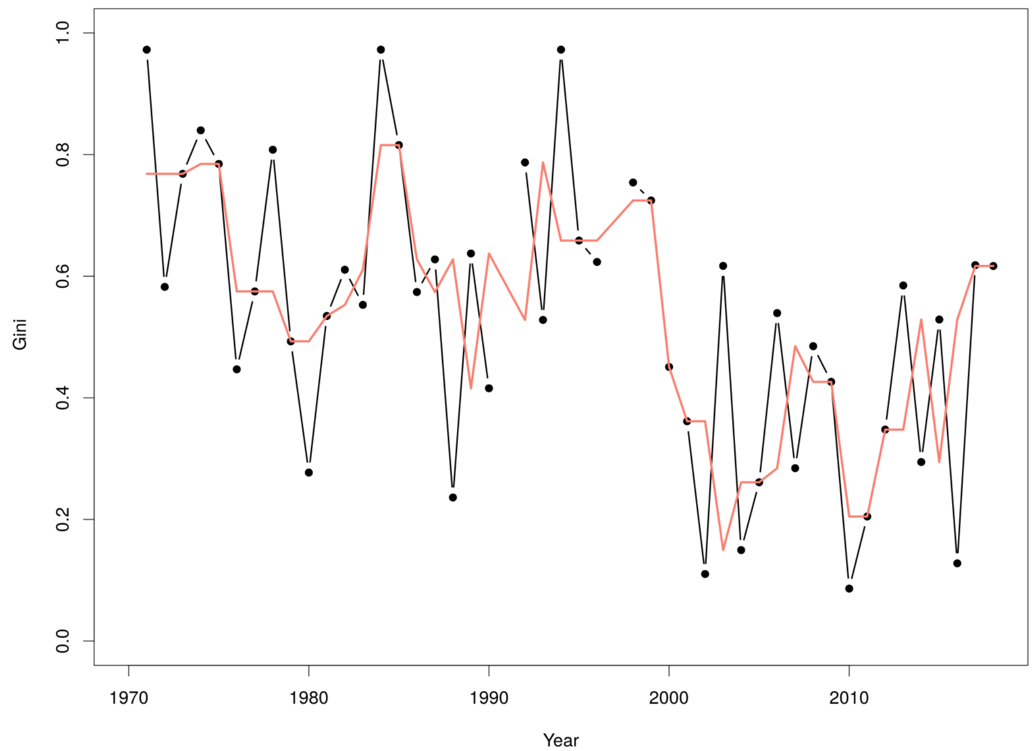

Figure 53. Time series of DFO survey trends for LFA 35–38 Gini index of patchiness.

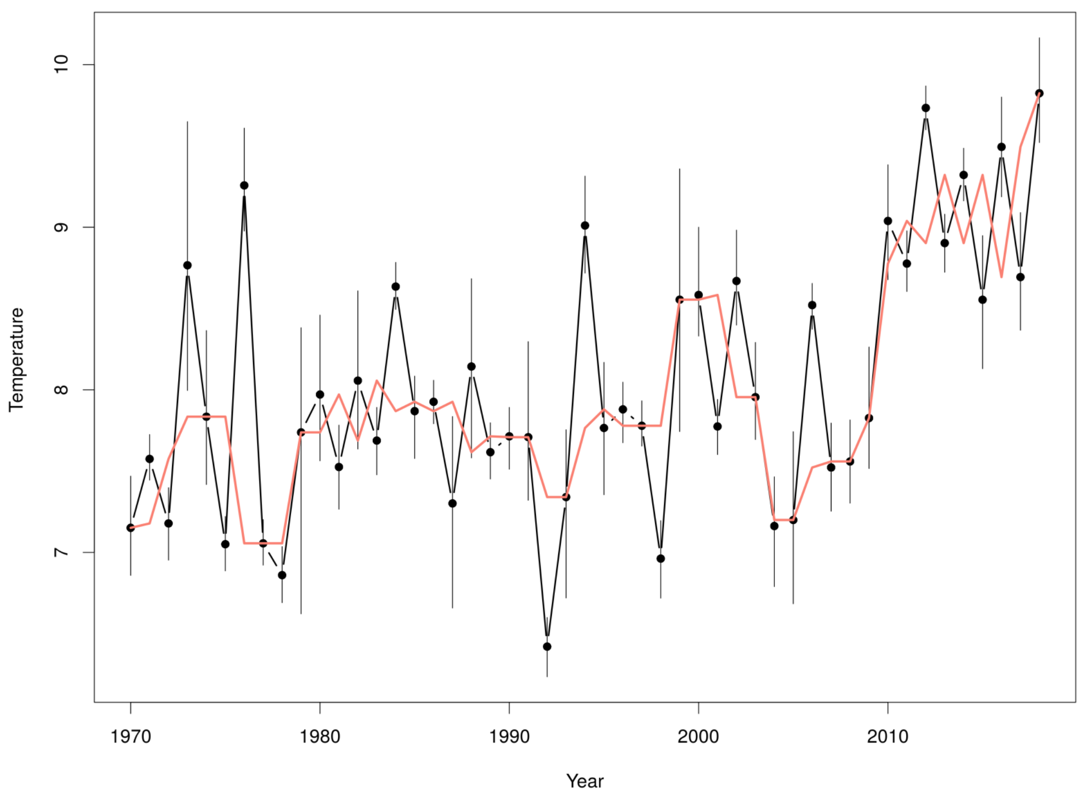

Figure 54. Time series of DFO survey bottom temperature trends for LFA 35–38.

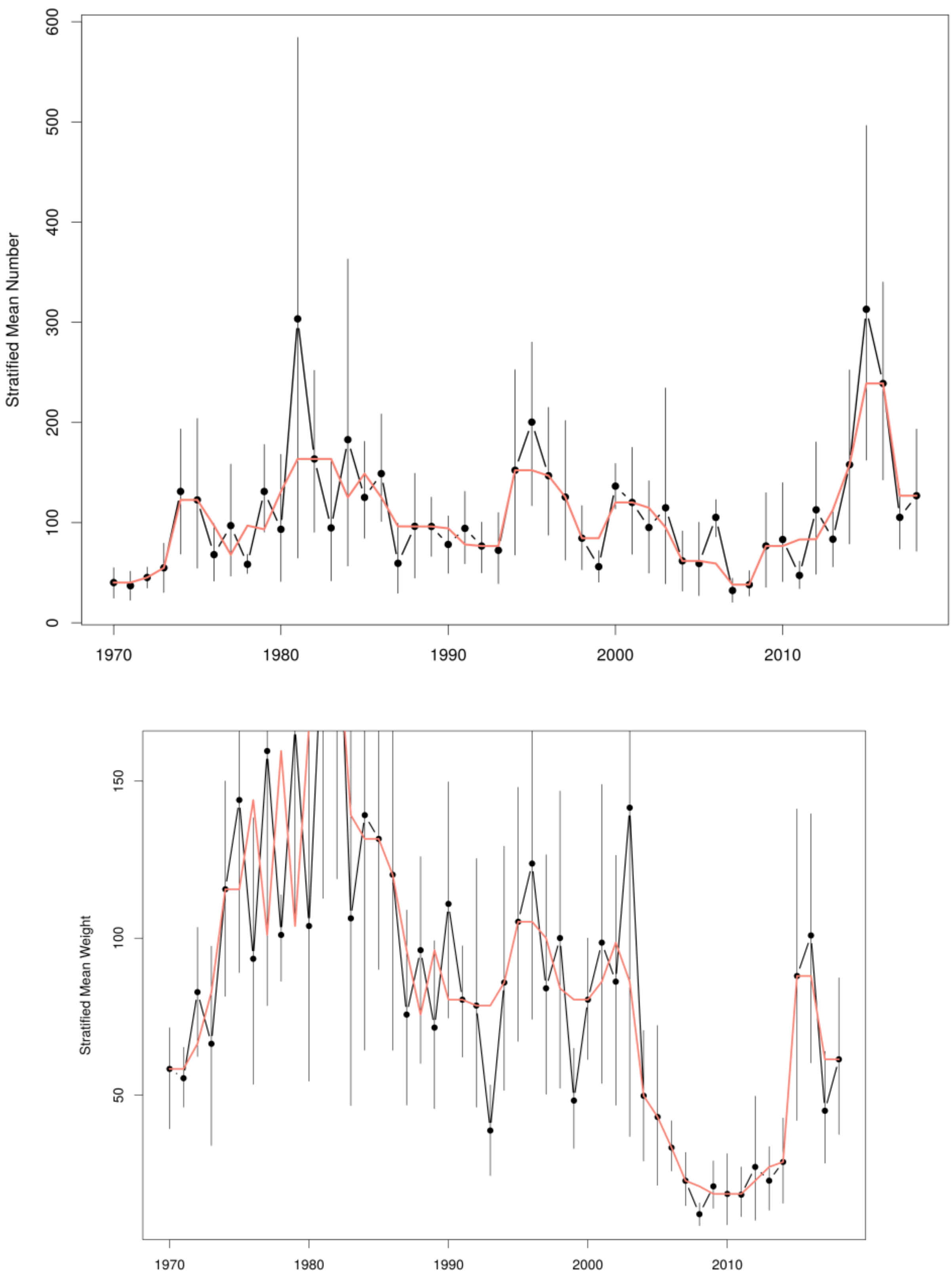

Figure 55. Plot of the stratified abundance and biomass estimates for Lobster predators from the DFO bottom trawl survey in LFA 35–38. Red line represents three-year running medians.

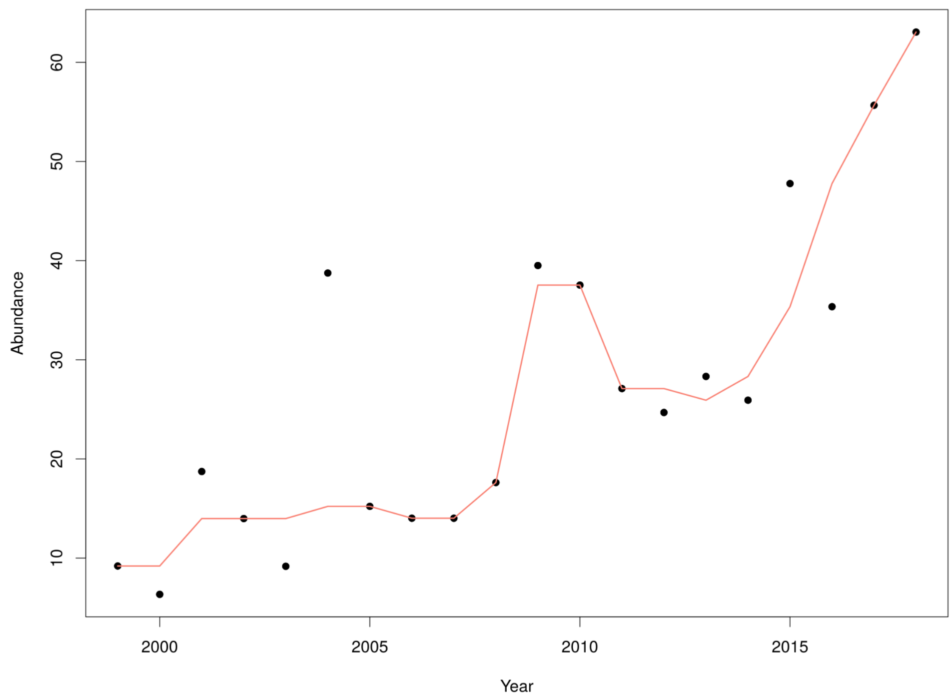

Figure 56. Time series of recruit Lobster abundance from scallop surveys in LFA 35. Red line represents three-year running median.

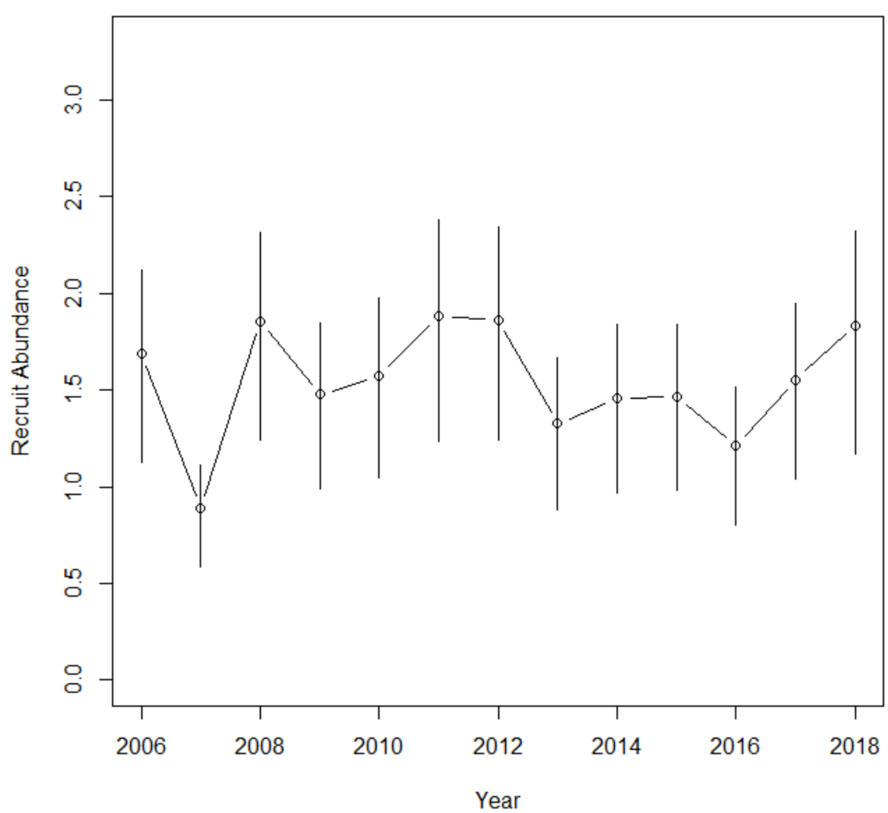

Figure 57. Time series of modelled recruit Lobster abundance from Fishermen and Scientist Research Society (FSRS) recruitment traps in LFA 35.

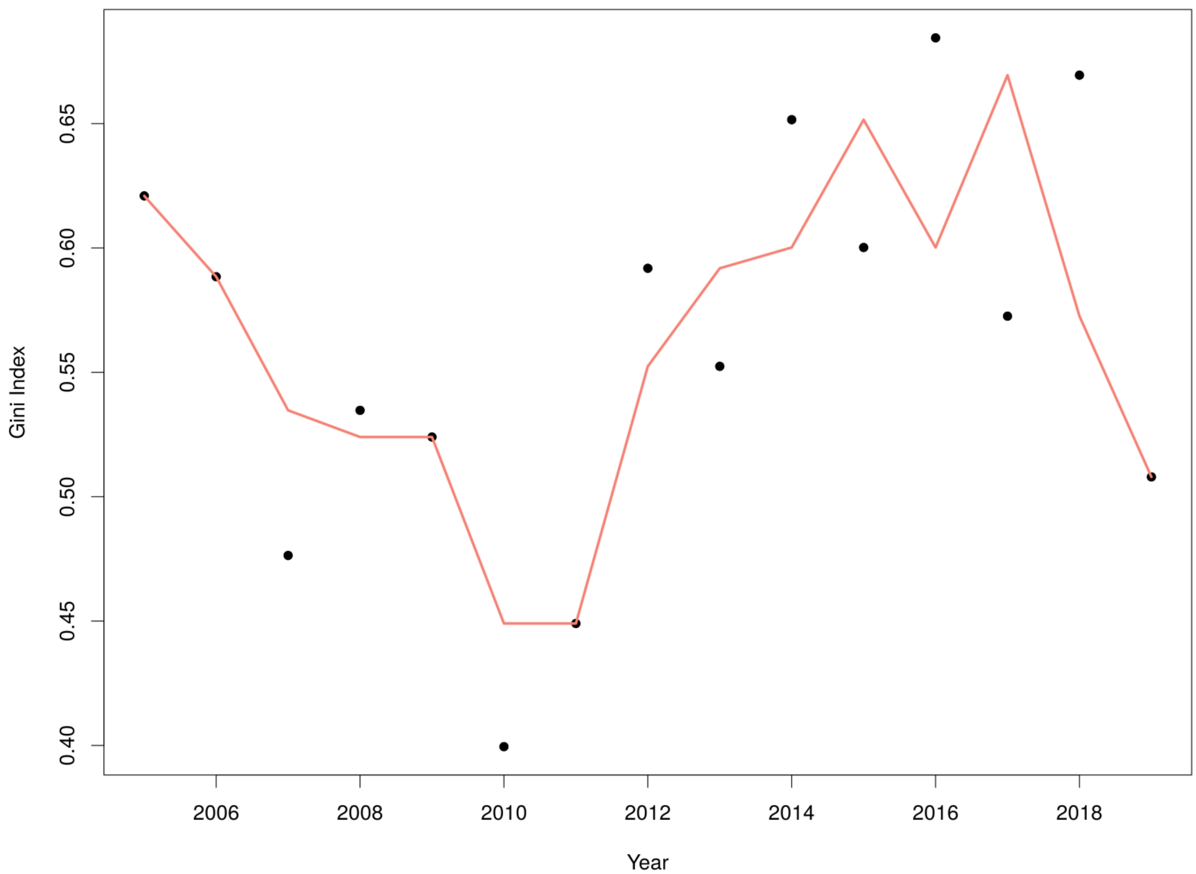

Figure 58. Plot of level of patchiness of landings of Lobsters within LFA 35. Patchiness was estimated by the Gini index.

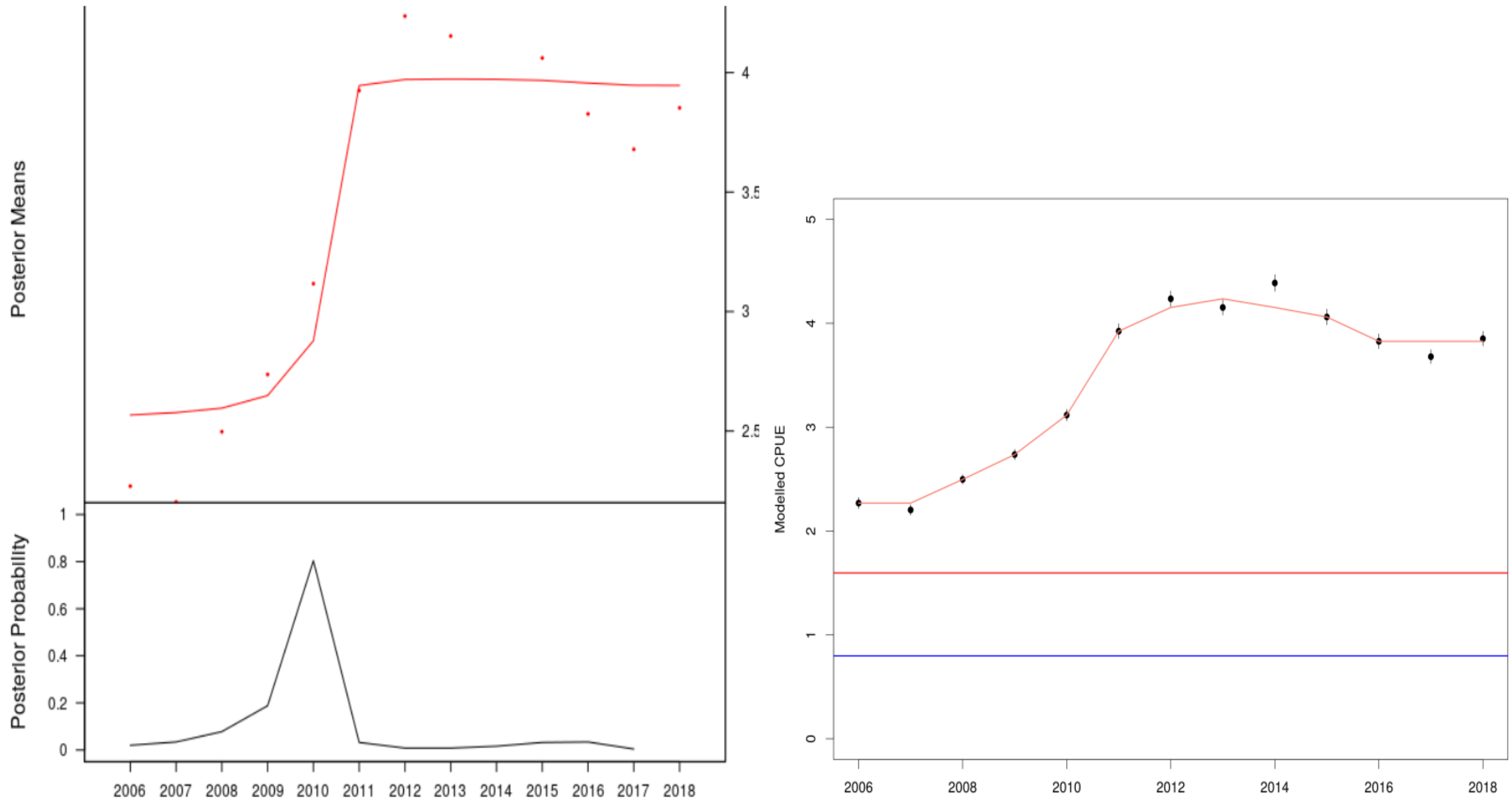

Figure 59. Plot of the Bayesian change point analyses on the commercial CPUE for LFA 35 (left). Modelled CPUE index from commercial data in LFA 35 (right). Green line represents the proposed USR and blue line represents the proposed LRP. The red line represents the three-year running median.

