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2018 Framework Assessment of the American Lobster (*Homarus americanus*) in LFA 27–33

Adam M. Cook, P. Brad Hubley, Cheryl Denton, Victoria Howse

Bedford Institute of Oceanography
1 Challenger Drive
Dartmouth NS, Canada
B2Y 4A2

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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 American Lobster fisheries in Lobster Fishing Areas (LFAs) 27–33 have been active for more than 100 years, with variable levels of productivity throughout that time. The current Lobster stocks in LFA 27–33 are supporting some of the highest landings on record for the region. All of these fisheries are effort controlled, with a limited number of licenses per LFA, trap limits per license, defined season lengths and minimum legal retainable sizes.

The last framework assessment for these fisheries was conducted in 2011 (Tremblay et al. 2011) and thoroughly reviewed the data sources, provided some options for preforming stock assessment and directions moving forward. During that framework it was determined that fishery landings was the best proxy for Lobster abundance from the available information and that it should be the primary indicator of stock status with defined reference points (Tremblay et al. 2012). The risks associated with relying on landings as a proxy for abundance were noted. Subsequent stock assessments and stock status updates have focussed on the changes in landings, Fishermen and Scientists Research Society (FSRS) recruitment traps and commercial trap catch rates to provide stock status information to resource managers. The focus of the current framework was to continue the work of the previous stock assessment framework, include additional analysis and data to determine the best approach for providing stock assessment advice given our available data streams.

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.

The current data to assess LFA 27–33 Lobster stocks include landings, commercial catch rates, FSRS recruitment trap surveys, Port and At-Sea sampling. Each of these data sources provides information on the Lobster in sampled areas; however most of our extended time series comes from fishery dependent data sources and therefore largely reflect removals from the LFAs rather than the Lobster population. The FSRS recruitment traps and At-Sea samples provide a broader depiction of the Lobster in the region.

A range of indicators were either updated or developed based on these data sources. The indicators represented biological status (e.g., median and maximum size, proportion large Lobster, proportion of berried females, proportion of new recruits in the fishery, reproductive potential), abundance or biomass (e.g., landings, commercial catch rates, FSRS recruitment trap catch rates) and exploitation (cohort analysis or change in ratio). These indicators were separated into primary, secondary and contextual categories.

Primary indicators define stock status, through comparing time series trends to reference points. The proposed primary indicator of biomass was commercial catch rates. The proposed primary fishing pressure indicator was the exploitation indices estimated through Continuous Change in Ratio (CCIR). Commercial catch rates was suggested as a better index of biomass than landings as using landings makes the strong assumption effective effort will be constant through time. This assumption may be presently true, but changes in management measures, if for example, stock status falls into the cautious zone, or if fishing operations are altered, will affect the continuity of the landings time series. There is currently no removal reference for any Fisheries and Oceans Canada (DFO) Maritimes Region LFA, however, the time series of estimates of exploitation from the CCIR provided robust estimates which can serve as the basis for adopting a removal reference.

Secondary indicators will represent important time series trends which will be tracked individually, but no reference points defined. The proposed secondary indicators will be

landings, fishing effort and the FSRS recruitment trap recruit and legal catch rate series. The remainder of the indicators will remain contextual with broad patterns tracked over time.

Methods to estimate by-catch through effort proration were provided with examples from LFA 27, 31B and 32 where up to date data was readily available.

A simulation model was developed to explore the biological implications of different Harvest Control Rules (HCR). Example simulations were conducted for several LFAs and HCR. 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 as determined from an analysis of tagging data. Other inputs include area specific size at maturity and CCIR exploitation rates. 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 Sizes (MLS), change in the duration of the fishing season, protection of a window size of Lobster and protection of Lobster above a maximum size.

INTRODUCTION

BACKGROUND

The inshore commercial fishery for American Lobster (*Homarus americanus)* has been active for over 100 years in Lobster Fishing Areas (LFAs) 27–33 (Tremblay and Eagles 1996). These areas cumulatively cover 21 000 km^2 from Cape Breton to Shelburne County and the fishery is primarily prosecuted within 15km (100m depth contour) from the shore in LFA 27–32 though the LFAs extend out to 92km (50 nautical miles) (Tremblay et al. 2011; Figure 1). LFA 33, prosecutes the Lobster fishery both inshore and more recently in offshore areas (Figure 1).

LFAs 27–33 account for 19.5% of Canadian landings and 10.9% of North American lobster in 2016 and produced approximately 18,000 tons of landed Lobster with a landed value of approximately 272.4 million dollars during the Oct 2015 to September 2016 seasons (Figure 2). These Lobster fisheries are effort controlled, with general restrictions on of the number of licenses, number of trap per license, Minimum Legal Size, and non-retention of berried females (Table 1).

Management measures for the Nova Scotia Lobster fishery have adapted over the last two decades primarily with increases to the Minimum Legal Size (MLS; Table 2). Currently all LFAs have a possession restriction on V-notched Lobster except areas 27 and 31a. Other measures include a maximum hoop size of 153mm in LFAs 28 and 29, maximum female carapace length of 135mm in LFA 30, closed carapace window of 114–124mm (carapace length) for LFA 31a, and v-notching and release of 110lb of mature females per license in LFAs 31b and 32 (Table 2).

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. These eggs are attached to the underside of the tail to form a clutch. These are then carried for another 10–12 months and hatch in 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 bottom seeking shelter. For their first few years of life, juvenile Lobster remain in or near their shelter to avoid predation, spending more time outside of the shelter as they grow (Lavalli and Lawton 1996). Nova Scotia Lobster 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 to moulting every 2 or 3 years for Lobster above 1.4 kg (Aiken and Waddy 1980).

Lobster mature at varying sizes depending upon local conditions (Aiken and Waddy 1980, Campbell and Robinson 1983, Comeau and Savoie 2002) with climatological factors such as temperature influencing the size at maturity. Generally, regions characterized by warmer summer temperatures have smaller sizes at maturity than regions with cooler summer temperatures such as the Bay of Fundy (Le Bris et al. 2017). Estimates of the size (carapace length) at 50% maturity (SoM) in the offshore areas varies regionally from 82 mm CL on the slope off New England and 92 mm CL for Georges Bank and Gulf of Maine (Little and Watson 2005), to approximately 93 mm CL for Northeast Georges and Browns Bank (Cook et al. 2017). In LFAs 27–33, the SoM has been estimated through several studies (reviewed in Tremblay and

Reeves 2004; Reeves et al. 2011), with the general consensus that SoM increases from east to west, with LFA 27 having a lower size at maturity than LFA 33. Decreases in size at maturity have been documented for many stocks and may be related to warming waters (Le Bris et al. 2017) and/or fisheries induced evolution as observed in other LFAs where Minimum Legal Sizes are smaller than the SoM (Haar et al. 2017).

In LFA 27–32 the MLS is above the SoM indicating a high proportion of the females caught have had the opportunity to breed prior to interception by the fishery. This is in contrast to LFA 33 and other inshore fisheries where the median size in the catch is below SoM and a small proportion of females have had the opportunity to breed. Between initial maturity and approximately 120mm female Lobster produce eggs every second year with a moult in intervening years. Based on laboratory studies using ambient inshore Bay of Fundy water temperatures, female Lobster 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 Lobster to spawn more frequently over the long term 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 Lobster have a much greater relative fecundity and are thus an important component to conservation. The Gulf of Maine, the management plan and past assessments have looked at maintaining the high reproductive potential in this area by preserving its size structure dominated by mature animals, which has been a key component of stock assessments (Pezzack and Duggan 1987, Pezzack and Duggan 1995).

DISTRIBUTION AND STOCK STRUCTURE

American Lobster (*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 Lobster 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 Lobster do not typically occur in commercial densities in the offshore.

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

Historic tagging studies suggest mature Lobster display seasonal movements into deep water (200–400 m) during the winter (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 27–33 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). That said self–seeding has been identified as an important source of juvenile Lobster in most LFA's (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. LFA 27 and LFA 33 were further subdivided into LFA 27 North and South and LFA 33 East and West for the estimation of some indicators as trends were not always coherent across these extremely large LFAs. The indicators generated from split LFAs were recombined to form a single LFA-wide indicator using methods appropriate to the indicator (details in specific indicator sections below).

PREDATORS

The predators of Lobster include Cunner, Sculpin, skates, cod, Spiny Dogfish, Sea Raven, wolfish, Haddock, hake, and crabs (Lavalli and Lawton 1996, Palma et al. 1998, Nelson et al. 2003, Hanson and Lanteigne 2000, Boudreau and Worm 2010, Steneck et al. 2011). Systematic sampling of groundfish food habits during the DFO Research Vessel (RV) survey on the Scotian Shelf has suggested that predation rates on Lobster is relatively low (36 stomachs containing Lobster of the 160580 stomachs examined between the 1960s and 2009—data sources reviewed by Cook and Bundy 2010). This likely does not reflect the predation pressure on Lobster larvae and juveniles and is more likely due to the timing and location of sampling as this survey is only conducted at depths greater than 50 m.

ENVIRONMENTAL IMPACTS

American Lobster utilize a variety of habitats from mud, cobble, bedrock, and eelgrass beds to depressions in the sand depending on the stage of their lifecycle or need for refuge (Lawton and Lavalli 1995). 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, providing 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 high risk of predation until they develop defense mechanisms as an adult (Lawton 1986). As adults the American Lobster require crevices in their habitat for moulting and mating but can utilize a broader range of habitat types than juveniles as their risk of predation is lower (Lawton and Lavalli 1995).

The primary environmental factor impacting American Lobster is temperature. Fluctuations in temperature affect all stages of the Lobster's lifecycle differently, influencing growth, reproduction, movement (McMahan et al. 2016 and Laufer et al. 2013). Bottom temperature is discussed below as an environmental parameter influencing the Lobster population and incorporated into the moult process model.

One 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 19–20ppt, and tend to avoid areas with a salinity of 21–22ppt

(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). As adults Lobster typically occupy areas where salinities are >25ppt, however, they can move to estuarine locations during seasonal movement to find optimal salinity and temperatures (Lawton and Lavalli 1995).

STOCK ASSESSMENT HISTORY

Lobster stocks in LFAs 27–33 have a long history of assessments which are conducted periodically through the Regional Assessment Process (RAP) and coordinated by the Canadian Science Advisory Secretariat (CSAS) (Table 3). 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 LFA 27–33 occurred in 2011. Prior to the 2011 document the LFAs 2733 stocks were assessed in four separate documents and three stock status reports. Recent stock status updates for LFAs 27–33 occurred in 2015 and 2016. Since the last framework document in 2011 and assessment in 2012, Science has provided advice on the development of reference points for inshore Lobster (Tremblay et al. 2012) and an overview of by-catch and discards in the Maritimes Region Lobster fishery (Pezzack et al. 2014).

The focus of the current framework was to continue the work of the previous stock assessment framework, include additional analysis and data to determine the best approach for providing an assessment of stock status given our available data streams.

DATA SOURCES

Most data sources used in this document are fishery dependent. Some localized fishery independent sampling does occur, however it does not cover significant proportions of the LFAs. 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 LFA 27–33, the consistency of the effort controls over the last 30–40 years (number of licenses, number of traps per license etc.) decreases some of the concerns over applying fishery dependent data to describe stock status.

The most up to date time series for some data sources are not used. Specifically, analyses using the Port, At-Sea and FSRS commercial sampling data do not contain the most recent years (2017, 2018). 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 rely on the most up to date data. The At-Sea sampling and FSRS recruitment traps projects have continued to present. Despite being discontinued, the Port sampling data was included in this framework as it provides some historical context in regions where no other biological sampling occurred. The most up to date information will be incorporated into the stock assessment following the framework.

LANDINGS AND EFFORT DATA

Mandatory logs

Landings data including historical records were summarized in Tremblay et al. (2011). The mandatory catch reporting system changed in 1995/1996 from a system based on dealer sales slips to one based on individual fishermen sending in monthly catch settlement reports. For all LFAs, the catch settlement report only provided information on daily catch by port landed and date of landing. Thus, landings data were reported by LFA, Statistical District or port landed. In November 1998, as part of their Lobster conservation plan, LFA 34 fishermen adopted an expanded catch settlement reporting system, called the Lobster Catch and Settlement Report which required them to provide information on daily catch and effort by reference to a grid system (e.g., Figure 3). Similar data were obtained in 2004 and 2005 during a pilot project in LFAs 27–32. Beginning in 2006 (2005-06 for LFA 33) a Lobster Catch and Settlement Report was introduced to all fishermen in LFAs 27–33.

Reported landings for LFA 28 are historically variable and low, ranging from 5–15mt from 1990 to 2001 (Tremblay and Reeves, 2004) and from 7–13mt in more recent years Validating the landings for LFA 28 prior to 1990 is not possible and we are most confident in landings since 1995.

As of 2002, Lobster landings were accessed from the MARFIS (Maritime Fishery Information System) database. Landings from the Gulf Region portion of LFA 27 were obtained from the Gulf Region Lobster group. Reporting levels were extensively examined in the last framework as mandatory logs came into effect (Tremblay et al. 2011).

From 2002 to present, landings reported by LFA were taken from the Slip portion of the MARFIS database. This represents the actual amount of Lobster 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. Landings from this portion are estimates. In most cases, the difference between the total Slip data and Log data are small. 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.

Inshore logbooks provided information on date, location (grid), effort, soak days and estimated catch. The logbooks also provide information on the fishery footprint expressed in terms of landings (Figure 3), effort (Figure 4), Catch Per Unit Effort (CPUE) (Figure 5), days fished (Figure 6) and licences (Figure 7) for each grid reported. From this information changes in fishing practices over time can be visualized, and incorporated in to analyses.

Voluntary logs

From 1981 to 2009, index fishermen kept fishing logs of daily catch and effort (number of trap hauls per day). Selection of participants was not random and was based on their willingness to contribute their information. It is assumed that annual fluctuations in the catch rates of voluntary logbooks reflect the fishery as a whole. The number of participating fishermen has varied within area and year, data becomes more reliable as there was increased participation after 1990 (Tremblay et al. 2011).

AT-SEA OBSERVATIONS AND BYCATCH

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 fishery (Table 4). Within each LFA sampling occurs from different groups. In LFA 27 the Cape Breton Fish Harvesters Association (formerly known as LFA27 Management Board), LFA 29, 31a and parts of LFA 31b are sampled by Guysborough County Inshore Fishermen's Association (GCIFA), and LFA 32 is sampled by the Fishermen and Scientists Research Society in association with the Eastern Shore Fisherman's Protection Association (ESFPA). The other 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. The locations of At-sea sampling for LFA 27–33 are shown in Figure 8 with carapace length frequency histograms shown in Figures 9–12 for LFAs 27, 31A, 31B and 32.

At-sea sampling data from the LFA 27–33 Lobster fishery reside in the Crustacean Research Information System (CRIS) database. In 2010, systematic collection of bycatch data began and the CRIS database was modified to allow entry of non-crustacean fish lengths. In addition, the sampling protocol was revised so that all species caught in the sample trap were measured. If a length measurement was not possible, for species such as urchins, whelks, starfish, their abundance was recorded.

Generic sampling protocols were typically used across all LFAs. In some cases, different sampling protocols were used and not all bycatch was assessed. Trips where less than 0.4% of the non-Lobster catch by weight was measured were removed from the bycatch analysis, assuming these represented trips where bycatch was not fully assessed (Table 5). Including trips with non-complete data would result in biased estimates of bycatch. Data that was documented in the remarks (counts of animals) was not used in this analysis. The measured bycatch data available allowed estimation of bycatch for LFAs 27, 31B and 32.

The estimated bycatch for each species was determined using the total number of sampled traps (N_s) and the total weight of each species (w_i) estimated from the numbers at length information for each by catch species and the length-to-weight conversion coefficients generated from the data collected during the DFO Summer Groundfish trawl survey. This was then prorated to the total for the fishery (B_i) using the total number of traps hauled during commercial fishing for that season (N_f) reported in the Lobster Catch and Settlement Reports.

$$B_i = \frac{N_f}{N_s} \cdot w_i$$

In LFA 27, effort is not available from the Gulf portion of the district. This effort was estimated using the Catch Per Unit Effort (CPUE) of Lobster for that season.

FSRS RECRUITMENT TRAP SURVEY

The Fishermen and Scientist Research Society (FSRS) is a partnership organization of fishermen and scientists concerned with long-term sustainability of marine fisheries in Atlantic Canada. They have been contracted by DFO to conduct a recruitment trap project involving fishermen participants who keep track of Lobster that are captured in project traps. Standard traps and size gauges are used to assign size groups to all Lobster captured. Participants of the project are located along the Atlantic coast of Nova Scotia with trap locations shown in Figure 13. The number of participants has varied through time, but as of 2015, 114 participants were active between LFA 27–33 (Table 6). Data recorded includes carapace size, sex, and presence of external eggs for all Lobster captured in standard traps every day during the commercial fishery. Soak times are typically one day except during the winter in LFA 33. The wire recruitment traps have modifications that lead to a higher retention of pre-recruit Lobster than the commercial traps, including a smaller mesh size (2.5cm), smaller entrance rings (12.5cm), and no slots (escape vents) to allow sublegal Lobster to escape. These modified traps provide a better indication of the abundance of pre-recruit Lobster than the commercial traps. The recruitment traps are the same throughout the study area to allow for standardized comparison between areas that may fish different designs of commercial traps, and traps are set in the same location throughout the season by fishers however, as commercial traps in some areas are moved substantial distances throughout the season, sometimes recruitment traps are also moved. 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 for 1996 to 2003 and 2003 to current day are provided in Table 7. Size groups 8 and 9 are in 5mm increments to give a clear indication of the number of Lobster just under the legal size limit. Carapace size frequencies from the FSRS recruitment traps are shown in Figures 14–20. Due to the changes in the size gauge in 2003, the trends in biological characteristics shown from the recruitment traps were only from 2004 onward.

FSRS COMMERCIAL SAMPLING

The FSRS commercial trap sampling project was initiated in 2004 within LFA 33 to collect information to characterize the Lobster captured within commercial traps. Unlike the recruitment trap project the trap design was variable with the fishing locations chosen by fishermen. Since 2004 there have been a variable number of participants in this project ranging from 31 in 2004 to 51 in 2006 (Table 8). The data collected included: carapace size measured by the FSRS gauge, sex, presence of eggs and v-notches as well as the location and depth of traps. The location of trap hauls was shown in Figure 21 indicating that most of the trap hauls have occurred in the nearshore region, similar to the recruitment traps.

PORT SAMPLING

Time series of Port samples were available from some LFAs. The length of the time series is variable and has not been continued in recent years in many LFAs. The process of Port sampling involves obtaining sex and carapace length from up to six crates of a fisherman's landed catch. In the past, samples were only allocated to Port location, however, since 2005, whenever possible the fishing grid was associated with the sample. A summary of the numbers of Port samples completed by year, number of weeks of the season sampled and LFA is available in Table 9.

BIOLOGICAL DATA ANALYSIS FOR DEVELOPMENT OF INDICATORS

The At-Sea, Port, FSRS Recruitment Trap and FSRS commercial trap sampling data sets all contain biological information that can be used to characterize the fishable and/or population structure. Each of these data sets varies in the length of time series and the types and quality of information they collect and therefore provide different snapshots of the Lobster stock.

At-Sea, FSRS Recruitment and FSRS Commercial samples provide information on the biological catch profile from a single trip and obtain information on more than the fishable component of the population as sublegal, berried and v-notched were available. Port samples will not contain the same level of stock information as regulations and conservation measures prohibit the retention of some categories of Lobster in some or all LFAs. Similarly the data collected from the At-Sea samples was more valuable in describing the size structure of the stock as the specific lengths are measured rather than the 5 or 10 mm bins used by the FSRS sampling programs.

Developing the within LFA (l) and fishing season (y) biological profiles (length frequencies, proportion of berried females, sex ratio, etc.) of the Lobster catch (S_{yl}) required the combining of the individual samples s_{ij} where i is the area sampled (grid number or Port where i=1:n areas sampled) and j was week of season (where j = 1: n weeks of the season). These samples were combined following a weighting scheme using the proportion (p_{ij}) of the within LFA annual landings L captured within area i and week of season j as:

$$S_{yl} = \sum_{i=1}^{n} s_{ij} \cdot p_{ij}$$

Where,

$$p_{ij} = \frac{L_{ij}}{L}$$

To assess the completeness of data sets, the Σp_{ij} with corresponding s_{ij} were estimated for each LFA and year combination. As many data sets were not complete (Σp_{ij} <1), a sensitivity analyses was conducted to explore the impact of the timing of sampling on estimated indicators. For the At-Sea data set, complete coverage was available in LFA 27 between 2011 and 2015 which offered the opportunity to examine the sensitivity of metrics to timing of sampling. Time series of indicators were estimated using only a subset of the full time series, specifically, indicators were estimated for weeks 1–3, weeks 4–6 and 7–9 to compare to the full data set. The same type of sensitivity analyses were conducted using the FSRS commercial data in LFA 33 from 2004–2016, by separating results into 4 week blocks from weeks 1–28 with which to compare to the complete data set.

TRENDS IN INDICATORS

Assessing whether trends in estimated indicators were statistically significant was done using Kendall's tau non-parametric test (Cotter 2009). This test evaluates whether a monotonic change in an indicator value was significant over time. There are more sophisticated methods for examining trends, however, due to the large number of LFA's and the large number of indicators examined, a simple trend analysis was considered sufficient to test for monotonic changes in the indicators over time.

BYCATCH RESULTS

There was much greater species diversity in the bycatch results in LFA 27 compared to LFA 31B or LFA 32, with 27 species recorded compared to 12 and 15, between 2011 and 2017 respectively. Within LFA 27, the bycatch species representing the largest bycatch weights in decreasing order were Shorthorn Sculpin, Atlantic Cod, Rock Crab, Cunner and Sea Raven (Table 10), with none representing more than 2% of the total landed weight of Lobster in any given year. In LFA 31B, the five bycatch species that represented the largest bycatch weights in decreasing order were, Atlantic cod, Rock Crab, Shorthorn Sculpin, Jonah Crab and Snow Crab with none representing more than 4% of the total landed Lobster weight in any given year (Table 11). In LFA 32, the five bycatch species that were the greatest contributors to the total weight of bycatch species in decreasing order were Jonah Crab, Rock Crab, Shorthorn Sculpin, Cod, and Longhorn Sculpin with none representing more than 6% of total landed weight in any given year (Table 12).

The effort proration adopted here to estimate the total weight of bycatch in the Lobster fishery is the preferred method. In other regions, bycatch were prorated by landed weight due to data deficiencies (Cook et al. 2017). Prorating bycatch by landings assumes the catch rate of bycatch species is directly proportional to the catch rate of the target species, which is likely not the case. It is integral to an effective bycatch project to obtain the length frequency and total abundance of the non-target species being captured. Given this information, accurate representations of the total weight of bycatch can be estimated.

BIOLOGICAL DATA SUMMARY

AT-SEA SAMPLES

Frequency and distribution of sampling has varied over the history of the LFA 27–33 fisheries. In recent years (since 2011) the amount of coverage, numbers of trips, number of weeks of the season and numbers of Lobster sampled has increased substantially in LFA 27, 31A, 31B, 32 and 33 (Table 4) owing to the increased activity of fishing associations in the data collections.

In LFA 27 the number of trips sampled has steadily increased since 2011 and currently 75–78 trips per year have been made, covering all 9 weeks of the season and all grids (Figure 22) and measuring in excess of 50,000 Lobster per year (Table 4). LFA 28 has data available from At-Sea samples collected in some years, specifically 1993, 2000 and 2001 (Table 4). During those years between 1 and 5 trips were made measuring between 113 and 130 Lobster. These samples represent less than 20% of the temporal and spatial coverage of the fishery (Figure 22).

LFA 29 has data available from 7 years of At-Sea samples between 1990 and 2015 with good spatial and temporal coverage in 2000 (Table 4, Figure 22). In each year where At-Sea samples were obtained between 273 and 1207 Lobster were sampled.

LFA 30 has a time series of At-Sea samples covering 13 years between 1990 and 2012. In most years, 2–4 At-Sea trips were made during a 1–2 week span measuring between 370 and 2400 Lobster. In 2000 and 2001, 20 trips were made throughout 8 weeks of the season measuring >4400 Lobster (Table 4; Figure 22).

At-Sea sampling in LFA 31A increased in 2008 from 2–8 trips per year to 12–25 trips per year since that time (Table 4; Figure 23). Good spatial and temporal coverage has been observed since 2008 (Figure 23) with between 6000 and 13600 Lobster measured annually. Similar to 31A, LFA 31B had a large increase in At-Sea sampling intensity in 2008 going from 2–5 trips per year to 14–59 trips per year (Table 4) representing 10000–36000 Lobster sampled annually. The spatial and temporal coverage is not as high as LFA 31A, largely due to not all areas being sampled in all years (Figure 23).

LFA 32 has consistently been At-Sea sampled between 2009 and 2013 with between 6 and 32 trips made annually (Table 4). The number of Lobster sampled during this period was between 1500 and 18000. The spatial and temporal coverage was greater than 50% in 2012, but has declined in recent years (Figure 23). In LFA 33 At-Sea sampling has been conducted in 11 years since 1985, with between 1 and 15 trips made annually with the exception of 2009 when 148 trips were made. The large amount of sampling in 2009 was part of the Species at Risk sampling program targeted to bycatch species, but also measured > 37000 Lobster (Figure 23; Table 4).

FSRS COMMERCIAL TRAP SAMPLING

The FSRS Commercial trap project was focussed on LFA 33, and provided seasonal coverage on a small number of traps per participant, but when combined by week and grid number provided a suitably large dataset for characterizing the temporal and spatial variability in the Lobster stock. Since 2004, between 18 and 27 of the 50 grids were sampled annually within LFA 33. The majority of samples were obtained from the inshore grids (Figure 21). Annually between 7000 and 18000 Lobster were sampled (Table 8). The spatial and temporal coverage of this trap project has declined since 2007 (Figure 23).

PORT SAMPLING

A long time series of Port samples were collected in LFA 27, 29, 31A, 31B, 32 and 33 (Table 9). Across the LFAs 16 to 20 years of Port samples were collected between 1985 and 2013 (Table 9). The number of samples and the numbers of Ports sampled vary considerably between years and regions. The overall temporal and spatial representativeness of the Port samples relative to the fishery was lower than the At-Sea sampling and the FSRS commercial sampling. This was due to the greater number of ports than grids available for partitioning the landings (Figures 22 and 23).

In LFA 27, between 4 and 56 samples were taken within a year, representing 1–11 Ports and 2–8 weeks. The spatial and temporal coverage of the Port samples relative to the fishery landings was relatively low (Figure 22). In LFA 29, between 2 and 62 samples were taken within a single year. The spatial and temporal coverage relative to the fishery distribution was relatively low (<0.2) throughout the time series (Figure 22).

In LFA 31A, between 2 and 9 samples were collected annually, covering 1 to 4 Ports and 1 to 4 weeks of the fishing season. Similarly in LFA 31B 2–4 samples were collected within a year representing 1–4 weeks in a single Port (Figure 23). In LFA 32 between 2 and 7 samples were taken within a year which represented 1 or 2 Ports and relatively few weeks throughout the season. The overall spatial and temporal sampling relative to the fishery was low in all years (Figure 23).

In LFA 33 between 2 and 16 samples were taken within a year which represented 1–7 Ports and relatively few weeks throughout the season. The overall spatial and temporal sampling relative to the fishery was low in all years (Figure 23).

FSRS RECRUITMENT TRAP SAMPLING

The recruitment traps have had consistent seasonal and spatial coverage throughout the duration of the project, although only results from 2004–2015 are shown here. LFA 27 has had good coverage with at least 9 weeks of sampling covering 9–13 grids and >11000 Lobster sampled annually. In the last several years, however, the proportion of total landings accounted for by recruitment traps has decreased (Table 6; Figure 22).

The coverage in LFA 28 has been low, with 1–2 participants and in recent years, there have been no participation from this LFA. LFA 29 has had good coverage throughout the time period, with most weeks being sampled and 2 or 3 grids being consistently covered annually (Table 6; Figure 22). LFAs 30, 31A, 31B and 32 have had a consistent level of sampling from the recruitment trap project and remains a good source of biological information within these LFA (Table 6; Figure 22, 23).

Coverage in LFA 33 has decreased in recent years, but this data source remains one of the primary sources of information for this LFA (Figure 23).

OVERALL BIOLOGICAL DATA

Each LFA has had some level of At-Sea sampling, Port sampling and / or FSRS recruitment trap sampling. LFA 33 has had the additional commercial trap sampling following similar protocols to the FSRS recruitment traps, albeit with non-standardized trap types. The time series of At-Sea sampling in LFA 27, 31A, 31B and 32 provide a good source of information on biological details of the Lobster captured in the traps in recent years, however, the historic data has been sparse in many LFAs. The most current, consistent and longest time series of data available for biological samples across all LFAs remains the FSRS recruitment traps and despite concerns over the ability of the traps to capture large Lobster, or accurately reflect catches in commercial traps it is considered a valuable data source.

STOCK STATUS INDICATORS

In the following section time series of stock status indicators will be either developed or updated. Each indicator will be presented separately with the justification for inclusion, the data included and analyses used in estimating the indicator as well as the trends for each of the applicable data sources. The sensitivity of each indicator to the timing of sampling (i.e., week of season) was explored. Within each section, there will be limited discussion of results as many of the stock status indicators are linked to similar fishery and population processes and will therefore be discussed in the section on **Combining Indicators**.

Some indicators developed here are directly linked to stock health and status (i.e., numbers landed), whereas others describe the characteristics of the population captured by the fishery (i.e., median size and sex ratio), or ecosystem considerations (i.e., temperature). These indicators provide a snapshot of the Lobster stock and are largely derived from fishery dependent data.

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 section, primary, secondary and contextual. The primary indicators will be used to define stock status and reference points will be developed later in the document. 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 status updates; however will only be displayed as part of a multivariate analysis to show the overall patterns over time. The indicators in each category will be identified in the **Overall Discussion of Indicators Section.**

BIOLOGICAL INDICATORS

Median and Maximum Size

Broad size distribution provides an indication of the stability of populations (Berkley et al. 2004). In populations that are heavily fished, size distributions skew toward smaller individuals as the increased total mortality (natural + fishing) decreases the probability of reaching old ages / large body sizes. Size distributions skewed toward small (or large) individuals may occur for a variety of reasons including the loss of large individuals or an increase in the abundance of small individuals. Using carapace length frequency distributions from samples collected during or from fishing operations the changes in the median and maximum were documented. The maximum of the size distribution was used to track changes in the large animals.

Data and Methods

The length frequencies of the At-Sea, Port and FSRS recruitment trap and FSRS commercial samples were described above. The median sizes of all samples were calculated from the landings weighted length frequencies. The maximum length indicator was estimated as the upper 95th quantile of landings weighted length frequency distributions. This metric was chosen over the absolute maximum length as it is less sensitive to sample sizes and the occasional capture of large Lobster. Medians were chosen as they are a more robust measure of central tendency than the mean. The median size from the FSRS size gauge data was shown in Figures as the center of the median size class.

Results

Across all LFAs, median size from the Port samples was consistently higher than the At-Sea samples and FSRS recruitment trap samples (Figure 24). This was due to Port samples reflecting the landed catch, where all Lobster measured were above respective MLS. As expected, FSRS recruitment trap samples had the smallest median size across all LFAs and time blocks, due to the lack of escape vents in the traps and the retention of small Lobster (Figure 24).

Across all LFAs, LFA 27 had the smallest median-sized Lobster with an overall median of 77 mm from the At-Sea samples (Figure 25, 26). The extreme high boxplot for LFA 28 At-Sea samples represents few samples and likely does not reflect an anomalously large bodied component of the Lobster stock in the region (Figure 25). LFA 29–32 have similar median-sized Lobster with medians from At-Sea samples of 84–87mm (Figure 25, 26). LFA 33 was intermediate to LFA 27 and 29–32 with a median from At-Sea samples of 81 mm (Figure 26). Within LFA 33, the median size of Lobster from the FSRS commercial samples was larger than the FSRS recruitment traps.

Median sizes were sensitive to the timing of sampling as can be seen in Figure 27, although differences were marginal. Median sizes at the start of the season were typically larger (82 mm) than mid (81mm) and end (80mm) of season sizes. The mid-season samples were most similar to full season medians. Similar patterns were observed when examining the sensitivity of sampling dates using the FSRS commercial samples, where the largest median-sized Lobster were observed in the first week of the season (Figure 28). Due to this sensitivity of timing of samples, the within LFA time series plots represented the mid-season samples for At-Sea and Port data sets (weeks 3–6 for LFA 27–32 and weeks 5 to 24 for LFA 33).

In most of the LFAs, there were few obvious changes in the median size of Lobster throughout the time series (Figure 29, 30). One exception was in LFA 27 (Figure 29), where the median size of Lobster has been steadily increasing since the mid-1990's (At-Sea Kendall's tau–0.69; p-value<0.0001) when incremental changes in the Minimum Legal Sizes were initiated (Table 2).

Among the LFAs maximum sizes were more similar across data sets than median sizes (Figure 31); however, the same pattern prevails, with Port samples being marginally larger than At-Sea and FSRS recruitment trap samples being the smallest. Due to the size bins within the FSRS data, maximum size could not be defined in all data sets as the largest size bin represent all Lobster greater than 131mm carapace length (Table 7).

Across all LFAs, LFA 27 had the smallest maximum-sized Lobster with an overall median of 100 mm from the At-Sea samples (Figure 32). Similar to median sizes in LFA 28, the extreme high boxplot for At-Sea samples represents few samples (Figure 32). LFA 29–32 have similar maximum-sized Lobster with medians from At-Sea samples of 114–121 mm. LFA 33 was intermediate to LFA 27 and 29–32 with a median from At-Sea samples of 112 mm (Figure 32, 33). The distribution of maximum sizes within the FSRS commercial samples was broader than those of the FSRS recruitment trap. Further, the median of the maximum sizes from the FSRS recruitment traps was lower than the FSRS commercial traps.

Maximum sizes were sensitive to the timing of sampling, such that early season maximum sizes with a median of 105 mm were smaller than mid- and late- season body sizes, with medians of 108 and 112 mm respectively (Figure 34). Similar to the median sizes, the mid-season maximum size were most similar to the full season maximum body sizes (108 mm). From the FSRS commercial traps in LFA 33, maximum size was larger at the start and end of season, than in the middle of the season (Figure 35), which may reflect inshore – offshore movement patterns of Lobster during the winter months as has been noted elsewhere (e.g., Tremblay et al. 1998). The broad size bins used during the FSRS sampling makes discerning small differences in size distributions difficult. Time series of maximum sizes from At-Sea and Port data sets were limited to the mid-season samples to remove the variability associated with the timing of sampling.

There was an indication of decreasing maximum size from the time series of results from LFA 30, 31A and 32, such that recent years maximum sizes were 5–10mm smaller than those observed in the late 1990's early 2000s (Figure 36, 37). Only those for LFA 31A were statistically significant (At-Sea Kendall's tau = -0.47; p-value<0.05). Maximum size has conversely been increasing in LFA 27 (At-Sea Kendall's tau -0.4; p-value < 0.01), presumably due to the increases in MLS, reducing the overall pressure on the Lobster stock and allowing a larger escapement of Lobster.

Overall, median and maximum carapace lengths have not shown dramatic shifts over time, with the exception of LFA 27, where increasing the MLS has had an impact on the size structure of the Lobster in the area.

Proportion of New Recruits

An indicator of the reliance of the fishery on newly recruited Lobster provides information on the size structure of the population, and its sensitivity to recruitment pulses was used in the previous framework (Tremblay et al. 2011). This indicator reflects the proportion newly recruited Lobster found in total landings using size frequency data. Based on growth rate studies the carapace length increases between 10–15 % per moult depending upon sex and maturity stage. Based on this criteria Lobster in the range of MLS to MLS + 11 mm were considered newly recruited animals (Tremblay et al. 2011). Fisheries that are more reliant on newly recruited animals will be more susceptible to changes in recruitment, with reduced potential to maintain high catch rates following several years of reduced recruitment.

Methods

The proportion of new recruits (p_r) in the fishery was determined using the carapace length frequency information from the At-Sea, Port and FSRS commercial trap samples. This indicator was estimated as:

$$p_r = \frac{\sum_{o=m}^{m+11} N_o}{\sum_{o=m}^{t} N_o}$$

where o represents each length category, t the largest size category , N_o the numbers at length, and m the MLS. This indicator was not estimated for the FSRS recruitment time series, as the ventless traps may not accurately reflect the ratios in the landings data, due to the decrease in catch rates of large Lobster.