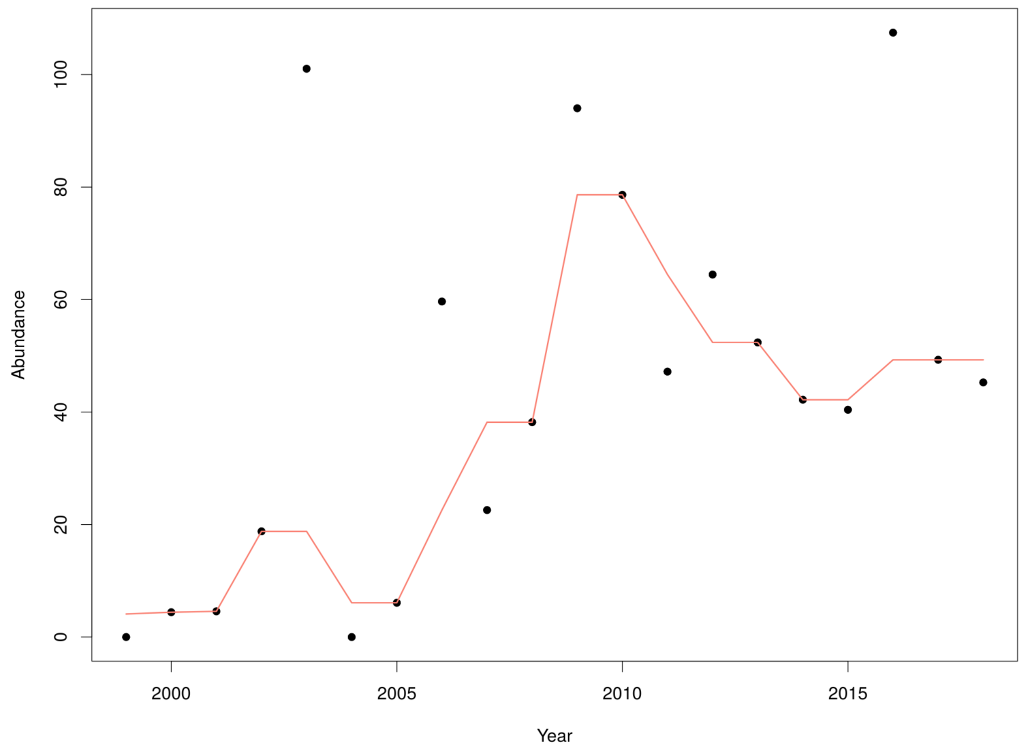

Figure 60. Time series of recruit Lobster abundance from scallop surveys in LFA 36. Red line represents three-year running median.

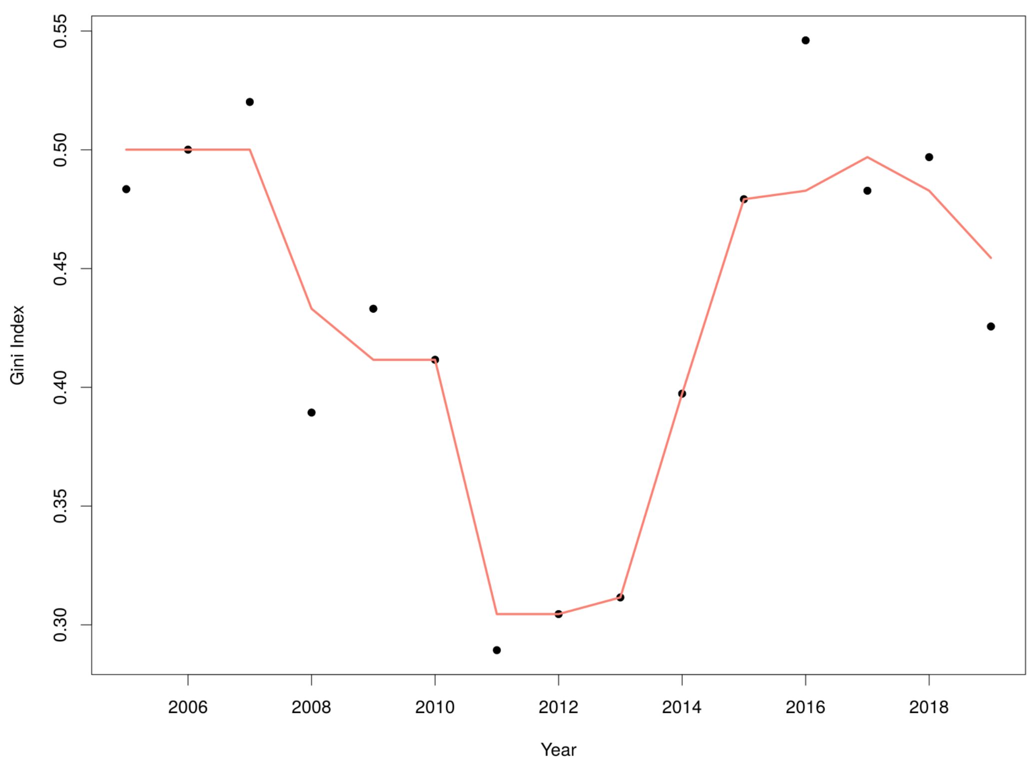

Figure 61. Plot of level of patchiness of landings of Lobsters within LFA 36. Patchiness was estimated by the Gini index.

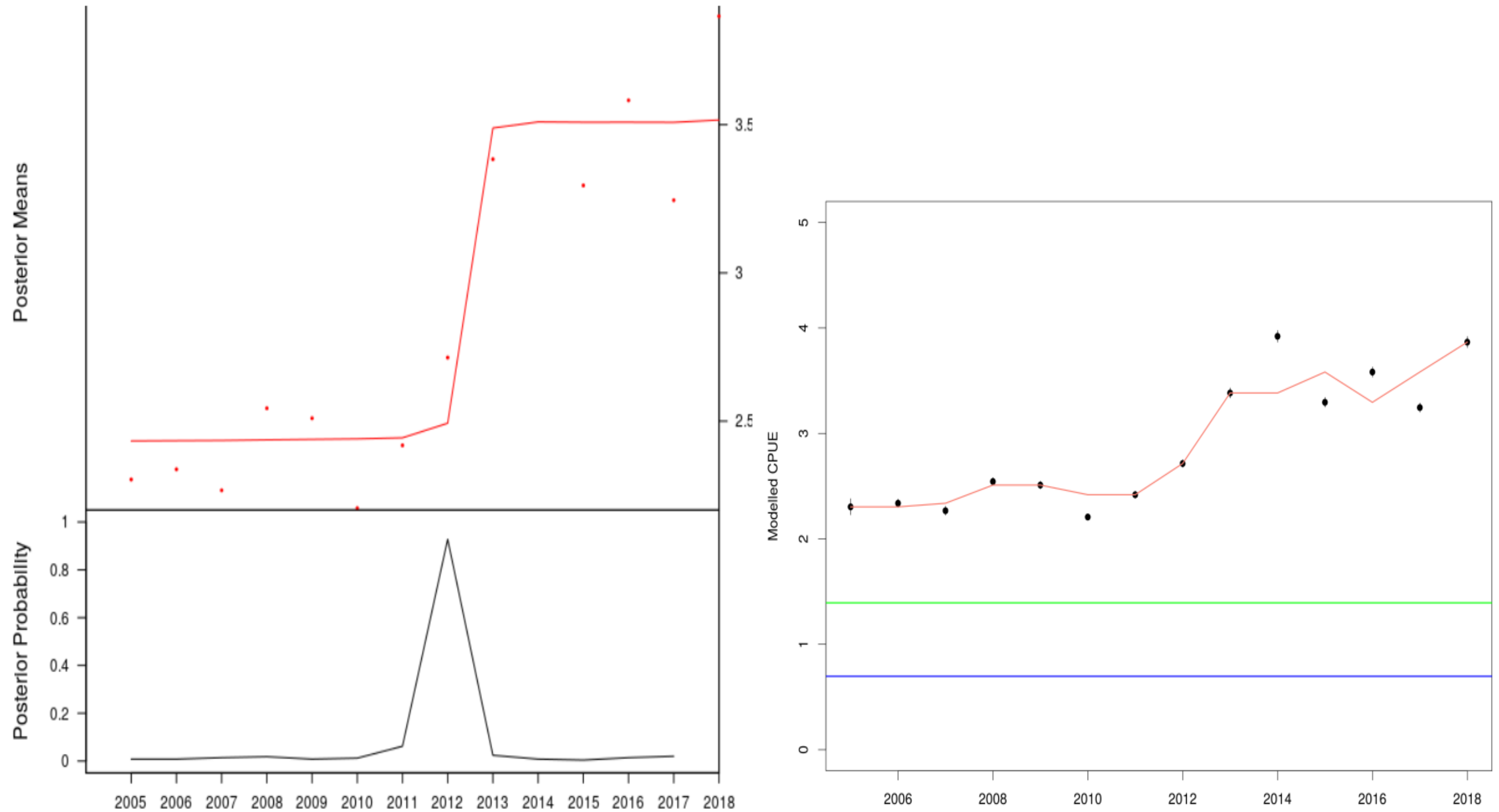

Figure 62. Plot of the Bayesian change point analyses on the commercial CPUE for LFA 36 (left). Modelled CPUE index from commercial data in LFA 36 (right). Green line represents the proposed USR and blue line represents the proposed LRP. The red line represents the three-year running median.

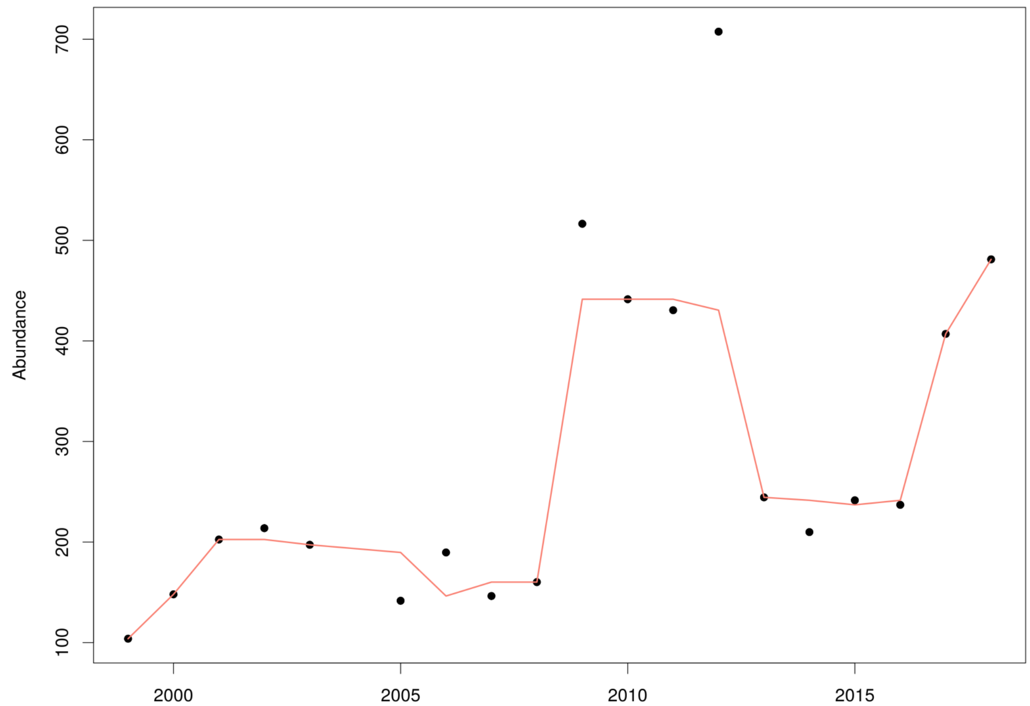

Figure 63. Time series of recruit Lobster abundance from scallop surveys in LFA 38. Red line represents three-year running median.

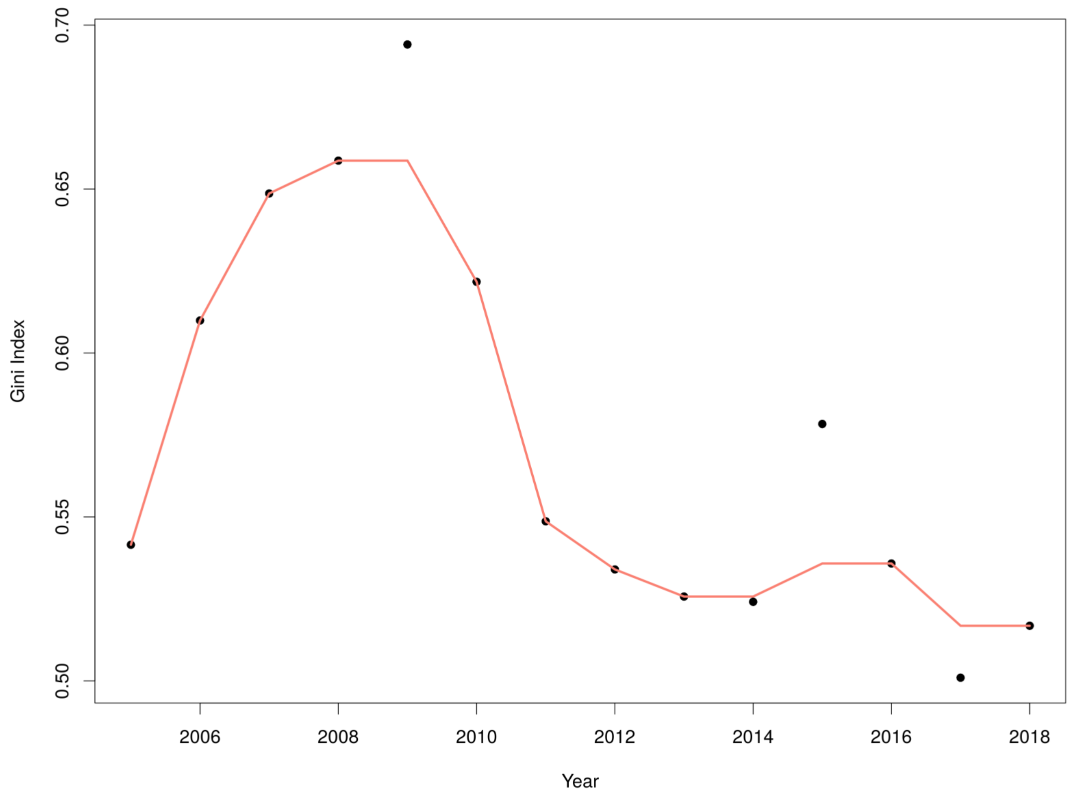

Figure 64. Plot of level of patchiness of landings of Lobsters within LFA 38. Patchiness was estimated by the Gini index.

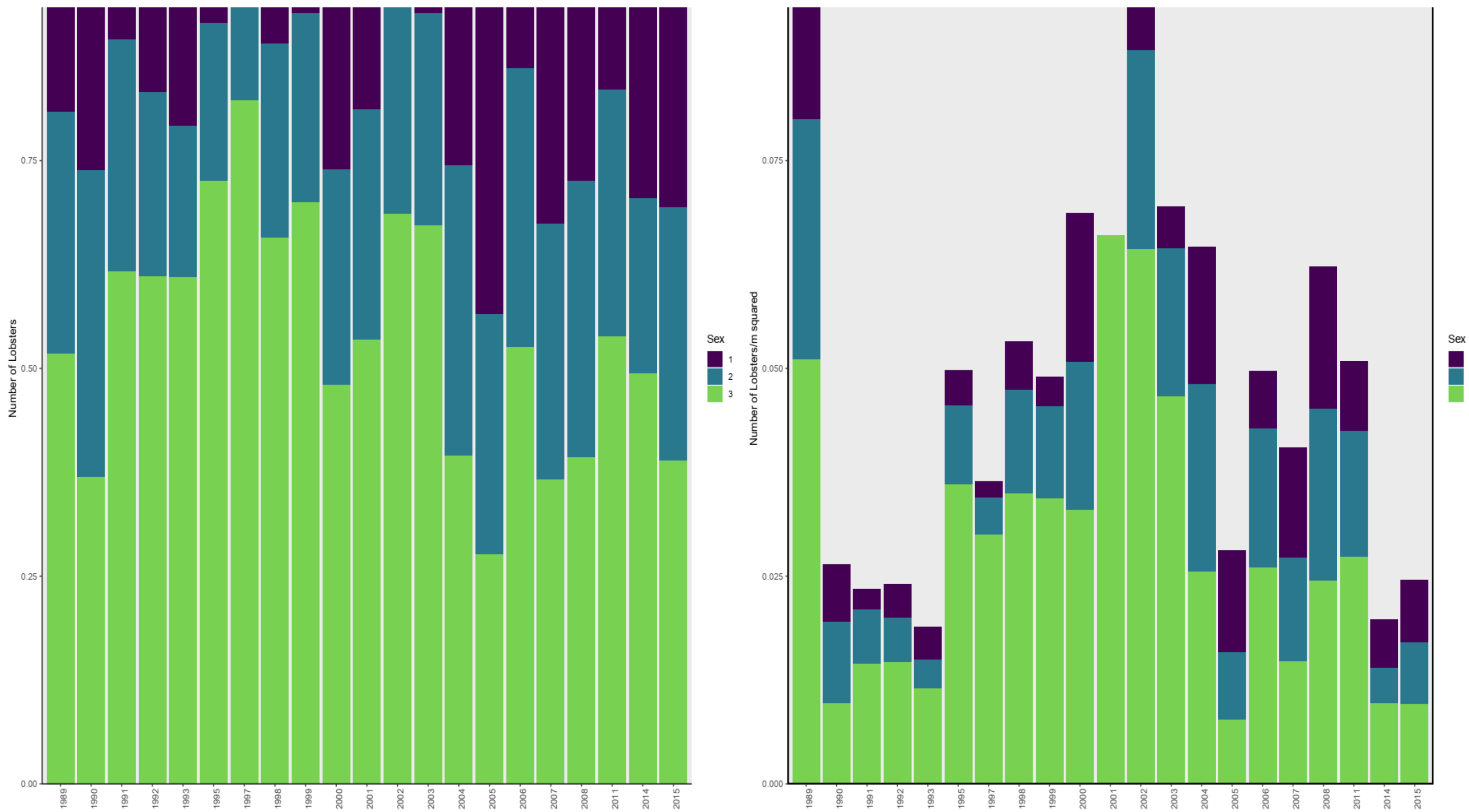

Figure 65. Stacked barplot of the proportion of sexs along the transect (left) and the mean densities (right), of male(1), female (2) and berried (3), from 1989 to 2015. Lobsters = m² per year from the Flagg Cove dive transect survey.

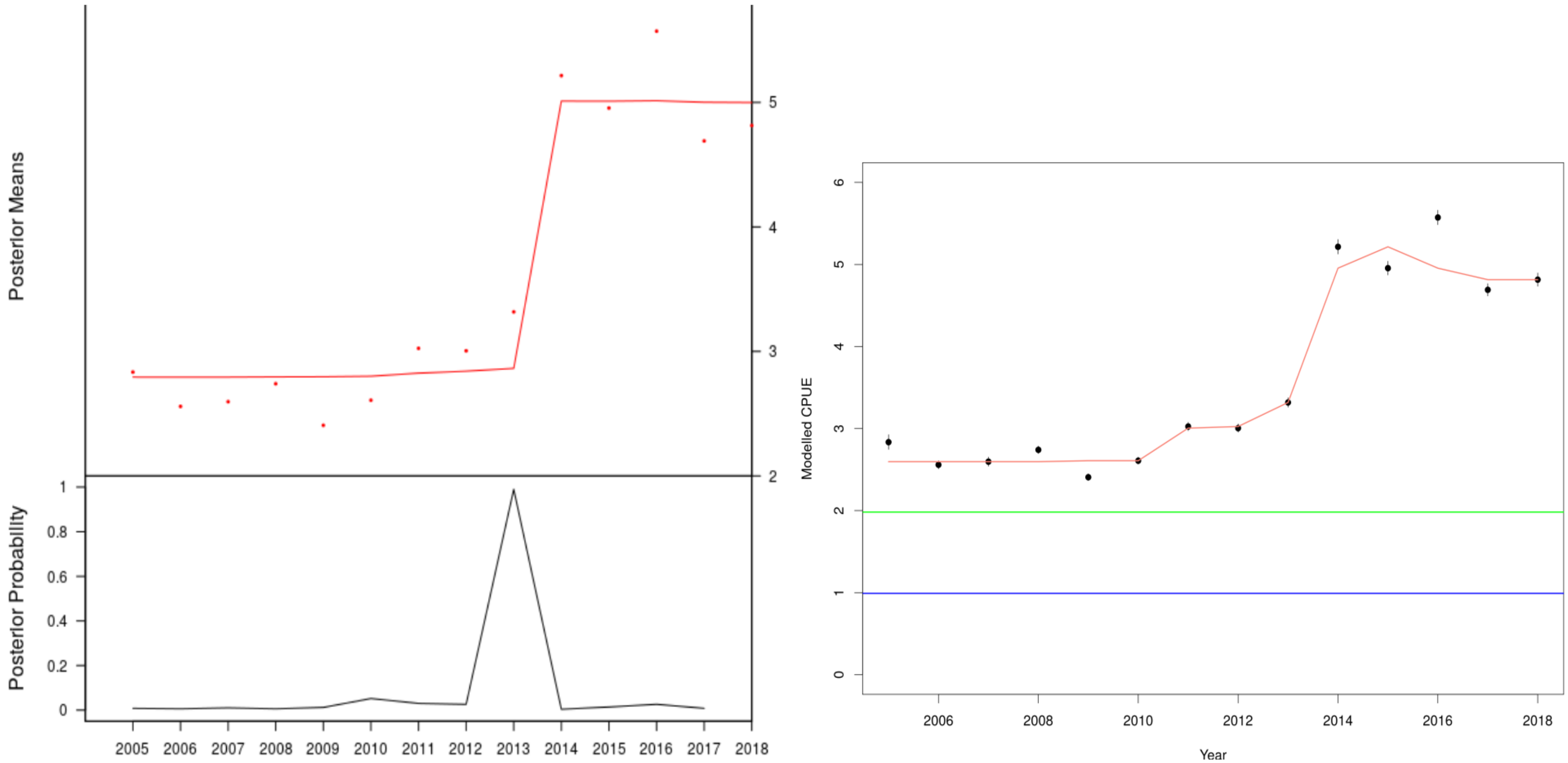

Figure 66. Plot of the Bayesian change point analyses on the commercial CPUE for LFA 38 (left). Modelled CPUE index from commercial data in LFA 38 (right). Green line represents the proposed USR and blue line represents the proposed LRP. The red line represents the three-year running median.

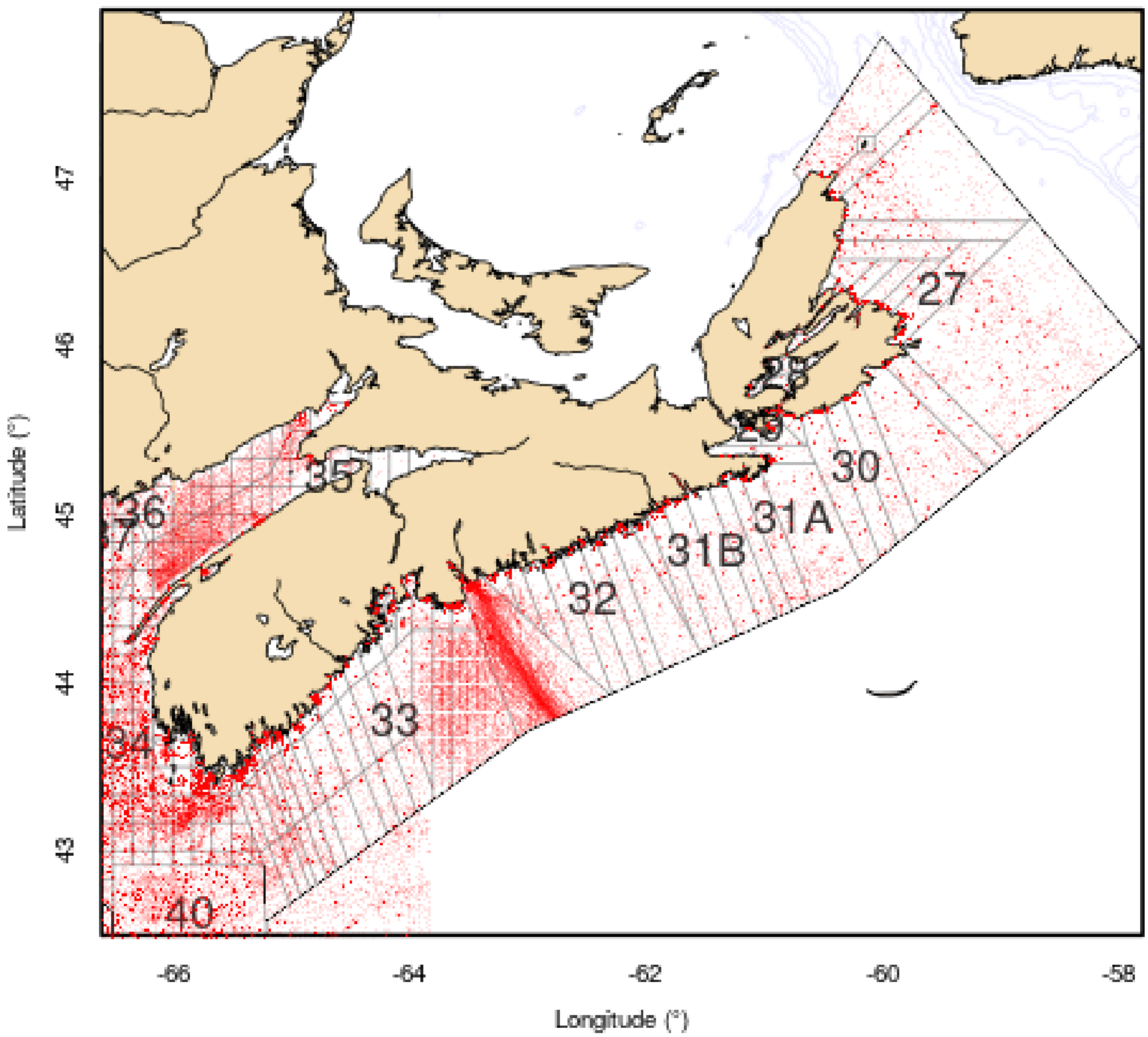

Figure 67. Locations of all temperature data used in the temperature model.

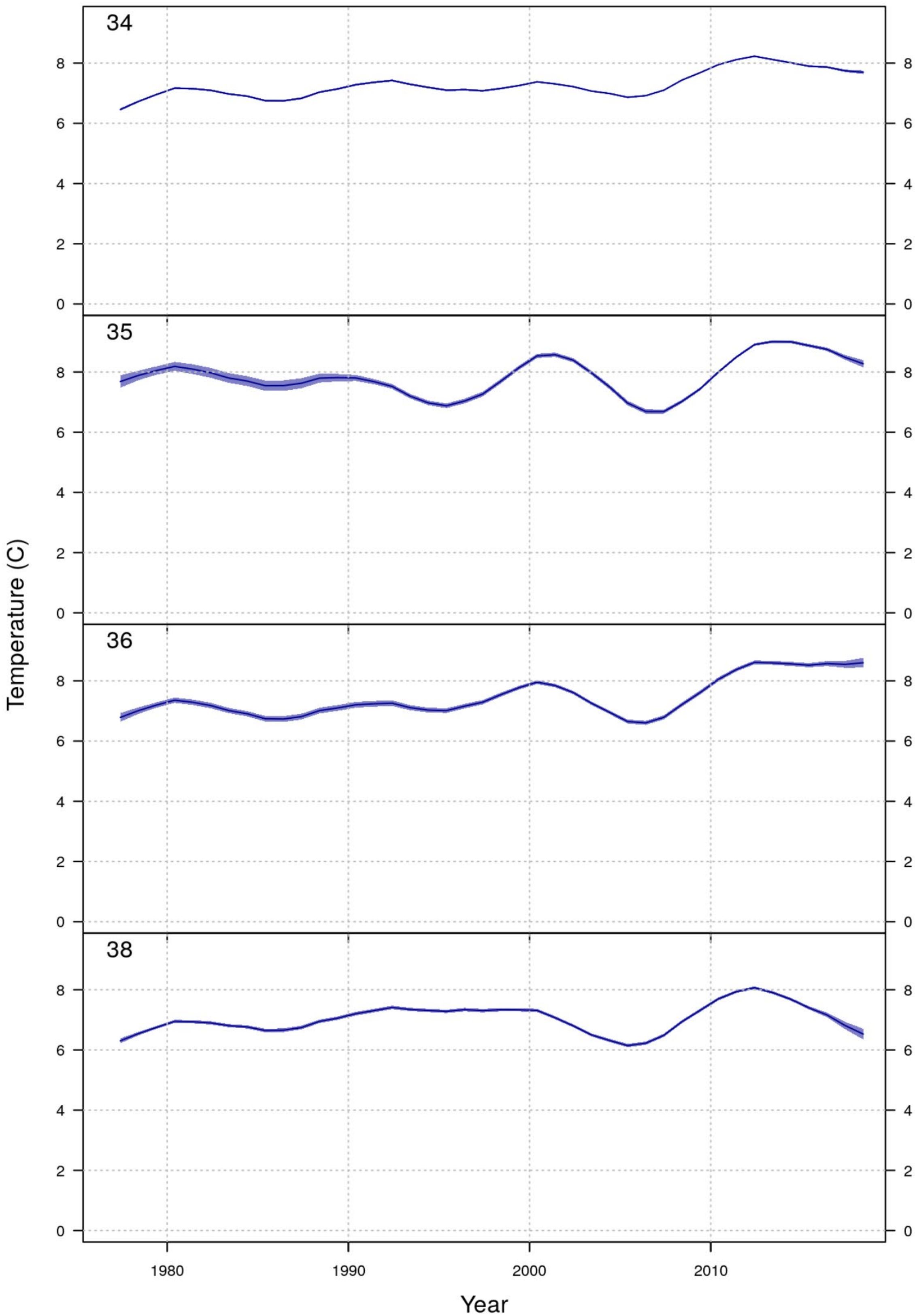

Figure 68. Predictions from the temperature model for June 1st at 25 m, to show the annual trends in each LFA. Light blue band represents the standard error of the prediction.

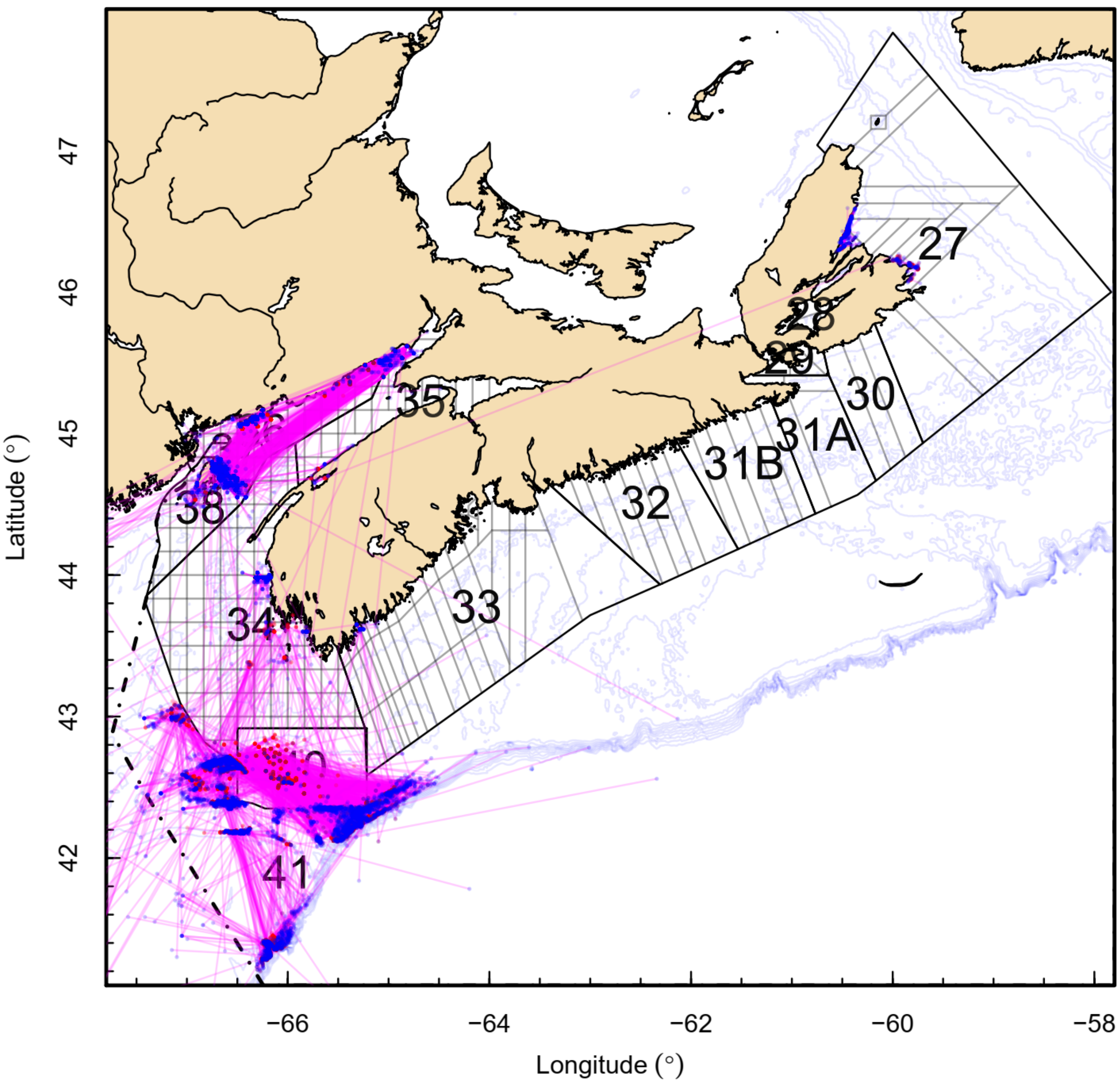

Figure 69. Locations of tagging mark-recapture data used for estimating moult probability and increment. Releases (red dots) are connected to their recaptures (blue dots) with a purple line.

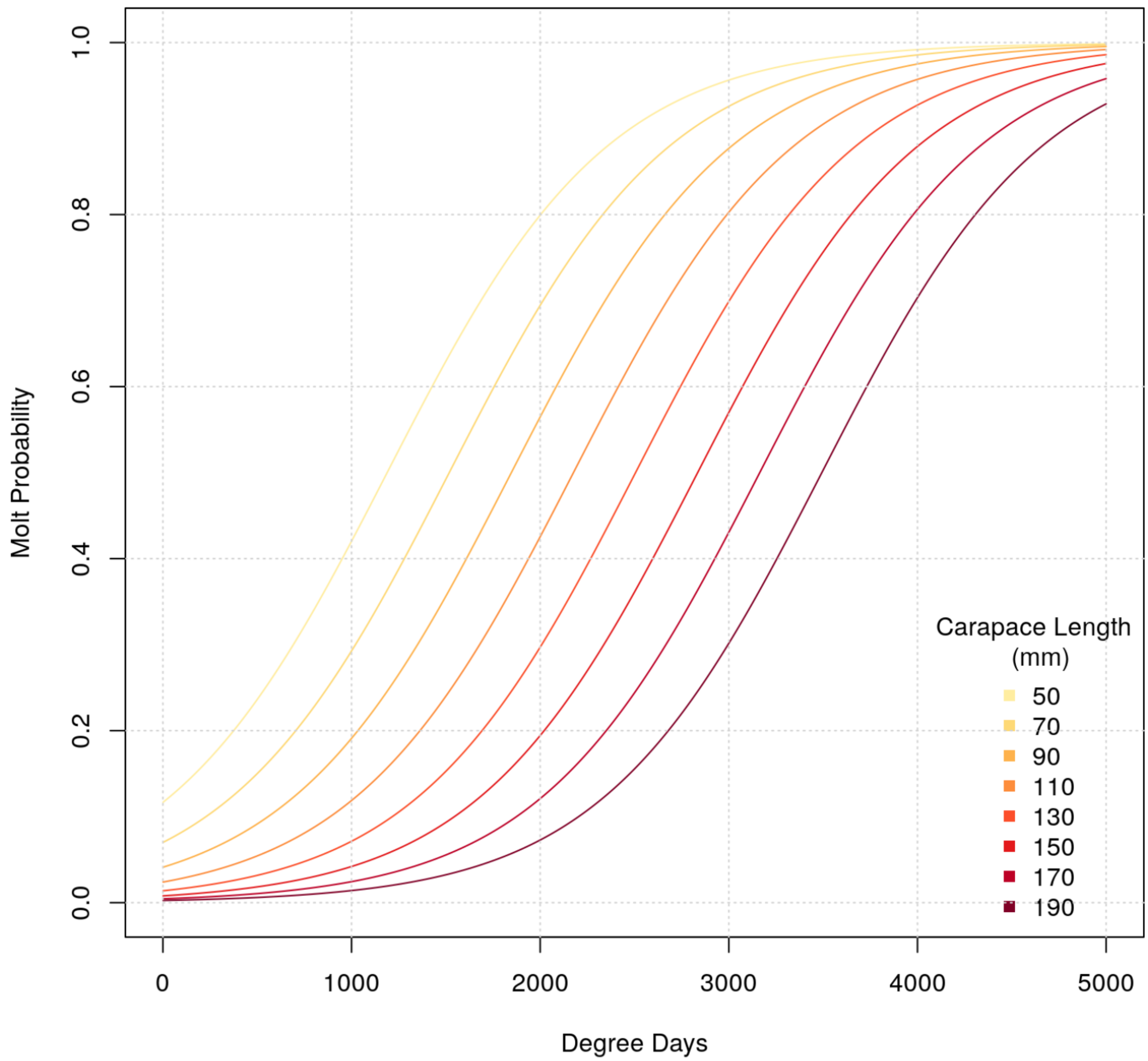

Figure 70. Predicted moult probabilities by number of degree days above 0◦C since last moult for various initial Carapace Lengths (CL)s from the moult probability model.

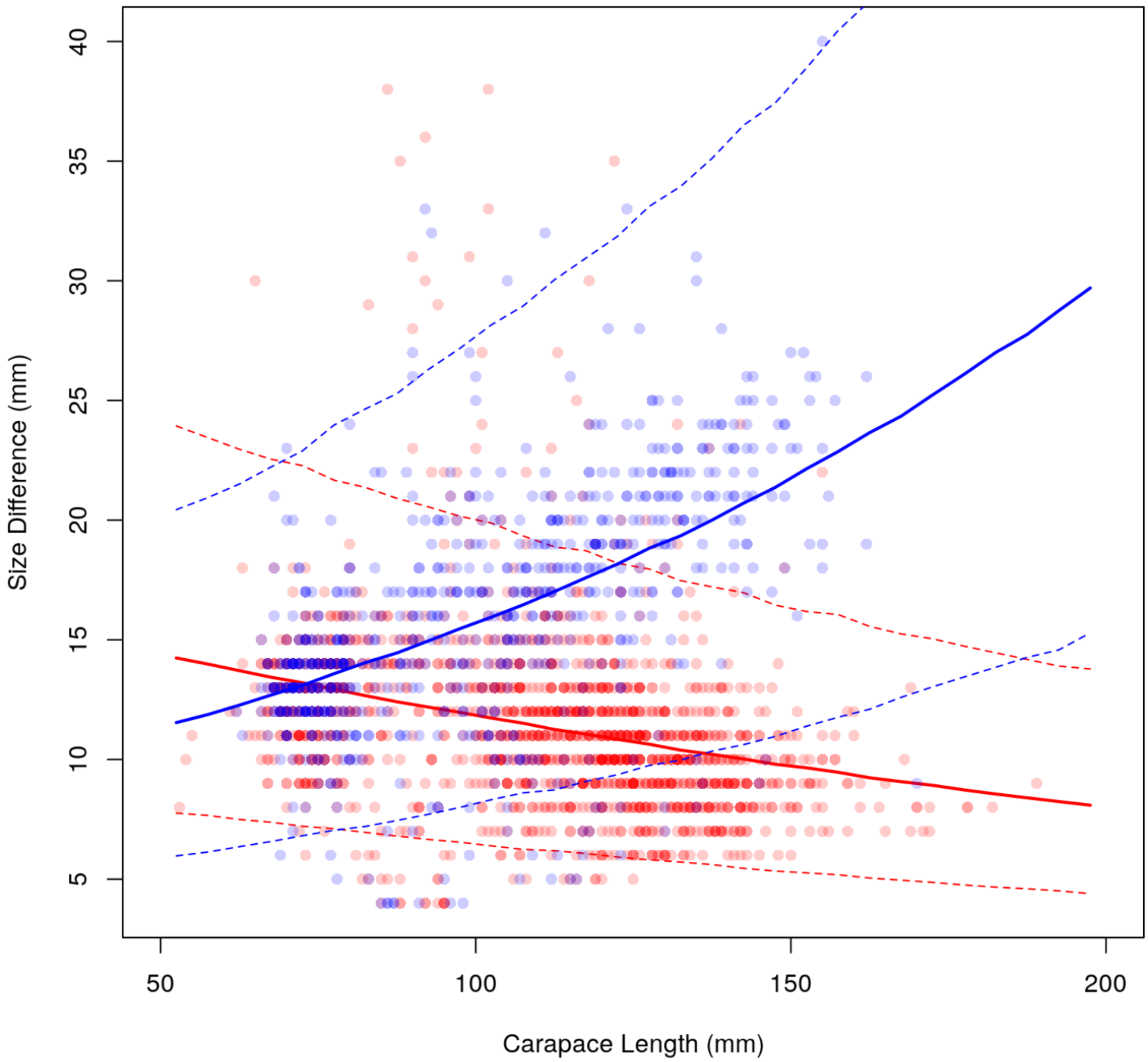

Figure 71. Moult increment as the size difference versus initial Carapace Length (CL) for males (blue) and females (red) from tagging data. Lines represent the fits and 95% credible interval of the moult increment model for each sex.