Results

Data sources representing the portion of new recruits in the landings composition were similar for both the At-Sea and Port samples (Figure 38), with slight differences within LFAs. LFA 30 At-Sea samples had a higher proportion of recruits than the Port samples which was likely due to the short time series of Port samples relative to the At-Sea samples (Figure 39, 40). In LFA 33, the higher proportion of recruits from the Port sampled data likely represent more consistent Port sampling as seen in the time series plot. Overall, LFA 27 and LFA 33 had higher reliance on newly recruited Lobster than any of the remaining LFAs with proportions from At-Sea sampling of 0.74 and 0.66 respectively (Figure 39, 40). The FSRS commercial samples in

LFA 33 showed substantially lower reliance on newly recruited Lobster, which was largely due to the size binning of the data which restricted the comparability with the other data sets.

The sensitivity analysis on the effect of timing of sampling on the indicator trends suggested that sampling early in the season resulted in higher proportion of new recruits, relative to mid or late season sampling (Figure 41, 42). Moreover, the mid-season sampling was most similar to the full season sampling, and as such the At-Sea and Port samples were filtered to mid-season for examining time trends.

The time series' of proportion of newly recruited Lobster has increased over the time series in LFA 27 (At-Sea Kendall's tau =0.34' p-value<0.05), whereas other LFAs suggested limited changes over time (Figures 43, 44). In LFA 27, the increasing MLS in recent years, likely resulted in the increased prevalence of newly recruited Lobster in the landings.

Proportion of Mature Lobster in Landings

This indicator represents the proportion of mature Lobster in the catch and is an indication of the resilience of the population. Stocks that are able to spawn (or have matured) prior to capture have a decreased likelihood of recruitment and growth overfishing, and are therefore more resilient to fishing pressure and environmental perturbations (Myers and Mertz 1998). This indicator relies on size frequency data, maturity ogives and MLS.

Methods

The annual and LFA specific estimates were developed using, the *a* and *b* from LFA specific length based maturity ogives (see accompanying document on simulation modelling for further details) to define the probability of mating at carapace length (pM_o) and the total numbers at length (N_o) from the size frequency data to define a weighted proportion mature (pM_w) as:

$$pM_w = \frac{\sum_{o=m}^{y}(pM_o \cdot N_o)}{\sum_{o=m}^{y}(N_o)}$$

where,

$$pM_o = \frac{1}{1 + e^{a+b\cdot o}}$$

and *m* represents the MLS and *y* the maximum size. Only the At-Sea and Port samples were included in this analysis.

Results

At-Sea and Port samples provide similar overall results in terms of the weighted proportion of mature Lobster in the catch (Figure 45). LFA 27, 28, 29, 30 and 31A all maintain a proportion mature in the range of 0.8 to 0.94 (Figure 46, 47). From east to west, LFA 31B, 32 and 33 have decreased proportion mature in the catch, with LFA 33 being the lowest across this group of LFAs with an overall median of 0.3 from At-Sea samples and 0.22 from Port samples (Figure 47). This indicator was not dependent on the timing of collection of samples (Figure 48). As such, the complete data sets were used in the time series examination.

Within LFA 27 there has been a steady increase in the proportion of mature Lobster in the catch (At-Sea Kendall's tau = 0.89; p-value<0.0001), which can be largely attributed to the increase in Minimum Legal Sizes (Table 2; Figure 49). A similar increase can been seen in LFA 31A, with the proportion of mature Lobster increased with the increases in MLS between 1997 and 2006 from 81 to 86 mm which subsequently decreased to 82.5 mm in 2007 (Figure 50). Changes in the Minimum Legal Sizes in other LFA's have occurred, however, their impact were not readily discernable from these analyses.

Overall, the reliance of immature Lobster was much higher in LFA 33 than other the LFAs examined here. This suggests reduced resilience in LFA 33 to environmental or anthropogenic changes. The large abundance of suitable habitat and abundance of Lobster within and adjacent to LFA 33 (LFA 34 and LFA 40 / 41 Cook et al. 2017) may offer some buffering capacity to this LFA. Reliance on up to date maturity ogives is integral to the estimation of this indicator. Data exists for performing this analysis for some LFAs; however it has not been fully explored.

Sex Ratio

The natural sex ratio of unfished Lobster populations is unknown, but presumed to be 1:1 as there is limited evidence of differential mortality in Lobster. Sex ratios, in fished populations are presumed to be skewed toward females as they are protected from fishing mortality when egg bearing, or v-notched. The implications of a highly skewed sex ratio are not known, however, as males are able to mate with a large number of females each year and females are able to carry sperm to fertilize eggs for more than 1 year prior to releasing eggs (Aiken and Waddy 1980), skewed sex ratio population may not be detrimental to the population's health.

Data and Methods

Sex ratios (S_f) were expressed as proportion females across all size classes (o=1,2,3….,y) as:

$$S_f = \frac{\sum_{o=1}^{y} N_o^f}{\sum_{o=1}^{y}\left(N_o^f + N_o^m\right)}$$

where No represent numbers at length o for males (m) and females (f). At-Sea, Port, FSRS recruitment and FSRS commercial samples were each used for estimation of this indicator.

Results

At-Sea and Port samples both had median sex ratios of 0.5, whereas the FSRS recruitment trap samples had a sex ratio skewed toward males with a proportion female of 0.44 (Figure 51).

Variations in sex ratio were greater between data sources with LFAs, than across LFAs (Figure 52, 53). LFA 33 was the exception with similar sex ratios below 0.5 for each data set with values between 0.45 and 0.48. Additionally, sex ratios varied little over the course of the season as can be seen through the sensitivity analyses in Figures 54 and 55 for LFA 27 At-Sea and FSRS commercial samples respectively. Time series trends within LFAs were therefore examined using the full date ranges.

No statistically significant time trends were evident for the sex ratios from any of the LFAs. The value of including this indicator for stock status trends is minimal at present, as patterns are similar across time and space. This indicator will not be included in further analyses.

Reproductive Potential

Reproductive potential is an important stock status indicator. In order for population sizes to be maintained or increase the production of new eggs and recruits must be greater than or equal to the losses from fishing and natural mortality. Efforts directed toward increasing MLS and other conservation measures (v-notching, windows) have largely been directed at increasing reproductive potential through the protection of large, reproductively viable individuals (Tremblay et al. 2011). Maintaining high levels of reproductive potential in stocks is important not only to specific LFAs, but also to the broader regional Lobster production (Quinn 2014). Two indicators of reproductive potential were estimated, the first being the observed proportion of berried females in the biological samples and the second being an indirect estimate of egg production based on the numbers of females at size, the size at maturity and fecundity at size.

Direct evidence of changes in the proportion of berried (egg-bearing) females from the biological samples would be important to note as these individuals are protected in all LFAs. Increases in the proportion of berried females suggest higher egg production and an increased reproductive potential. Only At-Sea and FSRS samples were used to estimate the proportion of berried females, as Port samples do not contain berried females.

The indirect estimate of reproductive potential, as estimated here, provide an integrated index combining female abundance at size (from biological samples), fecundity at size and size at maturity thereby producing an estimate of total eggs produced within the LFA. This metric can also be viewed as a surrogate for spawning stock biomass (SSB) which is often used in other species as one of the main indicators of stock status (Hilborn and Walters 1992).

It is important to note that the indirect reproductive potential presented here is an idealized reproductive potential rather than a realized reproductive potential, as the fecundity at size was assumed static. This metric ignores the reproductive failure and variable clutch size which have been characterized for some stocks and areas (Koopman et al. 2015), but their occurrence in LFA 27–33 have not been systematically evaluated.

Methods

Berried females (S_b) were expressed as a proportion of total Lobster across all size classes (o=1,2,3….,y) as:

$$S_b = \frac{\sum_{o=1}^{y} N_o^b}{\sum_{o=1}^{y}\left(N_o^b + N_o^{nb}\right)}$$

where N_o represent numbers at length *o* for berried (*b*) and non-berried (*nb*, male + female) Lobster. At-Sea, FSRS recruitment and FSRS commercial samples were each used for estimation of this indicator.

The integrative measure of reproductive potential used LFA specific length based maturity ogives (defined below in simulation model section in accompanying document) to describe the probability of mating at carapace length (pM_o), the total numbers of females at length (N_o^f) from the size frequency data and fecundity at length (F_o) relationship to develop an annual egg production (R) estimate as:

$$R = \sum_{o=1}^{y}\left(pM_o \cdot N_o^f \cdot F_o\right)$$

where,

$$pM_o = \frac{1}{1 + e^{a+b\cdot o}}$$

$$and$$

$$F_o = z \cdot o^x$$

Only At-Sea and Port sampled data were included in the indirect reproductive potential indicator due to the size bins used in the FSRS data collections.

Results

At-Sea and FSRS recruitment trap samples had very similar distributions of the proportion of berried females (Figure 58). LFAs 27, 29, 30, and 31A each had overall estimates of the proportion of berried females between 0.1 and 0.13 (Figure 59, 60). LFA 31A and 32 were slightly lower with medians of 0.08 and 0.05. LFA 28 had the highest overall median proportion berried females of 0.3, but only limited sampling has occurred in this LFA. LFA 33 had the lowest proportion of berried females with a median of 0.016 (Figure 60) which was likely due to the seasonal differences in the fishery timing with LFA 33 beginning in November and continuing until the end of May.

There was considerable sensitivity in the timing of samples for estimating the proportion of berried females, such that early season proportions were lower than mid or late season samples in both LFA 27 and LFA 33 (Figure 61 and 62). The increased proportion of berried females in LFA 27 was likely due to the release of new eggs which will hatch in the following spring / summer as the fishery in this area continues until July. In LFA 33, the increased proportion of berried females in May was likely due to the inshore migration of berried females as has been observed elsewhere (e.g., Tremblay et al. 1998). Due to these seasonal differences, the At-Sea data set were filtered to mid-season samples to ensure consistency in the time series.

Across many of the LFAs there have been increases in the proportion of berried females since the early 2000's which likely correspond to the conservation measures implemented. In LFA 27 the proportion of berried females increased in recent years with the increase in MLS (At-Sea Kendall's tau = 0.45; $p<0.001$; Figure 63, Table 2). LFA 30, the proportion of berried females in the FSRS recruitment trap samples has increased since 2004 presumably associated with the release of females >135 mm (Kendall's tau = 0.78; p-value <0.0001; Figure 63). Increases in both LFA 31A and 31B were also noted, however, only trends in LFA 31A were statistically significant (FSRS recruitment Kendall's tau = 0.76; p-value <0.0001; Figure 64).

The reproductive potential indicator was higher for the At-Sea compared to Port samples (Figure 65). LFA 27 had substantially higher reproductive potential than any other LFA due to its small size at maturity (SoM 50% 73 mm) and relatively high abundance (Figure 66). LFA 33 had the second largest overall estimate of reproductive potential, which was due to the high abundance in this LFA, as size at maturity was substantially larger (SoM 50% 96 mm) than other LFAs examined here (Figure 67). The reproductive potential indicator was not affected by the timing of sampling using the At-Sea collected data from LFA 27 (Figure 68), and as such the full time series of samples were used for examining time trends.

Similar to the proportion of berried females, increases in the time trends of reproductive potential were evident across most LFAs. Since the late 1990s to early 2000's each of LFA 27, 29, 30, 31A, 31B and 32 have had statistically significant increases in reproductive potential with all p-values < 0.01 (Figure 69, 70). LFA 33 did not show significant change in the level of reproductive potential from the information used here.

Bottom Temperature

Temperature is among the most impactful environmental parameter on American Lobster (McMahan et al. 2016) affecting their growth, reproduction, metabolic rate and survival (Laufer et al. 2013) as well as indirectly impacting the population through the spread of disease that impacts survival (Aiken and Waddy 1986). Lobster possess a temperature tolerance of -1°C to 30.5°C, and can survive rapid temperature increases of 16°C and decreases of 20°C (Lawton and Lavalli 1995). They furthermore detect minute changes to temperature resulting in behavioural thermoregulation (Jury et al. 2013) and movement along temperature and salinity gradients (Chang et al. 2010).

Every stage of the Lobster life cycle is affected differently by changes in temperature. Egg bearing females demonstrate seasonal migrations from the inshore to offshores areas to optimize the temperature for egg incubation thereby controlling egg development rates

(McMahan et al. 2016). Summer temperatures decreases can result delayed or even suspended spawning (Waddy and Aiken 2005). In larvae and juveniles, cold temperatures can inhibit development and settlement to the bottom (Wahle and Steneck 1991). As a newly settled juvenile, Lobster are restricted by their need for shelter and stay nearshore. When temperatures drop below the minimum for moulting, growth is impacted (McMahan et al. 2016).

In regions of the Gulf of Maine, which have experience increasing water temperatures over the past 20 years, growth rates have accelerated with Lobster reaching harvestable sizes at a presumed younger age (McMahan et al. 2016). In colder regions Lobster moult frequency is lower, but drops in temperature seasonally can also result in decreased moult frequency (McMahan et al. 2016). In some cases smaller Lobster in warmer regions are also moulting early enough in the season for both moulting and spawning to occur in the same year, rather than the typical annual delay between events (Waddy and Aiken 2005). When temperature increases occur over extended periods bacterial shell disease becomes a major risk to Lobster populations. Heightened seawater temperatures foster the growth and persistence of the bacteria in the environment and on Lobster shells (Laufer et al. 2013). These increased temperatures impact the growth and length of intermoult of Lobster and the duration of their exposure to disease causing agents (Glenn and Pugh 2006).

Methods

The temperature indicator included here comes from FSRS recruitment trap project which represents the longest time series of bottom temperature data available for this inshore region where the Lobster fishery occurs. The data is collected throughout the fishing season, and are therefore not directly comparable across LFAs.

Results

Despite time series not being directly comparable across LFAs, signals of broad scale temperature anomalies can be seen (Figure 71, 72). Specifically, the cold spring (fishing season) in 2015 was evident in all LFAs, but was most prevalent in LFA 29, 30, 31A, 31B, and 32 (Figure 71, 72). By comparison a more localized cold spring in 2003 was more evident in LFA 29 and 30. The warm 2012 year, which was reported to have caused regional changes in species distribution and abundance in snow crab (Zisserson and Cook 2017), was evident as a warm spring in LFA 29, 30, 31A, 31B, and 32.

Fishing Effort

Fishing effort can be used as a proxy for fishing pressure. It is an important contextual indicator for fisheries performance as increases in landings maybe due to increases in commercial-sized biomass or increased fishing effort or both. Fishing effort, number of trap hauls, in the Lobster fishery is controlled by season length, trap limits and limited number of fishing licenses. Consequently there is, in essence, a maximum fishing effort which can be deployed. This maximum is never met as factors such as weather conditions, seasonally variable catch rates, fishing partnerships all limit the total number of trap hauls.

Methods

The time series of total fishing effort is limited to the mandatory logbook records, 2005–present. The level of reporting from these mandatory logs books was variable prior to that time. Due to inconsistencies in effort reporting the effort indicator presented here represents the estimated Catch Per Unit Effort (CPUE) from the filtered logbook data multiplied by the slip reported landings by LFA.

Results

Effort has varied across LFAs with some coherency across the available time series. Specifically, effort levels were among the lowest on record in 2011 and 2013 for all LFAs except LFA 30 where effort was lower in 2010 and 2014. Similarly effort was among the highest levels in 2012 for LFAs 27, 29, 30, 31A, 31B and 33 (Figure 73, 74).

EXPLOITATION INDICATORS

Estimating removals from a population due to harvesting is a key parameter in assessing stocks. Total removals in absolute weight (i.e., landings) is one measure of removals, however, it is more relevant to population processes to describe the removals (*C*) relative to the total biomass (*B*) or other measure of stock biomass. Traditionally, these relative removals are described as either exploitation rate (*u*) $u = C/B$ or instantaneous fishing mortality (*F*). In typical quantitative stock assessment models, *F* is one of the key parameters and represents the instantaneous mortality due to harvesting and are a component of the losses in abundance of a cohort (*N*) over time (t) along with natural mortality (*M*).

$$N_{t+1} = N_t e^{-(F+M)}$$

Barring a full quantitative stock assessment model, simple cohort analysis (CA), relying solely on the interannual changes in the relative abundance of size classes in the landings can be used to get an approximate measure of *F*. Similarly, changes in relative abundance of exploitable (fishable component) and non-fishable (undersized or non-retained) within a fishing season can be used to approximate exploitation rates. The latter method is often called change-in-ratio (CIR; Paulik and Robson 1969). Both measures CA and CIR will be explored in this stock assessment framework.

Length based Cohort Analysis (CA)

Length based cohort analysis (CA; Jones 1981) has been used in a number of fisheries to estimate abundance and exploitation rates from size distribution of landings. This method is based on a simple age-based cohort analysis (Pope 1972), where end of year abundance (N_{t+1}) can be estimated by the starting year abundance, natural mortality, and landings (*C*) as:

$$N_{t+1} = (N_t e^{-0.5M} - C_t)e^{-0.5M}$$

Where M is split into pre-fishing and post fishing periods and landings are assumed to occur at mid-year. Using a sequence of cohort abundance at age, estimates of *F* can be obtained. As is typical in sequential population analysis, abundances at earlier ages can be recreated by starting with the oldest ages and working toward the youngest ages as:

$$N_t = (N_{t+1} e^{M} + C_t e^{-0.5M})$$

Jones (1981) modified the cohort analysis by incorporating a variable time-step Δt, rather than forcing annual sequences, which allowed the use landings at length to estimate catch at a sequence of time intervals, and estimated the Δt using von Bertalanffy growth parameters.

$$N_t = \left(N_{t+\Delta t} e^{M\Delta t} + C_t e^{-0.5M\Delta t}\right)$$

Further work by Cadrin and Estrella (1996) incorporated the specification of timing of landings (T_c), such that M can be more accurately partitioned through the Δt, yielding:

$$N_t = \left(N_{t+\Delta t} e^{T_c M\Delta t} + C_t e^{-(1-T_c)M\Delta t}\right)$$

The CA framework described relies on an annual length frequency, rather than tracking cohorts over time as is the basis for virtual population analysis (VPA) or statistical catch at length. CA therefore has a number of assumptions, including stationarity in each of recruitment, size frequencies, natural mortality, growth, and gear selectivity. Lobster populations, as have been shown in many species, do not conform to these assumptions; however, performing analysis on spatially discrete areas (such as LFAs) and combining data across multiple years can reduce the biases associated with invalidating some of the assumptions (Cadrin and Estrella 1996). Still, estimates of fishing mortality or exploitation derived from CA should be viewed as indices rather than absolute levels.

Methods

At-Sea, Port and FSRS commercial trap samples were used to generate the size composition of annual landings within LFAs. From each data source the weighted length frequencies were combined with the landings data to estimate the total numbers landed at length (N_o) as:

$$N_o = \frac{L \cdot p_o}{w_o}$$

Where p_o, or the proportion of total sample weight represented by each length group *o*, was estimated using the length frequency information the sampled numbers at length n_o and weight at length w_o

$$p_o = \frac{n_o \cdot w_o}{\sum_{o=1}^{m} n_o \cdot w_o}$$

$$where,$$
$$w_o = a \cdot {l_o}^b$$

The At-Sea and Port samples carapace sizes were grouped into 5mm bins. For the FSRS data, the aforementioned size bins were used to define the groups. Samples from each data set were prorated to the total seasonal landings within each LFA based on the proportion of landings represented by each regional (grid or Port) and week of the fishing season.

Cohort analyses were conducted on annual abundance at size as well as the abundance at size accumulated over three year period to reduce the impacts of interannual variation. Within LFAs estimates of *Δt* at length were obtained from the population simulation model (see simulation model described in the Biological Guidance of Harvest Control Rules) to account for area specific moult probabilities and growth increments. These *Δt* estimates were chosen over the use of von Bertalanffy growth parameters which are typically poorly defined for Lobster stocks, due to the absence of reliable size at age information. *F* on the oldest ages was set to 0.2, as sensitivity analyses showed ranges between 0.1 and 2 had no significant effect on estimates of exploitation (Figure 75). Natural mortality estimates for Lobster typically vary between 0.1 and 0.2 (Fogarty and Idoine 1989), here 0.15 was chosen as sensitivity analyses showed a linear relationship between *M* and exploitation (Figure 75) and CA exploitation estimates were treated as an index rather than absolute.

The time of catch, *Tc*, was the period in the year when the catch is taken with the year beginning in August following the moult. For LFA 27–32 *Tc* was set to 0.8 and LFA 33 *Tc* was set to 0.4. Slight variations around *Tc* did not significantly affect estimated of exploitation (results not shown).

Results

Exploitation indices were estimated for 95 Year x LFA combinations with annual estimates ranging from 0.11 to 0.69. Using the three year combined length composition within LFA the range across all LFAs and time blocks was 0.10 to 0.64. Within LFAs, annual estimates of exploitation were more variable than the three year combined (Figure 76, 77); hence the remainder of the discussion will be of the three year combined estimates, unless otherwise noted. The decreased variability in the combined length frequencies was largely due to dampening the impacts of strong cohort signals in the annual estimates rather than increasing sample sizes.

From lowest to highest, the ranking of overall mean exploitation indices across LFAs were, LFA 30, LFA 29, LFA 31A, LFA 31B, LFA 32, LFA 33 and LFA 27 (Figure 78)

From the Port samples exploitation indices were estimated for 34 Year x LFA combinations with annual estimates ranging from 0.12 to 0.67. Data were not available for all LFAs. By using the three year combined length compositions the range across all LFAs and time blocks was 0.15 to 0.64 (Figure 79 - 80). From lowest to highest, the ranking of overall mean exploitation rates across LFAs were, LFA 33, LFA 27, LFA 32, and LFA 29 (Figure 81).

Exploitation indices were estimated for 13 years of FSRS commercial sampling in LFA 33 with a range of 0.53 to 0.66 (Figure 82). By combining data across time periods, the variability of exploitation estimates decreased and the range was reduced to 0.54 to 0.62.

In LFA 27, using the At-Sea collected data, 20 estimates of exploitation were made, with the highest estimate in the 2007–2010 time block at 0.64, which has been steadily decreasing to the lowest exploitation in current years of 0.45 (Figure 83). There was evidence on decreased exploitation in years following the increase in Minimum Legal Sizes (MLS). Specifically, the increases in MLS between 1998 and 2002 yielded moderate decreases in exploitation. The recent decreases in exploitation correspond to increases in MLS from 76 mm to 82.5mm (Table 2).

Only sparse At-Sea sampling information was available for LFA 29, however Port sampling suggested a decrease in exploitation up to 2000 with a decrease thereafter (Figure 83).

Within LFA 30, eight three year combined estimates of exploitation ranging from 0.11 to 0.32 were made. Exploitation increased from 0.10 in 1999–2001 to 0.27 in 2005–2008 (Figure 76).

Both LFA 31A, 31B had the highest exploitation values of 0.43 in the 2009 to 2011 time block (Figure 77). In recent years exploitation has subsequently declined in both areas with estimates of 0.37 and 0.40 for LFA 31A and LFA 31B respectively.

LFA 32 had the highest levels of exploitation in the 2011–2013 time block at 0.44 with moderate reductions in recent years to 0.42 for the 2013–2015 period from the At-Sea sampling (Figure 80, 83).

Estimates of exploitation in LFA 33 have been variable, largely owing to the large spatial extent of the LFA and the relatively few At-Sea samples in most years. The FSRS commercial trap samples, however provided a much richer data source to explore the cohort analysis (Figures 82 and 83).

Applying the same sensitivity analysis to the cohort analysis that was applied to the other indicators suggested that the within season sampling period influenced estimates of exploitation (Figure 84). Specifically, early season samples (weeks 1–3) were higher than mid or late season samples, due to the changes in size distribution of the Lobster as shown in the median and maximum size indicators above.

The short or variable-length time series of At-Sea or Port sampling data, the sensitivity to timing of samples and the assumption of constant recruitment limit the usefulness of this indicator as an index of exploitation.

Continuous Change in Ratio (CCIR)

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 method (CCIR), 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. And 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 can be largely satisfied as the as there is little opportunity for large scale movements in the relatively short seasons (~9 weeks) in LFA 27–32 and previous tagging studies have suggested minimal movement between LFA's within a season (Tremblay et al. 1998). 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 (Zeigler et al. 2001), However, Tremblay et al. (2011) suggested that small differences in carapace length 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 the current analysis by comparing the estimated exploitation indices using either the monitoring effort or fishing effort as the predictor variable.

Justification and Data Inclusion

Methods

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 each LFA and time block are outlined in Table 13.

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

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

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:

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

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 (NUTS) MCMC sampler implemented in Stan (Hoffman and Gelman 2011). Normally distributed priors were chosen for A and B such that coefficients of variation were >5. Four chains were run for 35,000 iterations, following a burn-in of 2000, 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 BUGS (Bayesian inference Using Gibbs Sampling) sampling as NUTS is a more efficient sampler of parameter space. Example plots of observed and predicted values for a single year and LFA are provided in Figure 85.

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

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

Examples of the within season and LFA time series of estimated exploitation by sampling date are shown in Figures 86 and 87.

CCIR estimates of exploitation were determined for each year (2000–2016) and LFA, with the exception of LFA 28 where there was insufficient data to estimate exploitation rates in most years. Following recommendations of Tremblay et al. (2011) data were separated in LFA27 north and south and LFA 33 was separated into eastern and western components, as recruitment and harvesting patterns may not be consistent across these large LFAs. Total annual exploitation estimates from split LFAs were calculated as landings weighted averages. Berried females contained in either group were removed prior to analyses. Monitoring samples with <10 Lobster measured were not included in the analyses, nor were years with <10 sampling intervals.

The sensitivity to the assumption of equivalence of monitoring and fishery effort was examined by replacing the g_k in the above equation with $g_k' = \sum_{i=1}^{k} f_i$ where f_i represents the fishery landings between successive monitoring dates.

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.

Results

Across all models, posterior distributions of parameters were updated from the prior (Figures available upon request). Models converged with all chains within models possessing >90% acceptance rates and residual patterning was minimal. Model summary statistics are provided in Table 14.

Using cumulative monitoring effort or cumulative fishing landings as the predictor variable for the CCIR methods yielded similar estimates of exploitation (Figure 88–90). Furthermore, there were no biases associated with using either predictor variable. This result supports the assumption that monitoring effort can be used as a proxy for fisheries effort, which, as the time series of monitoring effort is longer, should be the continued method for estimating CCIR exploitation rates.

A total of 138 estimates of exploitation index were obtained between the years 2000 and 2016. Of the 138 estimates of exploitation, four possessed 95% credible intervals that contained 0, suggesting exploitation was not estimable in those specific Year x LFA combinations (Figure 91 to 93). Across all regions, estimable exploitation indices (lower credible interval >0) ranged from 0.27 to 0.93 and were consistently higher in some regions. Specifically, the mean exploitation index across all years within each LFA was highest for LFA 27 and lowest for LFA 30 (Table 14).

Within LFA 27, exploitation was higher for the north (0.81) than south (0.72), and has been largely without trend over the time series of estimates (Figure 91). This finding was similar to Tremblay et al. (2011) and Tremblay and Reeves (2004) using the CCIR method and cohort analysis respectively. The landings weighted exploitation rates from the combined LFA 27 were intermediate between the two regions.

LFA 29 had an overall mean exploitation index of 0.65, which was lower in 2008–2011 than either prior to 2008 or post 2011 (Figure 92). The timing of low exploitation corresponded to the years of highest landings within LFA 29. LFA 30 had the lowest estimate of exploitation for all the LFAs examined at 0.48. Exploitation rates have been declining from a high in 2008 of 0.74, to 2016 where exploitation was estimated at 0.31 (Figure 92). Similar to LFA 29, the highest landings on record have been observed during this time period.

LFA 31A had mean exploitation indices of 0.67, and was decreasing throughout the time series (Figure 92). There was indication of decreased exploitation in 2013 and 2015; however credible intervals for the estimated exploitation in those years were wider than other years. LFA 31B had mean exploitation rates of 0.58 (Figure 92). There was an apparent decline in exploitation between 2009 and 2013; however the wide credible intervals estimated during these years make interpreting trends difficult. Similar to other LFAs in the region, landings have been high since 2009.

Mean exploitation in LFA 32 was estimated at 0.66. Throughout the estimable period of 2000 to 2016, exploitation appear to be largely stable (Figure 93). Within LFA 33, the eastern and western components had mean exploitation indices of 0.66 and 0.7, yielding a mean landings weighted exploitation index of 0.68 (Figure 93). Between 2010 and 2015 exploitation was decreasing in both regions of LFA 33, however in 2016 estimates diverged with one of the lowest exploitation estimates in the west and an increase in exploitation in the east. Landings in LFA 33 have been steadily increasing since 2010, with 2016 having the highest landings on record. With the landings weighting, LFA 33 exploitation rates have been steadily decreasing since 2010.

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 Lobster, 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.

Overall Exploitation Indicators

The CCIR provided a more robust measure of exploitation, when compared to the cohort analysis. Exploitation indices estimated through cohort analysis are sensitive to variable recruitment, which given the evidence of increased Lobster production in LFA 27–33 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 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 change in ratio 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. It is therefore recommended that the CCIR estimates of exploitation be the stock status indicator used for exploitation.

ABUNDANCE AND BIOMASS INDICATORS

Landings

Levels of commercial landings are related to population abundance as fishery controls are input-(effort-controls) rather than output-based (total allowable catch). Changes in levels of fishing effort, catchability (including the effects of environment, gear efficiency), Lobster size distribution and the spatial overlap between distribution of Lobster and effort will impact landings, thereby weakening this relationship with in abundance.

Although many of the effort controls (number of licences, number of traps, season length etc.) have been consistent since the late 1970s (Tremblay et al. 2011), major changes in the effective Lobster fishing effort during the 1980s (vessels, traps and ship board electronics; i.e., sounders, radar, Loran, GPS, mapping) likely resulted in increased landings irrespective of changes in abundance. Despite the availability of landings records since 1892, a more consistent time series was considered from 1980 to present (Tremblay et al. 2011). Recent changes in the MLS of Lobster also confound the relationship between commercial landings and abundance such that under an increasing MLS fewer Lobster would need to be removed to reach the same landings levels. For this indicator, both the total landings in weight (tons) as well as the total abundance of landed Lobster were used. Landed abundance was estimated using the size frequency information obtained from the At-Sea, Port, and FSRS commercial samples.

Methods

Landings data were described in the **Data Sources** section above. The conversion of landed weight to abundance was previously described in the section describing the **Cohort Analyses.**

Results

In LFA 27, landings started at the lowest level during the time period used here in 1980 at 899 t (Figure 94). Landings steadily increased through 1980s to reach a high in 1990 of 3790 t which declined to 1347 t in 1998. Following that, increases in MLS were implemented and landings began to increase to the highest level on record in 2014 of 3844 t, representing a 185% increase. The numbers of Lobster landed did increase during the same period however, at a much reduced rate of 107%, owing to the increases in MLS from 71.5 mm in 1998 to 82.5 in 2014 (Figure 94).

Landings in LFA 28 have been relatively low and variable compared to adjacent LFAs. In this LFA between 5 and 21 t have been landed from the mid-1980's to present (Figure 94) with no discernable trend. Limited biological samples reduce the ability to track changes in the abundance of landed Lobster.

LFA 29–31B have all undergone similar changes in landings since 1980 with lows in 1980, increase through to the early 1990's and slight decreases thereafter (Figure 95–96). In each of these LFAs the major increases in landings began between 2000 and 2004 increasing to record highs in recent years. The percent increase in landings from the lowest to highest recorded since 1980 were (in order from lowest to highest) 3446% for LFA 30, 4480% for LFA 31A, 4630% for LFA 29 and 5948% for LFA 31B. Similar patterns in the numbers and weights landed occurred in these LFAs as changes in MLS were less dramatic than in LFA 27.

LFA 32 and LFA 33 both had similar patterns of landings changes since 1980. In these areas landing levels began at low levels in 1980, increased through the mid 1980's to early 1990s, and rather than showing the decline in through to the early 2000's as was evident in LFA 27–31B, landings remained constant and then increased to record highs in recent years (Figure 97). The percent increase in landings from the lowest to highest throughout the time period examined was 2218% for LFA 32 and 3747% in LFA 33.

In all areas, there were increases in landings since the early 1980's through the early 1990's, and then more dramatic increases since the early 2000's leading to record high landings in recent years. Lobster productivity is considered at an all-time high as changes in catchability, spatial distribution and changes in fishing effort cannot account for the dramatic increase in landings of >100% in all LFAs. Differences in the number and weight of Lobster removed were only prevalent in LFA 27, where large increases in MLS were undertaken.

Biomass of New Recruits Indicator

Using the new recruitment exploitation indices estimated above from the CCIR and the numbers at length from the biological sampling data sets an estimate of new recruit biomass was developed. This indicator represents an index of the biomass of Lobster in the size range from MLS to MLS + 11mm, the same as the proportion of new recruit indicator as well as the size bins used in the FSRS trap projects. As new recruits typically represent a significant proportion of the overall landings (see Proportion of New Recruits indicator above), it is valuable to track the changes in the biomass of new recruits.

Methods

Total biomass of new recruits (*Br*) was estimated as:

$$B_r = \frac{\sum_{o=m}^{m+11} N_o \cdot w_o}{u_k}$$

Where N_o and w_o were the numbers at weights at length (o) from the fisheries data and u_k was the CCIR estimated exploitation index and m was the MLS. In years and LFAs where multiple data sources were available for N_o and w_o (i.e., At-Sea or Port samples), the mean of the data sources was used to estimate B_r. This indicator was only estimated for years and LFAs where estimates of N_o, w_o and u_k were available. Error bounds on the B_r were obtained using the upper and lower credible intervals of u_k. These magnitude of these errors are likely under-estimated as the variability in N_o and w_o were not propagated through estimation of B_r.

Results

All regions where data was available have shown increases in the biomass of new recruits since the early 2000's (Figure 98–101). During this period, all of the LFA's have had increased biomass of new recruits of >100%. Ordering from lowest to highest percent increase between 2000 and 2016 was, LFA 27, LFA 33, LFA 32, LFA 29, LFA 31A and LFA 31B. The biomasses of new recruits estimated by this method should only be considered an index of recruit biomass as there was no estimation of the non-trapping component of the population, which can only be obtained through fisheries independent or non-trap based methods.

Commercial Catch Rates

Catch rates are a preferred indicator over landings data as they contain landings information but are also standardized to account for the level of fishing effort. This is especially important in an effort controlled fishery. Landings may follow the trend in overall abundance 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 abundance.

Catch rates however, may vary during the fishing season due to changes in abundance and catchability, which can be incorporated into catch rate models. Abundance, the underlying process behind this indicator, changes over time as Lobster recruit to the fishery (usually between seasons when moulting occurs) and during the season as Lobster 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 and voluntary logs. The time series of voluntary logs began in the mid 1980's in some LFAs whereas mandatory logs were not put in place until the mid to late 2000's. In years where the two data streams were collected simultaneously, there was overlap in the mean CPUEs suggesting the voluntary logs were a representative sample of the fishery, and a continuous time series can be created by merging the two data sources.

Methods

Voluntary and mandatory logs contain similar information on the date, catch and effort of the fishing activity. 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 was not available from the logs and location data which could be used to assign depth was 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 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 volume of the log data made considering vessel as a mixed effect unfeasible. Different formulations of temperature and day of season were tested and the formulation with the lowest Akaike information criterion (AIC) included both temperature and day of season and their interaction.

Results

The fits of the model to the log data for each LFA were presented in Figures 102 and 103. These figures show the variability in the data as well as the seasonal trends predicted by the model. The variability in CPUE was especially high in LFA 33. Normally the model would be used to predict CPUE for each LFA and season while keeping the other factors (temperature and day of season) constant to provide an index value that would be used as an indicator. However the choice of particular day of the season and temperature would be arbitrary and there isn't consistency across areas when it comes to the temperature at a given day of season. Alternatively, the average and standard deviation of the predictions for each day of the season were calculated in order to provide a single value for CPUE for a given LFA and season to be used as an indicator of stock health (Figure 104). When compared to the unmodelled CPUE derived from the total catch / total effort for a given LFA and season (Figure 105), they are similar in trend and magnitude for all areas except LFA 33. The difference in the magnitude between the modelled and unmodelled CPUE in LFA 33 was because the modelled catch rate is evenly weighted across every day of the season, assuming that effort is consistent throughout the season. This was the case for the LFAs with shorter spring seasons but in LFA 33 there is more effort in the first part of the season when the catch rates are higher which cause the unmodelled catch rates to be higher than the modelled ones.

Other considerations with modelled results relate to the nature of the effects of temperature and day of season (proxy for depletion) have on catch rates. It is assumed that increasing temperature would have a positive effect on CPUE while day of season representing the depletion of the stock would have a negative effect. This pattern was not always the present in the parameter estimates from the LFA specific models. The assumed direction of their effects were corroborated in LFA 33 where the longer season results in a stronger contrast in the temperature data which declines in the fall and increases in the spring. In LFA 27–32 which have shorter spring seasons both temperature and depletion generally increase throughout the each season. In these cases temperature and day of season are confounded and the model was unable to determine how their impacts on catch rates. Given that the trends are consistent between both modelled and unmodelled CPUE and the concerns with the current model, it was recommended that the unmodelled CPUE should be used as an indicator of stock health, until more a more exploratory analysis was conducted in the next framework.