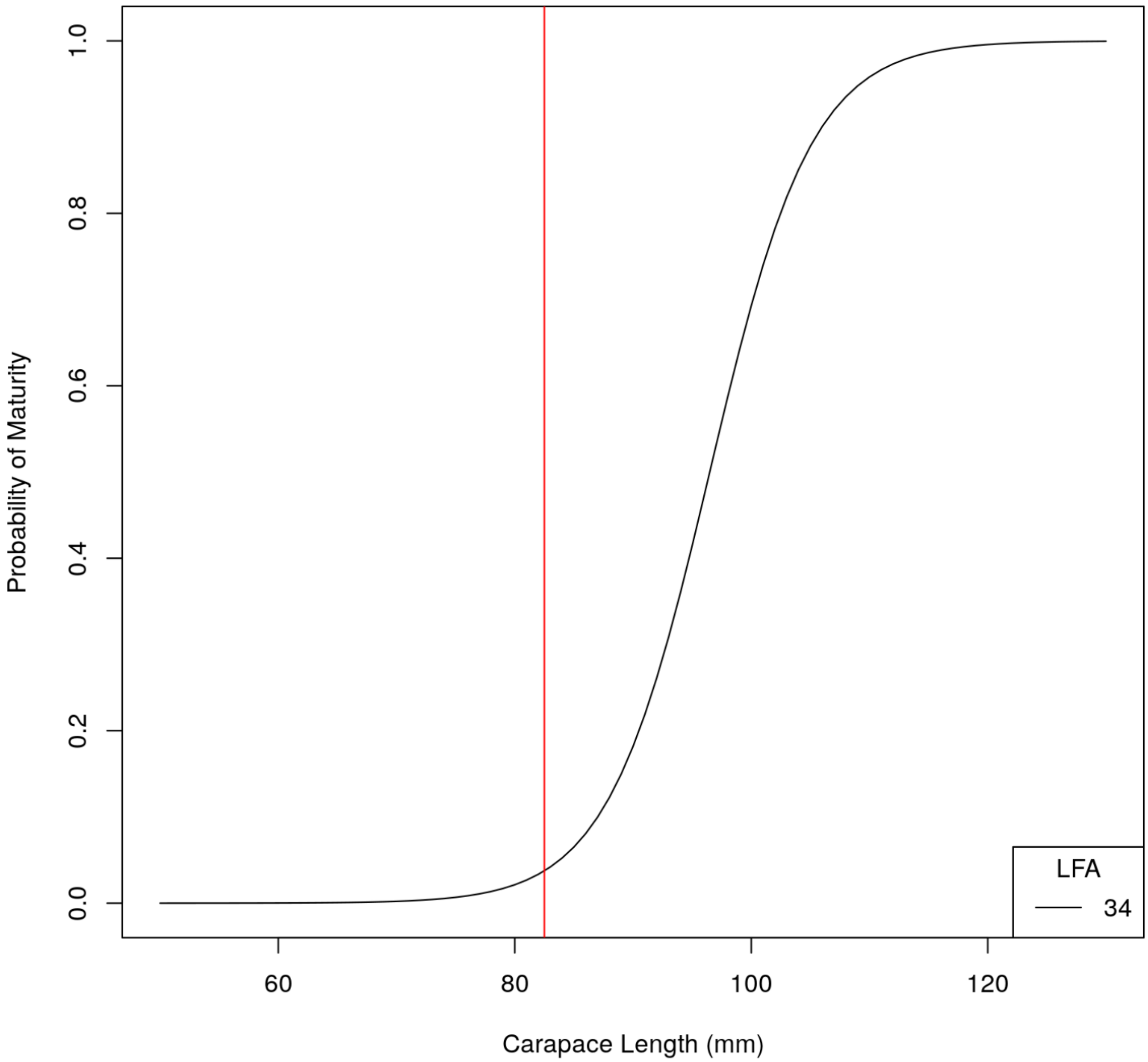

Figure 72. Size of maturity ogive for LFA 34.

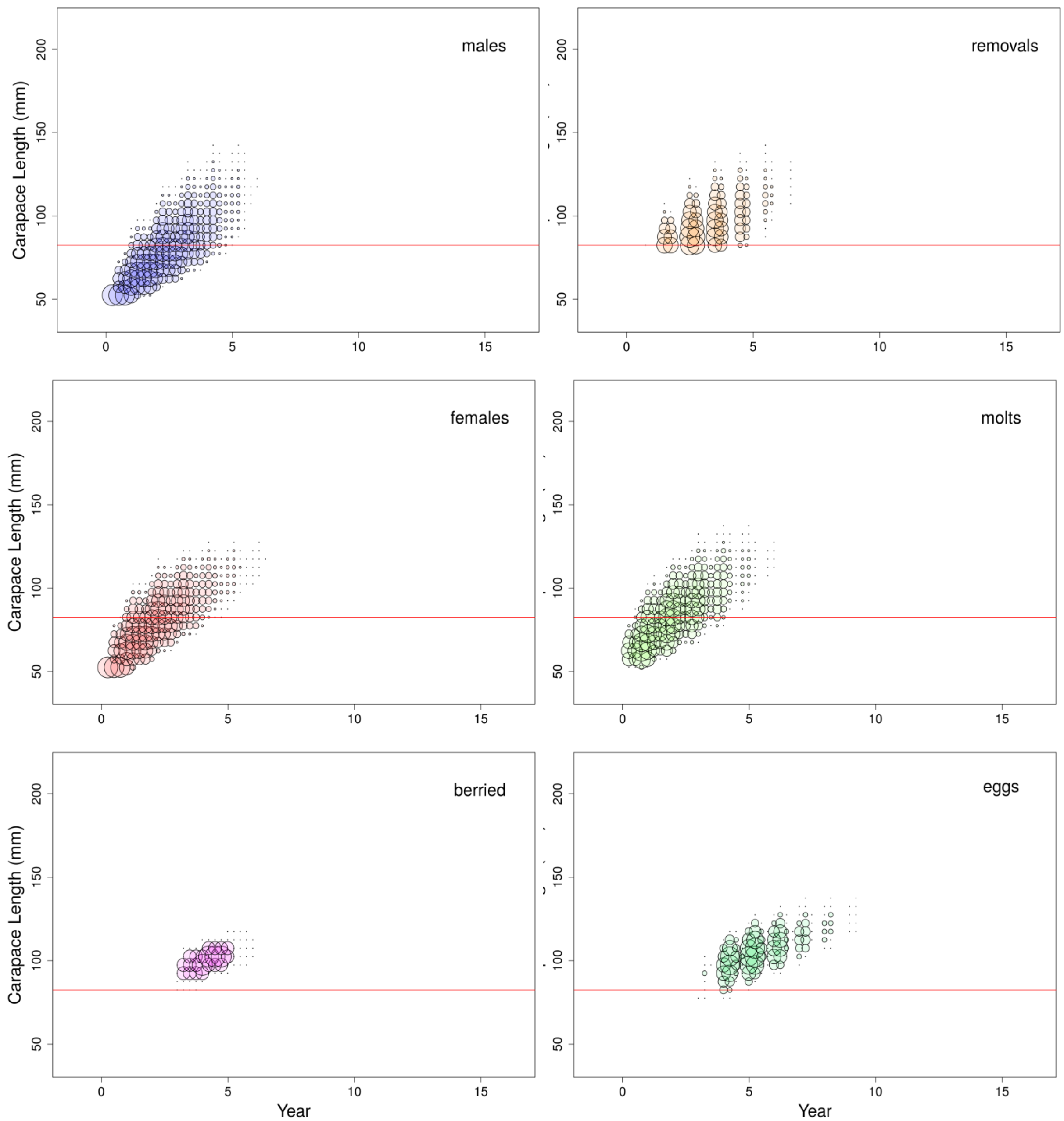

Figure 73. Bubble plots showing the simulated population assuming Continuous Change In Ratio (CCIR) exploitation estimates under the current management regime for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

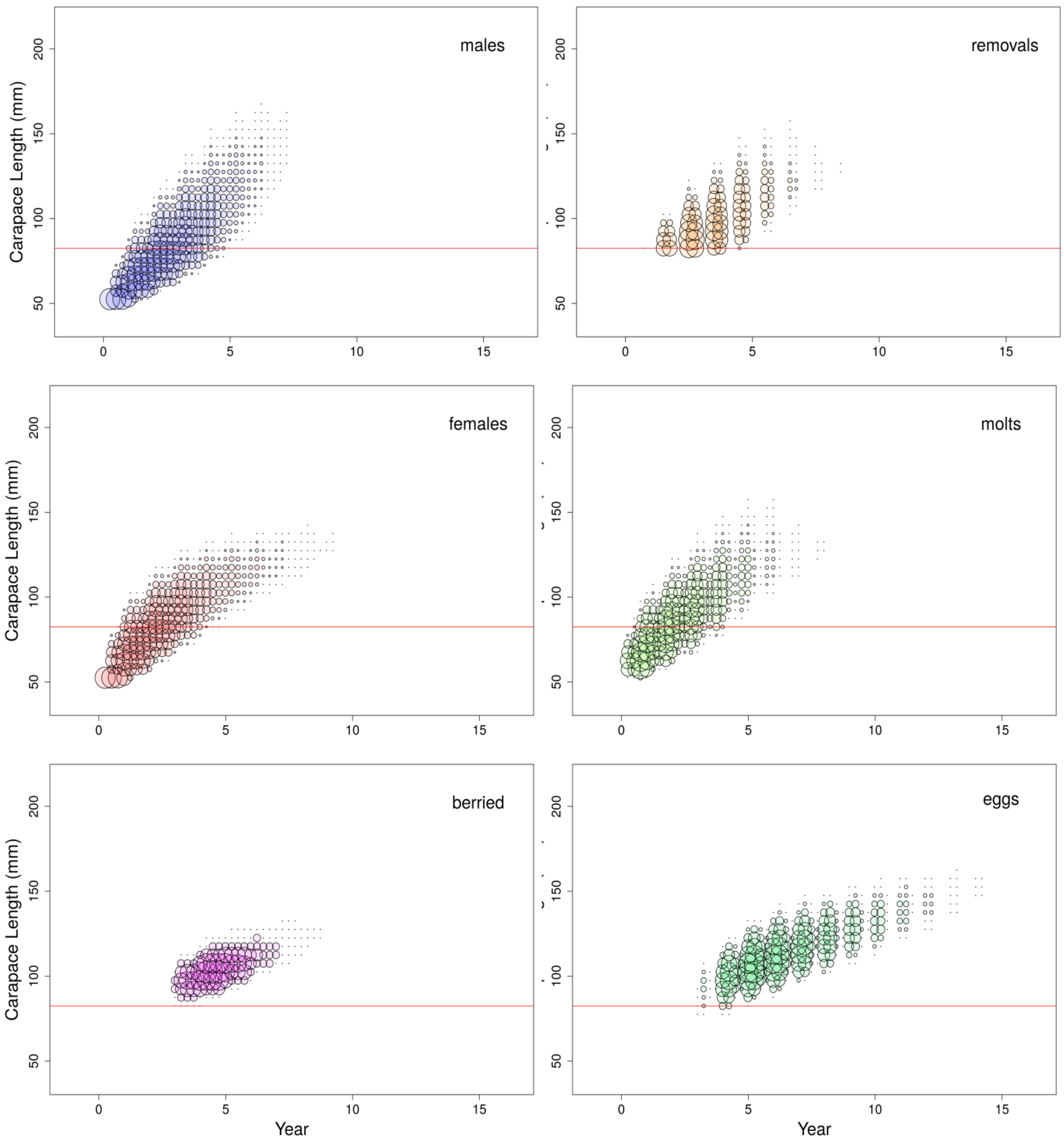

Figure 74. Bubble plots showing the simulated population assuming relF exploitation estimates under the current management regime for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

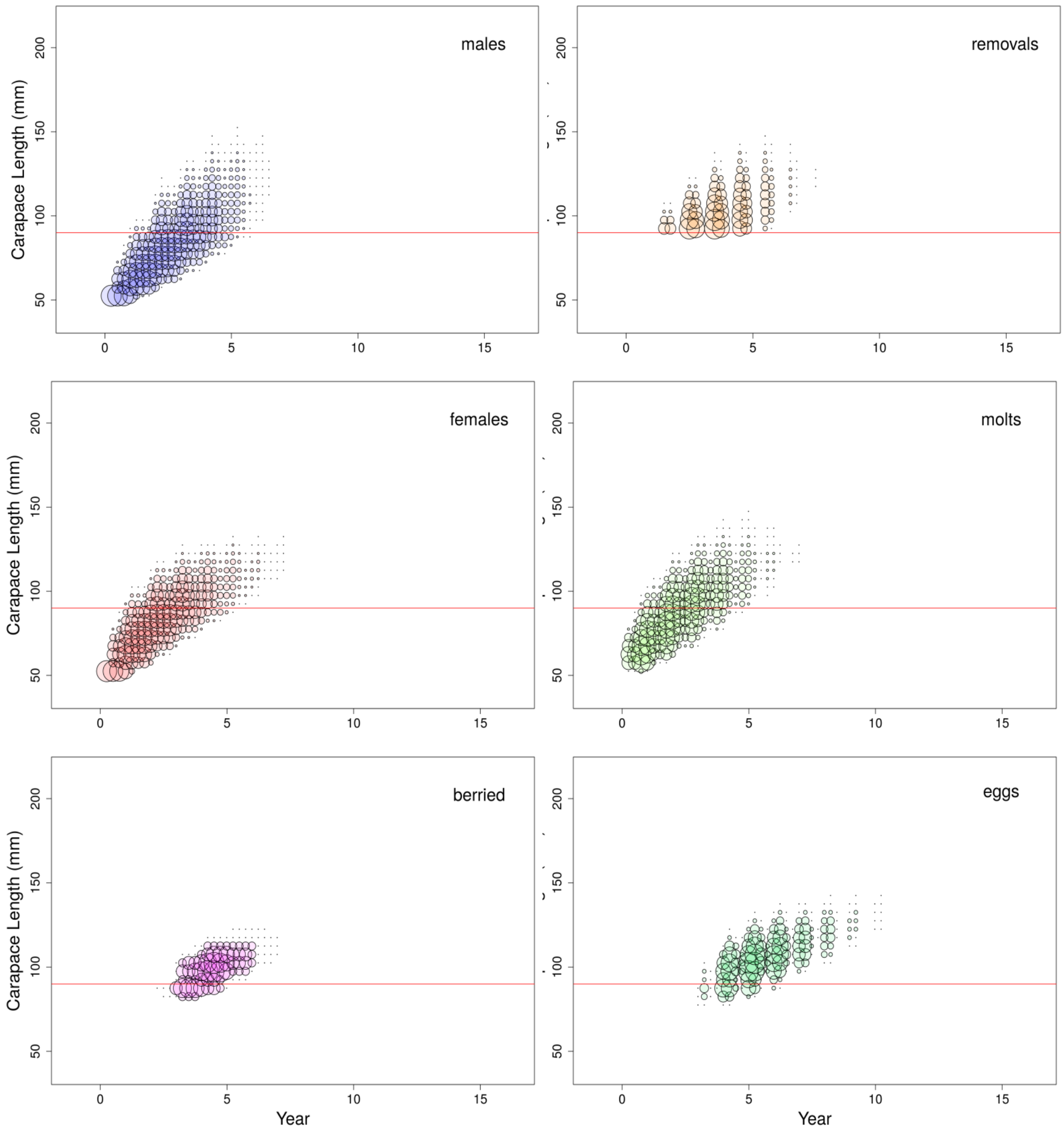

Figure 75. Bubble plots showing the simulated population assuming Continuous Change In Ratio (CCIR) exploitation estimates where Minimum Legal Size (MLS) was increased to 90 mm for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

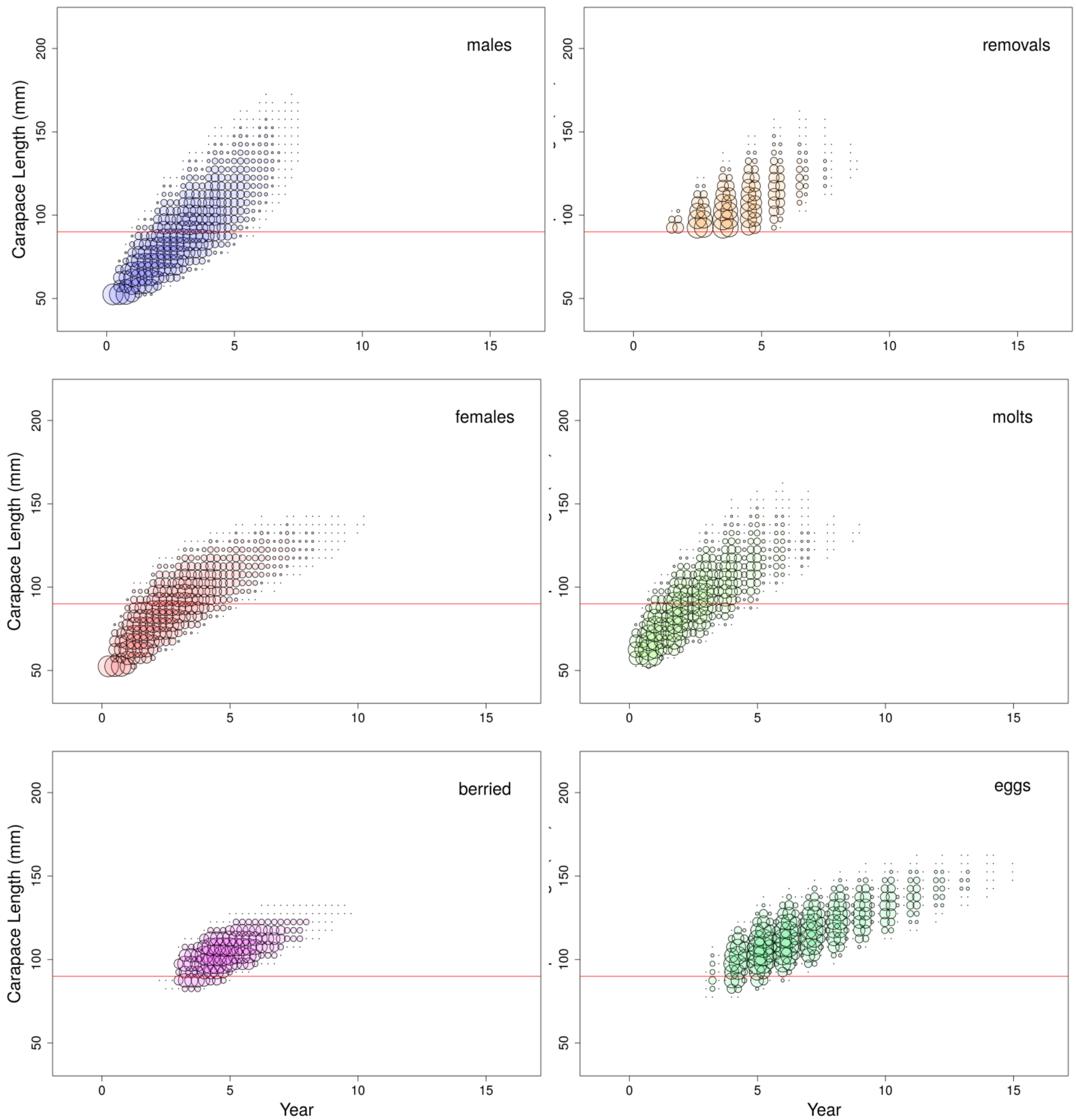

Figure 76. Bubble plots showing the simulated population assuming relF exploitation estimates where MLS was increased to 90 mm for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

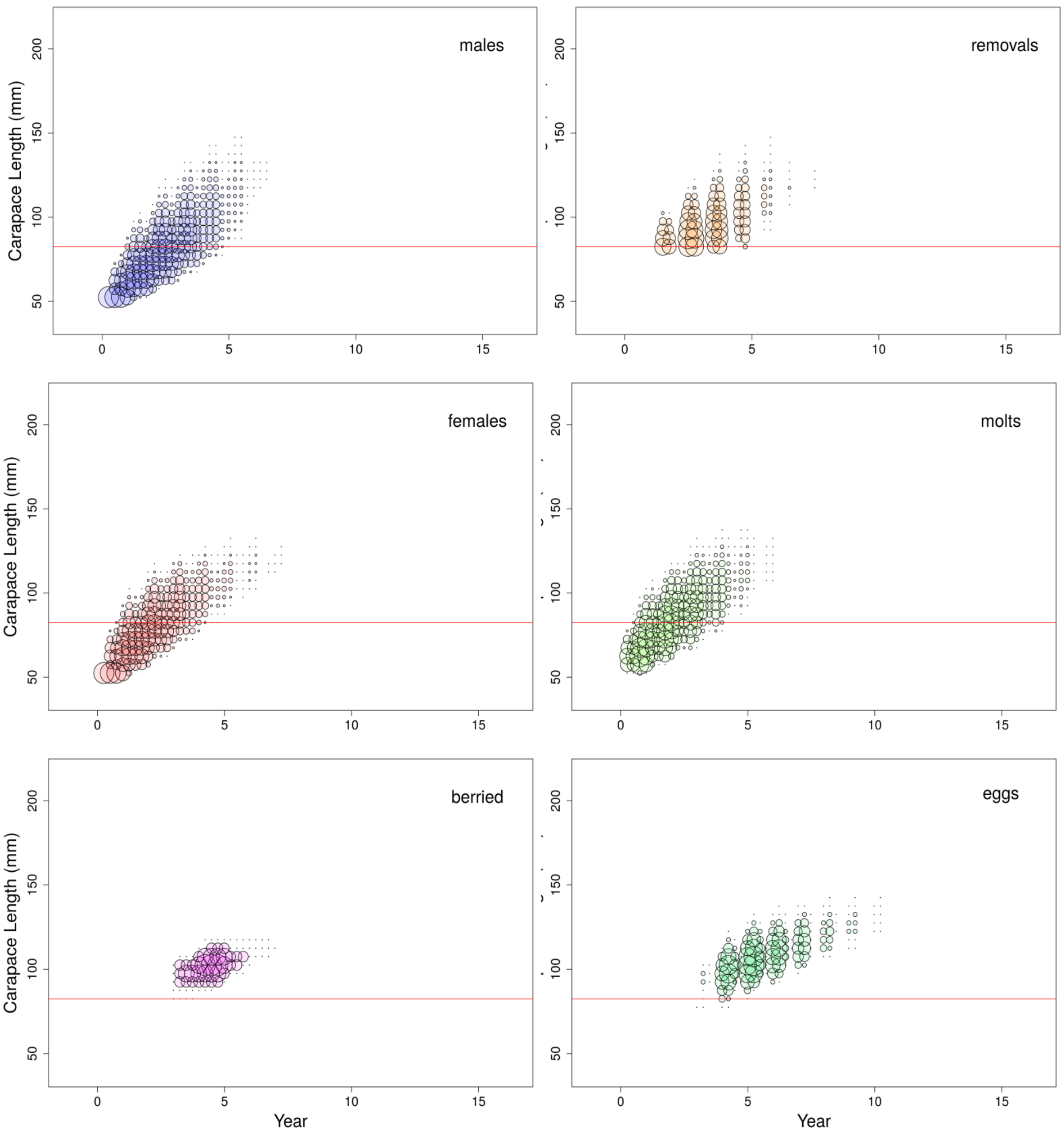

Figure 77. Bubble plots showing the simulated population assuming Continuous Change In Ratio (CCIR) exploitation estimates where the season was shortened by 50 percent for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

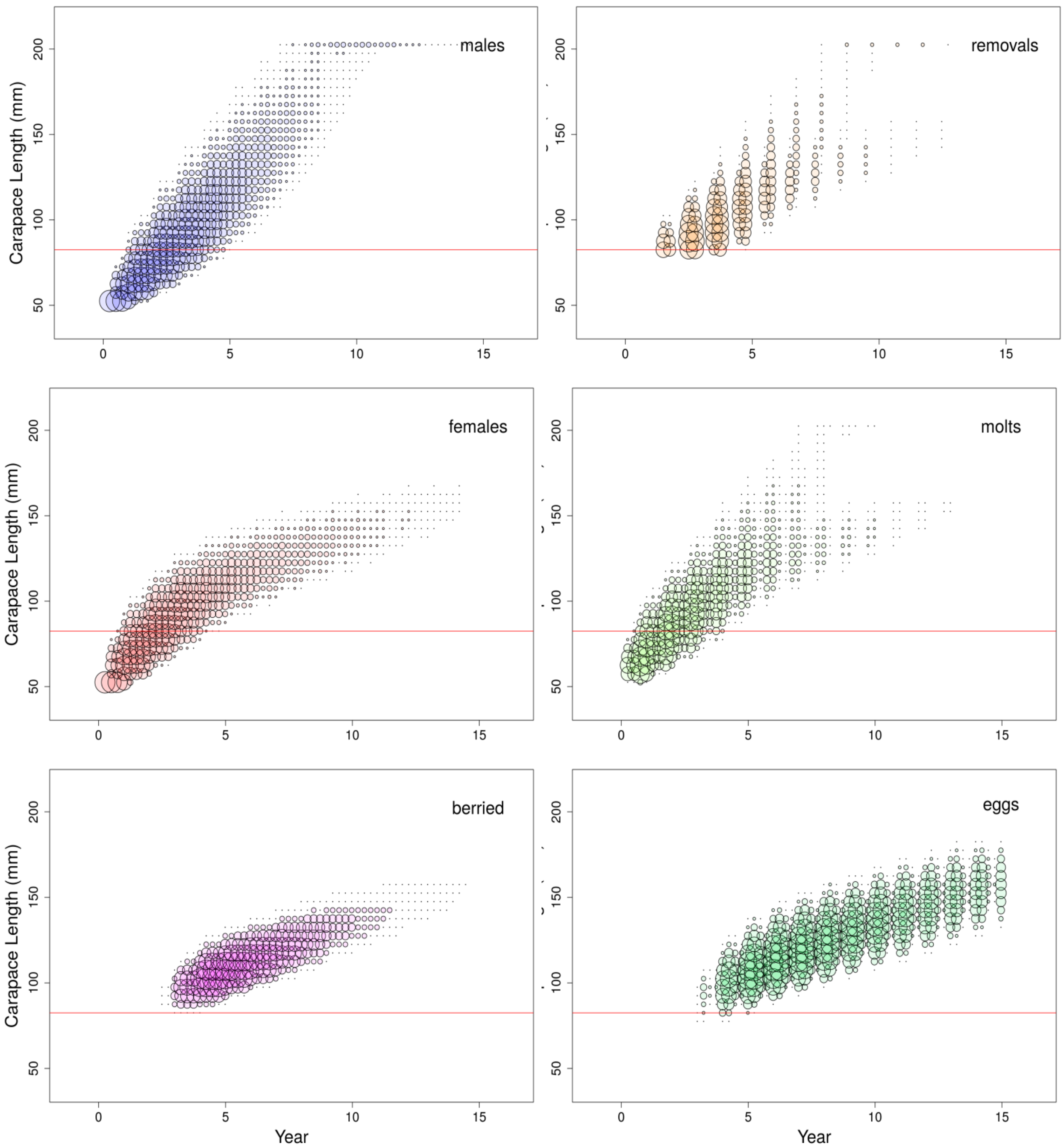

Figure 78. Bubble plots showing the simulated population assuming relF exploitation estimates where the season was shortened by 50 percent for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

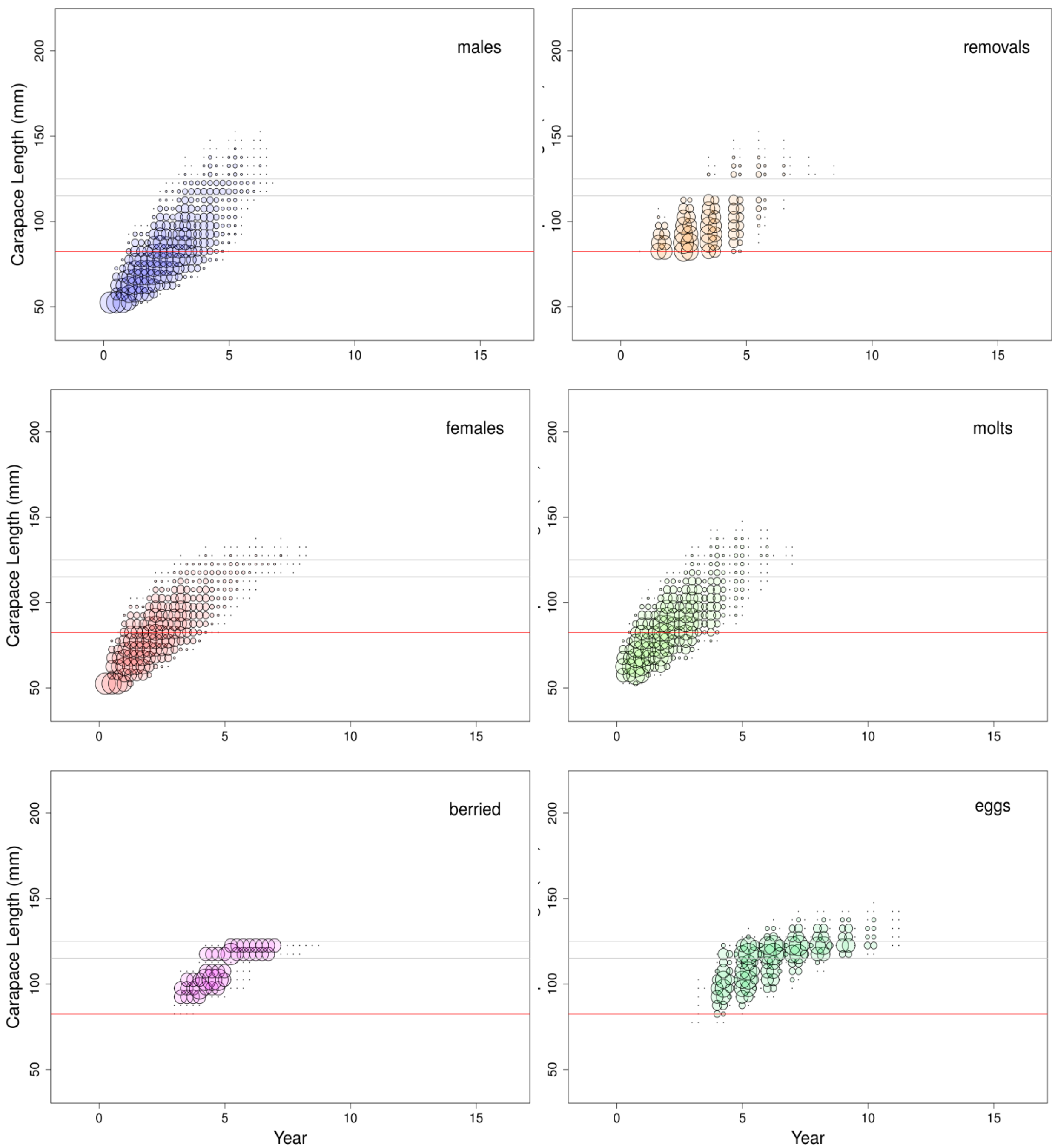

Figure 79. Bubble plots showing the simulated population assuming Continuous Change In Ratio (CCIR) exploitation estimates where a small window (115–125 mm) was implemented for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

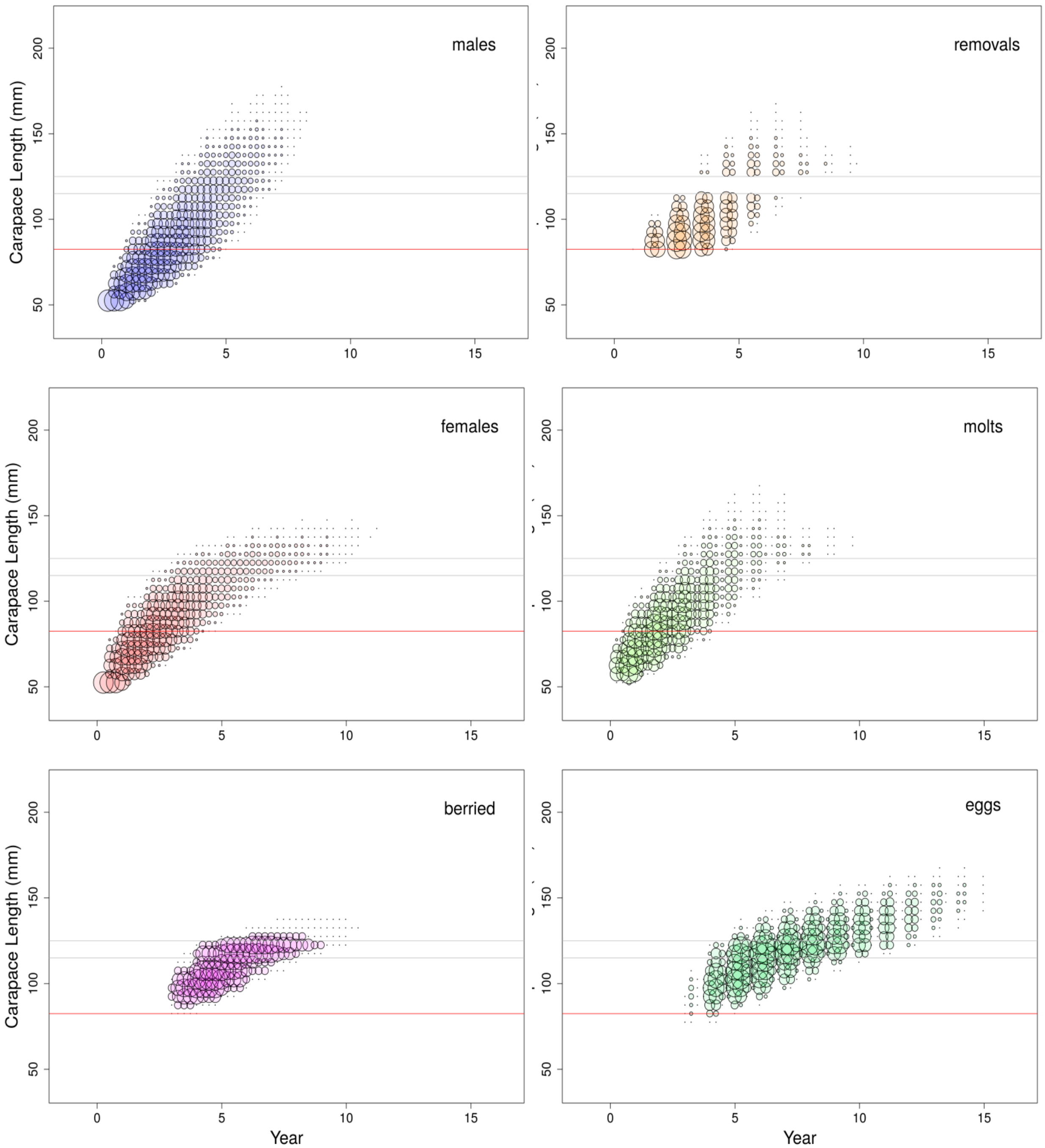

Figure 80. Bubble plots showing the simulated population assuming relF exploitation estimates where a small window (115–125 mm) was implemented for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

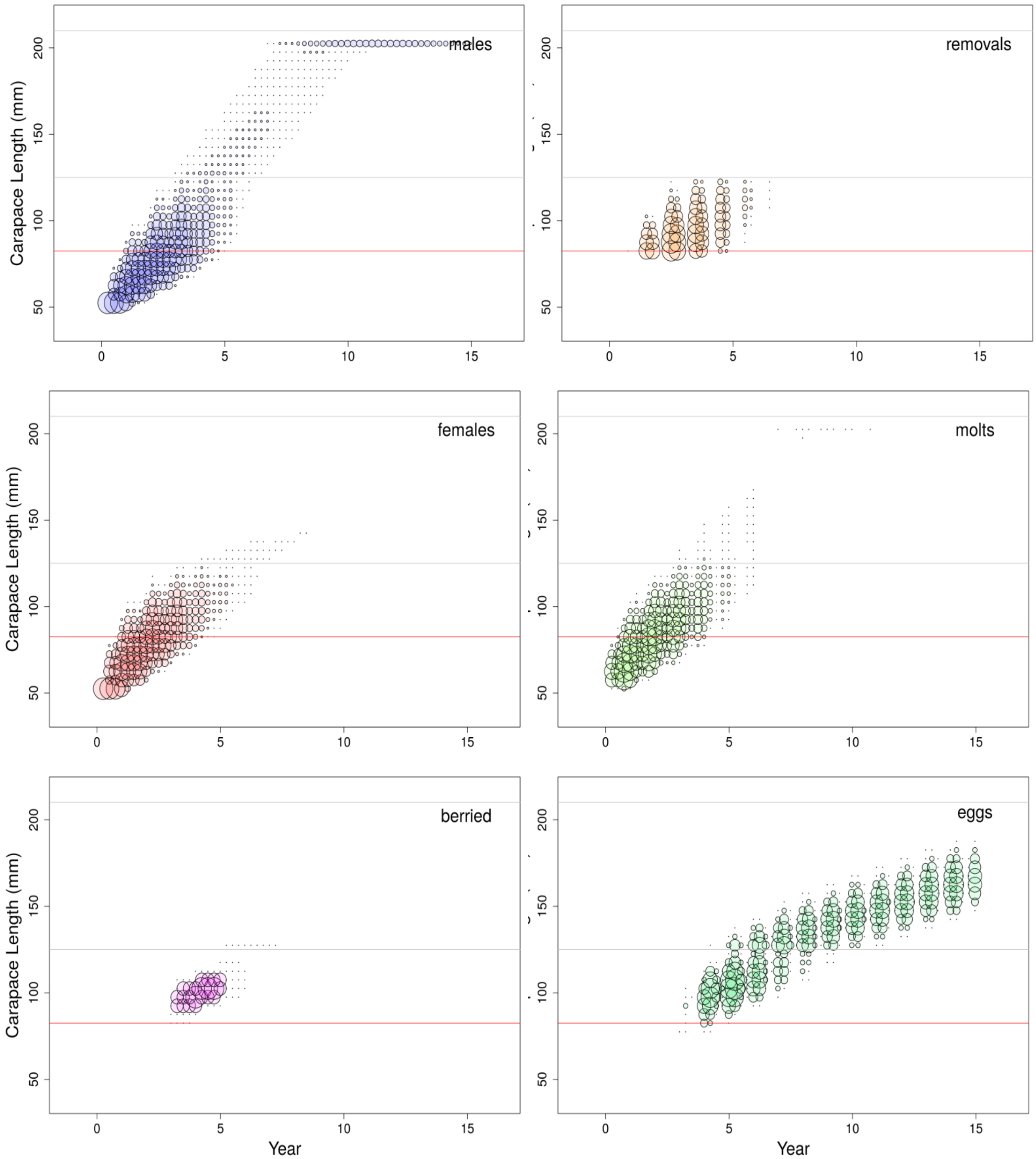

Figure 81. Bubble plots showing the simulated population assuming Continuous Change In Ratio (CCIR) exploitation estimates where a maximum size of 125 mm was implemented for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

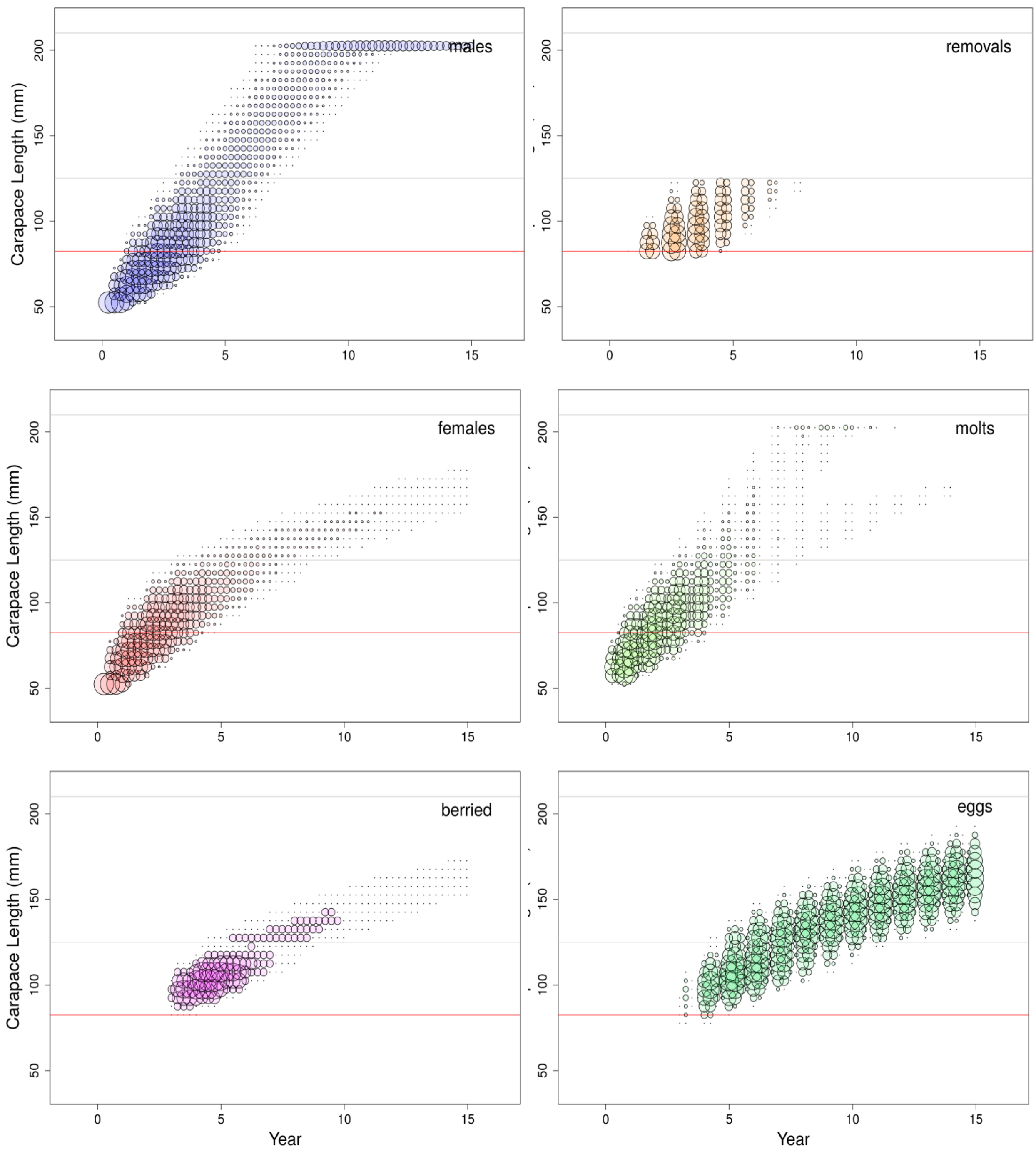

Figure 82. Bubble plots showing the simulated population assuming relF exploitation estimates where a maximum size of 125 mm was implemented for LFA 34. The diameter of the bubbles are proportional to the log number of Lobsters in a given size bin and time step.