FSRS Catch Rates

Justification

The FSRS recruitment trap survey provides the best information on the abundance of under-sized Lobster. It is also the only data on abundance for LFA 27–33 that is collected in a standardized manner. Details of how the data are collected are provided in the Data Sources section. The abundance index from the FSRS data is comprised of the total number of Lobster per trap for each legal, sublegal and recruit size class. Recruits are defined as sublegal Lobster 71mm - MLS (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 Lobster in traps other than abundance such as temperature and depletion for legal-size Lobster. The catch rate of sublegal Lobster is also affected by behavioural interactions with larger Lobster. Small Lobster are less likely to enter a trap where larger Lobster are already present. Temperature data are available directly from the loggers on the traps so there is no need to rely on the temperature model for that information.

Methods

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 area for each response type: numbers of each 1) subleagal, 2) recruits, and 3) legal Lobster caught. 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 Lobster caught and year. For legal-sized Lobster the predictors were temperature, the day of the season, and year as a factor. The resultant models were used to predict of the number of Lobster (for each size class) per trap for each area and year in the middle of the season with the temperature is set to 5ºC. For the sublegal-size-class models, the number of legal Lobster included in predictions was three.

Results and Discussion

The resulting indicators for each area are presented for sublegal (Figure 106), recruit (Figure 107) and legal-size Lobster (Figure 108). The credible intervals were derived from 95% quantiles of the posterior predictions. The model was also applied to FSRS commercial traps in LFA 33 which are essentially commercial traps where the data was collected as if they were recruitment traps (Figure 109). This trap study was designed to estimate the difference in catches between commercial and recruitment traps. The commercial traps tend to catch more legal-size and less recruit-size Lobster than the recruitment traps, but the trends are generally consistent, lending support to the use of commercial-sized Lobster catch rate estimates from FSRS recruitment traps as an indicator for the exploitable population.

COMBINING INDICATORS

In order to combine the patterns and trends estimated from the various indicators in a display that shows the changes over time, a modified version of the method developed by Brodziak and Link (2002) was implemented. Previous assessments for Lobster used a traffic light approach advocated by Caddy (2002), where each indicator required the definition of stock boundaries or reference points. For contextual indicators that are provided to describe not only the biological processes that influence production but ecosystem and fishery performance indicators, specific reference levels are not required, and may often be misleading. There were no trend analysis conducted as part of this multivariate analyses, this exercise is largely a visualization tool.

Methods

The LFA specific indicators described throughout the previous section were made directly comparable through statistical standardization (z-scores) after log transformations to normalize the appropriate indicators (abundance or biomass based) were applied. Indicators with fewer than 5 years of data were dropped from this analysis. As this data set was characterized by a number of missing values, classical multivariate analyses could not be applied as those methods typically require the deletion of all such cases. As such, the Pearson correlation coefficients were calculated for all possible pair-wise combinations. A variant of Principal Components Analysis (PCA) involving an eigen analysis was performed on the resultant correlation matrices of the indicators. Although it was recognized that the missing values can result in an ill-determined matrix, it was assumed that the relationships presented here are a first-order approximation of the 'true' correlational structure (Choi et al. 2005).

After eigen analysis, the component scores were ordered by the first eigenvector and color coded within each indicator. This allowed for the visualization of the coherent trends in the indicators over time. Several of the indicators were correlated as they were estimated using the same data inputs, such as landed weighted and landed abundance. Despite this potential redundancy, indicators were included in the analyses as they represent different characteristics of the Lobster biology or fishery within respective LFAs.

LFA 28 was not included in this analysis due to insufficient length of time series and number of indicators. Due to the size binning in the FSRS collected data, the indicators directly using the size frequency information were not included here. Further, the sex ratio results, which did not show strong patterns over space or time, were not included.

It is important to note, that the direction of PCA scores (positive or negative) do not necessarily relate to the directional change in productivity. For instance, decreasing and negative PCA scores for axis 1 do not necessarily indicate decreasing productivity indicators.

Results

LFA 27

The first two principal components described 28.9 % and 16.2 % of the variance of the 24 indicators used in this analysis respectively (Figure 110). The indicators that heavily contributed to the decrease in recent years in the first principal component were, landings, abundance, commercial and FSRS recruit catch rates, reproductive potential, proportion mature Lobster in the catch and body size indicators (Figure 110, 111). Similarly, the peak in the late 1980's early 1990s in the first component was due to the landings, and reproductive potential. The reproductive potential indicator was high in the late 1980's, despite having a low proportion of mature Lobster in the landings, suggesting this was due to the higher abundance levels. Recent increases in reproductive potential are due to a combination of both high abundance, and larger body size owing to the increase in MLS undertaken in this fishery.

In contrast the increases observed in the first component, the proportion of new recruits in the port samples was low in the mid 1980's when the landings were high, CCIR exploitation rates were low when landings were high and although variable, low temperatures were present when landings were high (Figure 111). The low CCIR exploitation rates combined high landings suggests there was an increase in the overall abundance, not just changes in the catchability of newly recruited Lobster, which is reflected in the biomass of recruits indicator. Further support to this conclusion comes from the FSRS recruitment catch rates which have been increasing in recent years.

The increases in MLS within LFA 27, from 70 mm in 1997 to 82.5 mm in 2015 had the intended impact, to increase the median and maximum size, the reproductive potential (both direct and indirect), and the overall abundance. Although current landings are similar to the highs in the late 1980's, fewer Lobster are being removed per year and the Lobster in LFA 27 should be more resilient to environmental and anthropogenic disturbances.

LFA 29

The first two principal components described 33.2 % and 18.3 % of the variability in the 20 indicators used in this analysis (Figure 112). The time series trends of PCA1 increase through the late 1980's, decline up to 2000 and then increase again to 2010, with a marginal increase since that time. The indicators that were the major contributors to the first principal component were reproductive potential, landings, commercial catch rates, and the FSRS recruit, short, and legal catch rates (Figure 113). During the late 1990's when landings and overall production fell, there were increases in the median and maximum size and proportion of mature Lobster in the catch. The increase since 2000 has been largely driven by the increase in productivity viewed as the increases in landings, catch rates and reproductive potential, measured as both the proportion of berried females and from the size frequency data (Figure 113). During the same period a decrease in CCIR exploitation was detected. The timing of the initiation of the increase in productivity corresponded to the implementation of additional conservation measures during 1998–1999. Specific measures in this LFA included increasing the MLS from 81 mm to 84 mm, introducing a maximum hoop size of 6 inches and reducing the trap limit from 275 to 250 per license. These conservation measures had the goal of increasing the proportion of mature Lobster in the fishery (increasing MLS), protecting large Lobster (restricting hoop size) and reducing exploitation (trap limits), all of which contributed to increasing productivity.

LFA 30

The first two principal components described 43.1% and 18.3% of the variability in the 16 indicators used in this analysis (Figure 114). The percent variability accounted for in this analysis was higher than in other regions, owing largely to the fewer number of indicators employed in analysis. PCA 1 was relatively stable until the late 1990's when it decreased until 2003 which was followed by an increase until 2010 and have been relative stable since that time. The indicators that comprise component 1 were landings, abundance, commercial catch rates, FSRS legal, short and recruit catch rates and reproductive indicators which have been increasing since 2003–2005. Additionally CCIR exploitation has been decreasing in recent years (Figure 115). The reduction in CCIR exploitation rates provides further support to an increasing overall population size. The decreasing body size in the At-Sea samples may not be reflective of changes in the population, as the highest years were those in which conservation measures were implemented. Specifically, in 1998–1999 LFA 30 included an increase in the MLS from 81 mm to 82.5 and the return of all females >135mm, both of which would have improved the reproductive capacity and overall productive potential of this LFA. Furthermore, with the increase in recruitment evident in the FSRS trap project, the overall median and maximum size would decrease due to a shift in the size distribution favoring the increased recruits.

LFA 31A

The first two components of the multivariate analysis described 41 % and 12.3 % of the overall variance in the 24 indicators available for this area (Figure 116). Similar to other LFAs there was a moderate increase in the time series for component 1 during the late 1980's and early 1990's, which was followed by a decline until 2003. From 2001 to 2010, there was an increase in component 1, which has been stable or moderately decreasing since. The indicators which largely comprise component 1 were the landings, biomass, commercial catch rates, FSRS legal, recruit and short catch rates and reproductive potential indicators which have all been increasing since 2002–2003 (Figure 117). During this same time period, the proportion of mature Lobster in the landings, CCIR estimated exploitation and maximum size were decreasing. Taken together, these patterns suggest increased productivity in LFA 31A since the early 2000's, which has been relatively stable since 2010. In the last several years, there has been a reduction in the proportion of berried females in the At-Sea samples which should be noted.

The conservation measures implemented in LFA 31A included changing the MLS from 81 to 86 mm between 1998 and 2000, then decreasing to 84 mm in 2004 and to 82.5 mm in 2007. Additional protection was placed on the females in 1998, such that females between 114 and124 mm were returned to the water (Table 2). The conservation measures need to be considered when examining the indicator trends, as the apparent decrease in maximum and median carapace length and proportion mature corresponds to the decreases in MLS following 2000 when MLS was 86 mm. This reinforces the notion that some of these indicators represent changes in the fishery and may not be reflective of changes in the Lobster within specific LFAs.

LFA 31B

The first two components of the multivariate analysis described 35.6 and 13% of the variability in the 21 indicators respectively. The time series for component 1 shows relative stability between 1980 and 2000, with slight increases in the late 1980's, and 2000. There was a greater increase in component 1 between 2005 and 2010, which has been stable or slightly decreasing since that time (Figure 118). As in other LFAs, the primary drivers of the trend is component 1 was the increases in landings, biomass, abundance, commercial catch rates, FSRS legal and recruit catch rates and reproductive potential indicators. The decrease in exploitation estimated through CCIR, proportion of the mature Lobster in the landings and maximum size also contributed to the first principal component (Figure 119). Similar to LFA 31A, trends in indicators based on fisheries data must be placed in context to changes in fishing practices and may not reflect changes in population characteristics. Specifically, the conservation criteria put in place in LFA 31B changed the MLS from 81–84 mm between 1998 and 1999 and then decreased to 82.5 mm in 2000. The largest median and maximum sizes as well proportions of mature Lobster in the landings occurred following these MLS increases, which have likely impacted the apparent decreasing trend in the size based indicators in recent years (Table 2). Further contributing to the decrease in these indicators was the increase in recruitment, evident from the FSRS recruitment traps, which would change the overall size distribution. That said, the increase productivity from higher landings, increased biomass of recruits, and reproductive potential was apparent, and although the relative impact of the conservation measures on improved productivity was not estimated, they likely contributed to the current status of the LFA.

LFA 32

The first two principal component axes describe 31.7 % and 17.2 % of the variability in the 21 indicator time series included in this analysis (Figure 120). The time series of component 1 did not show the same increase in the late 1980's and early 1990s that was evident in the more easterly LFAs, but did show the same increase since approximately 2003. The first principal component was described by the time series trends of increasing landings, abundance, commercial catch rates, FSRS legal, recruit and short catch rates and reproductive potential indicators (Figure 121). In LFA 32 there were also the decreasing trends of proportion of berried females, median and maximum carapace length. Exploitation indices estimated through the CCIR method have also been decreasing with increased landings, suggesting an increase in overall abundance. The change in production occurred several years after the implementation of conservation measures in 2000 (Table 2). These measures included increasing MLS from 81 mm to 82.5 and the v-notching and release of 110lbs of females, which would serve to increase the proportion of mature Lobster being captured and increase the overall reproductive potential.

Similar to other areas, the decrease in size metrics was largely due to the increase in new recruits, skewing the distribution toward more newly recruited individuals.

LFA 33

The first two principal component axes describe 25.7 % and 11.7 % of the variance in the 25 indicators used in this analysis (Figure 122). The trend in component 1 increased through the mid-late 1980's, declined and stayed stable between 1995 until 2005, when it began to increase and currently remains high. Indicators of biomass, landings, abundance, commercial catch rates, FSRS recruitment, legal and short catch rates and reproductive potential comprise the increasing trends in component 1 (Figure 123). In contrast, the declining exploitation estimated through CCIR, the declining proportion of mature Lobster in the landings and decreasing maximum size have been observed in recent years. Conservation measures implemented in LFA 33 included the increase in MLS from 81 to 82.5mm in 1998, whereas the increase in productivity began to occur in approximately 2005, with increased recruitment during that time.

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

Across LFA 27–33 there have been increases in productivity which began between 2000 and 2005, depending on the region. The main indicators driving the changes over time were largely the same across LFAs. Specifically, landings, commercial and FSRS catch rates, abundance, proportion of berried females and reproductive potential have all increased to the highest levels on record between 2008 and 2015. Exploitation indices have been decreasing in recent years. Specific factors that control recruitment, abundance and subsequent landings have not been determined, but are likely due to a combination of changing environmental conditions, predator release and increased conservation efforts.

Long-term increases in water temperature have been noted in other areas, which have likely resulted in increased moult frequency and growth rates (McMahan et al. 2016). Increased growth rates would allow for more rapid transition through the sensitive early life stages and perhaps increase survival rates and hence productivity. Long term data sets of regional temperature changes do not exist for the inshore areas of LFA 27–33 and many of the oceanographic and climatological models for the region do not provide sufficient resolution on long term scales to track the inshore temperature patterns. One initiative, the FVCOM (Finite-Volume Community Ocean Model; Chen et al. 2003) which has been used along the northeast United States costal zones to examine spatial and temporal trends in temperature, was not well resolved along the LFAs examined here. Simple descriptive models, as that developed below in the simulation model section, are useful in defining some of the broad patterns. There has been an increased focus in the climatology of the near shore regions of Nova Scotia more recently, which should help to describe the trends in bottom water temperatures in future.

Increases in survival and productivity of Lobster stocks also likely occurred as many of the predatory groundfish stocks decreased in abundance during the 1980s through to the 1990s and remain at low levels (e.g., Atlantic cod, Mohn and Rowe 2012; Bundy et al. 2017). Though the dramatic decrease in groundfish stocks has been documented in the offshore areas in Eastern Nova Scotia, similar long term data sets on biomass changes of groundfish in the inshore areas do not exist; however similar patterns of groundfish decreases in the inshore were likely to have occurred. The decrease in groundfish stocks would reduce the predation pressure on small Lobster allowing for greater survival through early life stages, improved recruitment and overall Lobster production, as has been suggested elsewhere (Boudreau and Worm 2011).

The conservation measures that have been put in place since the late 1990’s and early 2000’s including increasing MLS (LFA 27–33), protecting window-sized Lobster (LFA 31A), returning large females (LFA 30) and v-notching program (LFA 31B, 32) have allowed for increased reproductive potential and productivity in respective LFAs. The impacts of some conservation measures can be detected in some of the biological indicator trends shown above. These conservation measures should continue as protecting the reproductive components of the stock will buffer the impacts of years with suboptimal environmental conditions for Lobster production.

There is sparse information in some LFAs, and several of the long standing sources of size information have not been collected in recent years (i.e., Port sampling). The increased effort in some LFAs for At-Sea sampling has provided a valuable source of information on the size distribution and biological characteristics of the Lobster in the LFAs and this data source should be continued.

The indicators used here provide a snapshot of the Lobster within each LFA. Although many of the indicators are reliant on the commercial fishery and assume consistency in fishing practices and sampling protocols in order to assess time series trends, they remain the only data source available for assessing these Lobster stocks. As the conservation measures are well documented, and are typically the only synoptic changes to LFAs they should be considered when examining the indicator trends. For example, in LFA 31A the apparent decrease in maximum and median carapace length indicators corresponded to the decreases in MLS following 2000 when maximum size was 86 mm.

The FSRS recruitment trap project provides a stable and consistent source of information and indicators from most of the LFAs. The same study design has largely been in place since the introduction of the study in the mid-1990s. The 10 mm size categories used in these projects do not allow for fine scale detection of changes in the size structure over time, but are amenable to use for estimation of exploitation rates through the CCIR methods developed by Claytor and Allard (2003) and size-class based catch rate estimates. The FSRS recruitment traps provided an indicator of abundance for both recruit and commercial-size Lobster through trends in catch rates. The number of participants in this project varies between LFAs and over time, however, this data set represents most regions across many LFAs with data collections occurring throughout the fishing season. One exception was LFA 28, where the low participation limits the value of time series trends. Although the time series of trends from this project started in 1996, the most robust estimates were available 1999 to current. One additional source of information which was valuable to understanding the systems between LFA 27 and 33 was the bottom temperature time series collected during with the FSRS recruitment trap study. This temperature data set is among the longest time series of bottom temperature data available for the region and will be valuable moving forward trying to describe the impacts of climate on the increased productivity of Lobster in the region.

Indices of exploitation developed by the CCIR were more robust than those developed through the cohort analysis approach applied here. The cohort analysis exploitation indices were highly influenced by recruitment, such that increased recruitment rates resulted in increased exploitation rates. The CCIR estimated exploitation indices were largely negatively related to landings, suggesting that there was an overall increase in the abundance of newly recruited Lobster and not only an increase in the number of Lobster removed. Due to the sensitivity of the cohort analysis exploitation indicators, it is recommended they not be used in future stock assessments, unless they are incorporated into a fully integrated model, whereby growth and stock dynamics can be assimilated and some of the strong assumptions associated with this method can be relaxed.

The sensitivity of some indicators to the timing of sample collections should be noted. Specifically, the size based indicators and the proportion of berried females indicators were affected by the timing of sampling. Optimally, sampling design should mimic the spatial and temporal distribution of the fishery, however if resources are limited, effort should be made to collect information at the same time of year in order to generate a reliable time series of data.

Despite the caveats in applying the multivariate methods to the time trends of indicators, this method remains a useful option for providing a simple visualization of the patterns over time. It must be clear however, that this analysis was not designed to analyze trends, nor to provide direct advice to fishery managers. It was developed to guide the discussion and describe the patterns of changes within the suite of indicators.

Moving forward, the proposal for the indicators presented here will be to separate them into primary, secondary and contextual categories. Primary indicators will represent the focus for defining stock status, through defining of reference points and describing the time series trends relative to these reference points. The proposed primary indicator for describing stock status was the unmodelled commercial catch rates. Further, a fishing pressure or exploitation indicator, CCIR exploitation will be used in conjunction with CPUE to track changes over time. Secondary indicators will represent important time series trends which will be tracked individually, but no reference points will be defined. The proposed secondary indicators will be landings, FSRS recruitment trap recruit and legal catch rate series, landings and total effort (trap hauls). The indicators selected for describing the contextual information which will be included in the multivariate analysis with the matrix plots generated, include: berried female indices, new recruit indices, size based indices (maximum CL, median CL), idealized reproductive potential, biomass recruits, proportion of new recruits, proportion mature and bottom temperature.

PRECAUTIONARY APPROACH AND DEVELOPMENT OF REFERENCE POINTS

The Federal Government of Canada has committed to using the Precautionary Approach (PA) for managing fish stocks as part of the Sustainable Fisheries Framework. As a result DFO developed a policy document entitled “A fishery decision-making framework incorporating the Precautionary Approach” which explains how the precautionary approach will be applied in practice (DFO 2009). One of the key components of the framework is the definition of reference points and stock status zones. These zones are defined by a Limit Reference Point (LRP), which delineates the critical (red) and cautious (yellow) stock status zones, and an Upper Stock Reference (USR) which is the boundary between the cautious and healthy (green) zones (Figure 124). Within each zone a Removal Reference (RR) establishes the maximum removal rate.

The LRP defines the boundary below which serious harm is occurring to the stock, and is defined on the basis of biological criteria through Science Review Process (DFO 2009). The USR is the upper stock limit where removals should be progressively reduced in order to reduce the risk of reaching the LRP. The USR is developed by fisheries managers in consultation with the fishery and other interests in consultation with advice and input from Science (DFO 2009).

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

USR and LRP are usually defined in terms of biomass or spawning biomass (SSB) as these are typically the units that best describe the species current productivity. In quantitative fisheries assessments, modeled estimates of biomass or SSB where maximum sustainable yield (B_{MSY} or SSB_{MSY}) is attained can be used to guide the definition of zones. Specifically, under the PA policy, the default USR is defined as 80% of B_{MSY} and the LRP 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 and have been used elsewhere (e.g., Cook et al. 2017).

Development of an integrated Lobster stock assessment model has been undertaken at the University of Maine and has been successfully applied to stocks in Maine (Chen et al. 2005, ASFMC 2009). This model has not been successfully applied to Canadian Lobster stocks. As such there are currently no population models for Canadian Lobster with which to set model-based reference points.

Previous assessments have applied of egg-per-recruit (e/r) and yield-per-recruit models to inform stock status (e.g., Tremblay and Eagles 1998, Lawton et al. 1999), but these are equilibrium models, and given the Lobster stocks are clearly not in an equilibrium state, their results are not considered applicable (e.g., Miller and Hannah 2006). Until an integrated model can be developed and successfully applied to these LFAs reference points based on biomass or abundance proxies and removal reference proxies should be explored.

Currently, all inshore LFAs in the Maritimes Region have reference points based on total landed weight (Tremblay et al. 2012). Although it was recognized there were risks associated with treating landings as a proxy for commercial population biomass, an USR and LRP were developed for each of LFA 27–33. Within each area, the USR and LRP were defined as 80% and 40% of the median landings between 1985–2009. This 25 year period was chosen based on an approximate 2X generation time interval (approximately 10–15 year generation time) and covered both high and low productivity periods (Tremblay et al. 2012). To evaluate stock status relative to these reference points, a three running mean of landings was applied in order to lessen the impacts of interannual variability, which may be due to factors outside of changes in abundance. The currently accepted reference points are provided in Table 15, with current landings relative to reference points shown in Figures 125–127.

One of the more important risks associated with retaining landings as the primary stock status indicator rests in its reliance on a consistent management regime and levels of effective effort. In a situation where stock status falls below the USR, the PA states that a HCR should be implemented in order to rebuild the stock into the healthy zone. Any HCRs implemented will alter the management regime, and may therefore result in landings not reaching the USR, even if the stock abundance rebounds to what would be considered a healthy level.

Given this and other risks associated with landings based reference points it was recognized during the last framework, that work should continue to develop more robust stock status indicators. In the following section we will explore some alternative reference points based on the stock status indicators defined above.

Alternative Measures of Stock Status and Reference Points

Commercial Catch Rates

Commercial catch rates have the advantage over total landings as an indicator of abundance or biomass in that 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, 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 Lobster, 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).

The time series of commercial catch rates are made up of two data sources. The first was the voluntary log books which began in the 1980’s and continued until 2013 in some LFAs, although participation varied by region and time period. Mandatory logs have been in place in some LFAs since the mid 2000’s and provide a more complete data set with which to evaluate changes in catch rates (Tremblay et al. 2011). In years and LFAs where both voluntary and mandatory logs were available the magnitude and trends over time were similar (Tremblay et al. 2012). In the current analysis, we will treat these two commercial catch rates series as a single continuous time series, beginning in 1990, when there was increased participation in the voluntary logbook program.

The combined catch rate data series from 1990–2016 was used to define USR's and LRP for specific LFAs. This period was chosen as it represents both low and high productivity time periods and covers approximately 2 generations, as was used in the previous framework (Tremblay et al. 2012) and in the Quebec Region LFAs (Gendron and Savard 2012). The median of this time series was used as the proxy for B_{MSY}. Following the recommendations of DFO (2009), the USR and LRP were set to 80% and 40% of the B_{MSY} proxy. The trend that will be used to compare the commercial catch rates to the USR and LRP will be the 3 year running median, as this will dampen the impact of any anomalous years which may occur due to factors outside of changes in abundance.

Based on these estimates of USR and LRP, all LFAs are currently in the healthy zone (Figure 127–131), and have been since at least 2006.

Removal Reference Points

The DFO guidance on setting a removal reference was to define *F* not to exceed F_{MSY} when the stock is in the healthy zone (DFO 2009). Without a quantitative model relating biomass and landings to develop estimates of F_{MSY}, other approaches to defining removal references need to be explored. Much of the work in data limited stocks has been focussed on groundfish species, with studies using yield per recruit analyses, both F_{max} and $F_{0.1}$ have been suggested as proxies for F_{MSY}. F_{max}, defined as the maximum fishing mortality from the yield per recruit curve, has been discounted as a reasonable proxy as it often exceeds F_{MSY} (e.g., Cook et al. 2014) as it does not account for low recruitment at low stock sizes. $F_{0.1}$, defined as the fishing mortality rate at 10% of the slope of the yield per recruit curve at the origin (Gulland and Boerema 1973) is generally considered a more precautionary F reference (but see Mace and Sissenwine 1993). Even more simplistic approaches have been suggested, such as defining a removal reference as a proportion of natural mortality (*M*) (i.e., $F = 0.8M$ Thompson 1993). In Lobster stocks where estimates of M often vary between 0.1 and 0.2 (Fogarty and Idoine 1988), a midpoint F of 0.15, would suggest a removal reference of 0.12, which corresponds to exploitation rates of 0.11. Given estimates of exploitation estimated from the CCIR methods presented here, as well as those estimates from elsewhere, suggest exploitation rates >0.6 are not uncommon and have been maintained for multiple generations (Campbell and Robinson 1983; DFO 2013), other removal references were explored.

Using a data driven approach as has been applied elsewhere, the time series of exploitation indices developed using the CCIR methodology were used to propose LFA specific removal references. These indices of exploitation span the time series from 2000 to 2016 (although variant among LFAs), which represent the period of increased productivity in all LFAs examined. Given this increased production, it can be assumed that the estimated maximum exploitation index was likely below the rate that would negative impacts on the Lobster stocks.

CCIR represents an index of exploitation on new recruits, which constitute a large proportion of the total catch in most areas and most years. This method does not account for conservation measures directed toward protecting large Lobster. Therefore it is important to consider the CCIR estimate of exploitation as an index not an absolute value.

Two removal references will be proposed, the first represents the maximum LFA specific exploitation index estimated through the CCIR method (RR_c). This could be considered a conservative removal reference as stocks continued to increase or remain stable under this level of fishing pressure. The second proposed removal reference represents the 75th quantile of the posterior distribution of the maximum estimated CCIR exploitation rate within each LFA (RR_{75}). This would be considered a less precautionary removal reference, however, given that the regional Lobster stocks are currently in a highly productive state and population growth has not decreased under the range of estimates exploitation, a more flexible scope for exploitation would be an acceptable proxy for $F<F_{MSY}$.

To assess the stock status relative to the proposed removal references a three year running median of estimated exploitation be used as the metric to compare against the removal reference. By employing the running median, the impact of any single anomalous years will be decreased.

Removal references could not be defined from LFA 28 using this data source as there has been insufficient participation in the project to provide reasonable estimates of exploitation.

Through this choice of RR_c and $RR_{75,}$ all exploitation indices were lower than either proposed removal reference (Figures 132–135).

Due to the short time series of exploitation indices, the long term resilience of the Lobster stock to fishing pressure and the current high productivity, the suggestion would be to adopt the RR_{75} as a removal reference. If current productivity regimes change, a re-evaluation of reference points would be warranted.

Summary of Primary Stock Status Indicators

Landings is currently used as the primary stock status indicator for all LFAs across DFO Maritimes Region (Tremblay et al. 2012), as well as in other regions (DFO 2013). The justification for this stock status indicator is that landings are proportional to overall abundance as the fishery is effort controlled. This assumption has been examined in previous assessments through correlating landings with survey catches, and commercial catch rates (Tremblay et al. 2012, 2013—LFA 34 framework). The time series of mandatory commercial catch rates was not put forth as the primary indicator in the last assessment due to the short time series at that time. The advantage of using catch rates over total landings as the primary indicator rests it the ability to directly account for changes is effort, which may occur due to direct management measures (i.e., the implementation of Harvest Control Rules if the stock enters the Cautious Zone) or unforeseen circumstances such as large scale ice or storm events which may shorten seasons or interfere with harvesters ability to fish. Any source of effort change may have impacts on the total removals due to fishing and should be directly accounted for in primary stock status indicators. This therefore, leads to the suggestion that the commercial catch rate series, be adopted as the primary stock status indicator, with upper stock and limit reference points chosen following the same approach as was used in the development of the reference points for landings during the 2011 framework (Tremblay et al. 2011).

In developing exploitation indices, two methods were explored, the CCIR and cohort analysis. The results from the cohort analysis were strongly influenced by changes in recruitment, which, given the large increases in recruitment in recent years for LFA 27–33, reduce the applicability of these results. The CCIR, provided a robust method of developing an exploitation index. The time series of exploitation indicators were relative short compared to the long time series of fishery and the time period of estimates cover a period of rapid growth in the Lobster stocks. That said, using the 75th quantile break of the maximum estimated exploitation measure would provide a reasonable upper threshold for removals, given the information currently available. As there are no reliable exploitation rate estimates in LFA 28, a removal reference for this area will not be proposed.

The metric to assess stock status relative to the proposed reference points will be the 3-year running medians of commercial catch and exploitation. These running medians were chosen as they decrease the magnitude of interannual variability which may be due to factors other than changes in abundance.

Phase plots of the commercial catch rates the proposed USR, LRP and CCIR exploitation rate indicator (RR_{75}) are provided in Figures 136–139. The patterns catch rates and exploitation show increasing catch rates and decreasing exploitation indices in recent years for several of the LFAs. Most LFAs are well above the USR and exploitation was below the RR suggesting all are well within the healthy zone. In LFA 28, the stock status will be defined based on their catch rate alone, using Figure 126. Similar to other regions, LFA 28 is considered in the healthy zone.

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. Lobster 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 60–80mm moult approximately once a year, 140mm–160mm every second year and Lobster between 180–200mm likely moult every 3 to 4 years (Campbell 1983). Two moults during a single season can occur and has been reported in Lobster over 60mm 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 Lobster to 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 0ºC will inform the growth component in the simulation model for each LFA.

SIMULATION METHODS

Each simulation run tracks 1000 individual Lobster from carapace length 50mm to 200mm in 5mm 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 Lobster in time step *t*, of carapace length *l*, that have moulted *i* times and *j* time steps have passed since their last moult. The probability of Lobster moulting (*pM*) is a function of the carapace length (*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 carapace length (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. Lobster 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 140). 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 Generalized Additive Model (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(2πy)*, *cos(2πy)]* 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.

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

The fit to the seasonal patterns for various depths can be seen in Figure 141 for areas LFA 27N and 33W. The inter-annual variability for each area can be more clearly visualized when predicting at a 25m depth on June 1 of each year (Figure 142).

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). Although there was limited overlap between the tagging data and the overall area encompassed by LFA 27–33 (Figure 143), the analysis focussed on temperature as the main factor that cause variability in growth and assumes that variability in growth between areas is a function of different temperatures.

Moult probability

The tagging data was used to estimate the relationship between moult probability and carapace length and degree days since last moult. Recaptured Lobster that increased their carapace length 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 carapace length were the linear predictors. The resulting predicted probabilities for moulting were used in the simulation model to determine the number of Lobster moulting for a given length bin and number of degree days since last moult (Figure 144).

Moult Increment

Moult increment was estimated from the tagging data. In order to select Lobster that presumably have moulted only once, Lobster 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 145).

Size at 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 LFA 27–33 region has not been done. Until this analysis is completed a selection of available regional parameter values were used for different LFAs in the simulation analysis (Figure 146)(Millar and Hannah 2006).

Fecundity

The fecundity-carapace length 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

The average exploitation estimates from the CCIR analysis were used for each area. They were converted to annual fishing mortality rates,

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

where *E* is the CCIR exploitation 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 a window size of Lobster and protection of Lobster above a maximum size. Simulations of trap limits and v-notching were suggested as potential HCRs, 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 duration of 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 33 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 for each LFA. Evaluating simulation model performance was done by implementing the changes in MLS which have already taken place in LFA 27. Specifically, runs with MLS set to 70, 72.5, 75, 77.5, and 80 mm were performed.

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 from simulated cohorts were displayed as bubble plots for males, females and berried females for each LFA (Figures 147–191). These plots show the total number of Lobster in each size bin at each quarter-year ($N_{t,l}$) as the generation progresses over 15 years from an initial cohort at 50mm carapace length. Also shown were simulated removals due to the fishery, the numbers of Lobster moulting and the numbers of eggs released by the berried females. Some general patterns were consistent across areas such as males tend to grow faster than females due to higher moult frequency and increment.

Examining these results for different areas reveals how the different inputs affect the simulation results. 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 Lobster are removed from the cohort. For example LFA 27N and LFA 30 have similar temperature and size-at-maturity parameters but the exploitation estimates from the CCIR were much higher for LFA 27N than for LFA 30. Therefore the growth trajectories and abundance at size were similar until the Lobster reach MLS where they were depleted at a faster rate in LFA 27N, resulting in fewer older, larger Lobster from the same initial sized cohort (Figures 147 and156). In LFA 33W the exploitation was similar to LFA 27N but size-at-maturity and temperature tend to be higher, resulting in larger Lobster at a given age because the higher temperatures increased moult frequency (Figure 155). However, the larger size-at-maturity in LFA 33 resulted in fewer berried females as they enter the exploitable component prior to maturity. These results were generally consistent with the size frequency data reported in these areas that show a higher proportion of large Lobster in LFA 30 than in LFA 33 and LFA 27.

Outputs from each of the simulation runs were summarized by LFA in Tables 16–24.

In increasing MLS scenarios the average size of Lobster in the landings were larger which resulted in fewer Lobster being landed to reach the same total landings (Figures 156–164). In areas with larger size-at-maturity (LFA 33) increasing MLS gives smaller females a chance to spawn before becoming susceptible to fishing (Figure 163, 164) and in areas where size-at-maturity was lower it increases the overall number of females carrying eggs. 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 165–173) 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 and was therefore more effective than MLS changes for increasing reproductive potential.

A summary of the output in terms of landings and reproduction potential is compared across all areas for scenarios where simulated HCR was a change in the MLS (Figure 192), a season reduction (Figure 193). The summary of the results suggested that under current levels of exploitation estimated from the CCIR analysis 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 the CCIR analysis that indicate very high levels of exploitation and the analysis of moult increment which indicate high growth rates especially in males.

A change in the season length is generally more effective at increasing egg production than an increase in MLS in the ranges tested especially in warmer areas with larger size-at-maturity. In LFA 33W a season reduced to 80% yielded similar increases in egg production, 80%, as a change to the MLS to 90 mm did, 85% (Table 24). Yet a change to the season to 50% had a much bigger impact increasing egg production by 434% (Table 24). In LFA 27N the difference was less dramatic with changes to the MLS to 90mm increasing egg production by 90% and a season reduced to 50% increasing egg production by 113% (Table 16). Both HCRs were less effective in terms of percent increase in egg production in LFA 30 because exploitation rates were already lower there than any other areas but the increases were still quite large in terms of numbers. All the HCRs tested result in fewer Lobster captured in the fishery yet they also all result in larger total landings in terms of weight (Table 19). This is because the average size of the Lobster landed in the fishery will increase under these management measures. This was obviously the case with an increase in the MLS but it will also occur with a reduced season because reduced exploitation gives more Lobster the chance to grow. The impact on increased weight and reduced numbers in the landings was similar in most areas for a reduction in season by 50% and an increase in the MLS to 90mm (Tables 16–24).

Overall, a reduction in season to 50% tended to have greater benefits, especially in terms of egg production than an increase in the MLS. It also was likely 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 Lobster newly recruited to the fishery are the same for all sizes of Lobster. There was however some corroboration for the general conclusion that reduced exploitation will likely have positive effects on the harvestable biomass and egg production in observed data from LFA 27 where the MLS was increased from 70mm to 82.5mm over several years. In that instance comparing landings in the 1980s to today reveals that the total numbers of Lobster harvested declined for a similar amount of landings in terms of weight, which agrees with the results of the simulation where lower MLSs were tested. It is worth noting that these and other changes to the management regimes have already taken place and are partly responsible for the positive status of the current fishery.

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.

Framework recommendations

As recommended at the January framework, the additional harvest control measures of window size and maximum size were completed and presented alongside the original MLS and season length scenarios for each LFA (Tables 16–24). Generally the window size and maximum size are more effective in LFAs where growth is faster and Lobster mature later (i.e., LFA 33) compared to LFAs where growth is slower and Lobster mature at smaller sizes (i.e., LFA 27). Maximum size restrictions can increase the numbers of eggs produced but it does not address growth overfishing and always leads to reduction in landings over time.

Implementing *windows as an* HCR is similar to increasing the MLS in that it protects a certain size class of Lobster from harvesting but selects larger Lobster for protection that are capable of carrying more eggs. In areas where Lobster grow quickly (LFA 33) the large window size (20mm) was about as effective as a 10mm increase in the MLS at reducing the numbers of Lobster landed but significantly more effective at increasing egg production (Table 24). In slower growing areas (LFA 27) the window size is less effective at both reducing exploitation and increasing egg production because there are fewer Lobster that reach the window size (Table 16). If this HCR were to be implemented an appropriate window size would have to be determined for each LFA. Implanting window size for females only retains the benefits for egg production but is less effective at reducing exploitation.

Simulation testing of *maximum size* HCR revealed similar effects as the window size but is generally less effective at reducing exploitation and increasing egg production at the sizes tested because relatively few large Lobster survive to reach the maximum size at the current levels of exploitation. Maximum size is also the only HCR that consistently reduces the total landed weight because it doesn’t lead to larger Lobster being harvested. As with the window size measure a maximum size for females only retains the benefits for egg production but is less effective at reducing exploitation.

SOURCES OF UNCERTAINTY

The data sources available for assessing the Lobster stocks in LFA 27–33 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 impacts of predation pressure on Lobster is unknown, however was suspected to be a large 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 is not known, but work from elsewhere suggests climate may be an important driver of population process in Lobster.

RESEARCH RECOMMENDATIONS

Implementing fishery independent data collections would provide a valuable new source of information which would bolster our understanding of stock dynamics and Lobster production. In other areas, bottom trawl surveys have provided a reliable and useful sampling tool (Tremblay et al. 2013; Cook et al. 2017). Although, some Lobster habitats are not fully available to this type of sampling gear, when in high density, Lobster will use a broader range of substrate types, including those areas amenable to bottom trawling. Many of the inshore areas along LFA 27–33 are not suitable to bottom trawling, however, employing a fixed station survey design with a short wing-spread trawl would increase the likelihood of developing a robust index. The advantage of a bottom trawl to trapping study lies in 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 would avoid this potential bias and also allow 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 expand the scope of the studies would improve our understanding of the spatial and temporal variability in Lobster growth, production as well as their connectivity between regions.

The impacts of climate change on Lobster stock productivity has been studied in some regions, and 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, a stock assessment will be conducted in Autumn / Winter of 2018/19 using data to the end of 2018. 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.

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TABLES

Table 1: Numbers (No.) of licenses and management measures in LFAs 27–33 as of Dec. 31, 2016.

LFA	Season	Total No. of licenses	Trap Limit[1]	MLS (mm)	Other Measures
27	May 15–July 15	519[2]	275	82.5	N/A
28	April 30–June 30	14	250	84	Max. hoop size–153 mm
29	April 30–June 30	63	250	84	Max. hoop size–153 mm
30	May 19–July 20	20	250	82.5	Max. carapace length –135mm for females
31A	April 29–June 30	72	250	82.5	Closed window,114–124 mm
31B	April 19–June 20	71	250	82.5	V-notching and release of 110lb of mature females/ licence
32	April 19–June 20	157	250	82.5	V-notching, and release of 110lb of mature females/ licence
33	Last Mon. Nov–May 31	695	250	82.5	N/A

[1] Trap limit is for category “A” licence holder. Part-time or category “B” licences are allowed 30% and Partnerships 150% the limit of a single full-time licence.

[2]481 within Maritimes Region (38 licenses in the Gulf Region)

N/A- not applicable

Table 2: Conservation Measures by LFA combined with year implemented.

LFA	Year	MLS	Other Management Measures
27	1998–2002	70 →76	
	2006–2009	76 →81	
	2013–2015	81 →82.5	
28	1998–1999	81 →84	Trap limit reduced from 275 to 250
29	1998–1999	81 →84	Maximum hoop size of 6" Trap Limit reduced from 275 to 250
30	1998–1999	81 →82.5	Maximum size of females 135mm
31A	1998–2000	81 →86	Window size for females 114–124mm
	2004	86 →84	
	2007	84 →82.5	
31B	1998	81 →82.5	
	1999	82.5 →84	
	2000	84→82.5	v-notched and release 110 lbs females per licence
32	2000	81 →82.5	v-notched and release 110 lbs females per licence
33	1998	81 →82.5	

Table 3: List of lobster assessments in the Maritimes Region for LFAs 27–33 from 1991–2016.

LFA	Publication	1991	1996	1998	2001	2004	2011	2012	2014	2015	2016
27	Stock Status Update		96/116E	98/C3-59		04/032				15/017	
	Research Document		96/141	98/124		04/021 04/046	11/058	12/022 12/028	14/040		
	Stock Advisory Report						11/064				16/025
28	Stock Status Update		96/116E	98/C3-59		04/032				15/017	
	Research Document		96/141	98/124		04/021 04/046	11/058	12/022 12/028	14/040		
	Stock Advisory Report						11/064				16/025
29	Stock Status Update		96/116E	98/C3-59		04/032				15/017	
	Research Document		96/141	98/124		04/021 04/046	11/058	12/022 12/028	14/040		
	Stock Advisory Report						11/064				16/025
30	Stock Status Update		96/116E	98/C3-59		04/032				15/017	
	Research Document		96/141	98/124		04/021 04/046	11/058	12/022 12/028	14/040		
	Stock Advisory Report						11/064				16/025
31A	Stock Status Update		96/117E	98/C3-60		04/033				15/017	
	Research Document	91/21	97/01			04/046 04/038	11/058	12/022 12/028	14/040		
	Stock Advisory Report						11/064				16/025
31B	Stock Status Update		96/117E	98/C3-60		04/033				15/017	
	Research Document	91/21	97/01			04/046 04/038	11/058	12/022 12/028	14/040		
	Stock Advisory Report						11/064				16/025
32	Stock Status Update		96/117E	98/C3-60		04/033				15/017	
	Research Document		97/01			04/046 04/038	11/058	12/022 12/028	14/040		
	Stock Advisory Report						11/064				16/025
33	Stock Status Update		96/117E	98/C3-60						15/017	
	Research Document		97/01		01/019	04/046 04/071	11/058	12/022 12/028	14/040		
	Stock Advisory Report						11/064				16/025

Table 4: At-Sea samples summary data by year and LFA including, total number of trips sampled, numbers of Lobster measured and total numbers of traps sampled for LFA 27–33.

LFA	Year	NWeeks	NTrips	TotalLobster	TotalTraps	LFA	Year	NWeeks	NTrips	TotalLobster	TotalTraps
27	1985	4	6	826	422	31A	2001	4	6	866	1275
27	1986	6	8	3639	2056	31A	2002	5	8	889	1606
27	1990	7	12	8224	2863	31A	2003	4	6	1813	1429
27	1991	6	7	3943	1276	31A	2007	2	2	1885	496
27	1992	2	5	2627	1228	31A	2008	11	25	11357	3158
27	1993	9	33	7134	4194	31A	2009	7	23	13609	4156
27	1994	9	29	14589	7418	31A	2010	7	16	11512	3628
27	1995	2	4	1587	820	31A	2011	7	14	9843	3516
27	1997	2	2	589	493	31A	2012	7	14	8576	3498
27	1999	7	11	4129	2373	31A	2013	6	12	6685	2811
27	2000	4	14	7644	3481	31A	2014	9	11	8063	2747
27	2001	11	11	4833	2368	31A	2015	7	12	8372	2978
27	2002	8	9	4433	2333	31B	1987	1	2	330	353
27	2003	8	9	4247	2179	31B	2002	3	5	774	1025
27	2004	7	9	5489	2428	31B	2003	5	8	1733	1561
27	2005	3	6	2416	1096	31B	2004	1	1	266	237
27	2007	4	5	2095	433	31B	2008	9	59	35997	12868
27	2009	8	45	14232	5651	31B	2009	5	23	9063	2585
27	2010	5	5	2264	288	31B	2010	6	11	7255	2702
27	2011	9	27	14308	6222	31B	2011	5	11	8065	2715
27	2012	9	72	32247	17354	31B	2012	8	23	17498	5678
27	2013	8	68	52815	15763	31B	2013	8	18	11553	4377
27	2014	9	75	55609	15466	31B	2014	7	14	12627	3380
27	2015	9	78	71203	17311	31B	2015	6	16	12319	3738
28	1993	1	2	113	225	32	1987	1	2	310	356
28	2000	3	4	117	357	32	2001	3	8	1810	1884
28	2001	5	7	130	255	32	2002	3	6	841	1445

LFA	Year	NWeeks	NTrips	TotalLobster	TotalTraps	LFA	Year	NWeeks	NTrips	TotalLobster	TotalTraps
29	1990	3	3	511	533	32	2003	4	10	2008	2150
29	1991	2	2	275	318	32	2004	5	12	2077	2652
29	1993	2	2	273	518	32	2009	2	12	1506	1052
29	2000	9	18	1207	3500	32	2010	6	10	2532	2443
29	2008	2	2	456	116	32	2011	7	21	9349	5327
29	2013	1	1	648	232	32	2012	8	32	18607	8321
29	2015	2	2	1745	479	32	2013	9	28	12181	6528
30	1990	1	5	2741	1213	32	2014	6	6	4806	1460
30	1991	1	4	2061	1002	32	2015	5	6	3320	1497
30	1999	6	9	2395	2183	33	1985	6	15	815	446
30	2000	8	20	4664	4825	33	1986	5	15	2873	1355
30	2001	8	20	4477	4914	33	1987	5	12	1802	446
30	2002	2	2	489	494	33	2001	1	3	1171	734
30	2003	2	2	377	479	33	2002	9	10	1889	653
30	2004	2	2	724	481	33	2003	4	10	1960	1629
30	2005	2	2	772	475	33	2004	5	6	707	596
30	2007	2	2	460	254	33	2009	14	148	37761	20160
30	2008	2	2	567	131	33	2010	10	35	3021	1315
30	2009	1	3	1176	463	33	2012	1	1	208	233
30	2012	2	4	2751	630	33	2014	1	3	1122	545
31A	1987	1	2	408	417						

Table 5: Summary of the datasets used for bycatch analysis in LFA 27–33, 2011–2017

LFA	Total # of Samples	# of Samples used	# Lobster Measured	# Bycatch Animals Measured	# Bycatch Animals Counted
27	518	298	367,349	6,018	608
28	0	0	-	-	-
29	8	0	7,017	6	95
30	5	0	3,910	22	37
31A	86	0	63,650	-	1,349
31B	114	39	93,741	1,831	4,682
32	111	96	59,390	7,537	5,955
33	6	0	1,665	76	1,904

Table 6: Summary of FSRS recruitment trap samples by year indicating the number of participants, weeks, grids, Lobster and traps sampled by year and LFA.

LFA	Year	N Participants	NWeeks	N_Grids	TotalLobster	TotalTraps	LFA	Year	N Participants	NWeeks	N_Grids	TotalLobster	TotalTraps
27	2004	29	9	14	12060	4551	31A	2005	6	9	2	1559	440
27	2005	28	10	13	12331	4137	31A	2006	7	9	4	2628	636
27	2006	30	10	13	16863	4781	31A	2007	8	7	3	1838	440
27	2007	30	9	13	13563	4375	31A	2008	7	9	4	2677	643
27	2008	28	9	13	16512	4364	31A	2009	8	9	3	3779	858
27	2009	30	9	13	14275	4474	31A	2010	8	9	3	2981	853
27	2010	28	9	12	14885	4235	31A	2011	8	9	3	2866	793
27	2011	25	9	11	13613	3730	31A	2012	8	9	3	2670	856
27	2012	23	9	11	11434	3604	31A	2013	8	9	3	2604	801
27	2013	20	9	9	14344	2636	31A	2014	8	9	3	3269	833
27	2014	25	9	11	15803	3126	31A	2015	8	9	3	3386	834
27	2015	24	9	12	18862	3453	31B	2004	9	9	5	2384	1000
28	2004	2	9	2	604	295	31B	2005	11	9	6	3425	1127
28	2005	2	9	2	649	300	31B	2006	12	9	6	4804	1278
28	2006	1	9	1	746	145	31B	2007	12	6	6	2894	833
28	2007	1	7	1	262	95	31B	2008	11	9	6	3586	1207
28	2008	1	9	1	354	139	31B	2009	12	9	6	3957	1224
28	2009	1	9	1	798	230	31B	2010	8	9	5	2304	869
28	2010	1	9	1	361	145	31B	2011	8	9	5	2136	845
28	2011	1	9	1	594	230	31B	2012	10	9	5	3102	1108
28	2012	1	9	1	515	245	31B	2013	11	9	5	2686	1094
28	2013	1	9	1	331	150	31B	2014	11	9	5	3253	1115
29	2004	4	9	2	2635	868	31B	2015	12	9	5	3926	1356
29	2005	4	9	2	3490	975	32	2004	14	9	8	1908	1310
29	2006	6	9	3	8411	1605	32	2005	18	9	7	2261	1432
29	2007	8	7	3	8976	1505	32	2006	18	9	7	3343	1719
29	2008	8	9	3	9742	2089	32	2007	18	8	7	1794	1073
29	2009	7	9	3	9004	1778	32	2008	17	9	7	2980	1620
29	2010	7	9	3	7585	1731	32	2009	17	9	7	3396	1626
29	2011	7	9	3	6803	1817	32	2010	16	9	8	2760	1485
29	2012	8	9	3	6764	2233	32	2011	15	9	7	3209	1305
29	2013	8	9	3	6859	2017	32	2012	15	9	8	3789	1399
29	2014	7	10	2	7133	1744	32	2013	13	9	6	2431	842
29	2015	8	9	2	9553	2163	32	2014	15	9	7	4658	1574
30	2004	3	9	2	1405	646	32	2015	15	9	8	3635	1526

LFA	Year	N Participants	NWeeks	N_Grids	TotalLobster	TotalTraps
30	2005	4	9	2	2125	756
30	2006	7	9	3	6217	1478
30	2007	7	9	3	6592	1598
30	2008	6	9	3	6278	1304
30	2009	7	9	3	6708	1570
30	2010	8	9	3	6569	1755
30	2011	8	9	3	6270	1703
30	2012	7	9	3	6395	1695
30	2013	6	9	3	6121	1407
30	2014	6	9	3	6421	1358
30	2015	7	9	3	7371	1585
31A	2004	6	9	3	1206	446

LFA	Year	N Participants	NWeeks	N_Grids	TotalLobster	TotalTraps
33	2004	55	20	20	13872	4552
33	2005	55	20	21	17426	6156
33	2006	52	25	22	18323	6401
33	2007	49	22	23	17040	5600
33	2008	42	22	20	13529	4998
33	2009	45	27	21	18632	5915
33	2010	46	26	24	21416	6083
33	2011	44	26	22	20672	5367
33	2012	41	27	21	19431	5411
33	2013	40	24	21	20108	4811
33	2014	40	27	21	19483	4904
33	2015	39	25	20	19149	4965

Table 7: Size groups of gauges used in the FSRS recruitment and commercial trap projects.

1996–2003		*2003–Current*	
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 FSRS commercial samples by year indicating the number of grids sampled, numbers of Lobster measured and total numbers of trap hauls sampled within LFA 33.

Year	N_Grids	TotalLobster	TotalTraps
2004	18	7116	3179
2005	21	13121	6366
2006	23	13311	6480
2007	24	12634	6016
2008	22	9864	5296
2009	22	13139	6097
2010	27	14550	6503
2011	27	13940	5454
2012	25	17232	6294
2013	25	16398	5014
2014	20	12542	4411
2015	21	16273	5237
2016	23	18747	5103

Table 9: Summary of Port samples by year indicating the number of samples obtained, numbers of Lobster measured and total number of Ports sampled within LFA 27–33.

LFA	Year	NSamples	NWeeks	N_Ports	TotalLobster	LFA	Year	NSamples	NWeeks	N_Ports	TotalLobster
27	1985	45	9	3	5406	31A	2004	9	6	4	2165
27	1987	4	2	1	986	31A	2005	3	3	1	1501
27	1989	34	8	8	5639	31A	2006	9	4	3	3585
27	1990	20	5	8	3063	31A	2007	4	1	4	1085
27	1991	9	5	6	3712	31B	1986	2	2	1	475
27	1994	6	3	2	449	31B	1987	2	2	1	902
27	1995	4	3	2	1131	31B	1988	2	2	1	847
27	1996	56	8	11	13373	31B	1989	2	2	1	743
27	1997	32	6	11	10937	31B	1990	2	2	1	648
27	1998	25	5	10	9633	31B	1992	2	2	1	479
27	1999	26	9	9	9675	31B	1993	2	2	1	686
27	2000	24	6	11	9542	31B	1994	2	2	1	676
27	2001	22	6	9	8140	31B	1996	2	2	1	736
27	2002	10	2	5	4242	31B	1998	2	2	1	764
27	2003	10	4	5	5065	31B	1999	2	2	1	742
27	2004	6	2	3	3112	31B	2000	4	4	1	990
27	2005	4	2	2	1689	31B	2001	2	2	1	859
27	2007	4	3	3	2276	31B	2002	2	2	1	795
27	2008	9	3	5	4342	31B	2003	2	2	1	794
27	2009	9	2	5	4130	31B	2004	3	3	1	1054
29	1985	2	2	1	969	31B	2005	2	2	1	929
29	1989	7	5	2	1535	32	1985	2	2	1	751
29	1990	3	2	2	873	32	1986	3	3	1	687
29	1991	3	3	2	869	32	1987	2	2	1	798
29	1993	5	3	3	1509	32	1988	2	2	1	898
29	1994	11	2	6	2504	32	1989	2	2	1	664
29	1995	4	2	2	1126	32	1990	2	2	1	692
29	1996	4	2	2	1009	32	1991	2	2	1	516
29	1997	4	3	2	1407	32	1992	2	2	1	534
29	1998	62	9	11	7143	32	1993	2	2	1	710
29	1999	6	4	4	1325	32	1994	2	2	1	711
29	2000	18	9	2	4042	32	1996	2	2	1	641
29	2001	6	4	2	1395	32	1998	2	2	1	597
29	2002	3	3	2	1168	32	1999	4	3	2	1295
29	2003	4	2	2	1759	32	2000	7	6	2	1696
29	2004	4	2	3	1509	32	2001	4	4	2	1387
29	2005	2	2	1	1027	32	2002	4	2	2	1532
29	2009	3	2	2	2590	32	2003	4	3	2	1548

LFA	Year	NSamples	NWeeks	N_Ports	TotalLobster	LFA	Year	NSamples	NWeeks	N_Ports	TotalLobster
29	2011	4	1	2	1176	32	2004	3	3	1	1199
30	1993	2	2	1	716	33	1985	11	4	5	3313
30	1994	2	2	1	636	33	1986	8	4	5	3960
30	1995	3	2	1	594	33	1987	17	9	6	6614
30	1996	2	2	1	445	33	1988	15	9	5	5568
30	1998	10	8	2	2802	33	1989	12	7	5	4153
31A	1985	2	2	1	811	33	1990	8	7	4	3148
31A	1986	2	2	1	708	33	1991	7	5	4	2607
31A	1987	2	2	1	860	33	1992	8	4	4	2630
31A	1988	2	2	1	660	33	1993	10	4	5	3534
31A	1989	2	2	1	755	33	1994	7	6	4	2726
31A	1990	2	2	1	715	33	1995	7	4	4	2649
31A	1991	2	2	1	718	33	1996	9	3	4	3598
31A	1992	2	2	1	578	33	1997	8	3	4	3461
31A	1993	2	2	1	601	33	1998	16	7	7	5690
31A	1994	2	2	1	699	33	1999	10	4	6	3895
31A	1998	4	4	1	1149	33	2000	10	2	6	4007
31A	1999	2	2	1	781	33	2001	11	3	7	3876
31A	2000	5	5	1	780	33	2007	5	4	4	2038
31A	2001	4	2	2	985	33	2008	3	1	3	1350
31A	2002	5	3	3	1711	33	2009	8	3	5	3085
31A	2003	6	4	3	1809	33	2010	8	5	5	3410
						33	2011	6	2	6	2623
						33	2012	2	1	2	845
						33	2013	2	1	2	934

Table 10: LFA 27 Annual estimates of bycatch (MT) using an effort based method. Species in bold are the top 5 species for estimated weight caught.

SPECIES	2011	2012	2013	2014	2015	2016
COD(ATLANTIC)	**18.50**	**38.01**	**15.41**	**16.42**	**11.50**	**18.94**
WHITE HAKE	0.00	0.00	0.00	0.00	0.00	0.28
SQUIRREL OR RED HAKE	0.00	0.00	0.00	0.00	0.00	0.17
POLLOCK	0.00	0.04	0.00	0.00	0.00	0.08
TOMCOD(ATLANTIC)	0.55	0.00	0.00	0.00	6.15	0.00
AMERICAN PLAICE	0.00	0.03	0.00	0.00	0.00	0.00
WITCH FLOUNDER	0.00	0.44	0.00	0.14	0.00	0.35
YELLOWTAIL FLOUNDER	0.00	0.87	0.00	0.00	0.04	0.00
WINTER FLOUNDER	0.00	3.06	0.61	2.76	1.86	2.80
STRIPED ATLANTIC WOLFFISH	3.59	0.89	0.00	0.00	1.44	1.96
SPOTTED WOLFFISH	0.00	0.50	0.00	0.00	0.00	0.00
MACKEREL(ATLANTIC)	0.00	0.03	0.00	0.00	0.00	0.00
GREENLAND COD	0.00	0.00	0.00	0.00	3.53	0.00
CUNNER	**1.57**	**6.02**	**3.12**	**5.20**	**10.31**	**17.41**
LONGHORN SCULPIN	1.65	1.78	2.68	3.20	1.43	1.20
SHORTHORN SCULPIN	**14.44**	**55.87**	**12.64**	**33.50**	**21.79**	**28.54**
SEA RAVEN	**0.00**	**5.69**	**1.33**	**6.43**	**7.30**	**21.19**
LUMPFISH	0.00	0.00	3.20	1.52	0.66	0.96
ROCK GUNNEL(EEL)	0.16	0.00	0.05	0.00	0.00	0.00
OCEAN POUT(COMMON)	0.00	0.00	0.63	1.44	1.10	1.63
EELPOUTS(NS)	0.18	0.00	0.00	0.00	0.90	0.00
JONAH CRAB	1.92	0.07	1.06	0.86	0.00	0.01
ATLANTIC ROCK CRAB	**27.94**	**41.79**	**16.93**	**6.92**	**7.13**	**22.89**
SNOW CRAB (QUEEN)	0.00	0.00	0.27	0.00	0.75	0.00
TOAD CRAB	0.83	0.34	14.87	19.47	2.24	0.00
GREEN CRAB	0.00	0.00	0.00	0.00	0.00	0.00
RED DEEPSEA CRAB	0.00	1.00	2.25	0.00	0.00	0.00
AMERICAN LOBSTER	4,498	4,561	7,208	7,559	8,367	8,620

Table 11: LFA 31B Annual estimates of bycatch (MT) using an effort based method. Species in bold are the top 5 species for estimated weight caught.

SPECIES	2011	2012	2013	2014	2015	2016
COD(ATLANTIC)	**0.00**	**0.00**	**4.33**	**11.56**	**29.07**	**18.02**
WINTER FLOUNDER	0.00	0.00	0.00	0.00	0.00	0.09
CUNNER	0.00	0.00	0.22	0.00	0.00	0.55
LONGHORN SCULPIN	0.00	0.00	0.09	0.00	0.05	1.09
SHORTHORN SCULPIN	**0.00**	**0.00**	**3.24**	**4.04**	**22.61**	**25.97**
SEA RAVEN	0.00	0.00	0.00	0.00	0.00	0.47
LUMPFISH	0.00	0.00	0.00	0.00	0.55	0.00
ROCK GUNNEL(EEL)	0.00	0.00	0.00	0.00	0.00	0.00
JONAH CRAB	**35.43**	**16.33**	**2.28**	**1.44**	**0.64**	**0.80**
ATLANTIC ROCK CRAB	**4.88**	**8.52**	**6.96**	**4.19**	**10.09**	**22.55**
SNOW CRAB (QUEEN)	**0.00**	**0.00**	**0.00**	**3.43**	**0.00**	**0.00**
TOAD CRAB	0.00	0.00	0.00	0.23	0.00	0.00
AMERICAN LOBSTER	1,198.23	1,283.87	1,031.41	1,705.00	966.56	1,444.49

Table 12: LFA 32 Annual estimates of bycatch (MT) using an effort based method. Species in bold are the top 5 species for estimated weight caught.

SPECIES	2011	2012	2013	2014	2015	2016
COD(ATLANTIC)	**0.00**	**4.13**	**5.34**	**2.88**	**14.99**	**7.96**
POLLOCK	0.00	0.02	0.33	0.27	0.00	0.00
TOMCOD(ATLANTIC)	0.00	0.00	0.00	0.00	0.00	0.26
AMERICAN PLAICE	0.00	0.00	1.08	0.00	0.00	0.00
WITCH FLOUNDER	0.00	0.00	0.00	0.37	0.00	0.09
YELLOWTAIL FLOUNDER	0.00	0.00	0.00	0.37	0.00	0.00
WINTER FLOUNDER	0.00	0.00	0.33	0.00	4.28	4.38
CUNNER	0.00	0.04	0.14	2.08	1.09	1.81
LONGHORN SCULPIN	**0.00**	**0.58**	**0.88**	**3.06**	**3.88**	**1.30**
SHORTHORN SCULPIN	**0.00**	**4.25**	**10.28**	**10.27**	**19.55**	**23.77**
SEA RAVEN	0.00	0.40	0.93	1.69	1.84	0.00
JONAH CRAB	**57.03**	**59.65**	**19.41**	**1.10**	**0.41**	**5.55**
ATLANTIC ROCK CRAB	**36.49**	**22.07**	**16.08**	**7.85**	**5.54**	**10.65**
TOAD CRAB	0.12	0.02	0.02	0.00	0.00	0.00
GREEN CRAB	2.14	0.00	0.01	0.00	0.00	0.00
AMERICAN LOBSTER	1,225.47	1,824.60	1,325.67	2,728.47	1,928.06	2,545.25

Table 13: Reference (Ref) and exploitable (Exp) class definitions for the CCIR analyses to estimate exploitation rates using the change in proportion of exploitable class compared to reference class Lobster.

LFA	MLS	Year Range	RefLower	RefUpper	ExpLower	ExpUpper	FSRSRefLower	FSRSRefUpper	FSRSExpLower	FSRSExpUpper
27	73	2000	71	73	73	81	8	8	8	9
27	74.5	2001	71	74.5	74.5	81	8	8	8	9
27	76	2002–2006	71	76	76	81	8	8	8	9
27	77.5	2007	71	76	77.5	81	8	8	9	9
27	79	2008	71	76	79	90	8	8	9	10
27	81	2009–2013	71	81	81	90	8	9	10	10
27	82.5	2014–2016	71	81	82.5	90	8	9	10	10
29	84	2000–2016	76	84	85	90	9	10	10	10
30	82.5	2000–2016	76	82.5	83	90	9	10	10	10
31A	86	2000–2003	76	81	86	90	9	9	10	10
31A	84	2004–2006	76	81	84	90	9	9	10	10
31A	82.5	2007–2016	76	81	84	90	9	9	10	10
31B	82.5	2000–2016	76	81	84	90	9	9	10	10
32	82.5	2000–2016	76	81	82	90	9	9	10	10
33	82.5	2000–2016	76	81	82	90	9	9	10	10

Table 14: Summary statistics from CCIR binomial models for LFA 27–33. Nref refers to the number of reference class lobster, Nexp the number of exploited class Lobster. Exploitation estimates were given as ERfl, ERfu, ERfm and Erf75 which represent the lower and upper 95th credible intervals, the median of the posterior and the 75th quantile of the posterior distributions. Ndates represent the number of sampling dates used in the analyses. wAIC was the 'widely-applicable' information criteria.

LFA	Yr	Acceptance.rate	NRef	NExp	ERfl	ERfm	ERfu	ERf75	Ndates	wAIC
27S	2000	0.936	315	871	0.713	0.813	0.881	0.839	41	196.77
27S	2001	0.932	465	831	0.529	0.676	0.781	0.715	47	221.09
27S	2002	0.944	561	492	0.420	0.614	0.751	0.667	45	203.70
27S	2003	0.934	735	529	0.618	0.742	0.832	0.776	49	248.88
27S	2004	0.933	699	489	0.505	0.668	0.785	0.713	49	233.82
27S	2005	0.933	745	541	0.714	0.810	0.881	0.837	49	209.73
27S	2006	0.935	1064	722	0.643	0.747	0.823	0.775	49	241.05
27S	2007	0.940	1206	534	0.546	0.685	0.785	0.723	49	238.35
27S	2008	0.941	1283	1462	0.648	0.733	0.800	0.758	51	279.54
27S	2009	0.939	2206	812	0.681	0.762	0.829	0.787	48	258.01
27S	2010	0.924	2086	910	0.583	0.683	0.764	0.713	50	266.32
27S	2011	0.932	1893	827	0.573	0.684	0.770	0.716	49	241.35
27S	2012	0.938	1655	618	0.315	0.497	0.634	0.547	50	281.25
27S	2013	0.937	3062	1030	0.710	0.778	0.835	0.799	44	259.27
27S	2014	0.948	3157	1117	0.732	0.793	0.842	0.812	53	329.70
27S	2015	0.943	3229	1377	0.718	0.778	0.829	0.797	55	325.65
27S	2016	0.927	3839	1459	0.674	0.740	0.794	0.760	53	354.98
27N	2000	0.945	189	488	0.842	0.915	0.957	0.932	36	131.58
27N	2001	0.954	411	613	0.642	0.771	0.859	0.805	45	233.22
27N	2002	0.928	477	322	0.833	0.909	0.958	0.928	39	167.05
27N	2003	0.928	1128	789	0.694	0.779	0.845	0.803	48	247.13
27N	2004	0.925	1269	753	0.774	0.839	0.890	0.857	51	249.82
27N	2005	0.934	1295	653	0.749	0.825	0.882	0.846	50	265.79
27N	2006	0.932	1331	833	0.695	0.779	0.846	0.804	49	267.36
27N	2007	0.924	961	237	0.620	0.775	0.877	0.815	44	200.53
27N	2008	0.931	1730	1201	0.843	0.884	0.917	0.897	53	308.04

LFA	Yr	Acceptance.rate	NRef	NExp	ERfl	ERfm	ERfu	ERf75	Ndates	wAIC
27N	2009	0.944	2415	747	0.713	0.789	0.851	0.811	51	290.99
27N	2010	0.918	2538	739	0.804	0.860	0.905	0.877	51	276.96
27N	2011	0.928	2457	803	0.614	0.716	0.788	0.743	50	281.26
27N	2012	0.942	1766	607	0.839	0.894	0.935	0.909	51	265.33
27N	2013	0.921	1650	446	0.707	0.805	0.876	0.833	43	218.19
27N	2014	0.933	2151	529	0.726	0.807	0.872	0.832	49	249.40
27N	2015	0.935	2011	469	0.493	0.646	0.758	0.689	50	264.34
27N	2016	0.944	1260	456	0.662	0.774	0.856	0.806	45	225.11
29	2004	0.922	488	232	0.439	0.684	0.830	0.744	38	157.17
29	2005	0.929	1013	259	0.865	0.927	0.968	0.943	53	214.43
29	2006	0.927	2161	1135	0.720	0.788	0.842	0.809	61	342.11
29	2007	0.918	2148	1271	0.504	0.610	0.698	0.643	45	272.98
29	2008	0.945	2528	1520	0.370	0.494	0.596	0.531	61	324.52
29	2009	0.938	2387	1678	0.587	0.669	0.739	0.695	60	337.36
29	2010	0.934	2180	1319	0.334	0.478	0.592	0.519	61	368.75
29	2011	0.933	1801	1027	0.336	0.495	0.615	0.539	59	303.03
29	2012	0.934	1725	975	0.559	0.670	0.755	0.702	61	311.23
29	2013	0.928	1487	855	0.122	0.334	0.505	0.400	59	292.53
29	2014	0.921	1639	866	0.745	0.815	0.869	0.834	59	312.92
29	2015	0.932	2739	1089	0.554	0.649	0.728	0.678	58	331.72
29	2016	0.927	2788	1121	0.704	0.772	0.825	0.792	60	320.22
30	2004	0.897	92	72	-0.359	0.490	0.822	0.644	13	61.34
30	2005	0.934	444	286	0.330	0.608	0.775	0.675	39	164.48
30	2006	0.944	1129	1421	0.328	0.483	0.602	0.527	51	286.02
30	2007	0.934	1069	1455	0.655	0.742	0.806	0.766	51	286.95
30	2008	0.929	1008	1666	0.668	0.749	0.815	0.773	52	308.97
30	2009	0.944	1082	1685	0.054	0.277	0.448	0.341	51	264.99
30	2010	0.904	1094	1369	0.467	0.596	0.693	0.633	52	291.96
30	2011	0.913	1029	1198	0.320	0.484	0.612	0.532	49	275.37
30	2012	0.937	1007	1083	0.310	0.480	0.611	0.531	54	332.64

LFA	Yr	Acceptance.rate	NRef	NExp	ERfl	ERfm	ERfu	ERf75	Ndates	wAIC
30	2013	0.925	1013	807	0.301	0.488	0.627	0.541	51	254.93
30	2014	0.938	969	1016	-0.167	0.132	0.357	0.216	54	289.59
30	2015	0.924	1464	1188	0.226	0.409	0.551	0.463	53	311.58
30	2016	0.925	1684	1861	0.146	0.317	0.457	0.368	57	328.89
31a	2004	0.886	101	56	0.470	0.827	0.967	0.892	13	51.19
31A	2005	0.936	137	186	0.600	0.818	0.926	0.864	24	90.09
31A	2006	0.924	394	435	0.431	0.648	0.785	0.702	50	234.15
31A	2007	0.919	285	383	0.500	0.712	0.846	0.764	37	157.44
31A	2008	0.935	381	554	0.388	0.612	0.759	0.669	56	243.44
31A	2009	0.938	565	940	0.565	0.699	0.796	0.737	60	284.43
31A	2010	0.939	397	795	0.712	0.821	0.889	0.847	58	261.29
31A	2011	0.922	418	719	0.479	0.661	0.785	0.709	54	236.49
31A	2012	0.927	394	552	0.473	0.663	0.791	0.712	56	227.99
31A	2013	0.941	358	457	0.138	0.454	0.662	0.539	48	205.06
31A	2014	0.937	379	467	0.427	0.649	0.793	0.704	54	248.00
31A	2015	0.933	483	602	0.107	0.407	0.613	0.488	57	246.52
31A	2016	0.930	675	692	0.581	0.716	0.815	0.753	57	248.24
31B	2002	0.920	86	125	0.240	0.681	0.872	0.762	18	80.13
31B	2003	0.921	230	198	0.334	0.648	0.826	0.719	33	118.58
31B	2004	0.916	285	273	-0.267	0.279	0.592	0.410	36	154.25
31B	2005	0.920	543	643	0.517	0.680	0.794	0.723	53	217.80
31B	2006	0.921	822	962	0.674	0.770	0.842	0.797	58	275.90
31B	2007	0.945	492	589	0.347	0.568	0.717	0.624	38	179.72
31B	2008	0.943	523	846	0.650	0.766	0.849	0.798	56	256.47
31B	2009	0.942	561	894	0.319	0.529	0.678	0.585	57	267.16
31B	2010	0.941	193	340	0.031	0.451	0.695	0.556	39	161.06
31B	2011	0.930	277	321	0.616	0.782	0.881	0.821	41	189.86
31B	2012	0.934	537	578	0.155	0.426	0.615	0.499	57	275.24
31B	2013	0.931	384	513	0.002	0.364	0.596	0.454	45	213.84
31B	2014	0.932	505	596	0.359	0.574	0.719	0.631	53	229.43

LFA	Yr	Acceptance.rate	NRef	NExp	ERfl	ERfm	ERfu	ERf75	Ndates	wAIC
31B	2015	0.930	612	737	0.232	0.466	0.639	0.529	59	267.25
31B	2016	0.939	757	997	0.659	0.755	0.828	0.783	59	294.78
32	2000	0.875	71	124	0.724	0.900	0.972	0.932	16	64.27
32	2002	0.911	73	96	0.195	0.715	0.913	0.807	14	55.91
32	2003	0.929	90	118	-0.397	0.430	0.766	0.579	16	72.10
32	2004	0.923	121	131	0.107	0.602	0.834	0.705	18	73.52
32	2005	0.932	227	271	0.518	0.739	0.863	0.788	35	149.68
32	2006	0.928	422	507	0.457	0.645	0.778	0.696	50	246.78
32	2007	0.929	220	194	0.417	0.705	0.867	0.773	29	112.12
32	2008	0.937	330	448	0.153	0.481	0.686	0.562	42	175.88
32	2009	0.940	451	443	0.381	0.604	0.760	0.663	50	207.96
32	2010	0.928	284	329	0.517	0.715	0.839	0.766	41	171.32
32	2011	0.929	443	474	0.577	0.729	0.832	0.769	49	215.04
32	2012	0.925	704	475	0.718	0.819	0.889	0.845	56	252.63
32	2013	0.923	368	305	0.416	0.660	0.803	0.716	37	152.37
32	2014	0.940	867	818	0.499	0.641	0.744	0.679	59	285.52
32	2015	0.930	553	616	0.283	0.511	0.672	0.574	53	218.04
32	2016	0.940	588	671	0.504	0.663	0.774	0.706	56	262.48
33W	2000	0.931	1183	809	0.742	0.818	0.874	0.839	72	366.61
33W	2001	0.912	1405	851	0.654	0.744	0.815	0.769	71	344.52
33W	2002	0.943	2109	1282	0.744	0.802	0.852	0.820	91	414.55
33W	2003	0.932	1531	1155	0.204	0.384	0.528	0.438	66	336.73
33W	2004	0.921	1942	1161	0.740	0.801	0.851	0.819	70	369.44
33W	2005	0.931	2214	1232	0.567	0.660	0.737	0.687	72	366.95
33W	2006	0.933	2587	1184	0.783	0.835	0.876	0.850	82	403.18
33W	2007	0.934	2417	1305	0.769	0.823	0.865	0.839	75	371.60
33W	2008	0.923	1940	890	0.569	0.674	0.757	0.705	72	365.90
33W	2009	0.934	2539	1179	0.676	0.750	0.809	0.772	90	440.11
33W	2010	0.935	3570	1607	0.542	0.627	0.701	0.653	95	495.63
33W	2011	0.932	2914	1465	0.796	0.841	0.878	0.854	88	471.14

LFA	Yr	Acceptance.rate	NRef	NExp	ERfl	ERfm	ERfu	ERf75	Ndates	wAIC
33W	2012	0.940	2459	1201	0.753	0.809	0.856	0.826	103	480.42
33W	2013	0.928	2828	1603	0.686	0.747	0.799	0.766	86	478.95
33W	2014	0.943	3004	1614	0.466	0.560	0.641	0.590	91	506.79
33W	2015	0.934	2699	1502	0.524	0.621	0.698	0.650	92	522.99
33W	2016	0.921	3093	2006	0.281	0.410	0.518	0.449	100	558.27
33E	2000	0.937	295	302	0.677	0.815	0.902	0.850	31	156.24
33E	2001	0.929	210	211	0.537	0.771	0.901	0.823	18	79.44
33E	2001	0.925	228	253	0.063	0.469	0.714	0.567	17	98.95
33E	2003	0.936	381	345	0.544	0.722	0.838	0.766	34	138.30
33E	2004	0.922	262	202	0.519	0.747	0.879	0.801	19	79.63
33E	2005	0.928	484	410	0.761	0.855	0.918	0.879	35	161.38
33E	2006	0.947	783	520	0.462	0.631	0.749	0.677	58	285.17
33E	2007	0.935	864	704	0.586	0.705	0.793	0.738	54	234.00
33E	2008	0.937	640	522	0.382	0.576	0.713	0.629	52	226.41
33E	2009	0.934	964	595	0.647	0.755	0.836	0.784	59	264.99
33E	2010	0.934	873	549	0.554	0.693	0.796	0.732	53	224.14
33E	2011	0.945	1172	735	0.526	0.652	0.750	0.690	66	301.56
33E	2012	0.920	1598	1028	0.491	0.606	0.698	0.640	72	370.20
33E	2013	0.923	1289	921	0.493	0.618	0.718	0.655	68	317.19
33E	2014	0.938	1242	880	0.260	0.444	0.586	0.498	66	329.80
33E	2015	0.933	1269	1195	0.344	0.497	0.619	0.542	72	343.53
33E	2016	0.932	1597	1220	0.559	0.660	0.741	0.690	82	393.61

Table 15: Current upper stock (USR) and limit reference (LRP) points for LFA 27–33.