APPENDIX A : LENGTH FREQUENCIES

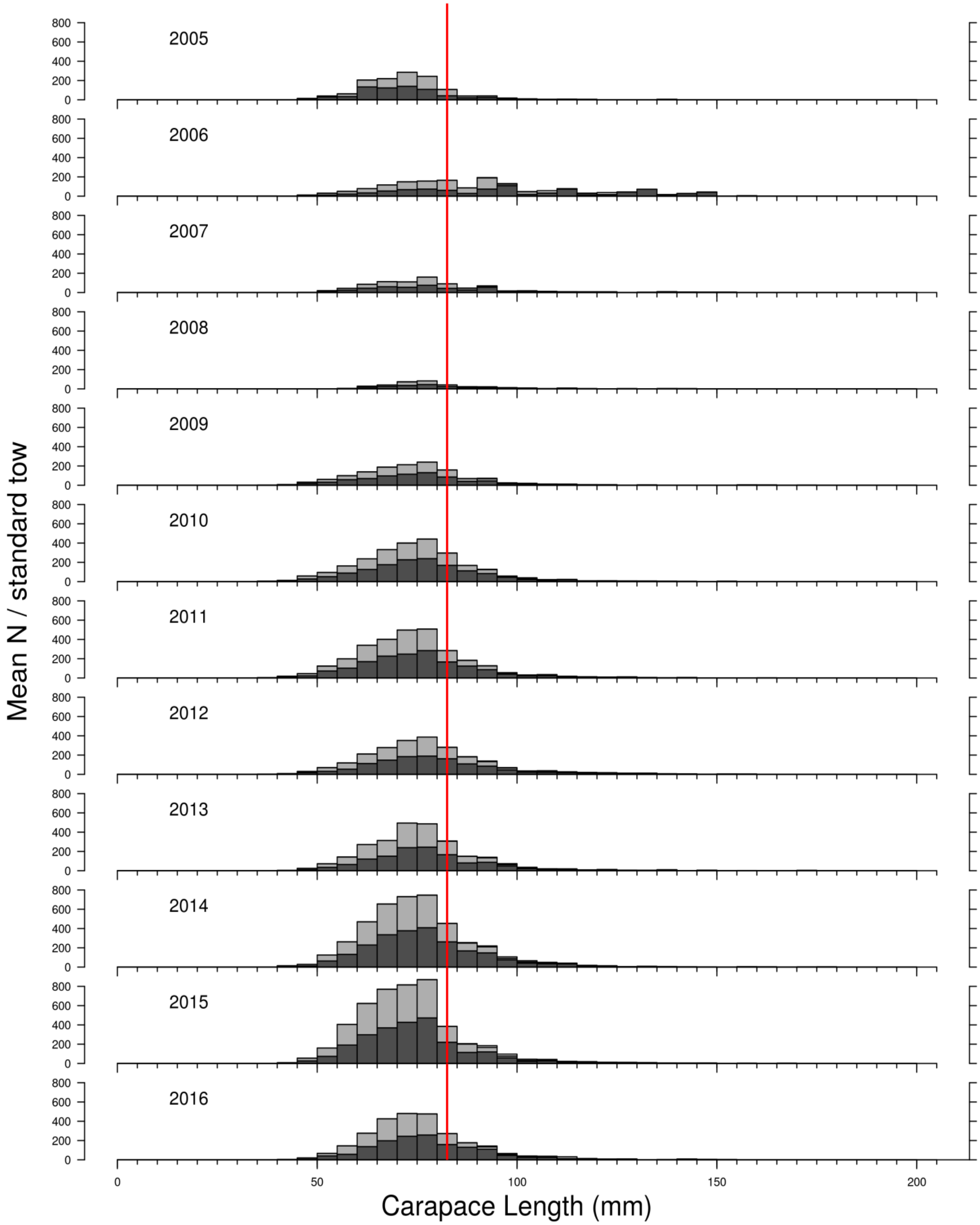

Figure A.1. Carapace Length (CL) frequencies from Inshore Lobster Trawl Survey (ILTS) survey in LFA 34 from 2005–2016 when the balloon trawl was used. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS).

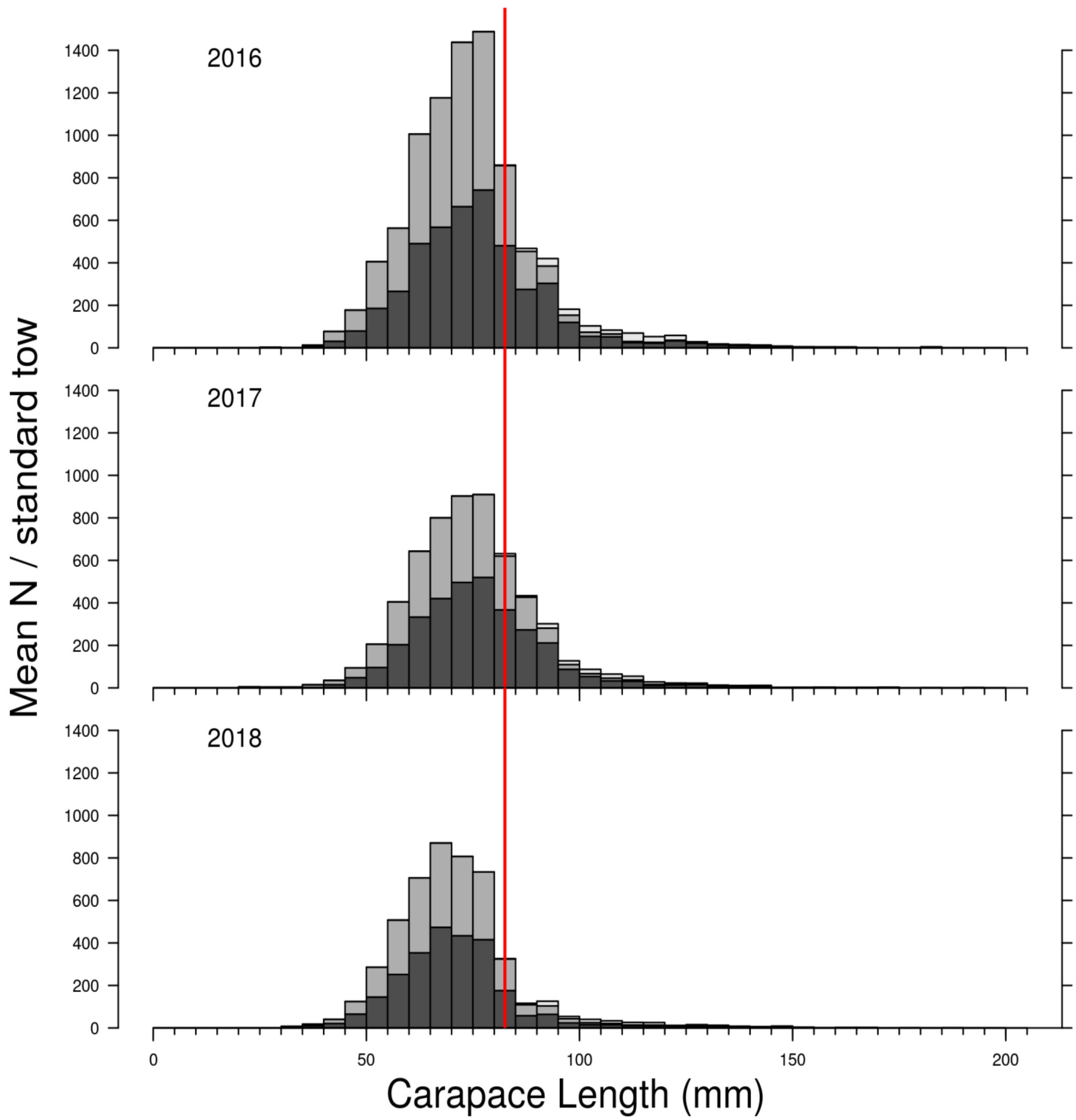

Figure A.2. Carapace Length (CL) frequencies from Inshore Lobster Trawl Survey (ILTS) survey in LFA 34 from 2016–2018 when the nest trawl was used. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS).

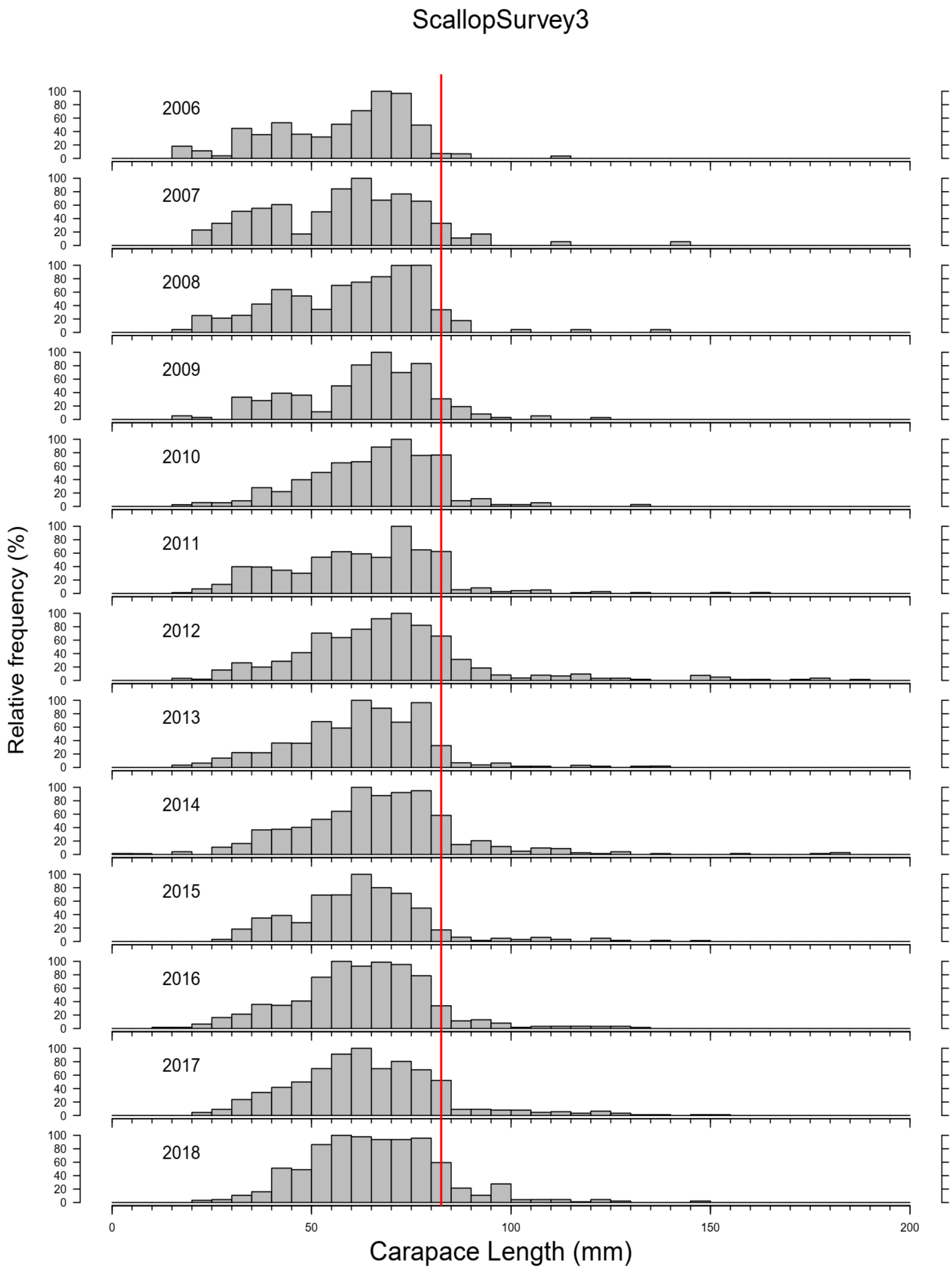

Figure A.3. Carapace Length (CL) frequencies from scallop survey in LFA 34 conducted in June 2006–2018. Red line: Minimum Legal Size (MLS).

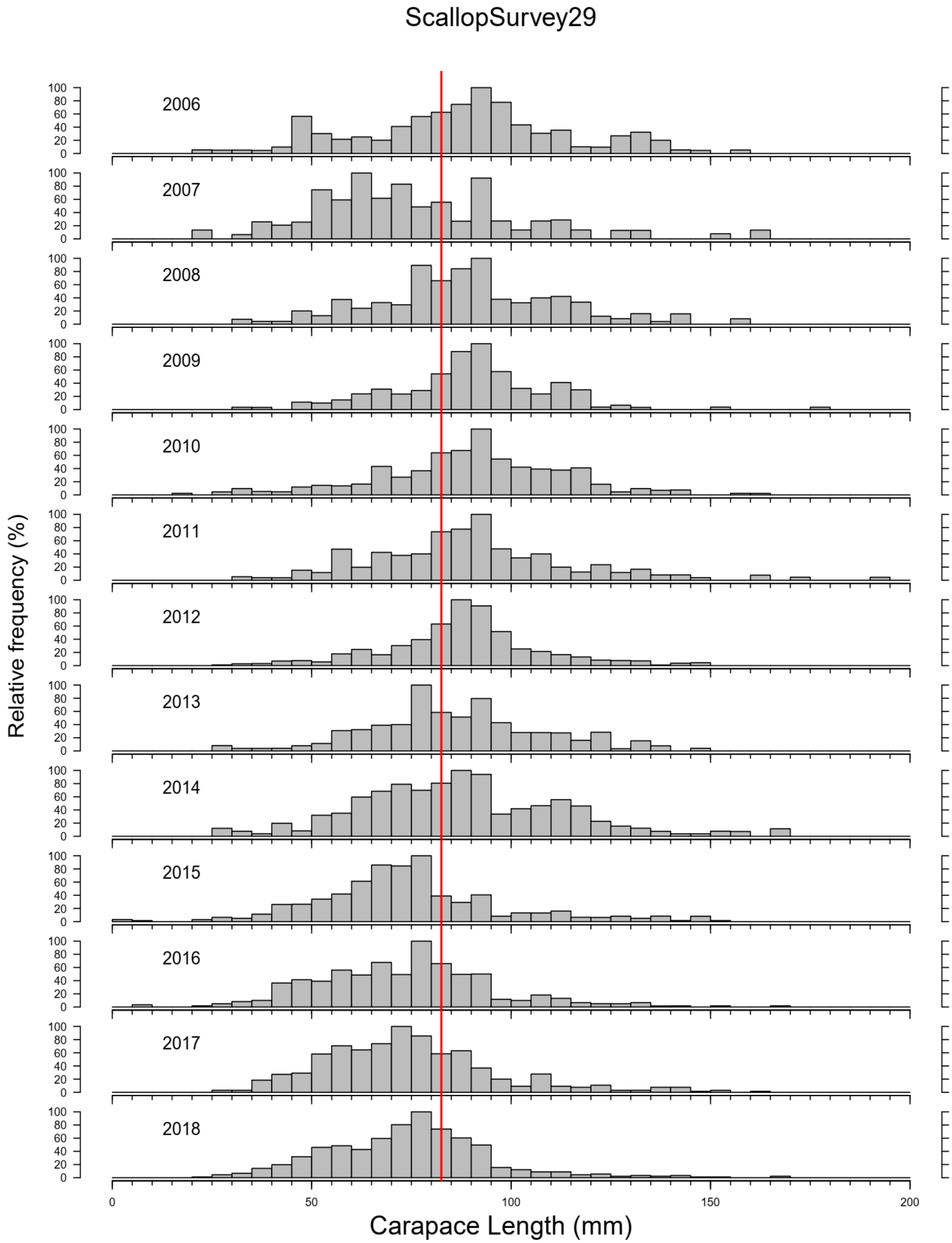

Figure A.4. Carapace Length (CL) frequencies from scallop survey in LFA 34 conducted in Sept 2006–2018. Red line: Minimum Legal Size (MLS).

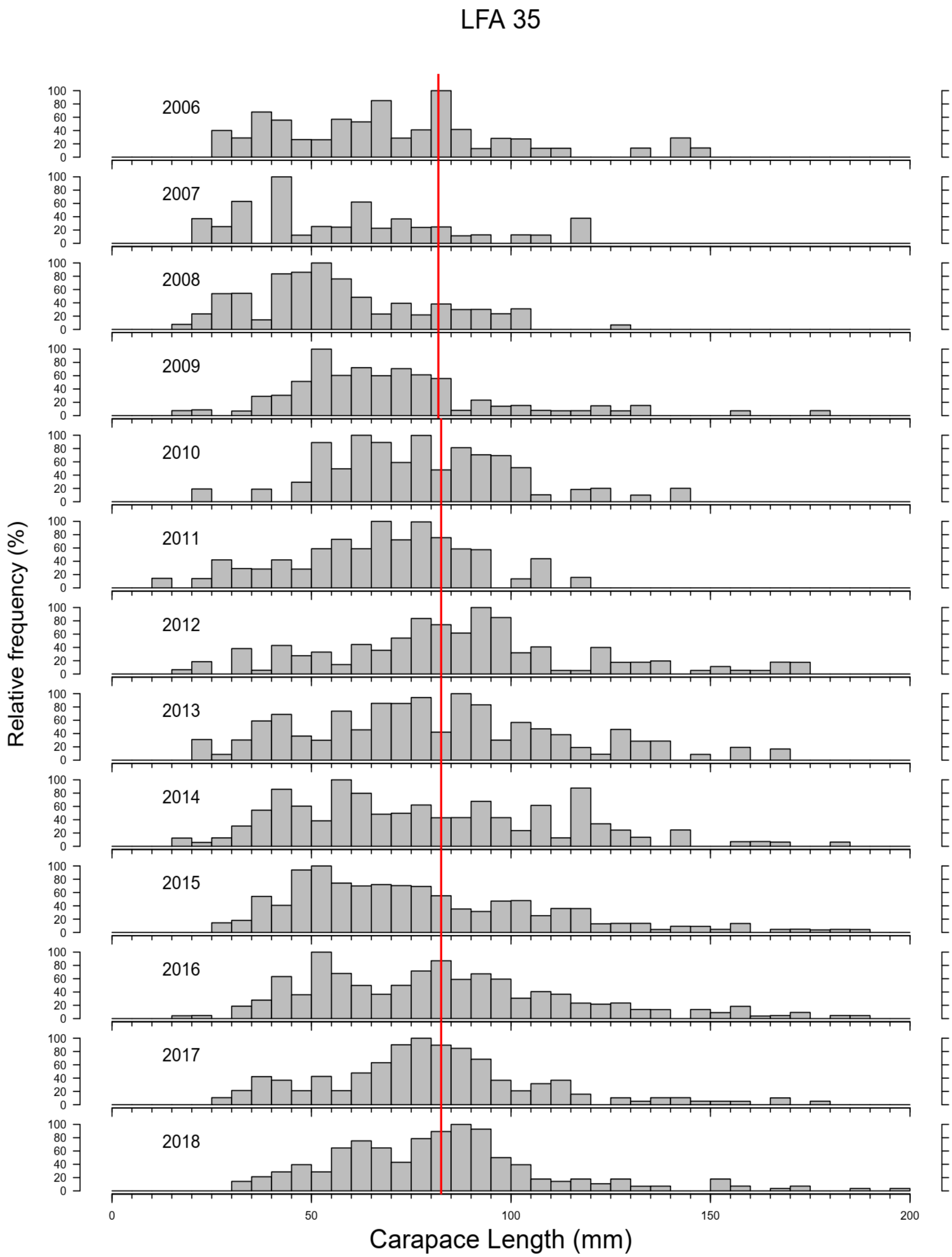

Figure A.5. Carapace Length (CL) frequencies from scallop survey in LFA 35 conducted in July 2006–2018. Red line: Minimum Legal Size (MLS).

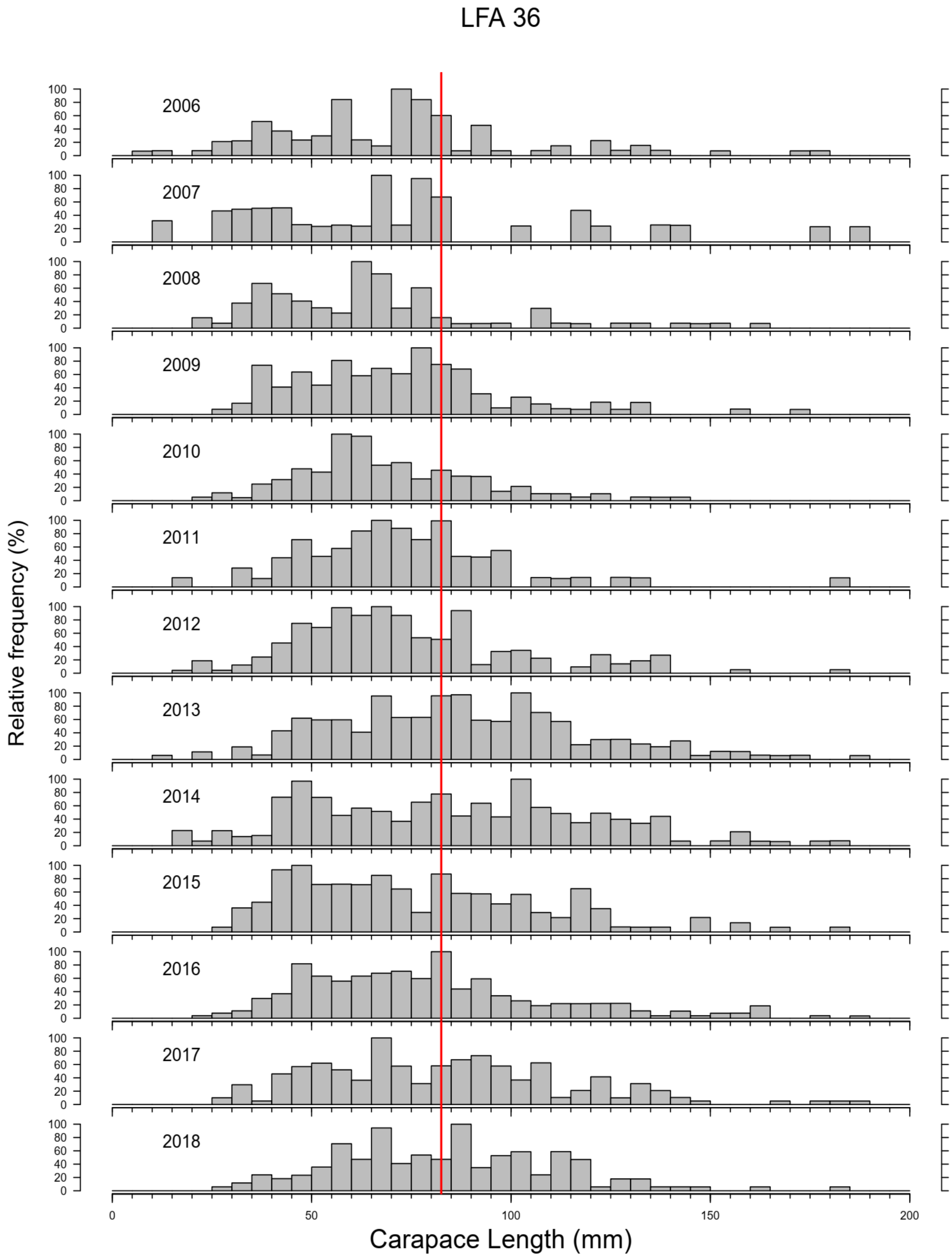

Figure A.6. Carapace Length (CL) frequencies from scallop survey in LFA 36 conducted in July 2006–2018. Red line: Minimum Legal Size (MLS).