LFA	USR	LRP
27	1629	814
28–29	120	
30	79	40
31	250	125
32	242	121
33	1838	919

Table 16: Percent change in egg production, numbers and weight of Lobster landed with various harvest controls for LFA 27N.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase Minimum Legal Size	90 mm	90	-9	17
	87.5 mm	50	-5	10
	85 mm	31	-4	7
Shorter season	50%	113	-8	14
	60%	72	-5	10
	70%	45	-3	7
	80%	25	-2	3
	90%	11	-1	1
Window size	105–125 mm	62	-2	4
	115–125 mm	11	0	1
Females only	105–125 mm	62	-1	0
	115–125 mm	11	0	0
Maximum legal size	135 mm	2	0	-1
	130 mm	4	0	-2
	125 mm	10	-1	-3
Females only	135 mm	2	0	0
	130 mm	4	0	0
	125 mm	10	0	-1

Table 17: Percent change in egg production, numbers and weight of Lobster landed with various harvest controls for LFA 27S.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase Minimum Legal Size	90 mm	76	-9	16
	87.5 mm	43	-5	9
	85 mm	25	-4	6
Shorter season	50%	114	-9	14
	60%	74	-6	10
	70%	47	-4	7
	80%	26	-2	3
	90%	11	-1	2
Window size	105–125 mm	63	-3	5
	115–125 mm	13	-1	1
Females only	105–125 mm	63	-2	0
	115–125 mm	13	0	0
Maximum legal size	135 mm	2	0	-2
	130 mm	5	-1	-3
	125 mm	11	-1	-4
Females only	135 mm	2	0	0
	130 mm	5	0	-1
	125 mm	11	0	-1

Table 18: Percent change in egg production, numbers and weight of Lobster landed with various harvest controls for LFA 29.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase Minimum Legal Size	90 mm	76	-9	15
	87.5 mm	43	-5	9
	85 mm	24	-3	6
Shorter season	50%	168	-11	16
	60%	110	-8	11
	70%	69	-5	7
	80%	38	-3	4
	90%	17	-1	2
Window size	105–125 mm	90	-4	6
	115–125 mm	21	-1	1
Females only	105–125 mm	90	-2	0
	115–125 mm	21	0	0
Maximum legal size	135 mm	6	-1	-3
	130 mm	11	-1	-5
	125 mm	22	-2	-7
Females only	135 mm	6	0	-1
	130 mm	11	0	-1
	125 mm	22	-1	-2

Table 19: Percent change in egg production, numbers and weight of Lobster landed with various harvest controls for LFA 30.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase Minimum Legal Size	90 mm	43	-10	11
	87.5 mm	26	-6	7
	85 mm	14	-4	4
Shorter season	50%	90	-16	7
	60%	64	-11	6
	70%	43	-8	5
	80%	26	-5	3
	90%	12	-2	1
Window size	105–125 mm	55	-7	3
	115–125 mm	16	-2	1
Females only	105–125 mm	55	-5	-3
	115–125 mm	16	-1	-1
Maximum legal size	135 mm	3	-2	-8
	130 mm	7	-3	-10
	125 mm	13	-5	-14
Females only	135 mm	3	-1	-2
	130 mm	7	-1	-3
	125 mm	13	-2	-4

Table 20: Percent change in egg production, numbers and weight of Lobster landed with various harvest controls for LFA 31A.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase Minimum Legal Size	90 mm	74	-9	15
	87.5 mm	42	-5	9
	85 mm	23	-3	6
Shorter season	50%	160	-11	15
	60%	105	-7	11
	70%	66	-5	7
	80%	37	-3	4
	90%	16	-1	2
Window size	105–125 mm	88	-4	6
	115–125 mm	21	-1	1
Females only	105–125 mm	88	-2	0
	115–125 mm	21	0	0
Maximum legal size	135 mm	5	-1	-3
	130 mm	11	-1	-5
	125 mm	21	-2	-7
Females only	135 mm	5	0	-1
	130 mm	11	0	-1
	125 mm	21	-1	-2

Table 21: Percent change in egg production, numbers and weight of Lobster landed with various harvest controls for LFA 31B.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase Minimum Legal Size	90 mm	60	-8	14
	87.5 mm	35	-5	9
	85 mm	18	-3	5
Shorter season	50%	186	-13	16
	60%	128	-9	12
	70%	84	-6	8
	80%	48	-4	5
	90%	21	-2	2
Window size	105–125 mm	116	-5	7
	115–125 mm	32	-1	2
Females only	105–125 mm	116	-3	0
	115–125 mm	32	-1	0
Maximum legal size	135 mm	12	-2	-7
	130 mm	23	-3	-10
	125 mm	40	-5	-13
Females only	135 mm	12	-1	-2
	130 mm	23	-1	-2
	125 mm	40	-2	-4

Table 22: Percent change in egg production, numbers and weight of Lobster landed with various harvest controls for LFA 32.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase Minimum Legal Size	90 mm	76	-7	16
	87.5 mm	42	-4	10
	85 mm	22	-3	6
Shorter season	50%	234	-10	18
	60%	157	-7	13
	70%	100	-5	9
	80%	56	-3	5
	90%	24	-1	2
Window size	105–125 mm	147	-4	8
	115–125 mm	37	-1	2
Females only	105–125 mm	147	-3	0
	115–125 mm	37	-1	0
Maximum legal size	135 mm	14	-1	-5
	130 mm	28	-2	-7
	125 mm	50	-3	-10
Females only	135 mm	14	0	-1
	130 mm	28	-1	-2
	125 mm	50	-1	-2

Table 23: Percent change in egg production, numbers and weight of Lobster landed with various harvest controls for LFA 33E.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase Minimum Legal Size	90 mm	62	6	16
	87.5 mm	35	-4	10
	85 mm	18	-2	6
Shorter season	50%	346	-11	24
	60%	218	-7	17
	70%	132	-5	11
	80%	71	-3	7
	90%	28	-1	3
Window size	105–125 mm	224	-5	11
	115–125 mm	62	-1	3
Females only	105–125 mm	224	-3	1
	115–125 mm	62	-1	0
Maximum legal size	135 mm	39	-2	-9
	130 mm	70	-4	-11
	125 mm	120	-5	-15
Females only	135 mm	39	0	-1
	130 mm	70	-1	-2
	125 mm	120	-1	-3

Table 24: Percent change in egg production, numbers and weight of Lobster landed with various harvest controls for LFA 33W.

Harvest Control		Eggs produced	Numbers landed	Weight landed
Increase Minimum Legal Size	90 mm	85	-6	18
	87.5 mm	46	-4	11
	85 mm	25	-2	7
Shorter season	50%	434	-9	21
	60%	262	-6	15
	70%	154	-4	10
	80%	80	-2	5
	90%	31	-1	2
Window size	105–125 mm	293	-3	9
	115–125 mm	67	-1	2
Females only	105–125 mm	293	-2	1
	115–125 mm	67	0	0
Maximum legal size	135 mm	30	-1	-4
	130 mm	59	-2	-6
	125 mm	108	-3	-8
Females only	135 mm	30	0	-1
	130 mm	59	0	-1
	125 mm	108	-1	-2

FIGURES

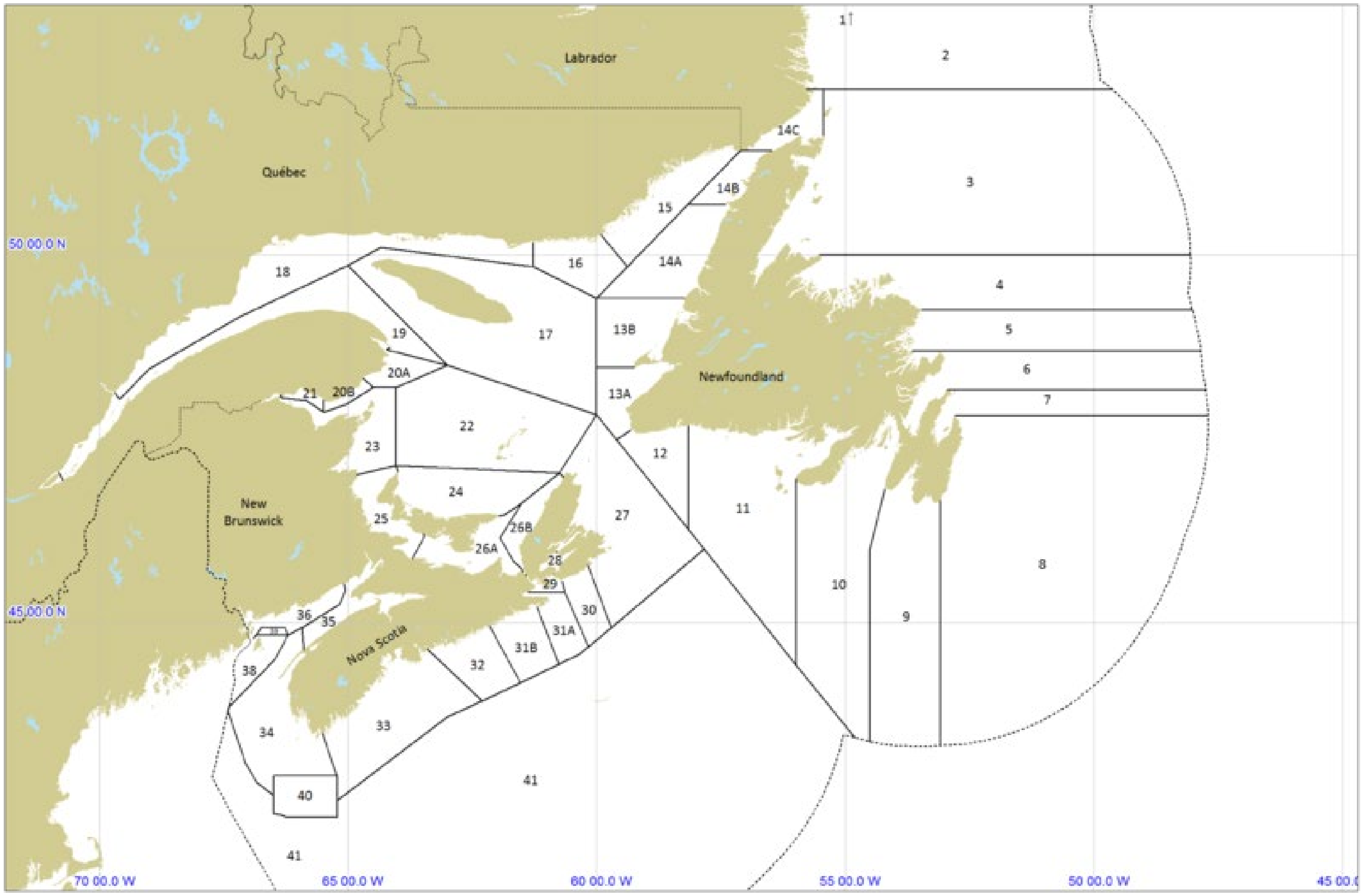


Figure 1: Map of the Lobster Fishing Areas in Atlantic Canada using the boundaries identified in the Atlantic fishery regulations.

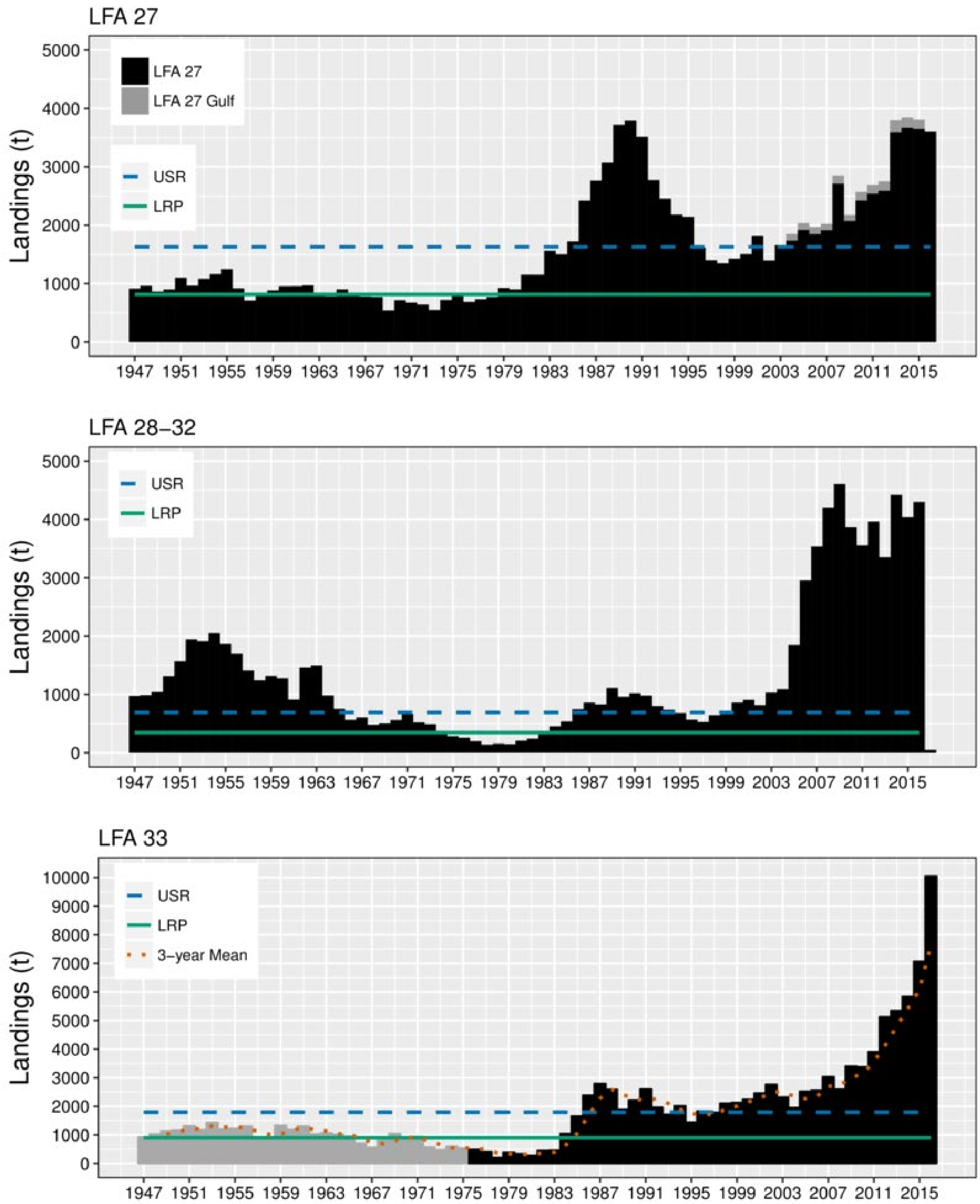


Figure 2: Time series of Lobster landings by LFA.

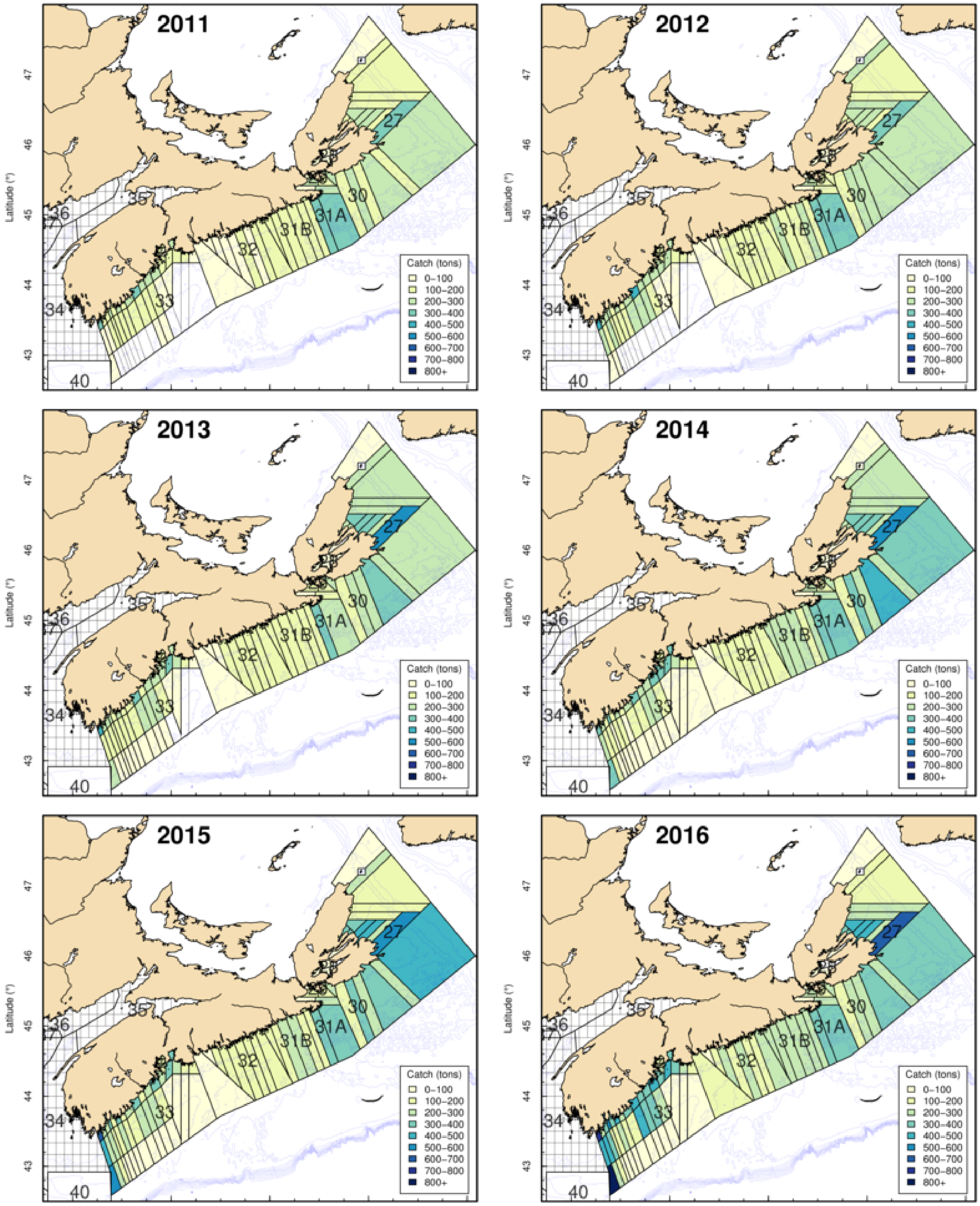


Figure 3: Map of the fishery footprint expressed as the amount of landings in each grid of LFAs 27–33 from 2011–2016.

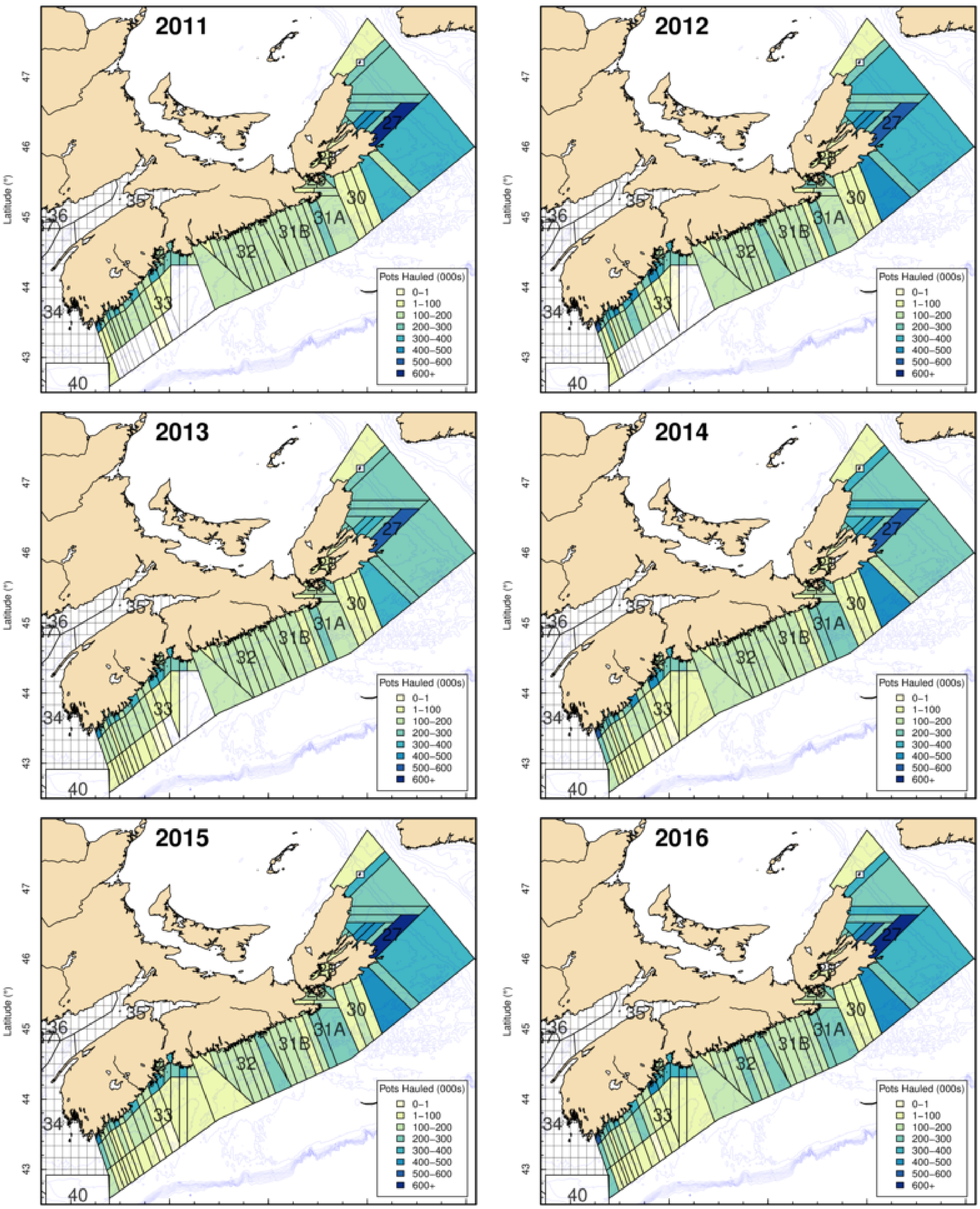


Figure 4: Map of the fishery footprint expressed as the amount of effort in each grid of LFAs 27–33 from 2011–2016.

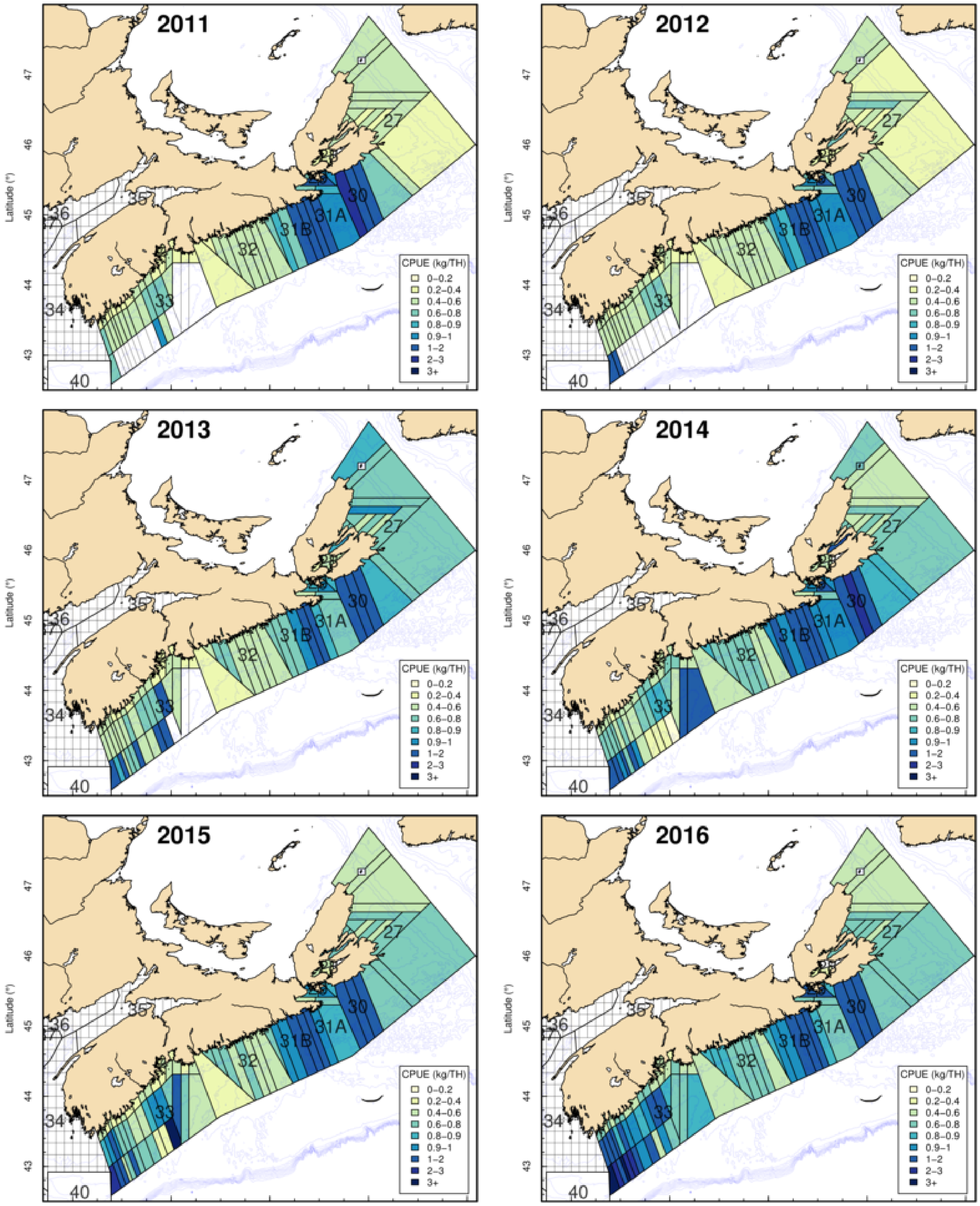


Figure 5: Map of the fishery footprint expressed as the amount of CPUE in each grid of LFAs 27–33 from 2011–2016.

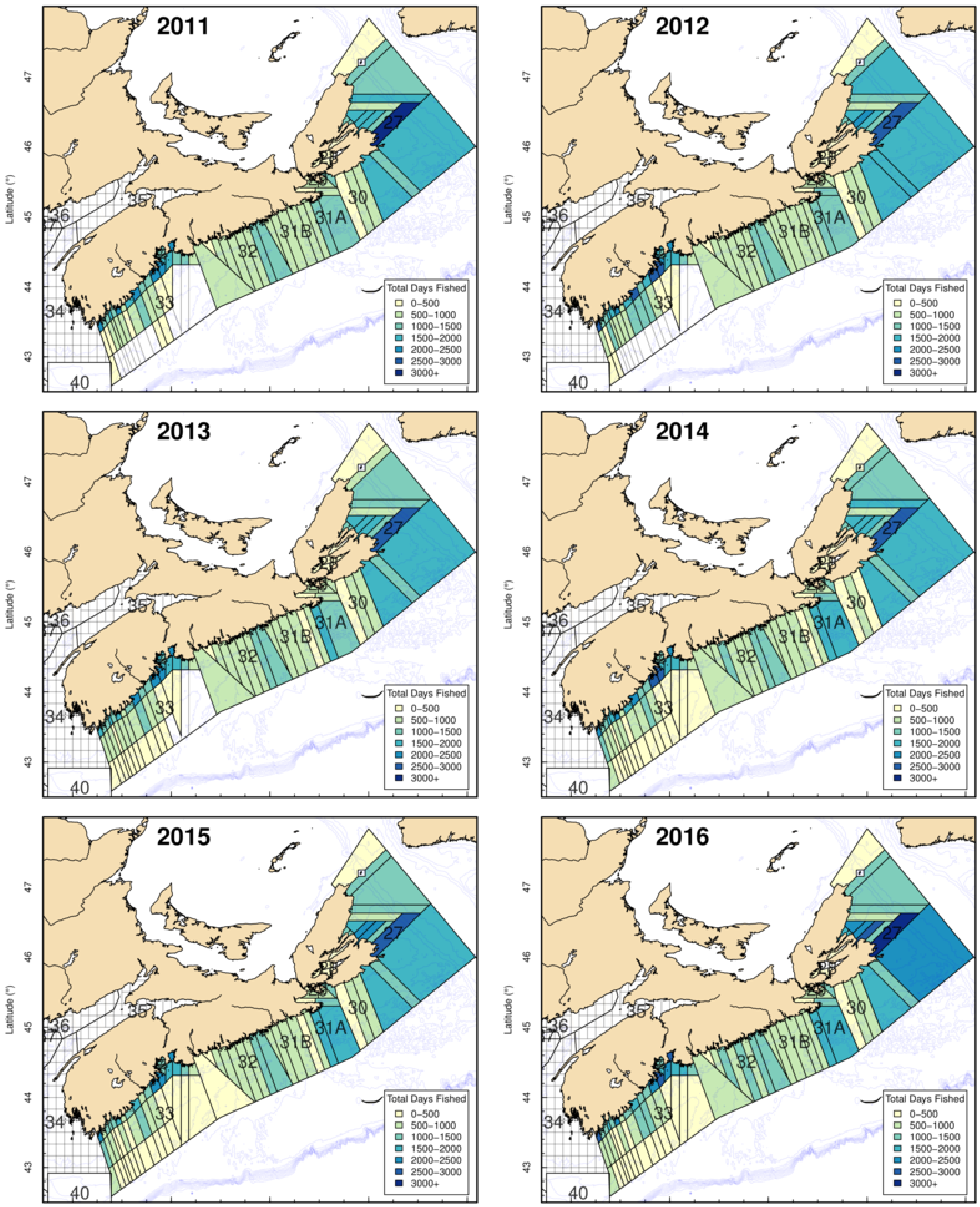


Figure 6: Map of the fishery footprint expressed as the amount of days fished in each grid of LFAs 27–33 from 2011–2016.

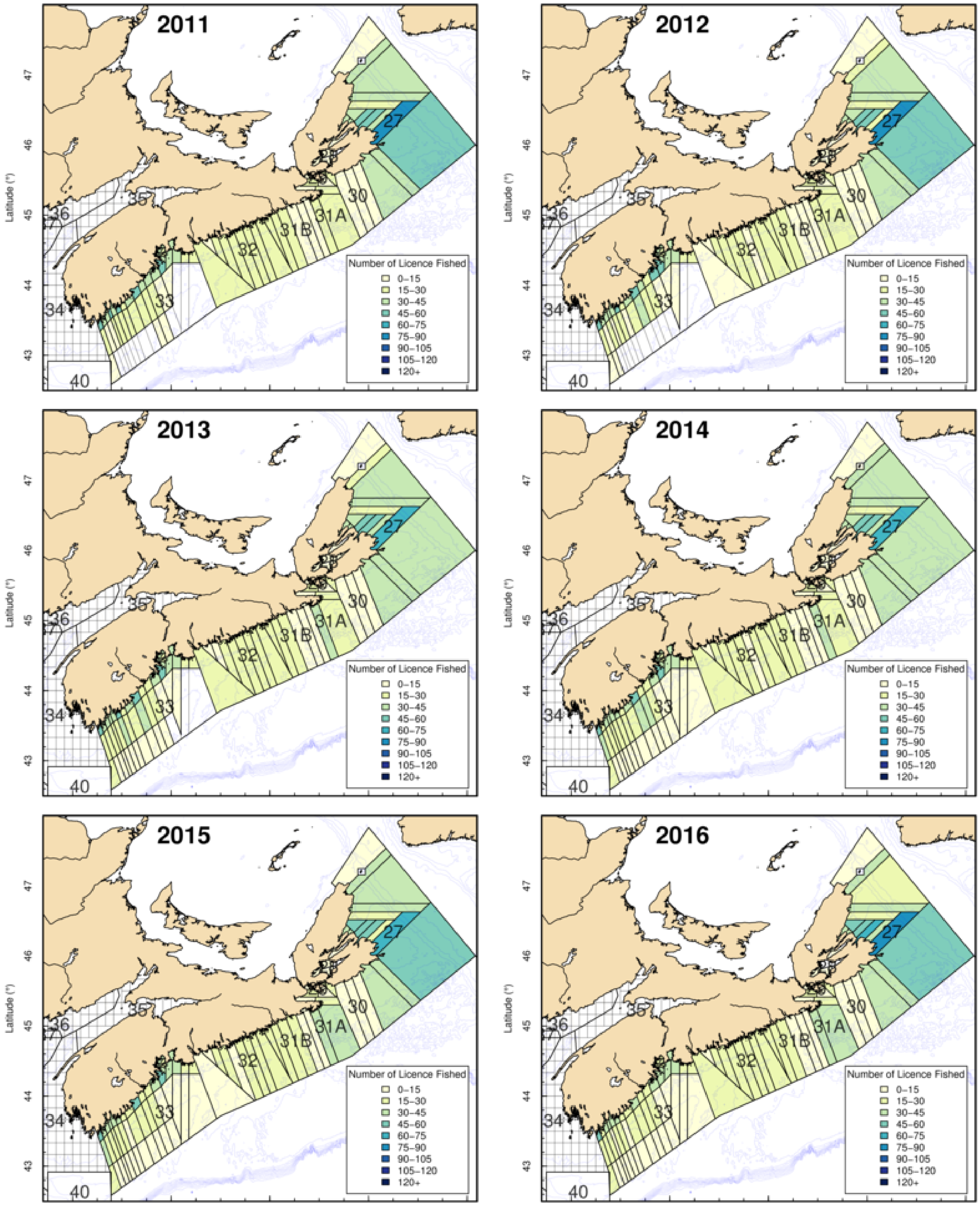


Figure 7: Map of the fishery footprint expressed as the amount of licenses in each grid of LFAs 27–33 from 2011–2016.

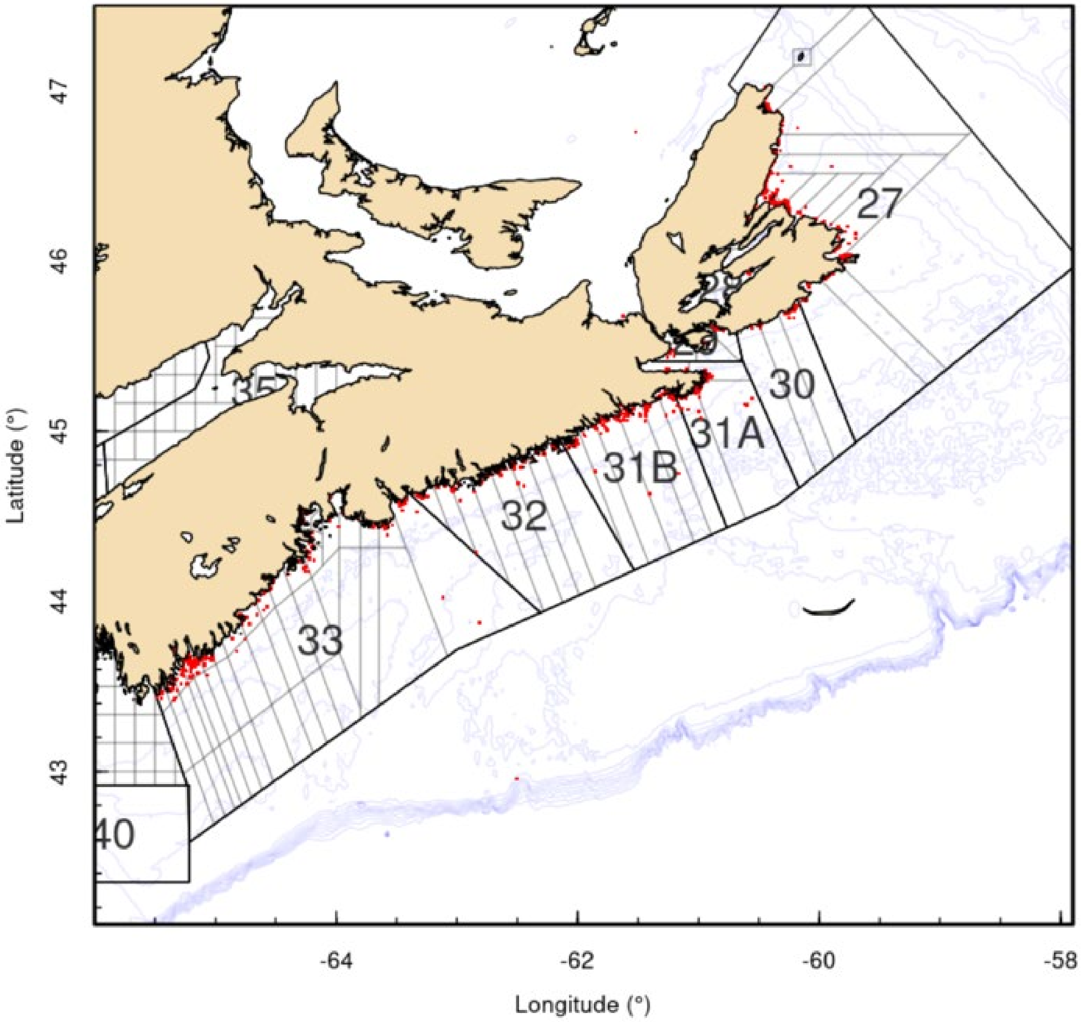


Figure 8: Centroid of the at sea sampling trips across LFA 27–33 between 1977 and current.

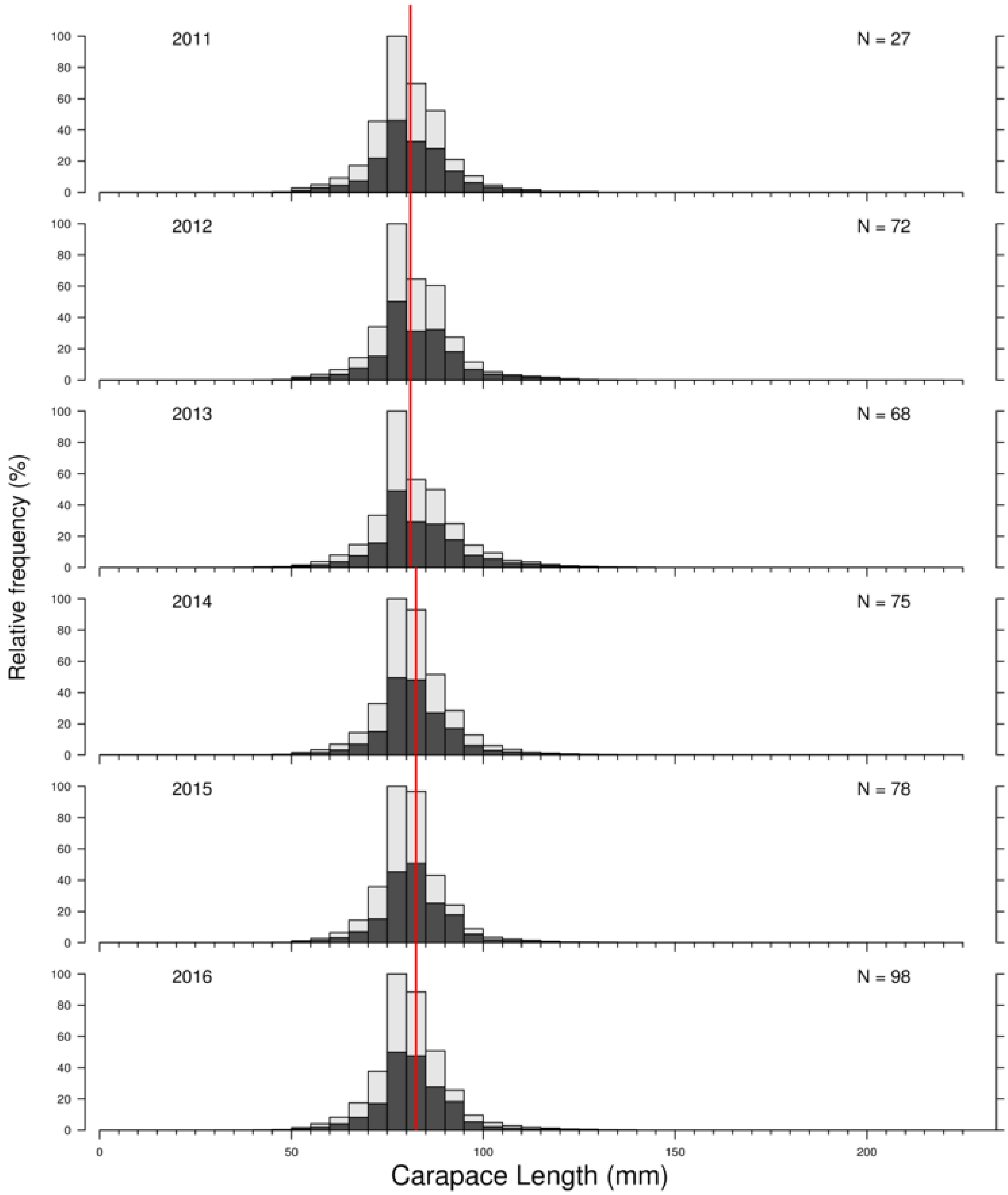


Figure 9: Carapace Length Frequencies from at sea sampling in LFA 27. Dark grey: males, light grey: females, red line: MLS.

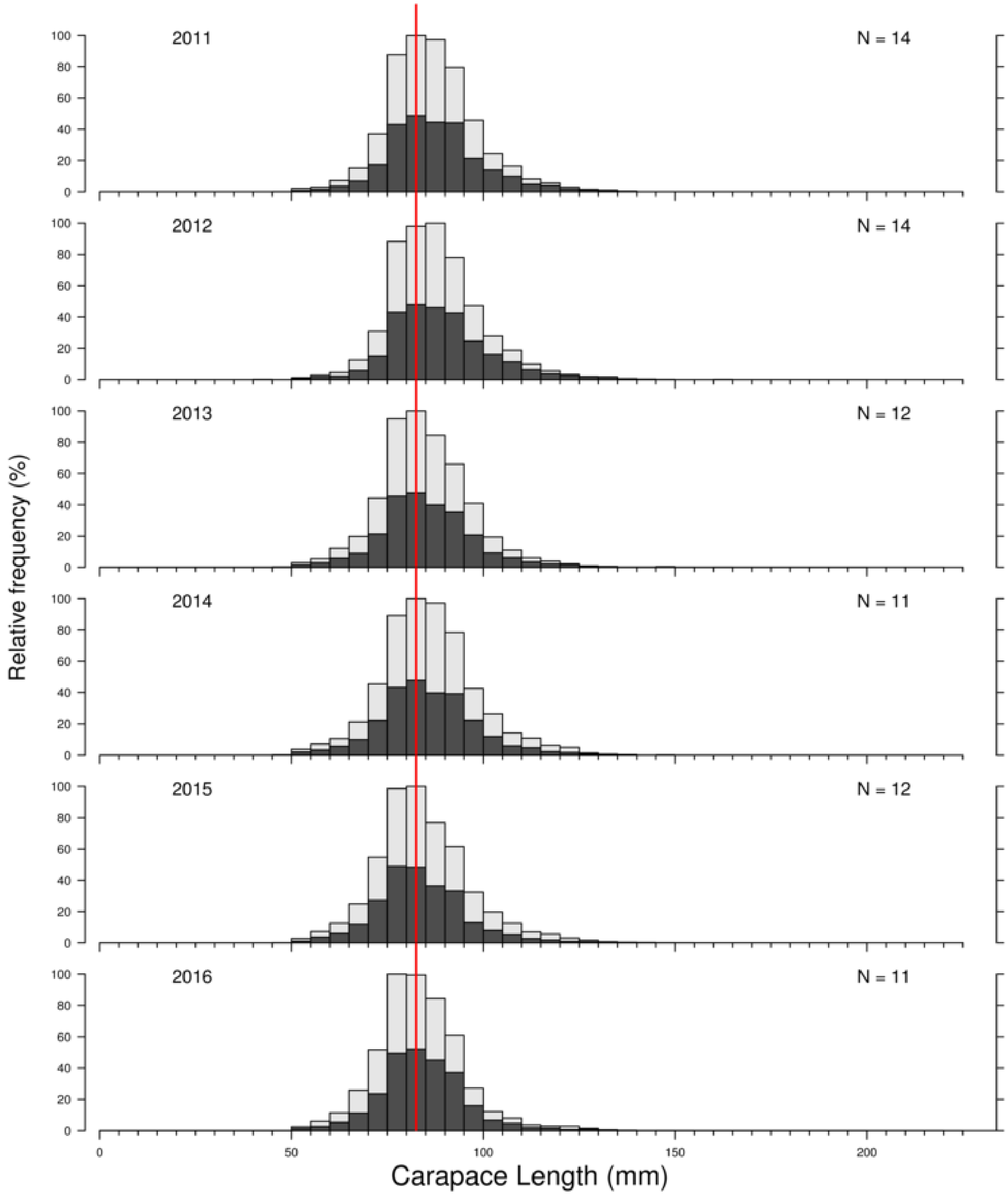


Figure 10: Carapace Length Frequencies from at sea sampling in LFA 31A. Dark grey: males, light grey: females, red line: MLS.

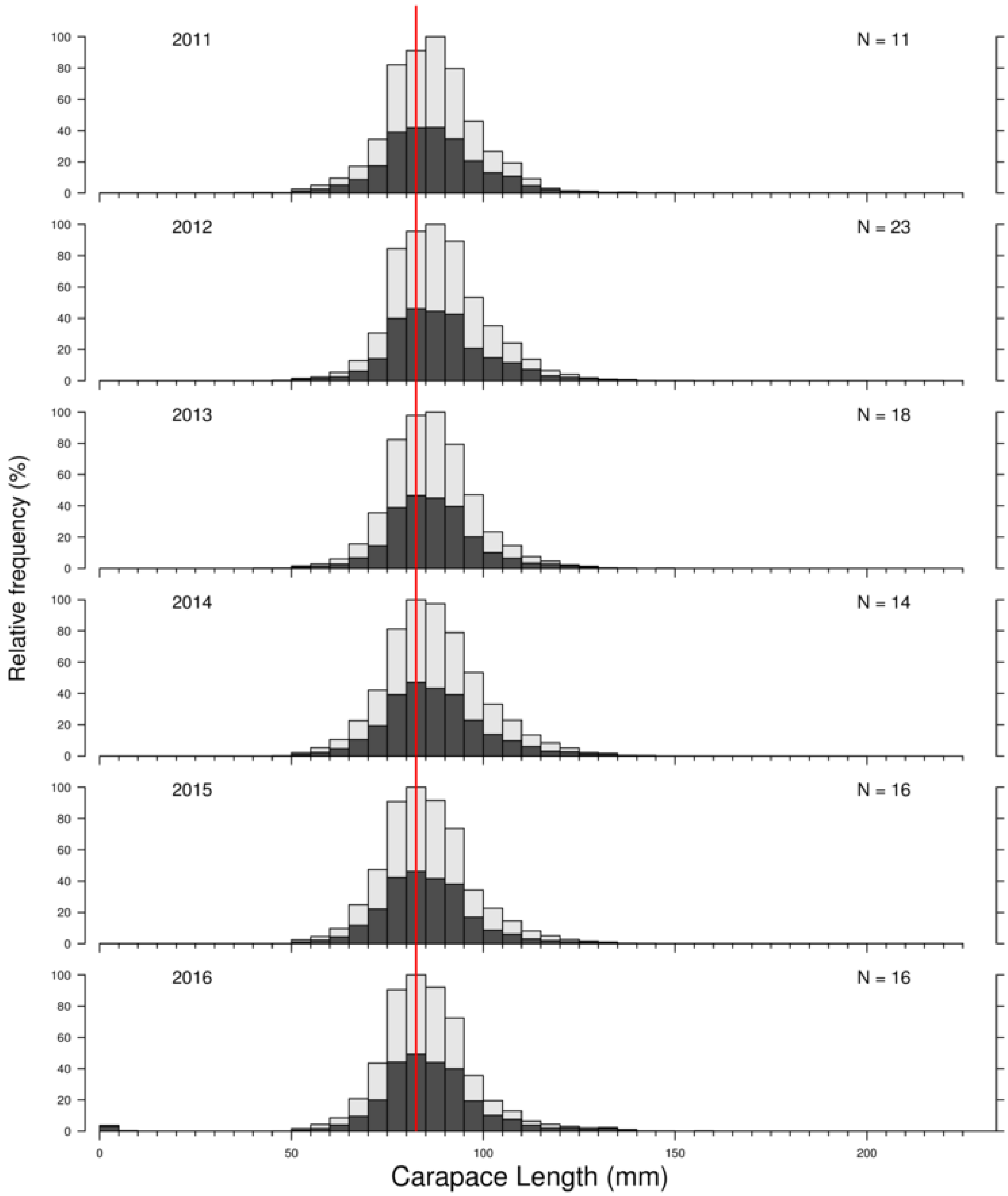


Figure 11: Carapace Length Frequencies from at sea sampling in LFA 31B. Dark grey: males, light grey: females, red line: MLS.

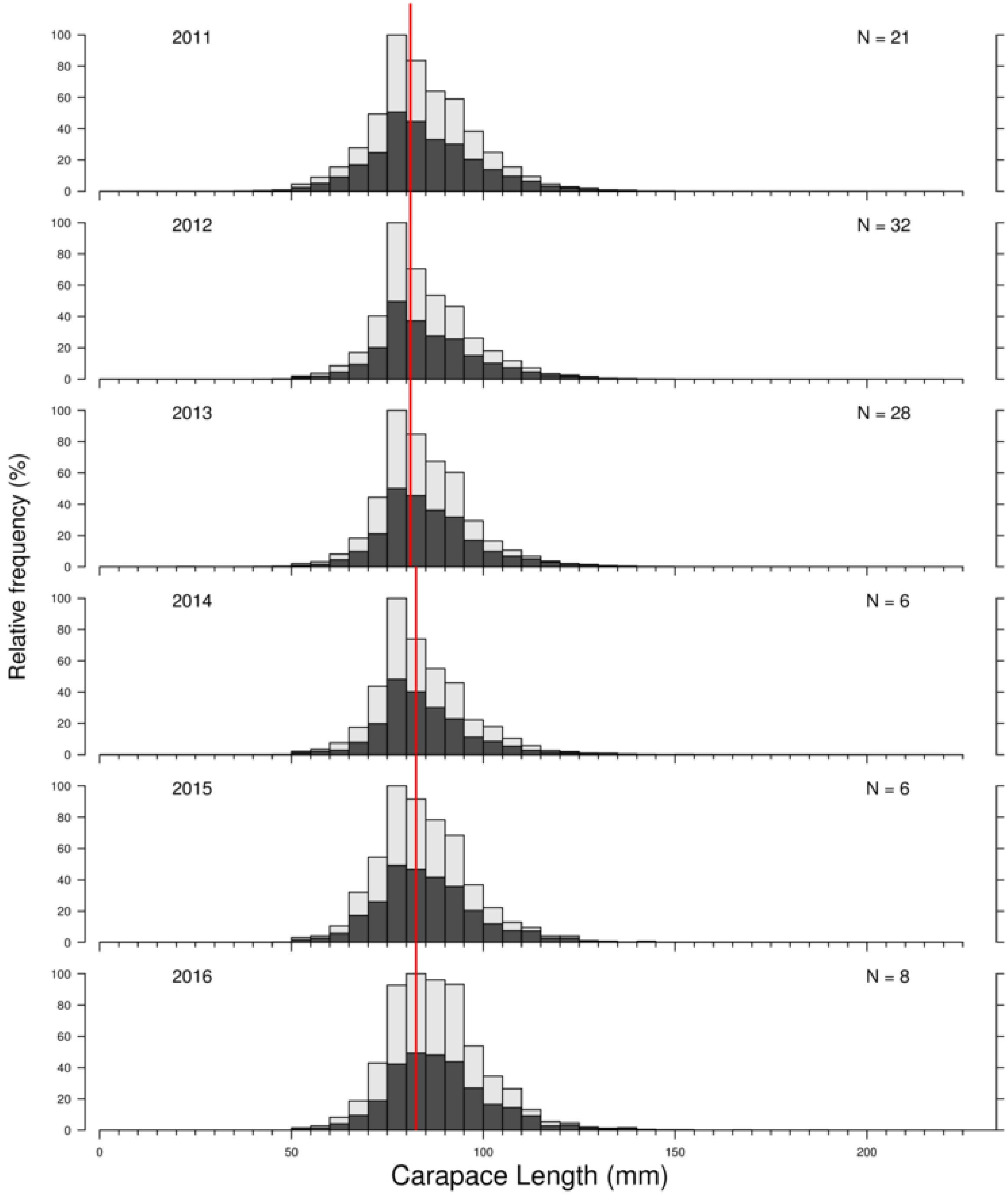


Figure 12: Carapace Length Frequencies from at sea sampling in LFA 32. Dark grey: males, light grey: females, red line: MLS.

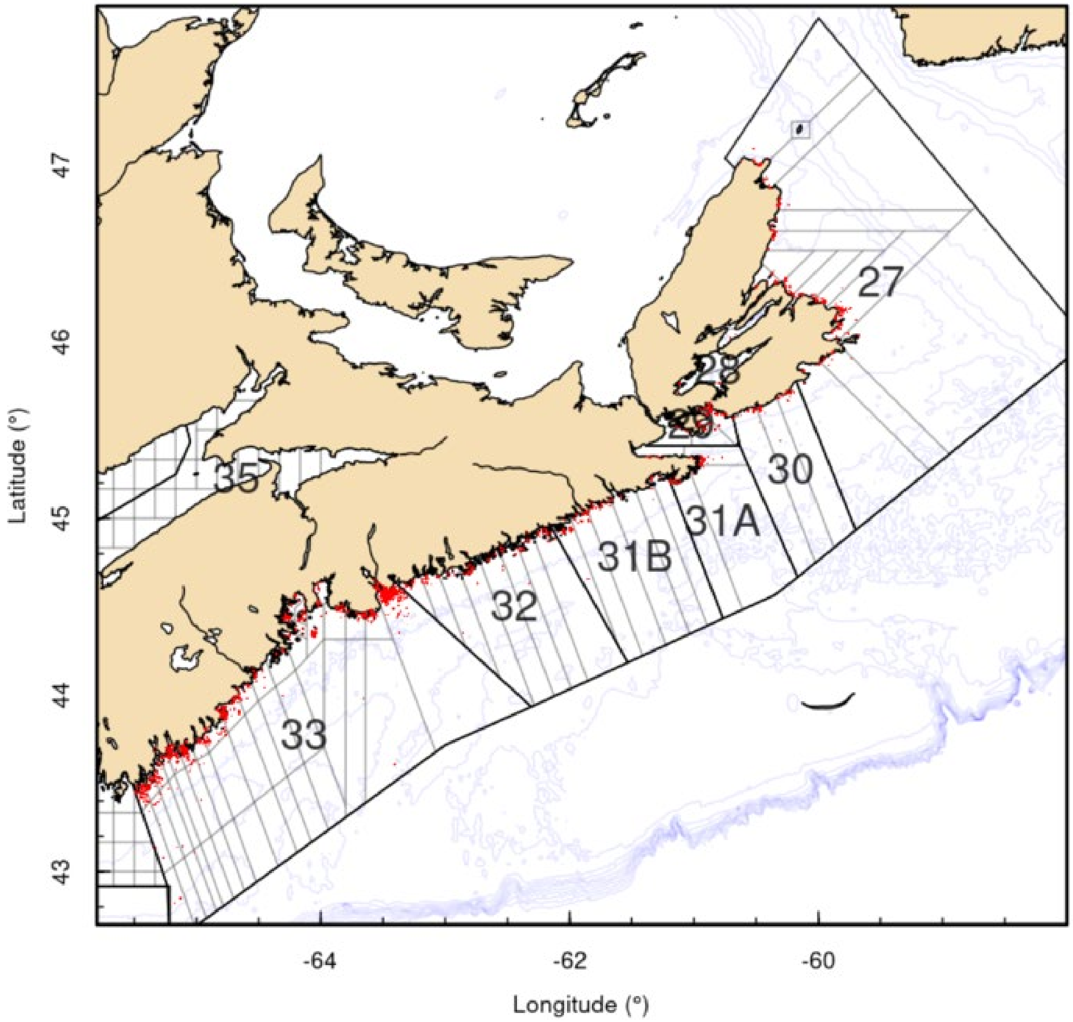


Figure 13: Location of the FSRS recruitment trap samples collected between 2004 and 2017.

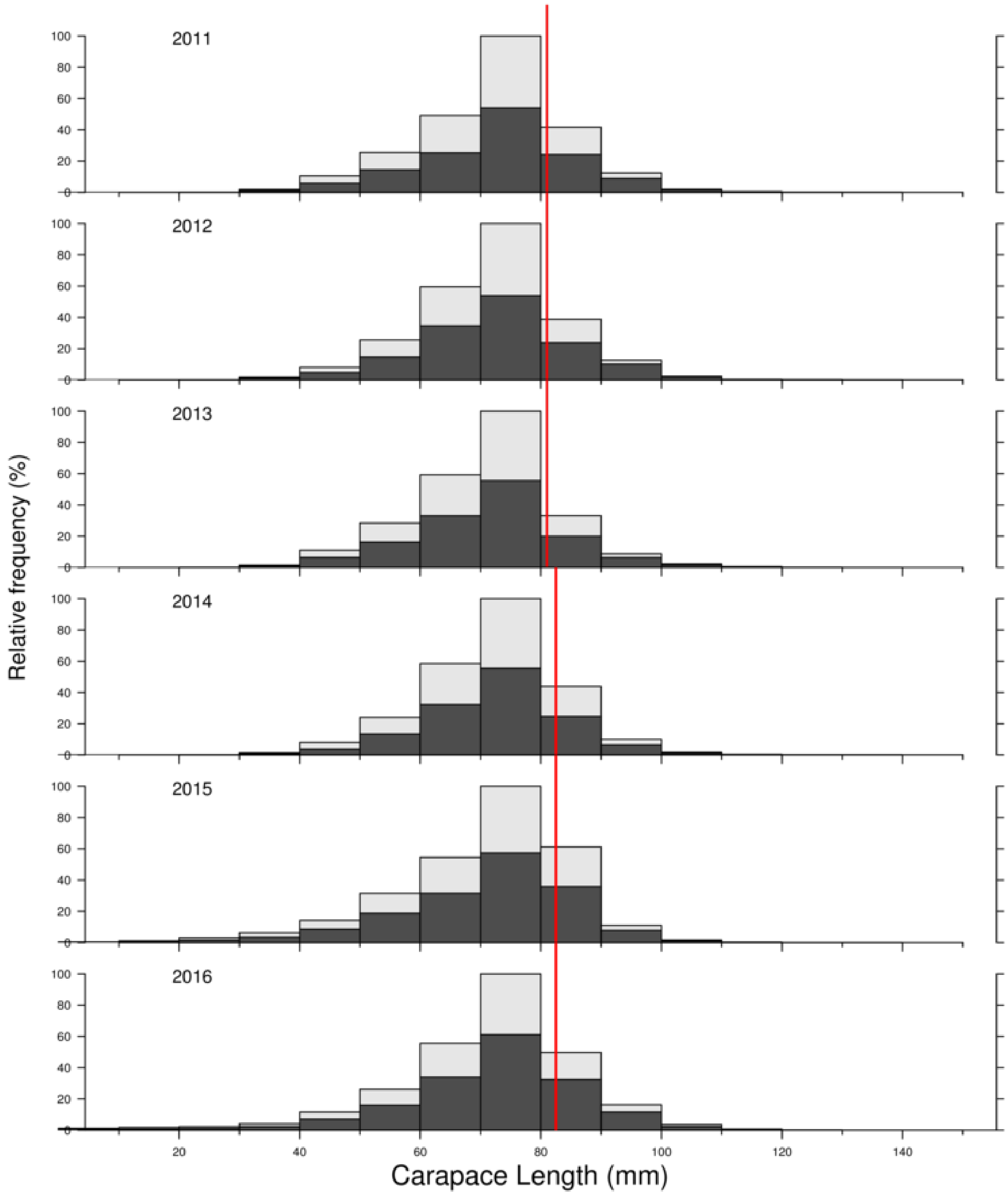


Figure 14: Carapace Length Frequencies from at FSRS recruitment traps in LFA 27. Dark grey: males, light grey: females, red line: MLS.

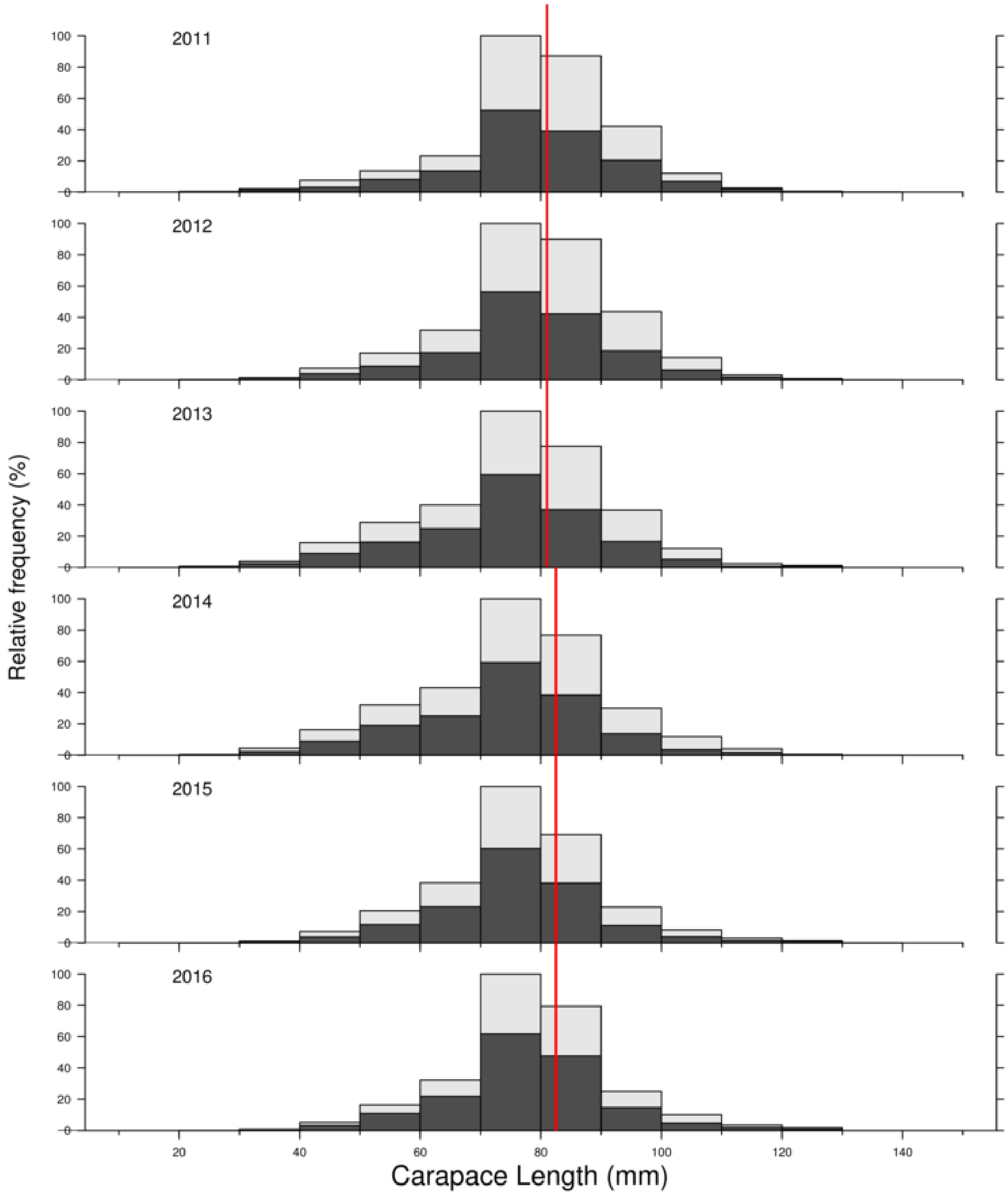


Figure 15: Carapace Length Frequencies from at FSRS recruitment traps in LFA 29. Dark grey: males, light grey: females, red line: MLS.

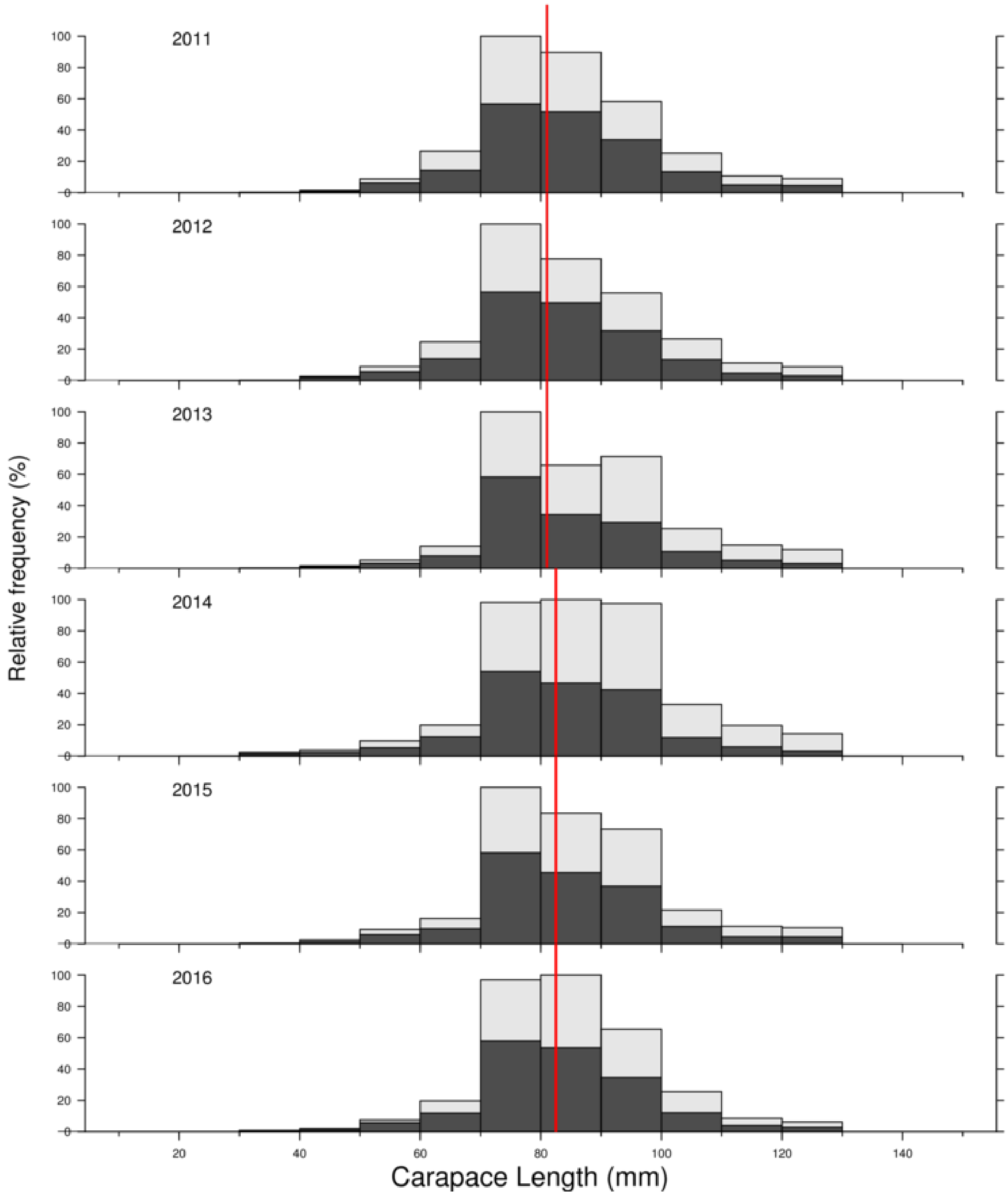


Figure 16: Carapace Length Frequencies from at FSRS recruitment traps in LFA 30. Dark grey: males, light grey: females, red line: MIS.

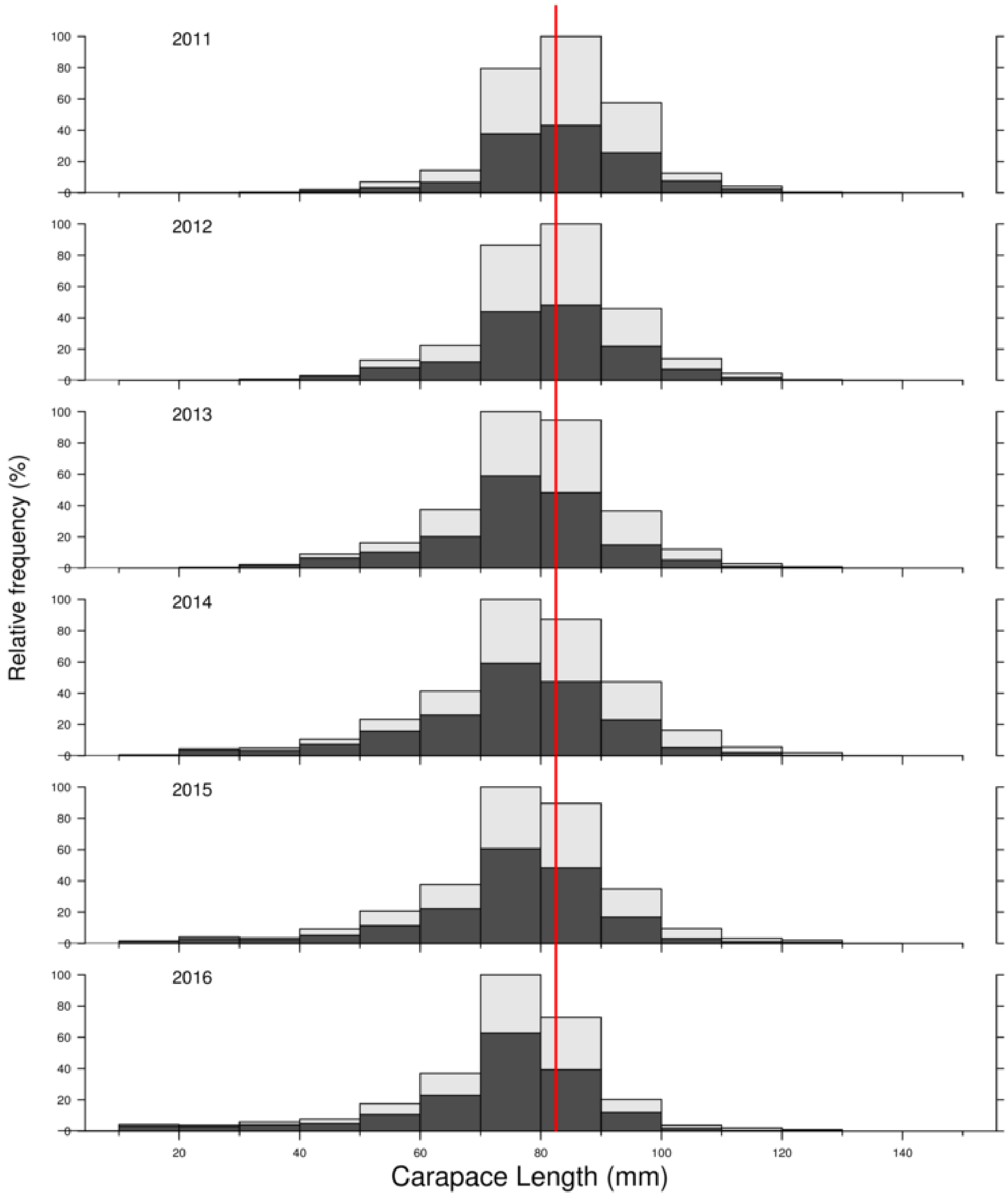


Figure 17: Carapace Length Frequencies from at FSRS recruitment traps in LFA 31A. Dark grey: males, light grey: females, red line: MLS.