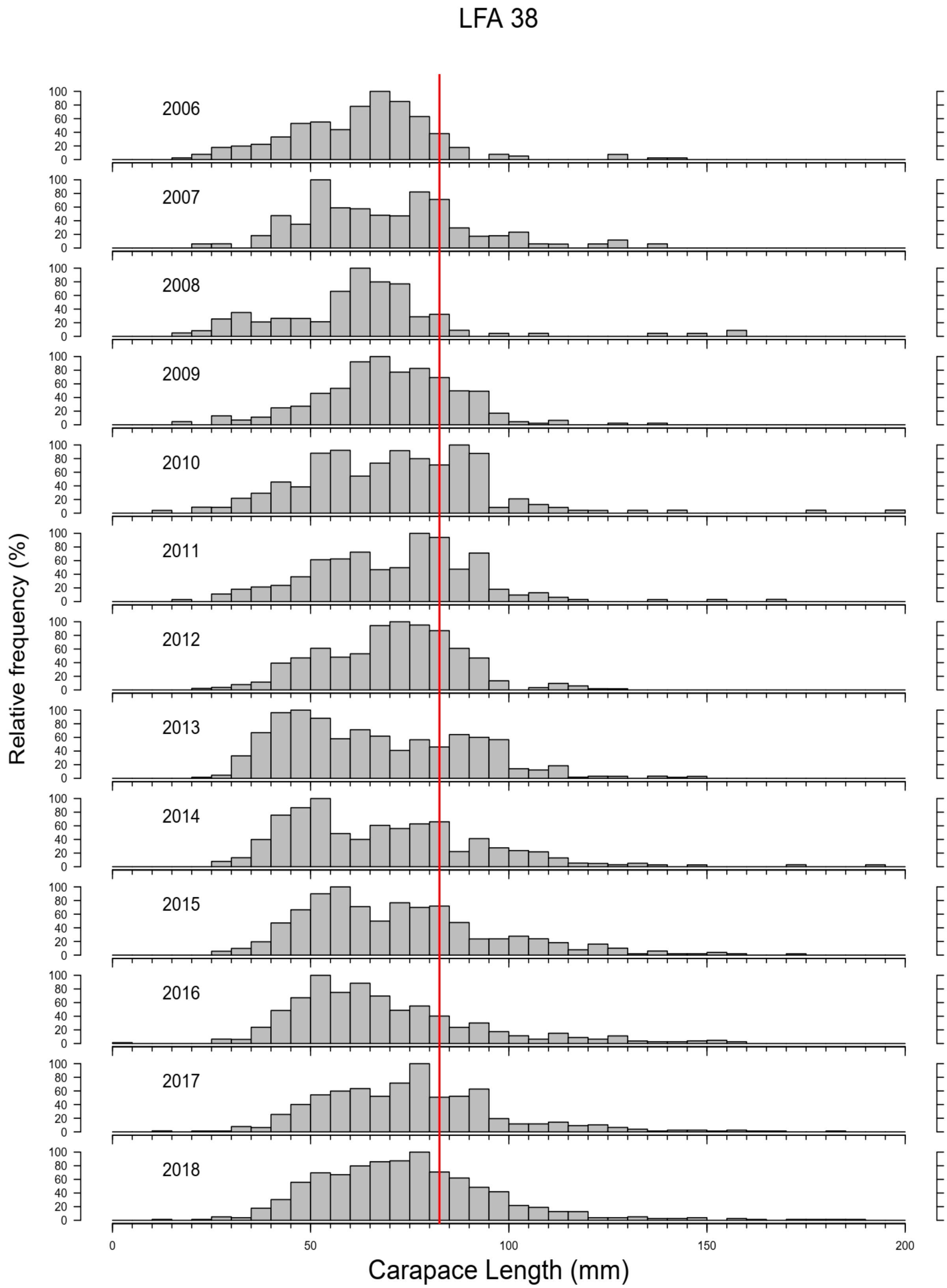

Figure A.7. Carapace Length (CL) frequencies from scallop survey in LFA 38 conducted in Aug 2006–2018. Red line: Minimum Legal Size (MLS).

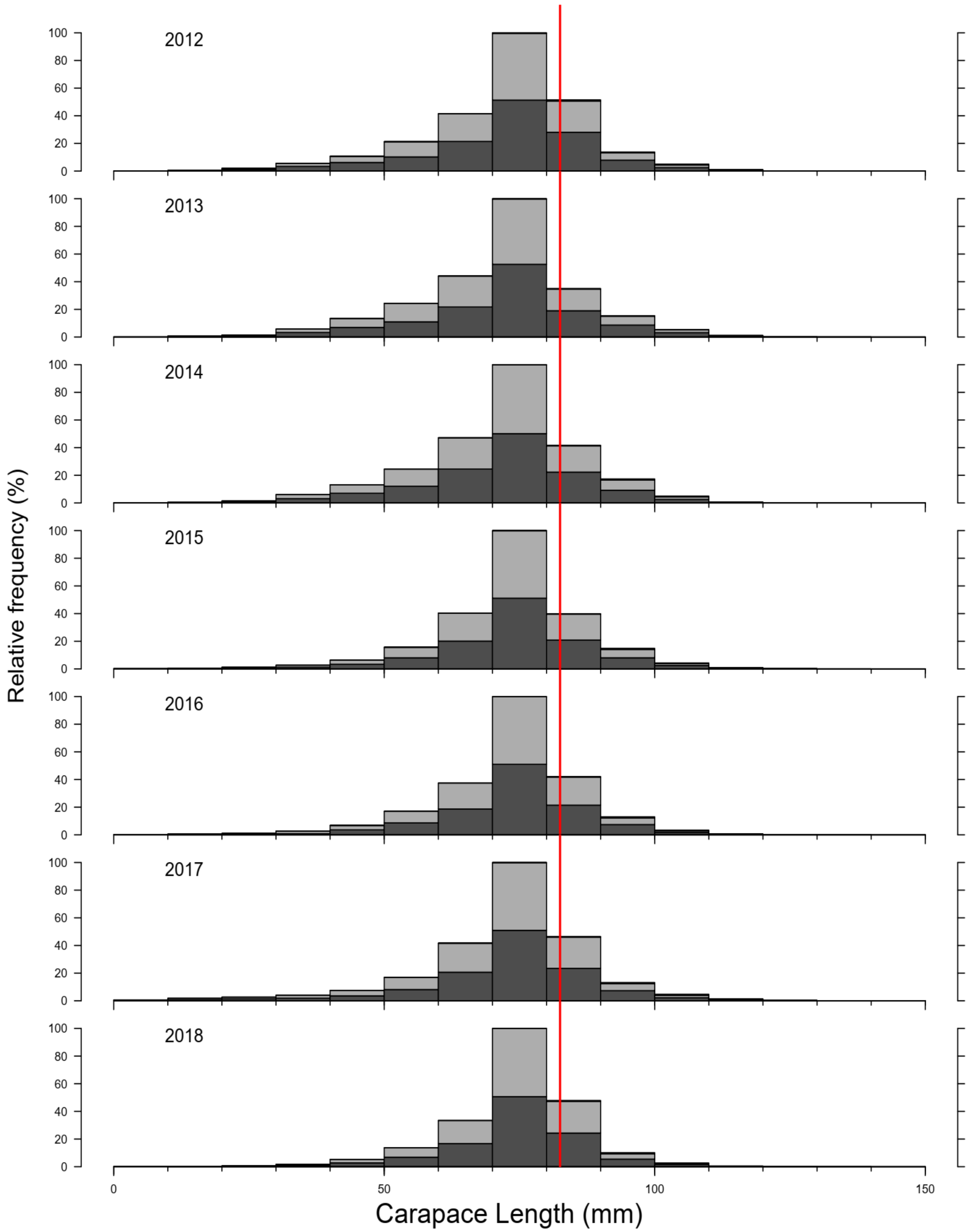

Figure A.8. Carapace Length (CL) frequencies from Fishermen and Scientist Research Society (FSRS) recruitment traps in LFA 34. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS).

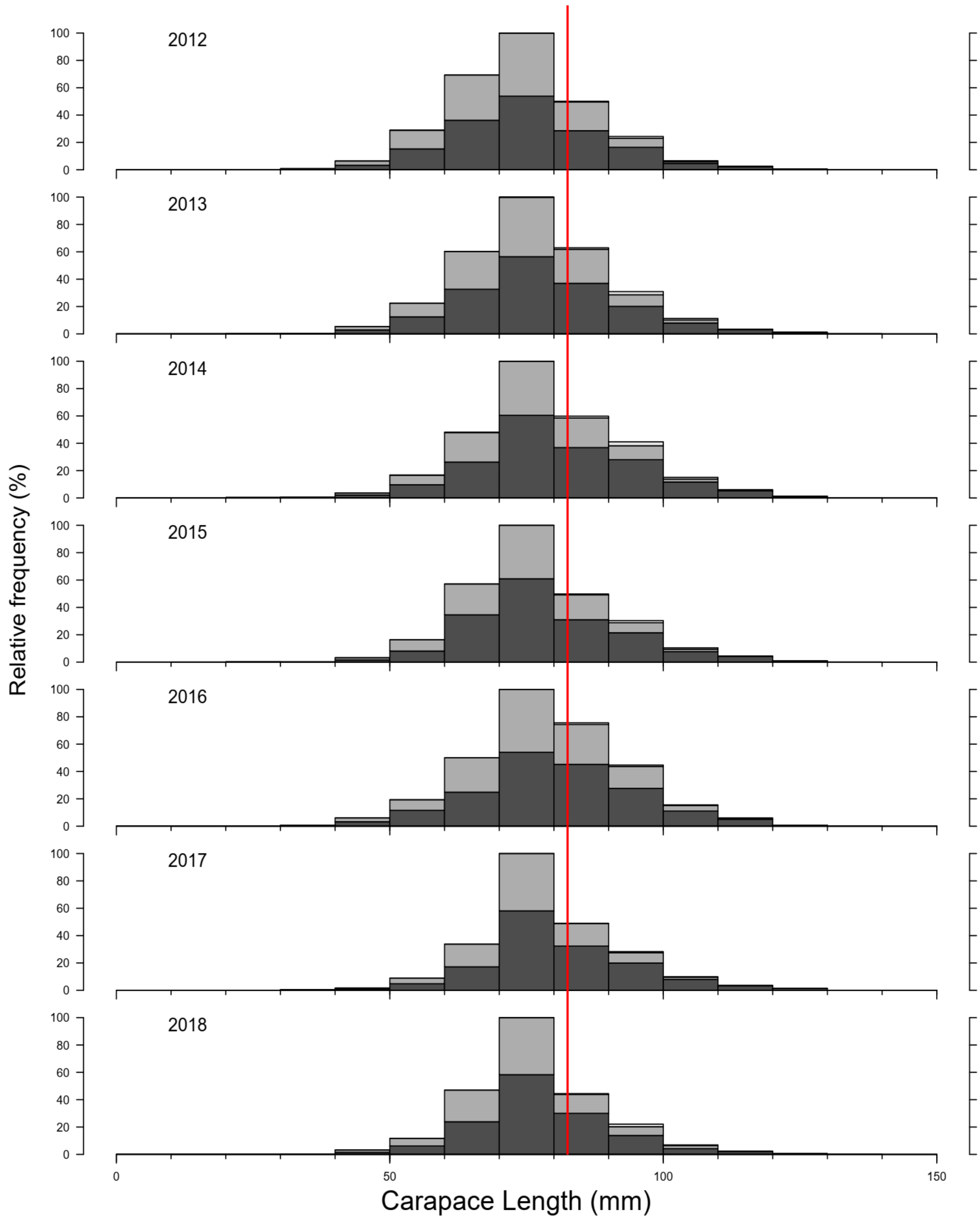

Figure A.9. Carapace Length (CL) frequencies from Fishermen and Scientist Research Society (FSRS) recruitment traps in LFA 35. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS).

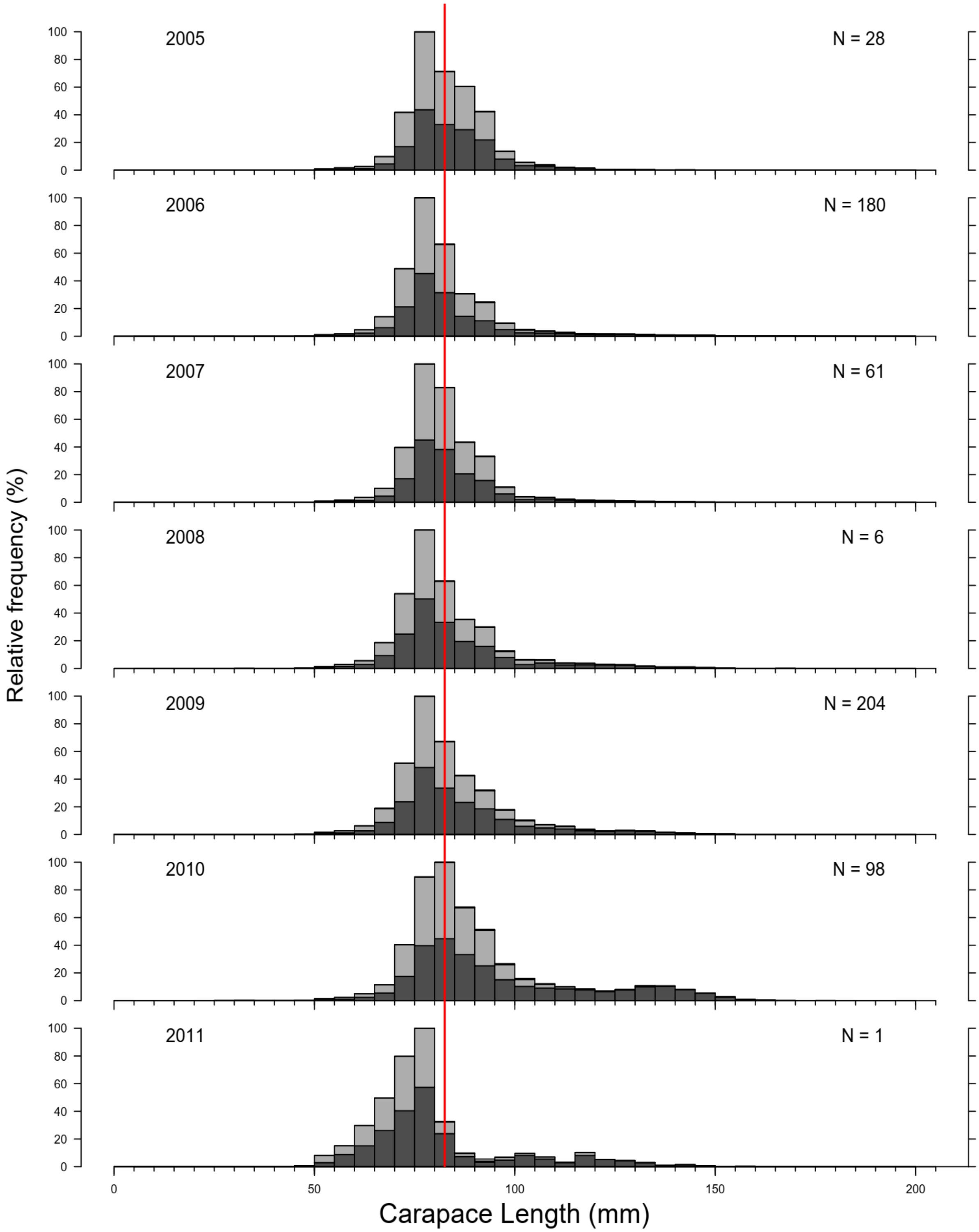

Figure A.10. Carapace Length (CL) frequencies from at-sea sampling in LFA 34 between 2012 and 2018. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS), N: number of samples.

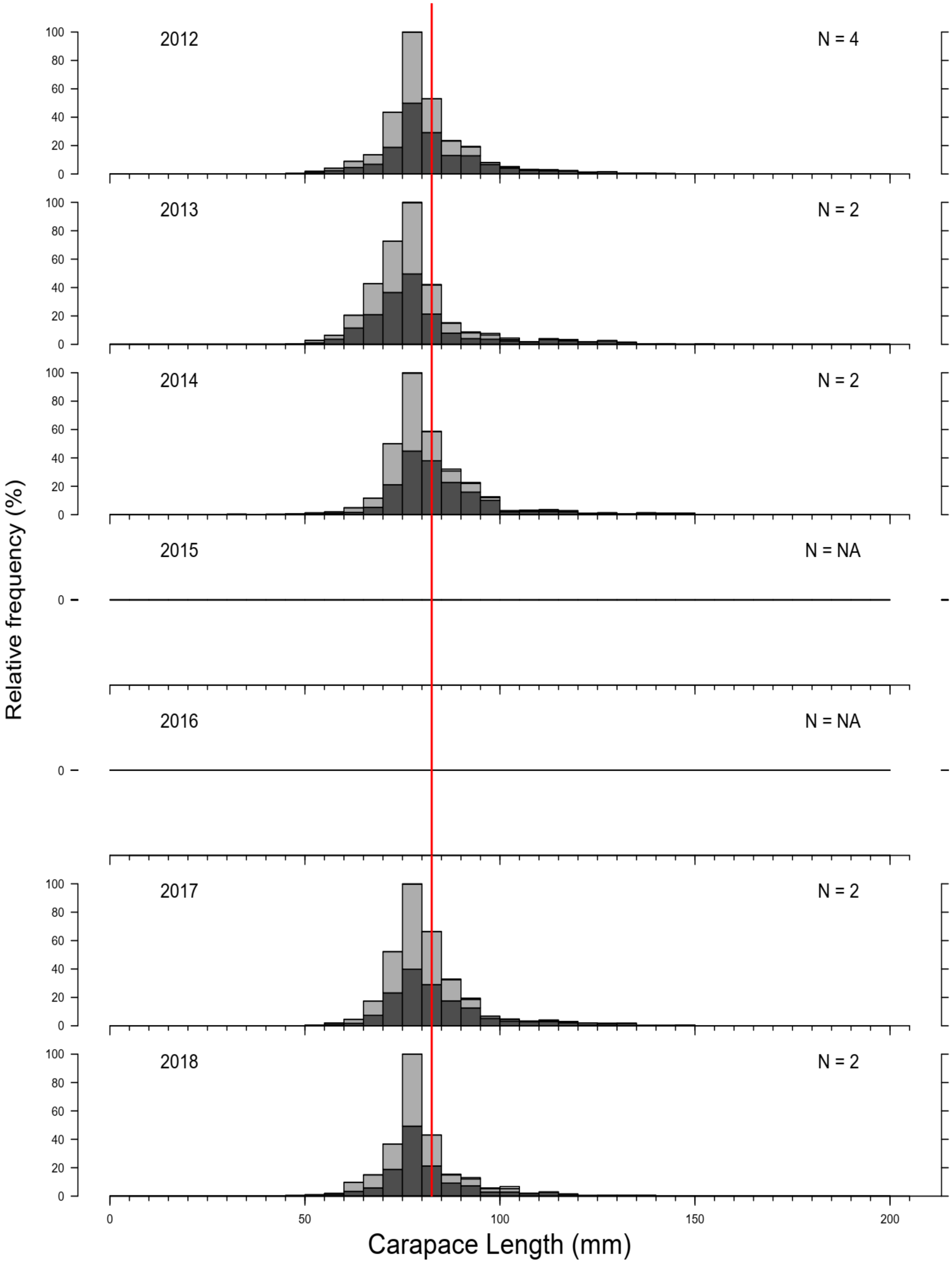

Figure A.11. Carapace Length (CL) frequencies from at-sea sampling in LFA 34 between 2012 and 2018. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS), N: number of samples.