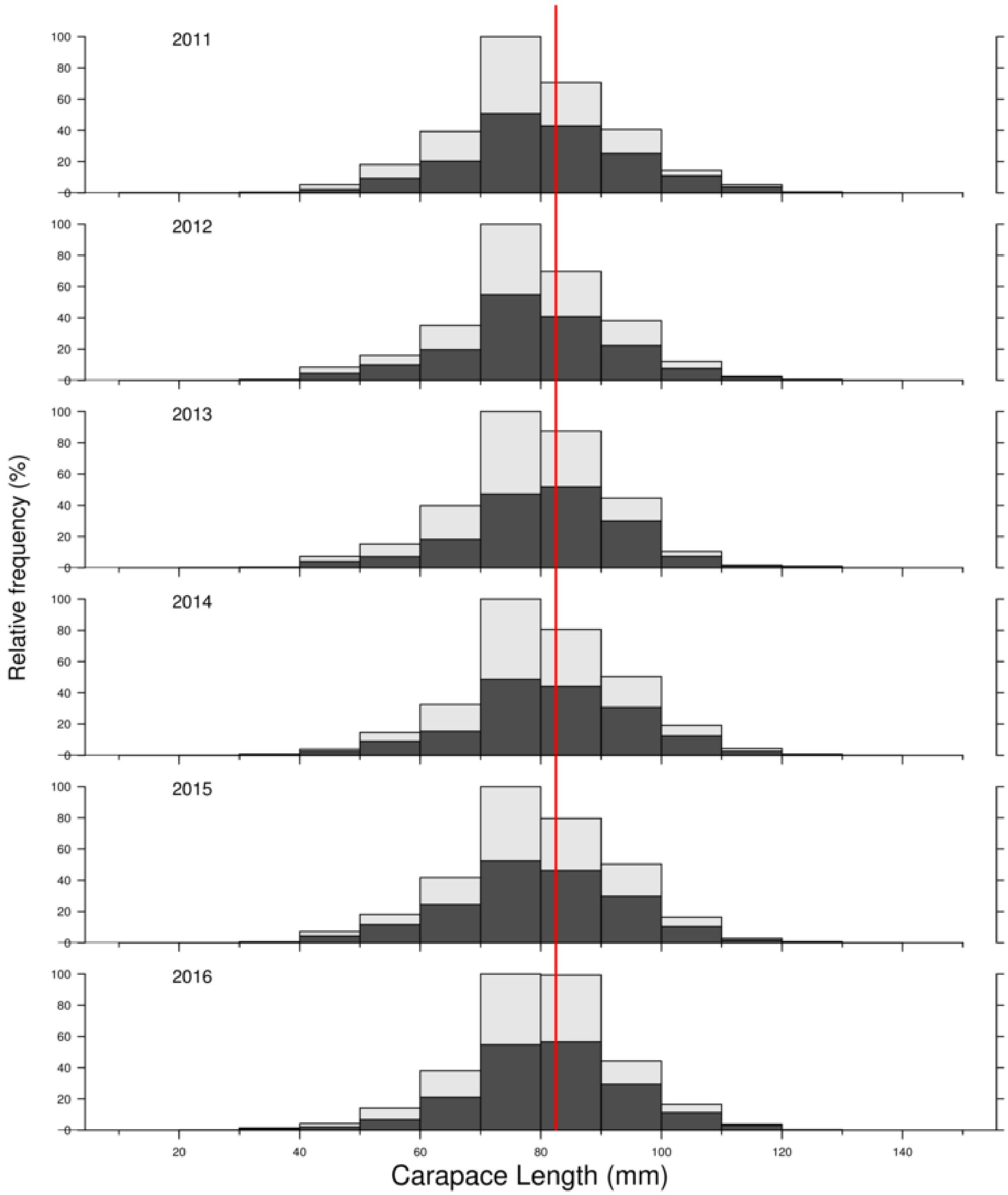


Figure 18: Carapace Length Frequencies from at FSRS recruitment traps in LFA 31B. Dark grey: males, light grey: females, red line: MLS.

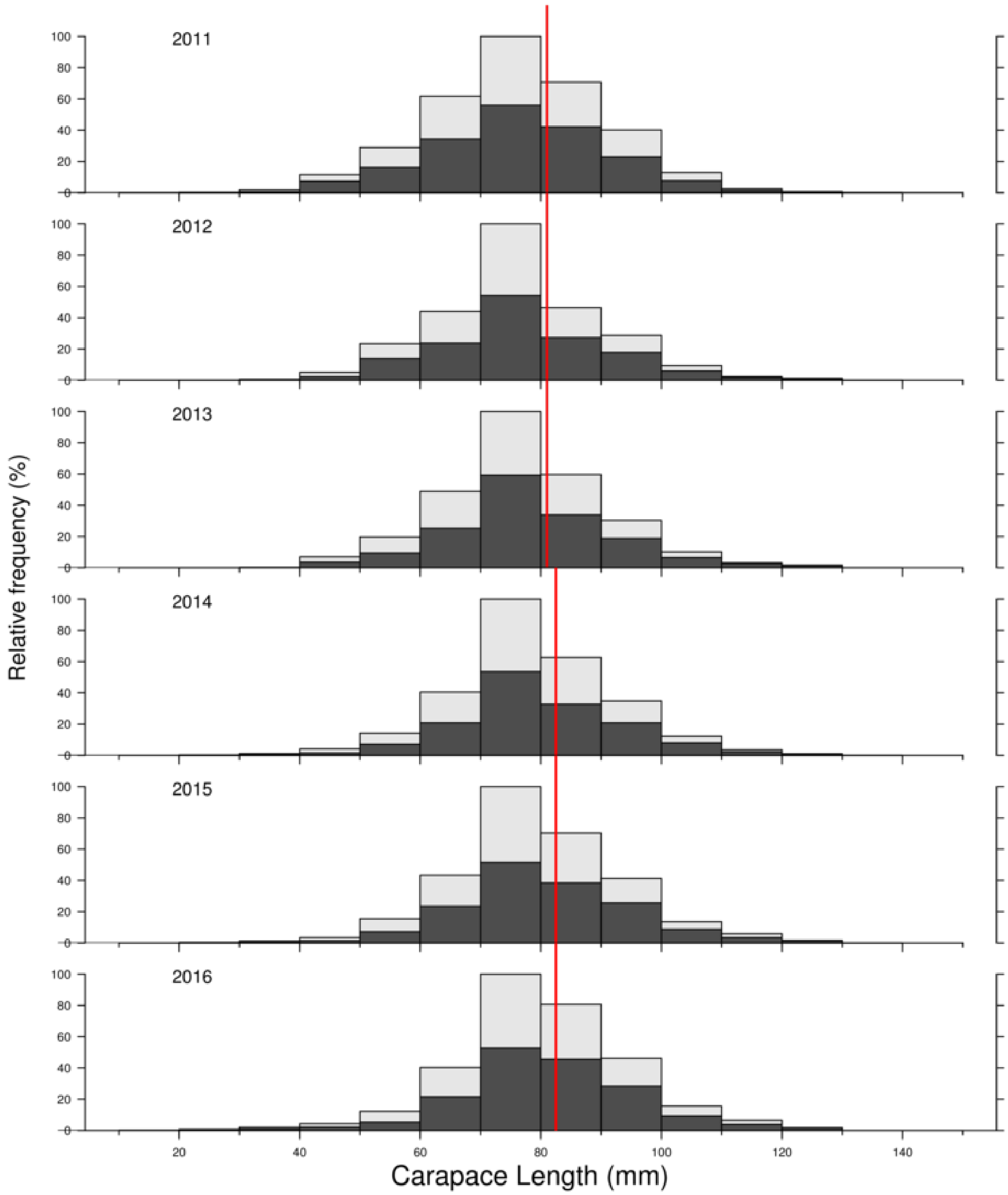


Figure 19: Carapace Length Frequencies from at FSRS recruitment traps in LFA 32. Dark grey: males, light grey: females, red line: MLS.

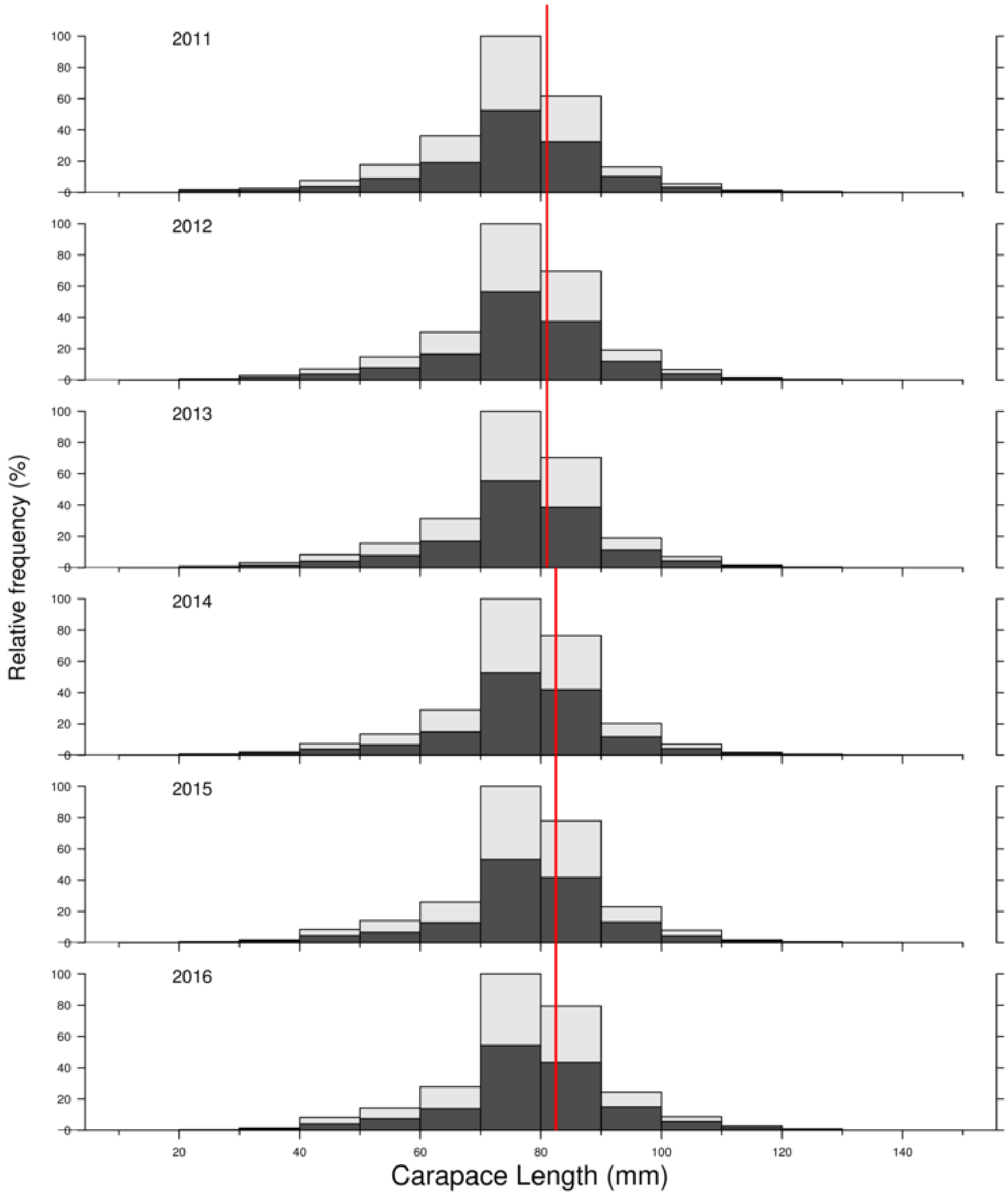


Figure 20: Carapace Length Frequencies from at FSRS recruitment traps in LFA 33. Dark grey: males, light grey: females, red line: MLS.

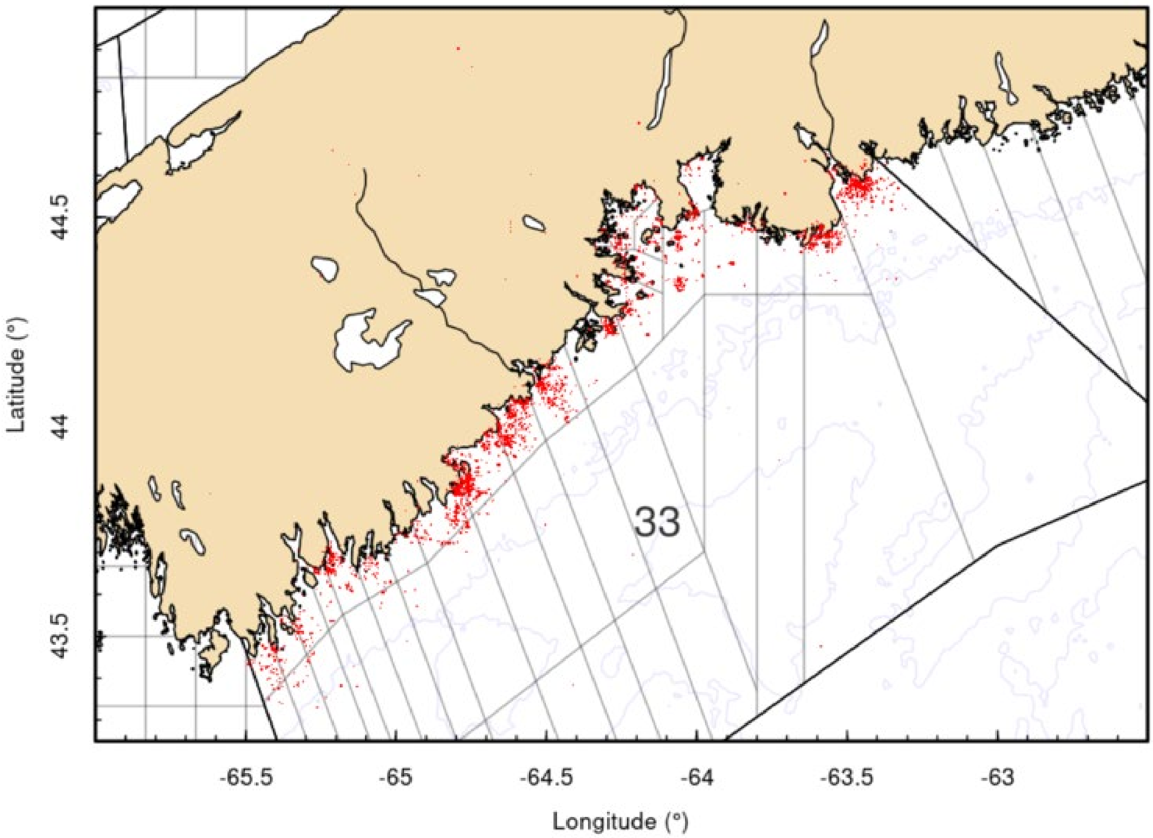


Figure 21: Location of the FSRS commercial trap samples collected between 2004 and 2017.

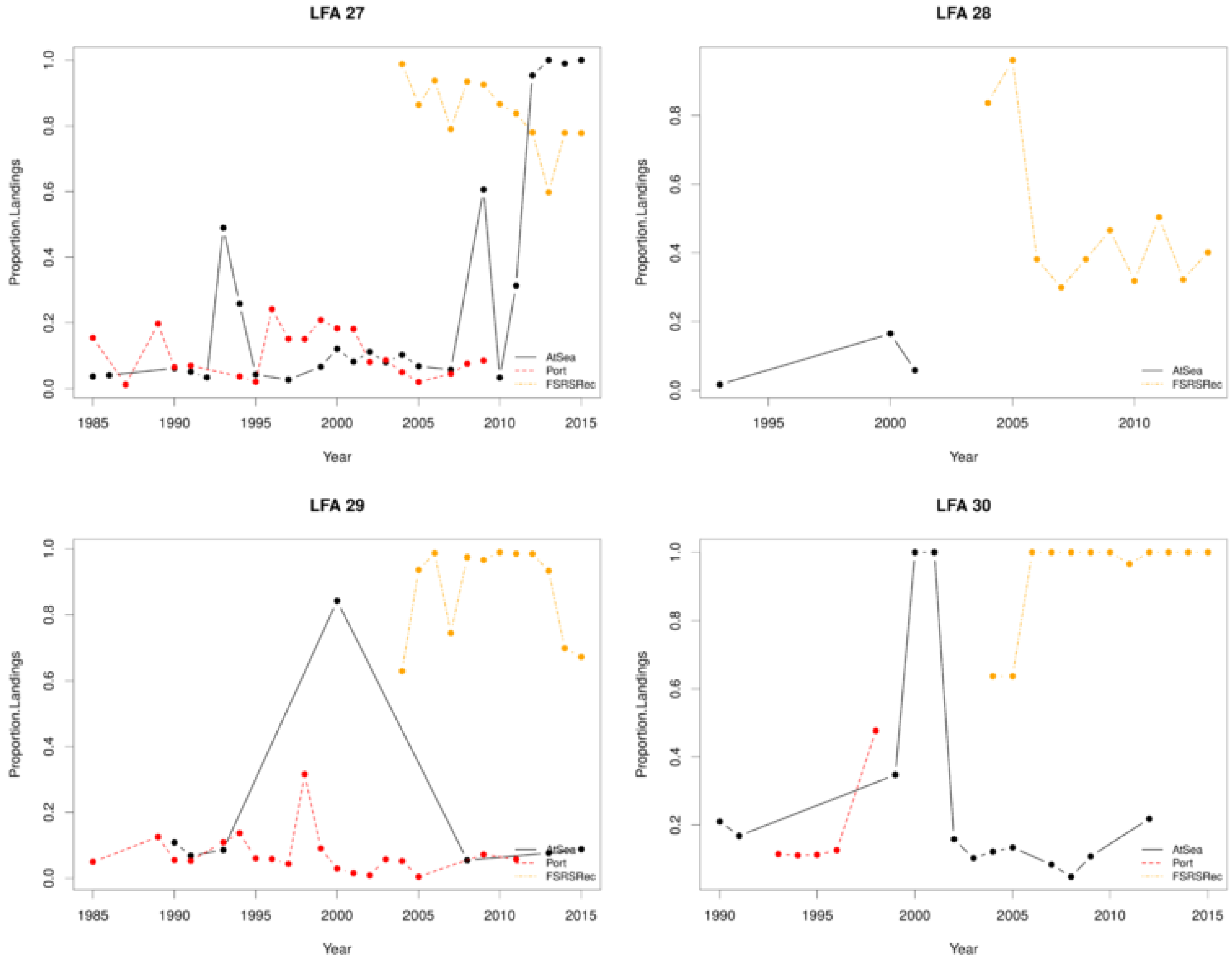


Figure 22: Estimated proportion of the week of season x area (grid or port) landings accounted for by the different biological sampling methods.

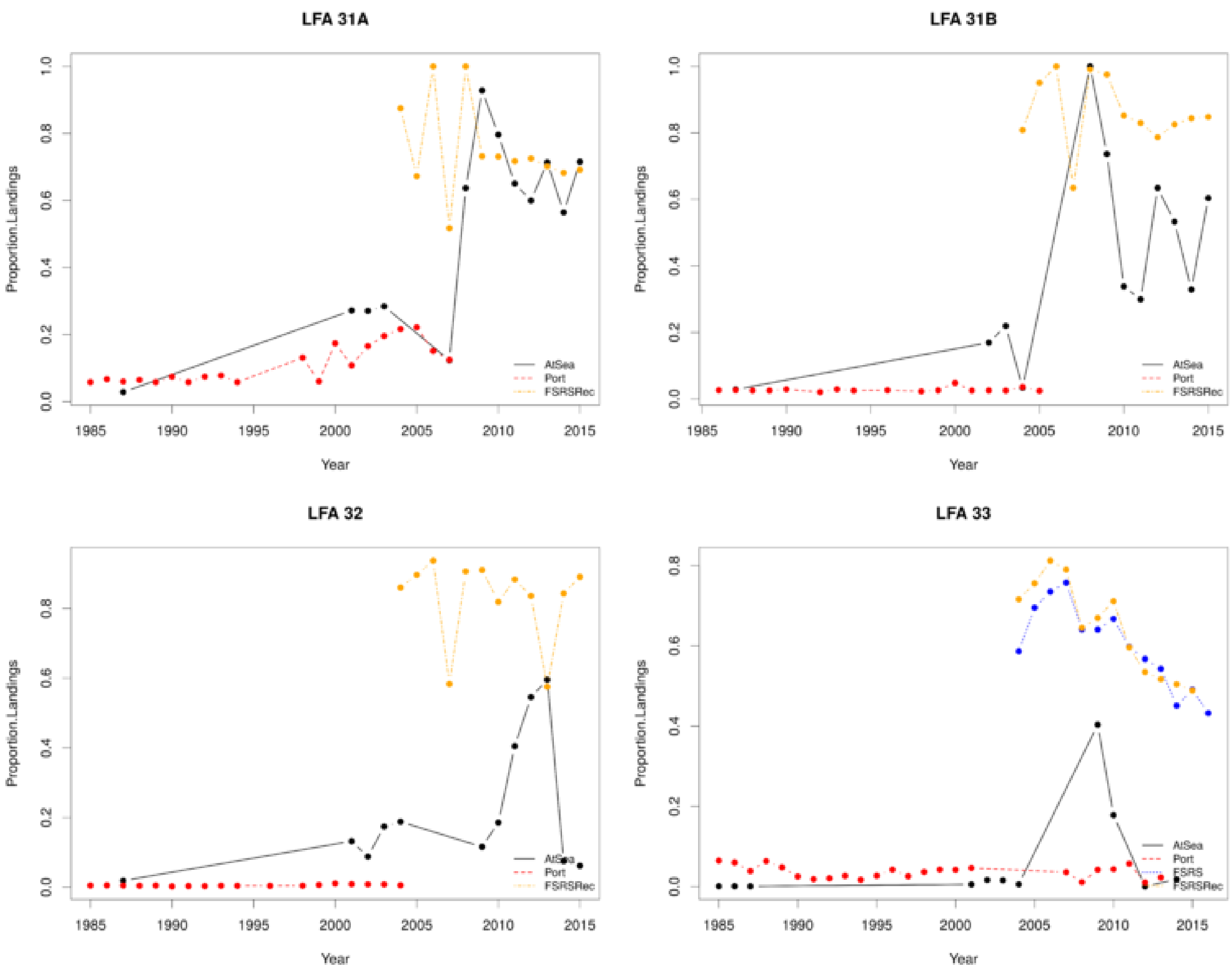


Figure 23: Estimated proportion of the week of season x area (grid or port) landings accounted for by the different biological sampling methods.

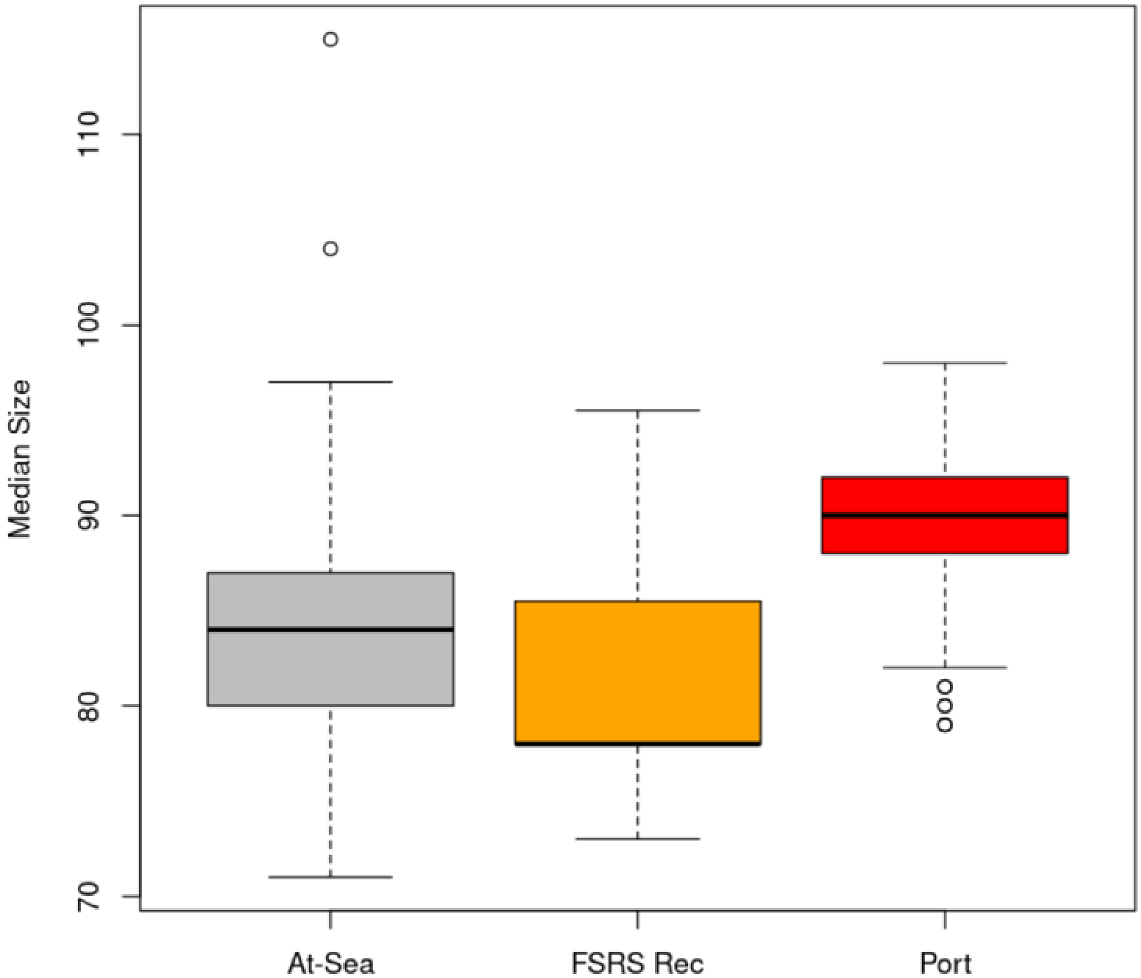


Figure 24: Boxplot of the combined estimates of median size by data source.

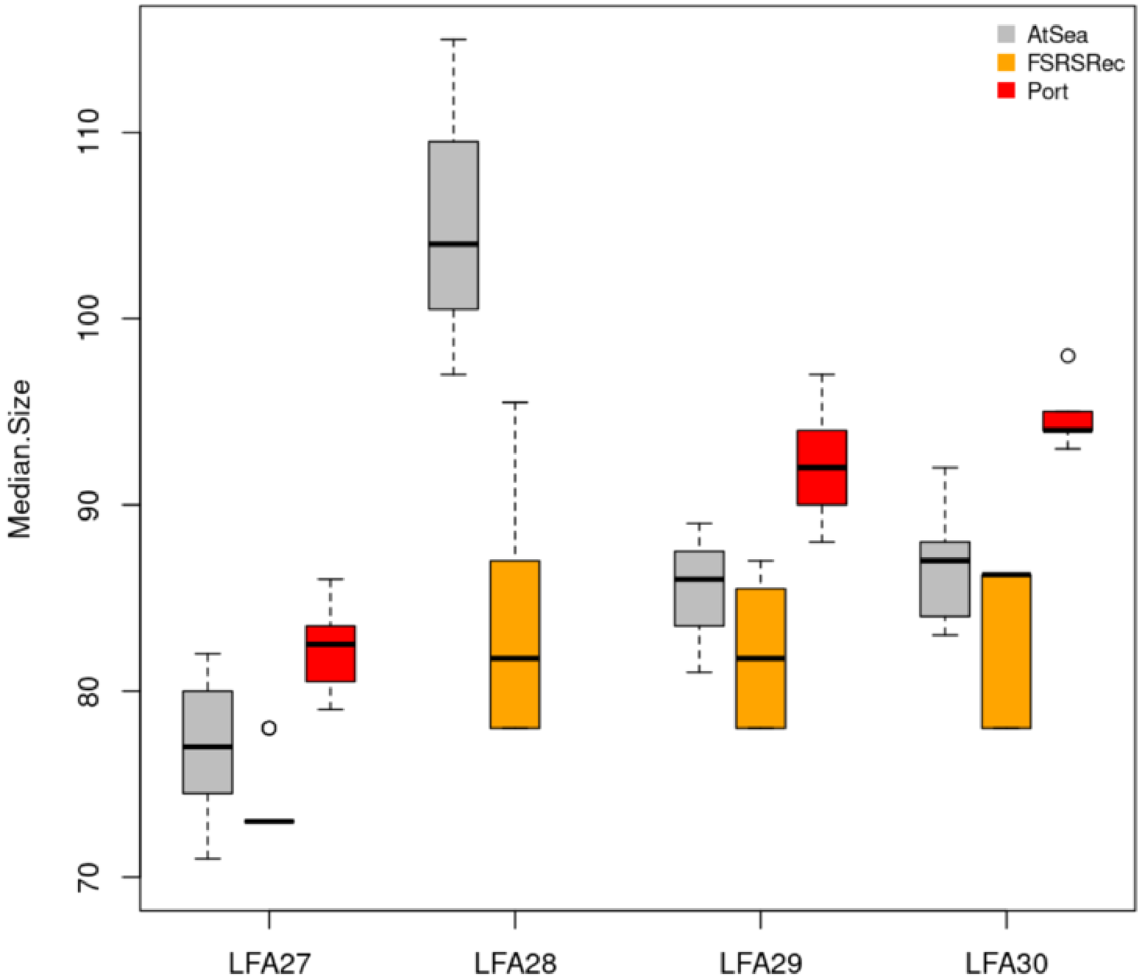


Figure 25: Boxplot of the annual estimates of median size by data source for LFA 27–30.

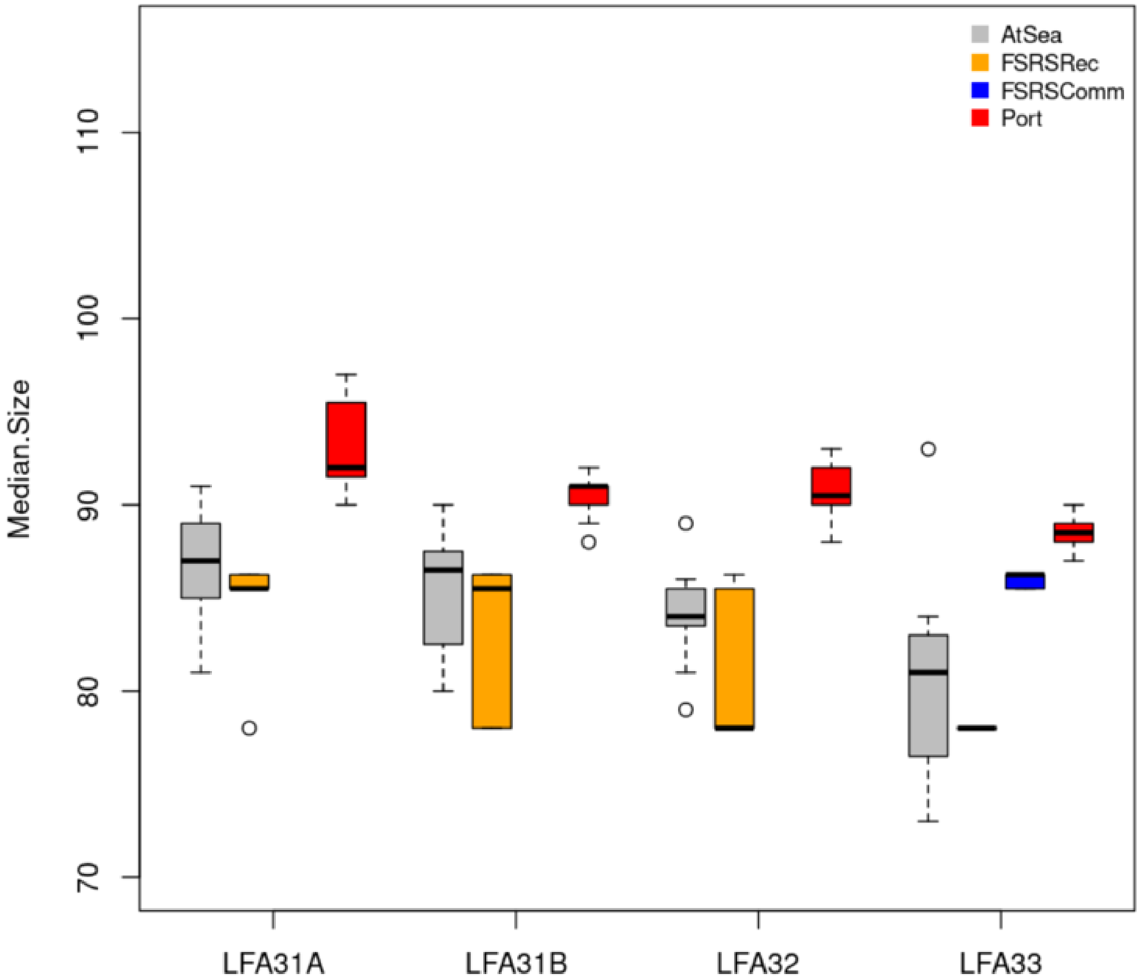


Figure 26: Boxplot of the annual estimates of median sizes by data source for LFA 31A–33.