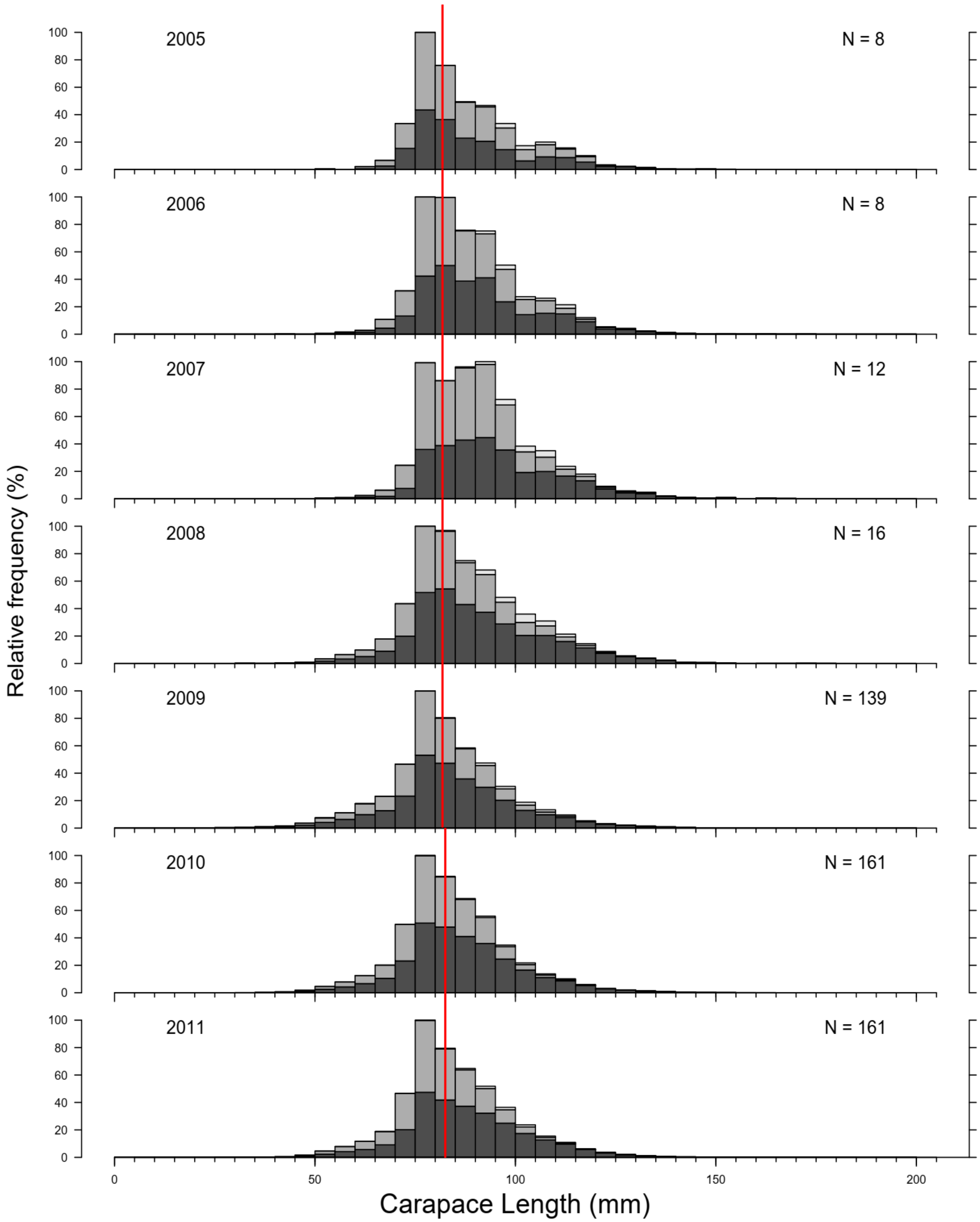

Figure A.12. Carapace Length (CL) frequencies from at-sea sampling in LFA 35 between 2005 and 2011. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS), N: number of samples.

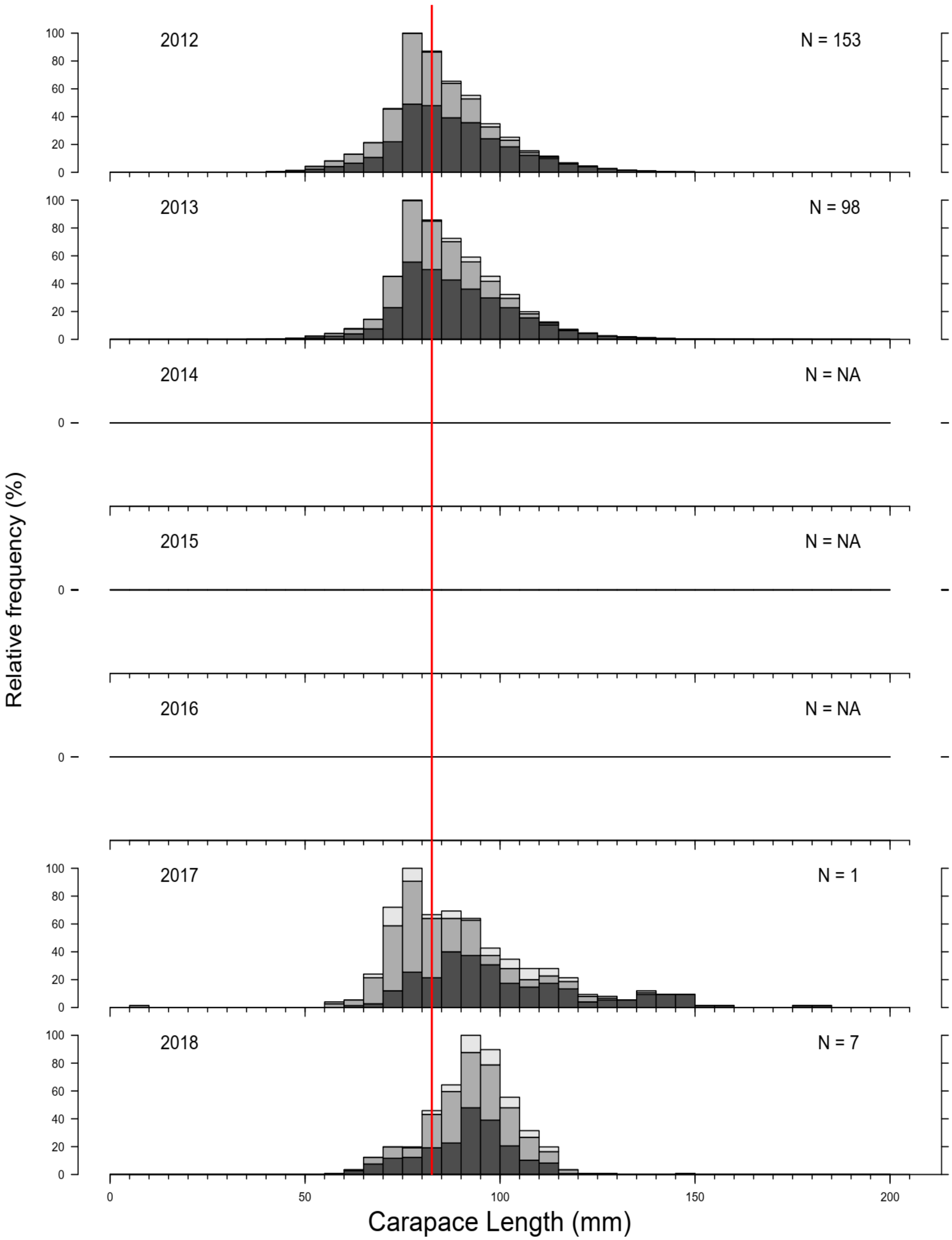

Figure A.13. Carapace Length (CL) frequencies from at-sea sampling in LFA 35 between 2012 and 2018. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS), N: number of samples.

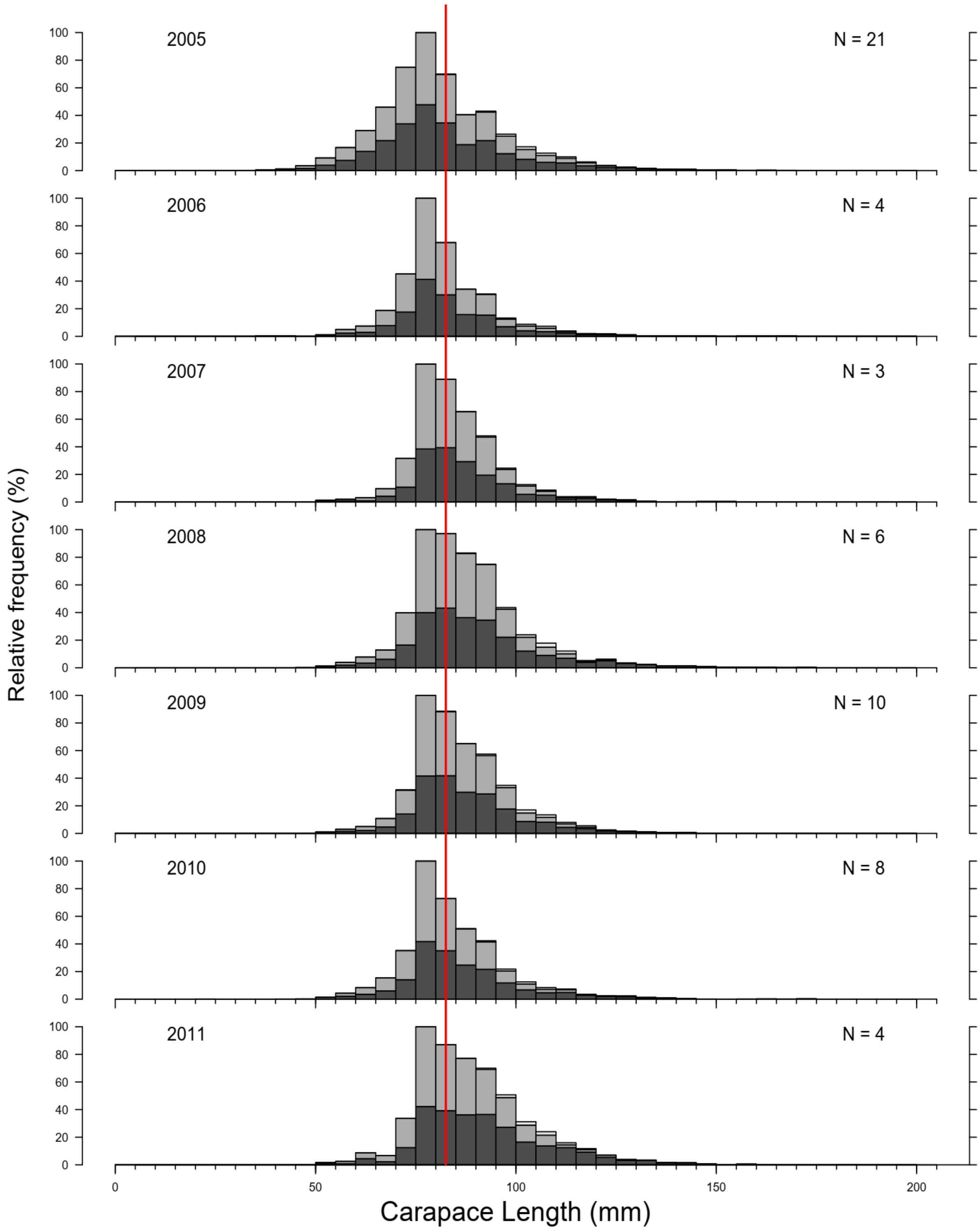

Figure A.14. Carapace Length (CL) frequencies from at-sea sampling in LFA 36 between 2005 and 2011. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS), N: number of samples.

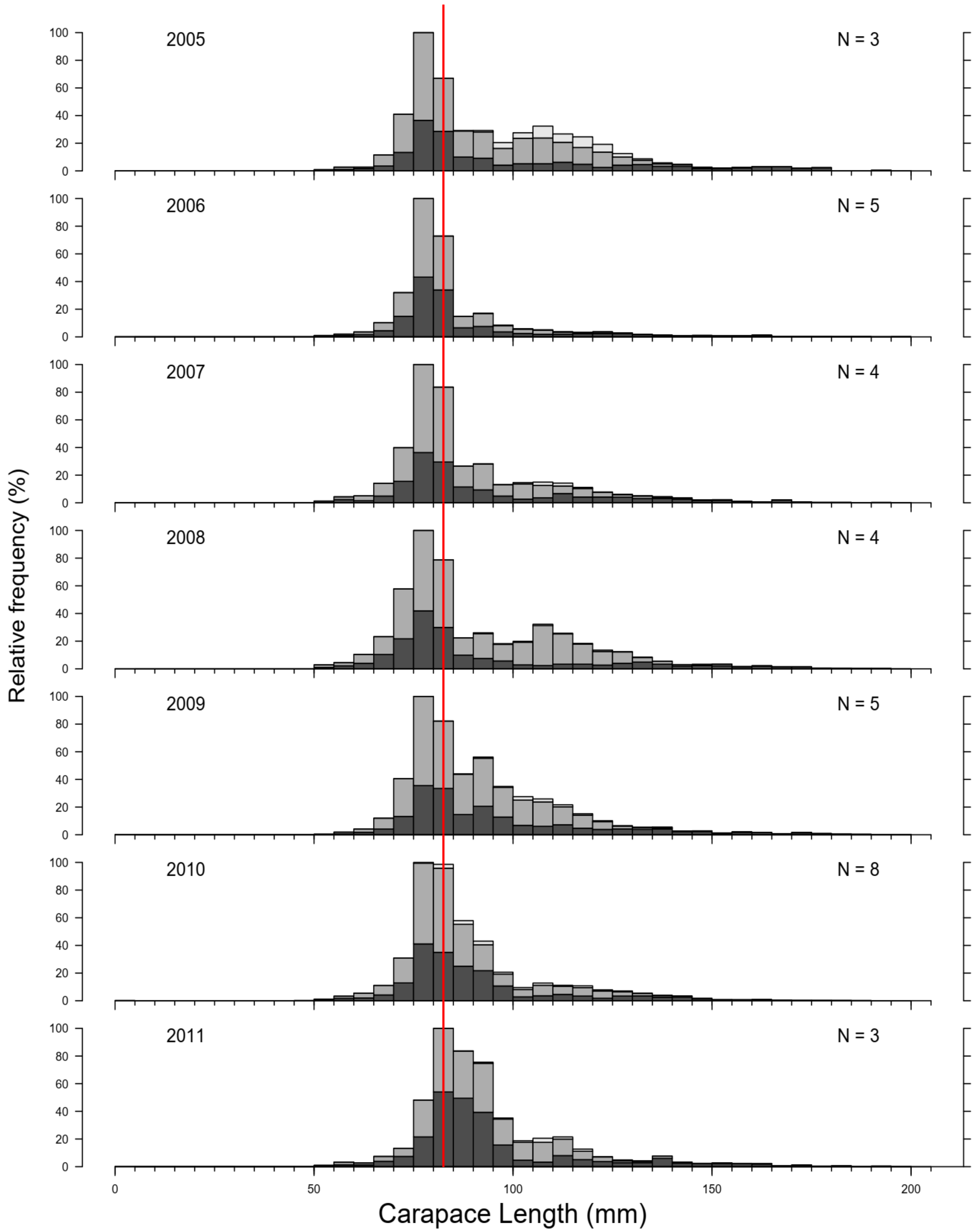

Figure A.15. Carapace Length (CL) frequencies from at-sea sampling in LFA 38 between 2005 and 2011. Dark grey: males, light grey: females, red line: Minimum Legal Size (MLS), N: number of samples.

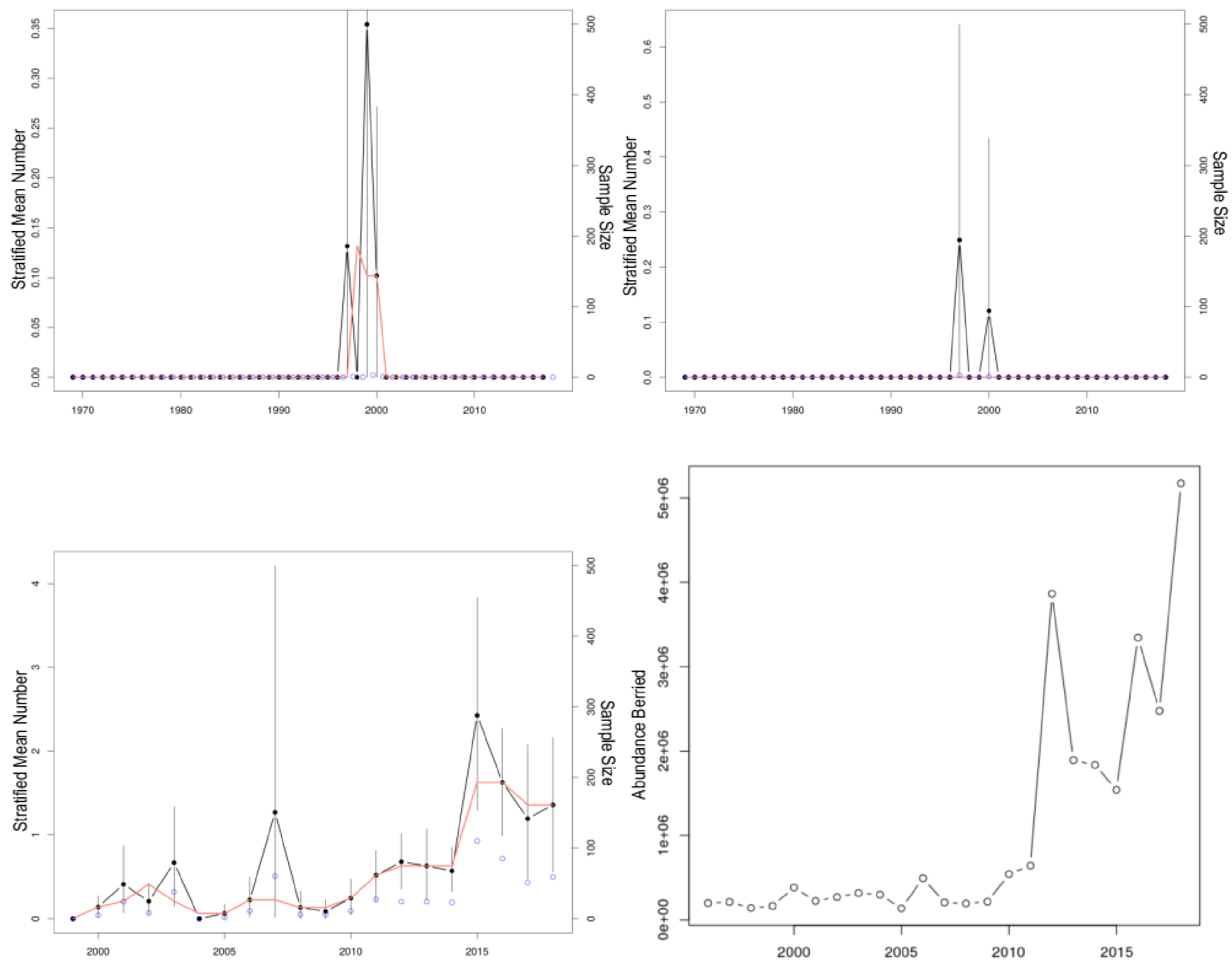

Figure A.16. Time series trends in berried abundance for Lobsters within LFA 34 captured in trawl surveys. Clockwise from top left, NFall, NSpr, ILTS and DFO. Orange lines represent three-year running medians.

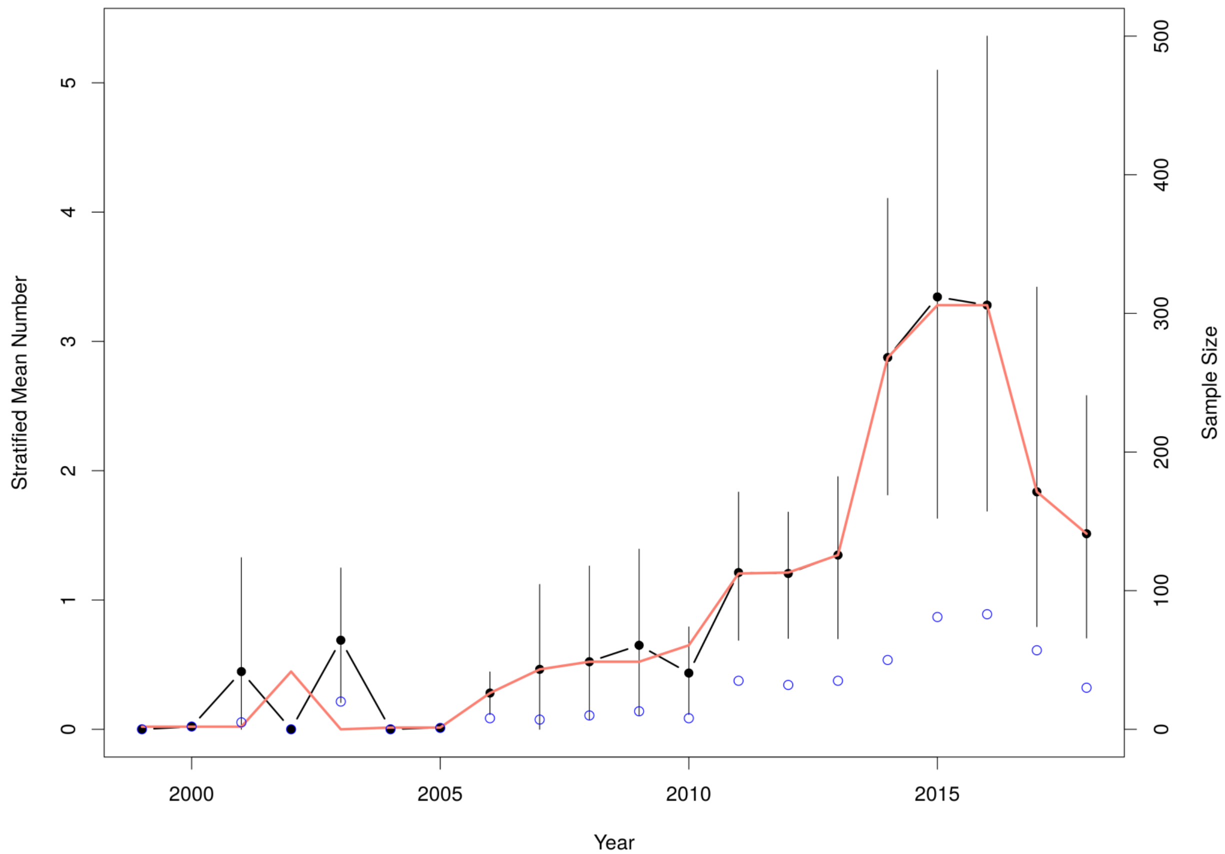

Figure A.17. Berried Female abundance LFA 35–38 from DFO summer RV surveys.