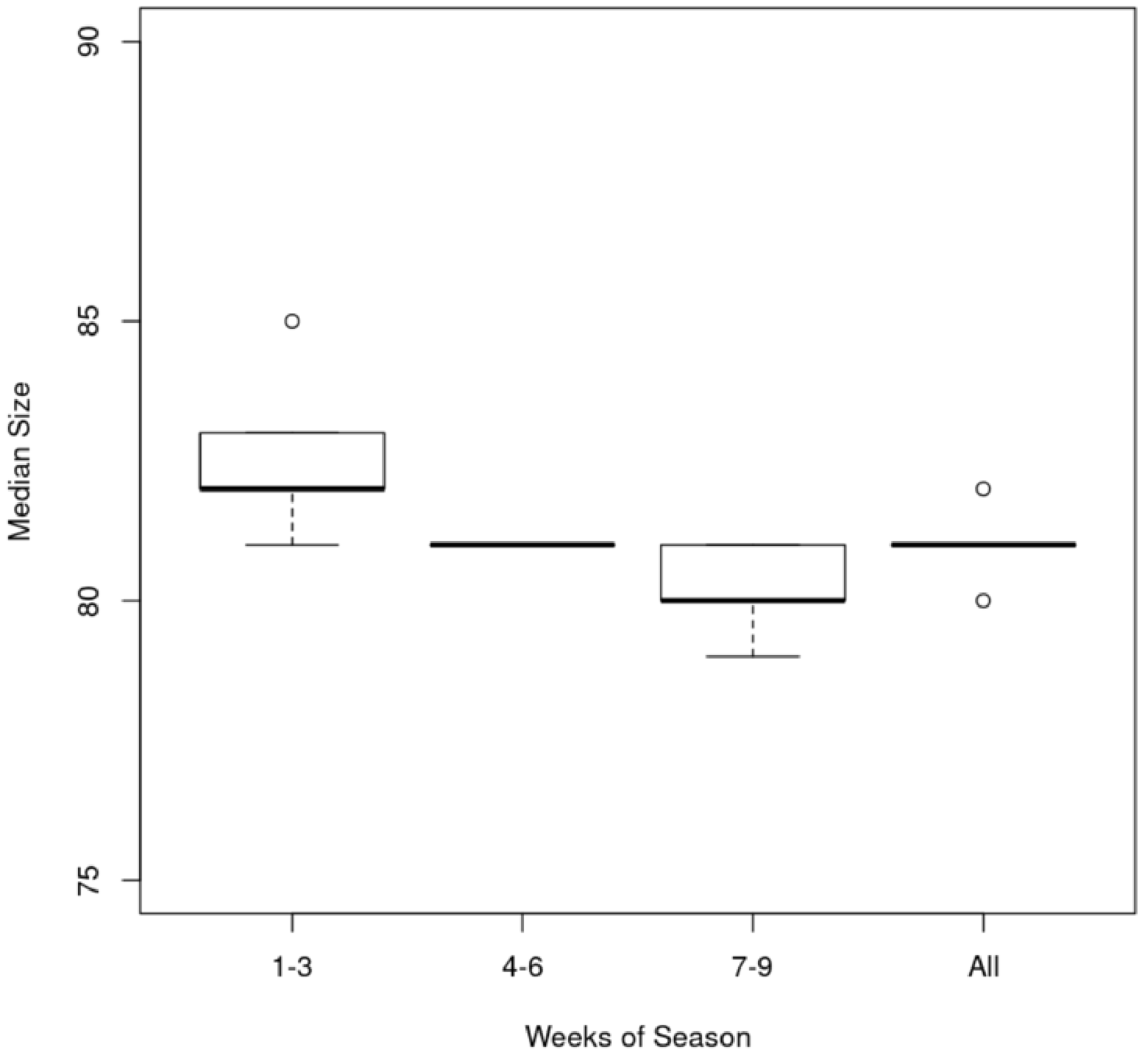


Figure 27: Boxplots of estimated median carapace length from sea sampling dates (weeks of season) observed from LFA 27 during the 2011–2015 seasons.

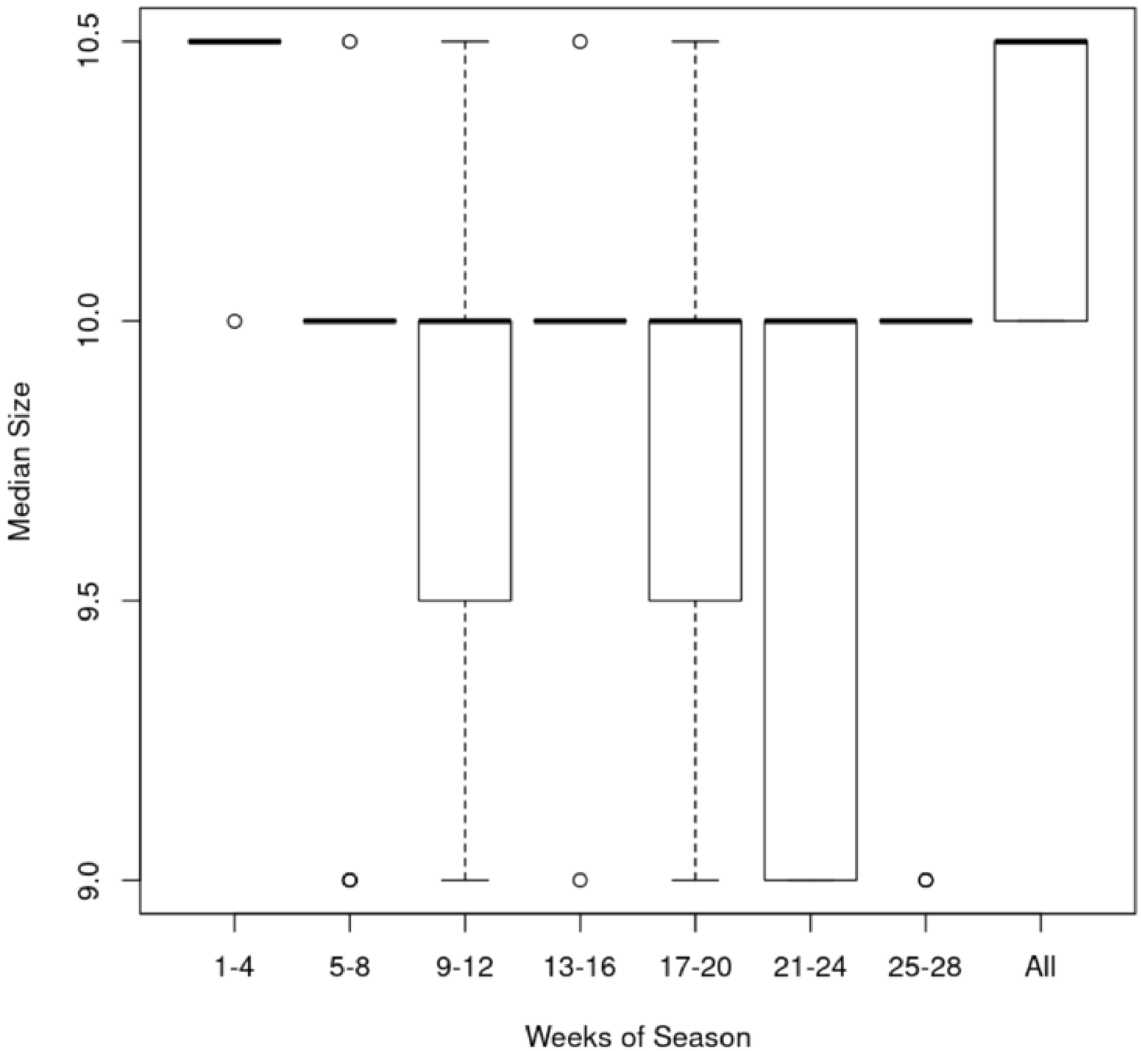


Figure 28: Boxplots of estimated median carapace length from FSRS commercial sampling dates (weeks of season) observed from LFA 33 during the 2004–2016 seasons.

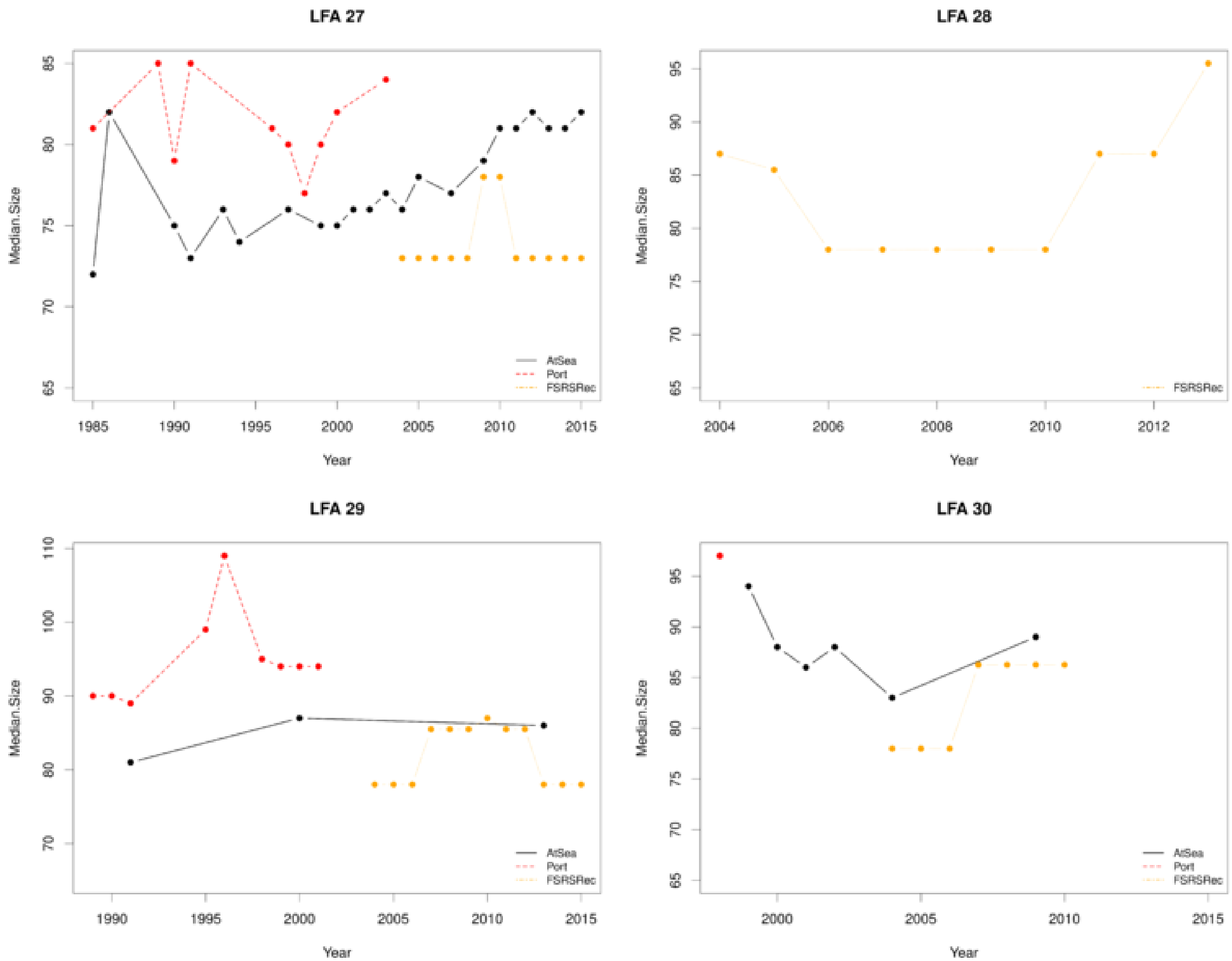


Figure 29: Estimated median carapace length of lobster samples taken from at sea samples, port samples, and / or the FSRS recruitment trap project. Median sizes from FSRS recruitment traps represent the center of the size bin converted to mm from the gauge used to measure carapace length of Lobster. Results represent mid-season samples only.

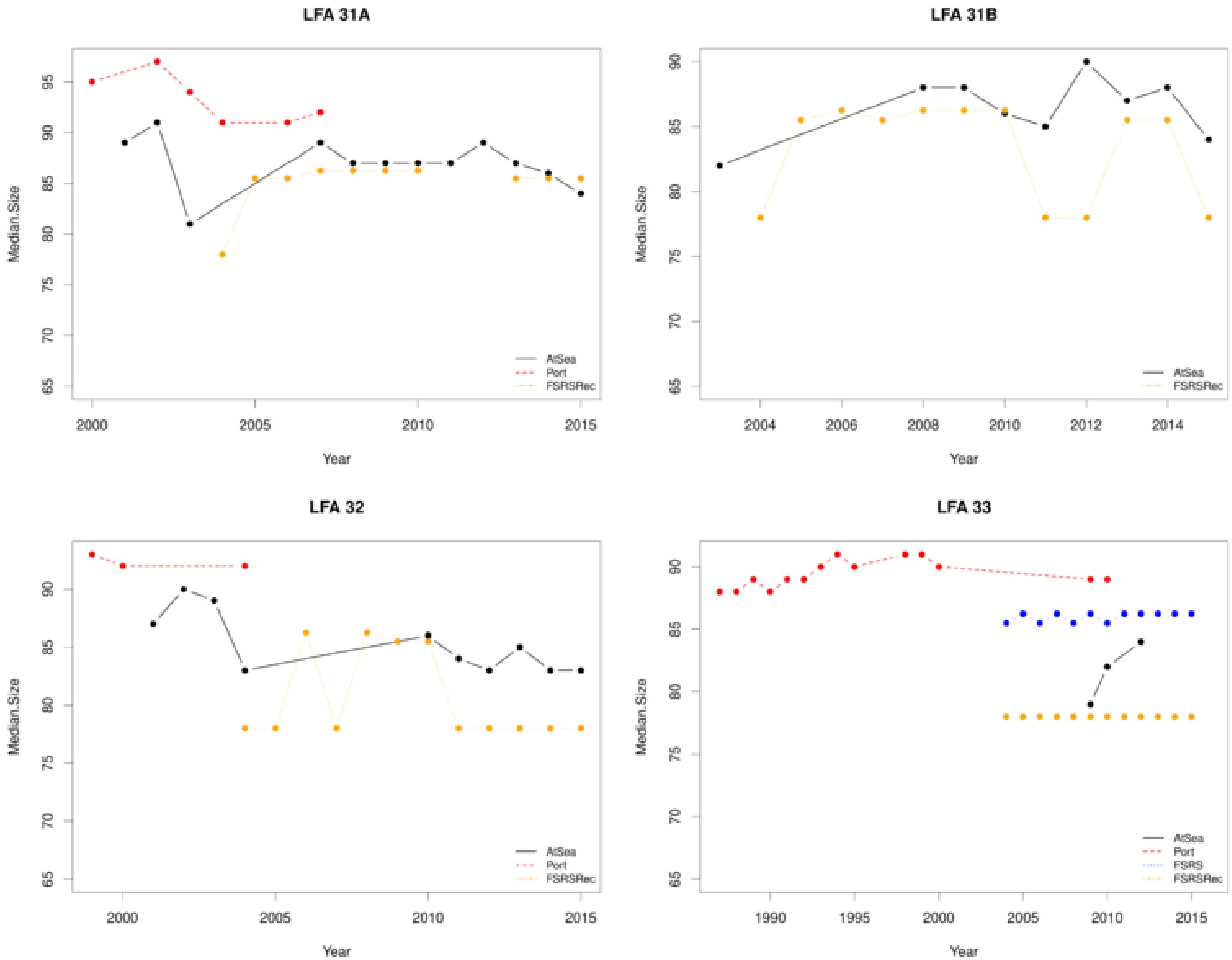


Figure 30: Estimated median carapace length of lobster samples taken from at sea samples, port samples, and / or the FSRS recruitment trap project. Median sizes from FSRS recruitment or commercial traps represent the center of the size bin converted to mm from the gauge used to measure carapace length of Lobster. Results represent mid-season samples only.

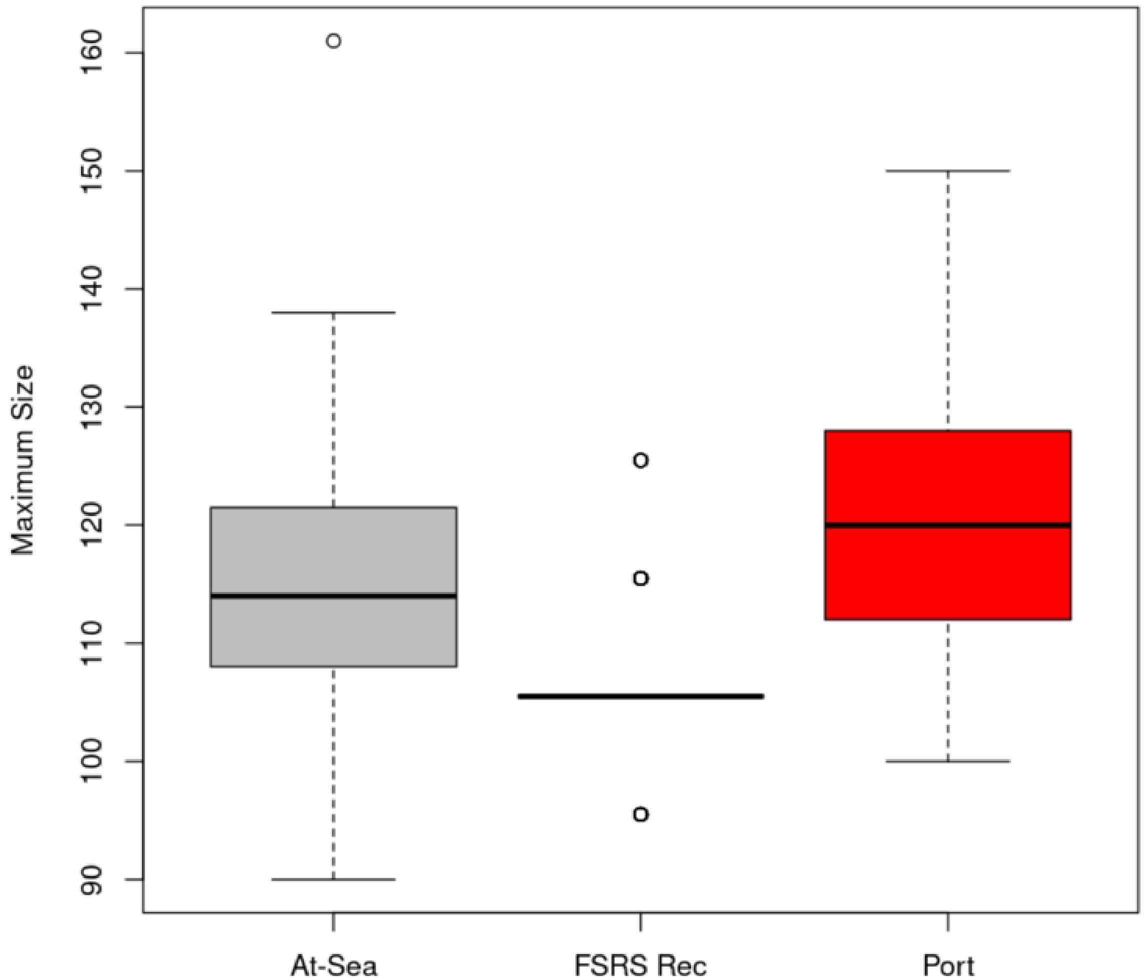


Figure 31: Boxplot of the combined estimates of maximum sizes by data source.

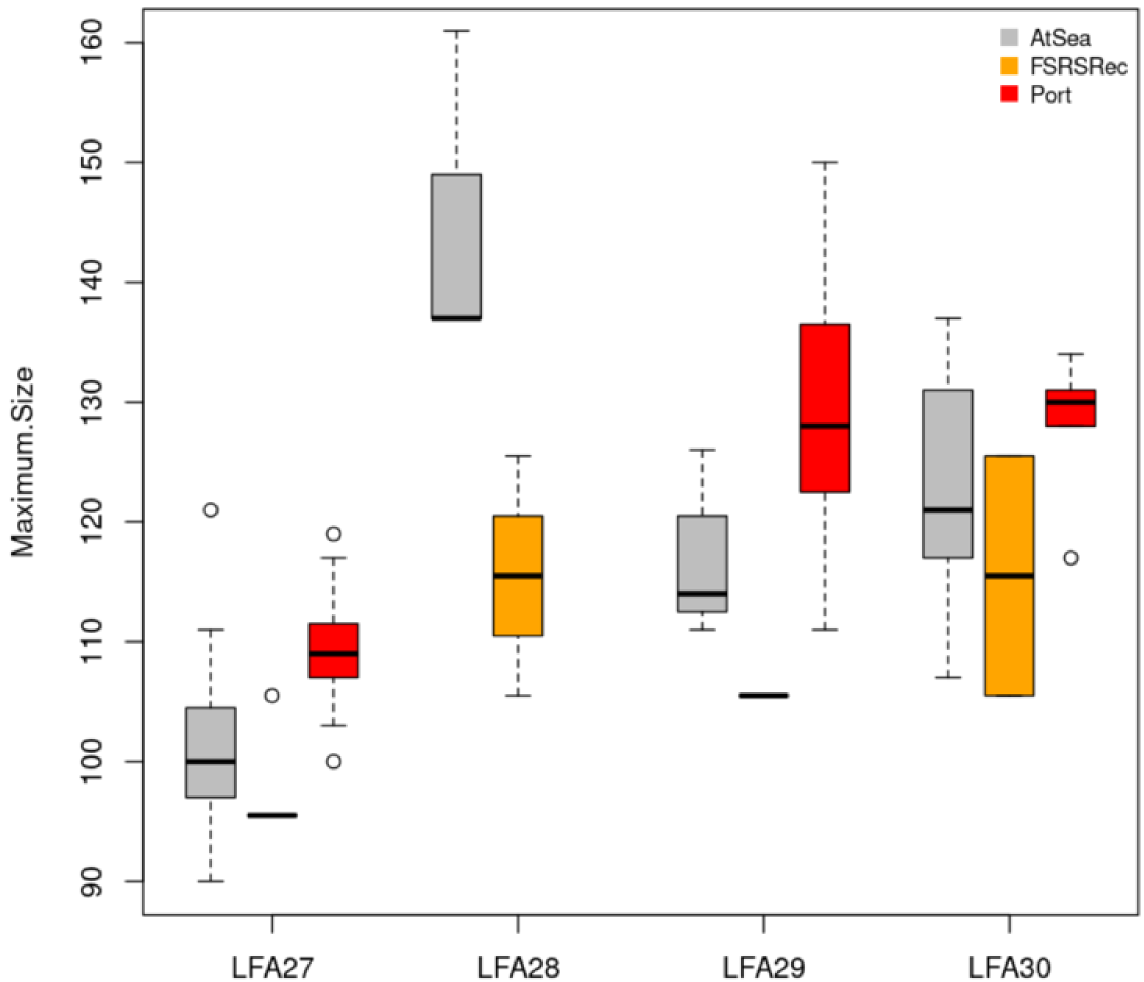


Figure 32: Boxplot of the annual estimates of maximum sizes by data source for LFA 27–30. Within LFAs FSRS samples where maximum size was in the largest size category were not included.

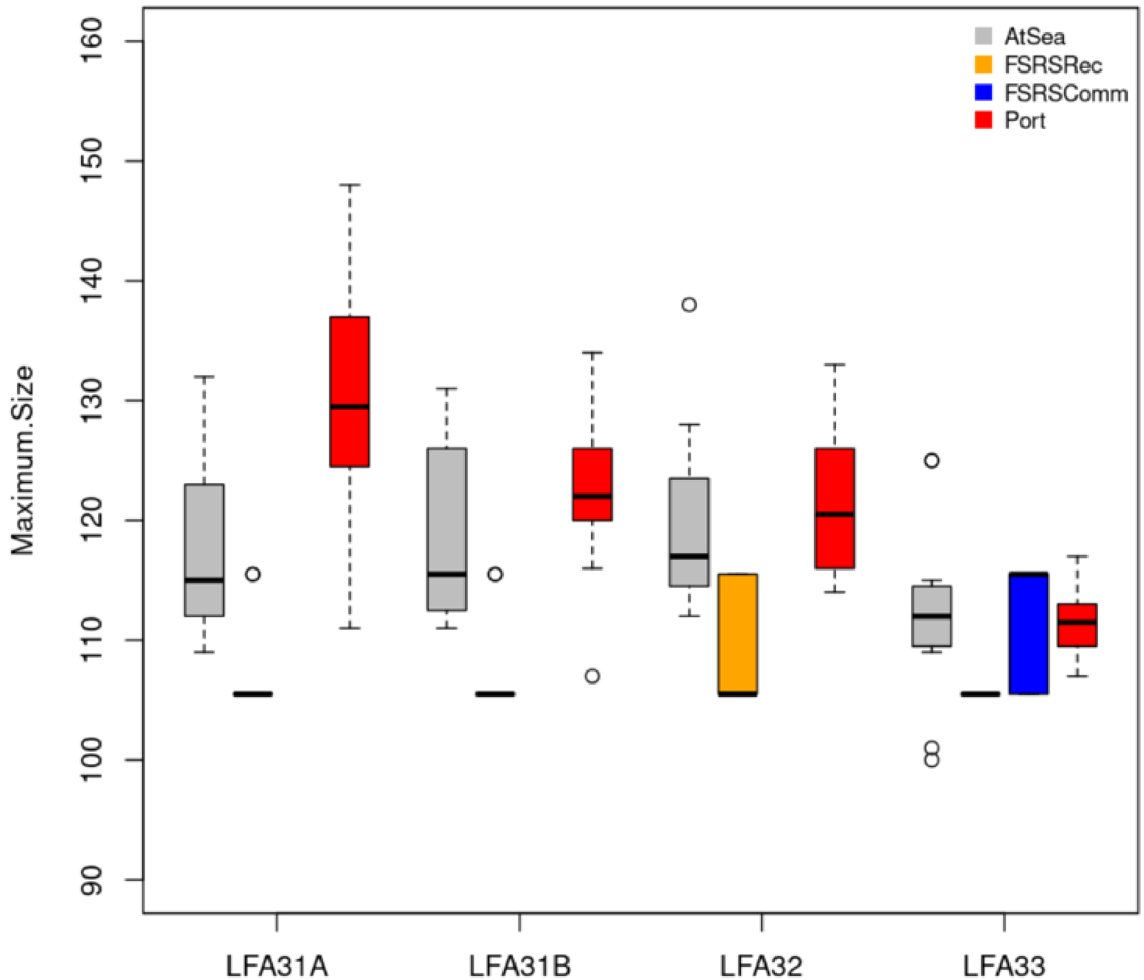


Figure 33: Boxplot of the annual estimates of maximum sizes by data source for LFA 31A–33. Within LFAs FSRS samples where maximum size was in the largest size category were not included.

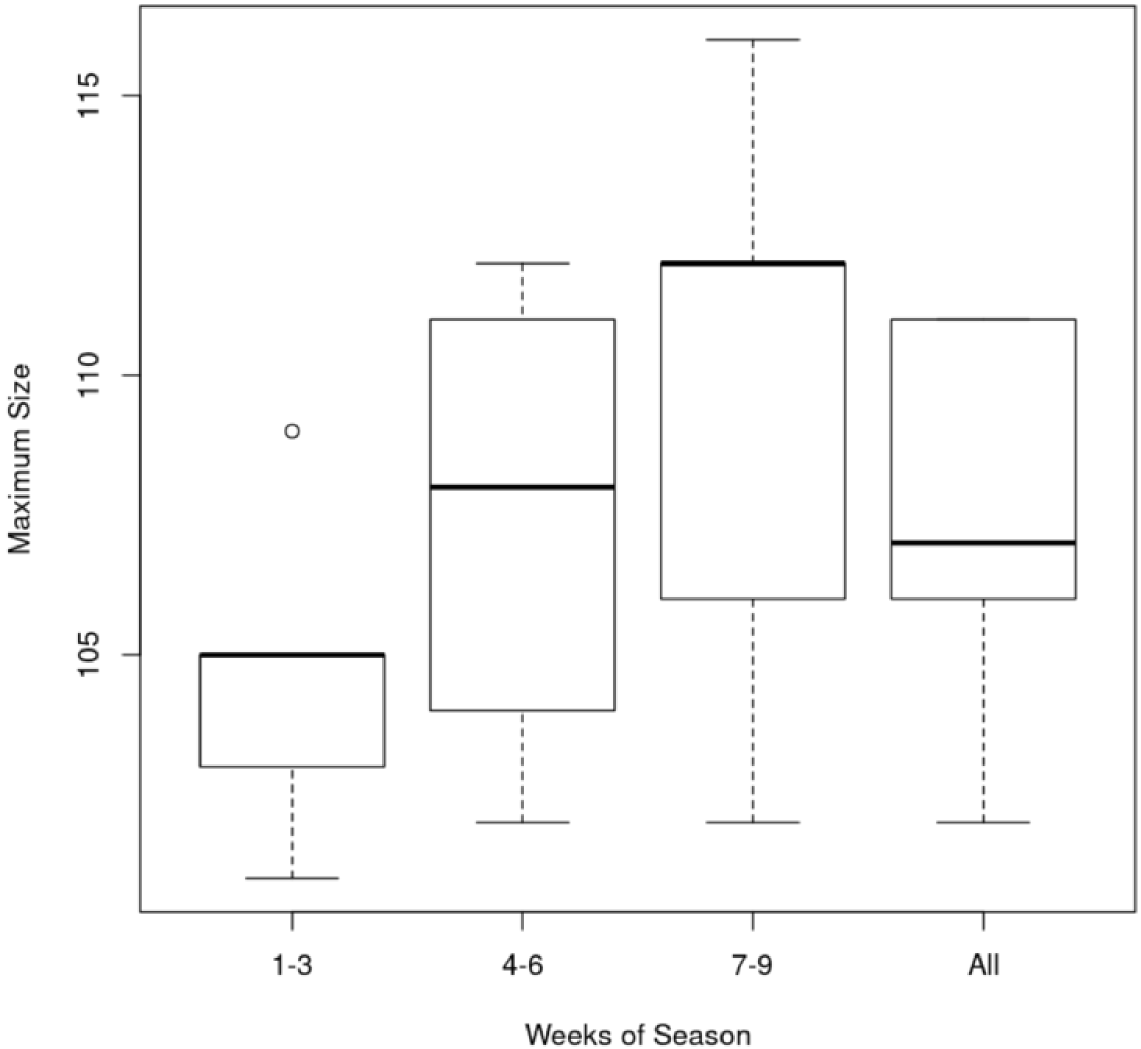


Figure 34: Boxplots of estimated maximum carapace length from sea sampling dates (weeks of season) observed from LFA 27 during the 2011–2015 seasons.

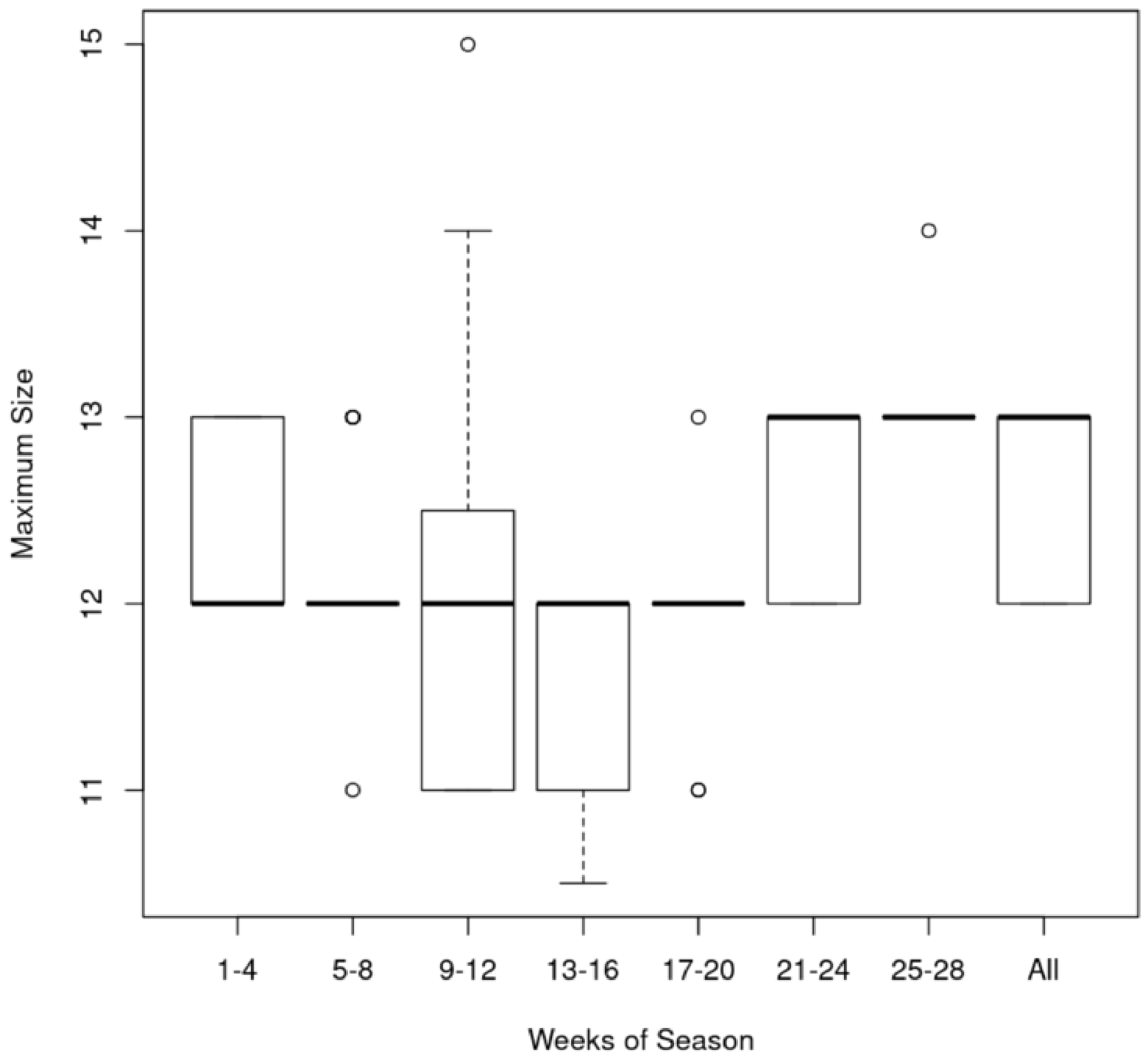


Figure 35: Boxplots of estimated maximum carapace length from FSRS commercial sampling dates (weeks of season) observed from LFA 33 during the 2004–2016 seasons.

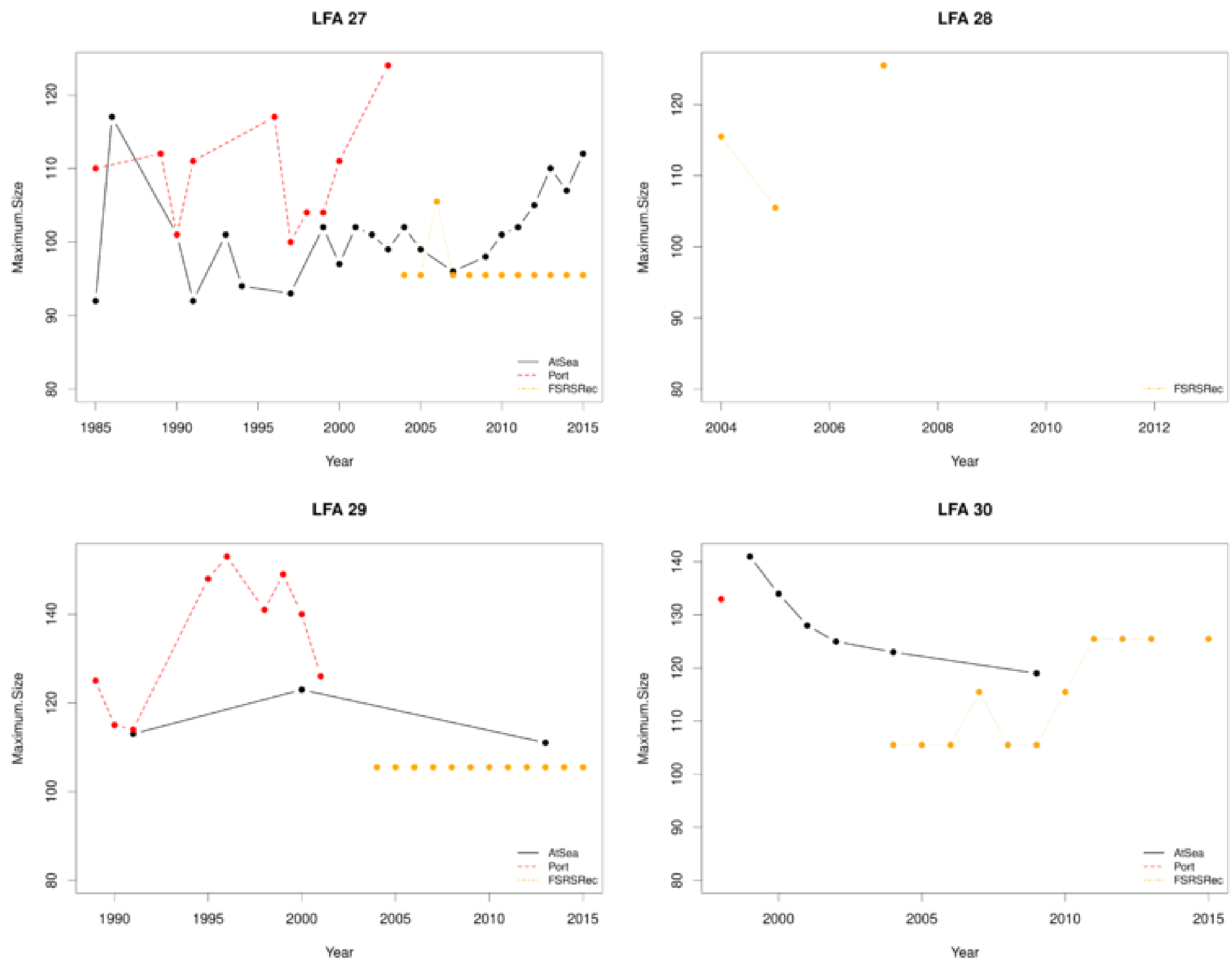


Figure 36: Estimated maximum carapace length (upper 95th quantile) of lobster samples taken from at sea samples, port samples, and /or the FSRS recruitment trap project. Maximum sizes from FSRS recruitment traps represent the center of the size bin converted to mm from the gauge used to measure carapace length of Lobster. FSRS results with maximum sizes in the largest size bin were not included in these figures. Data were only from mid-season samples.

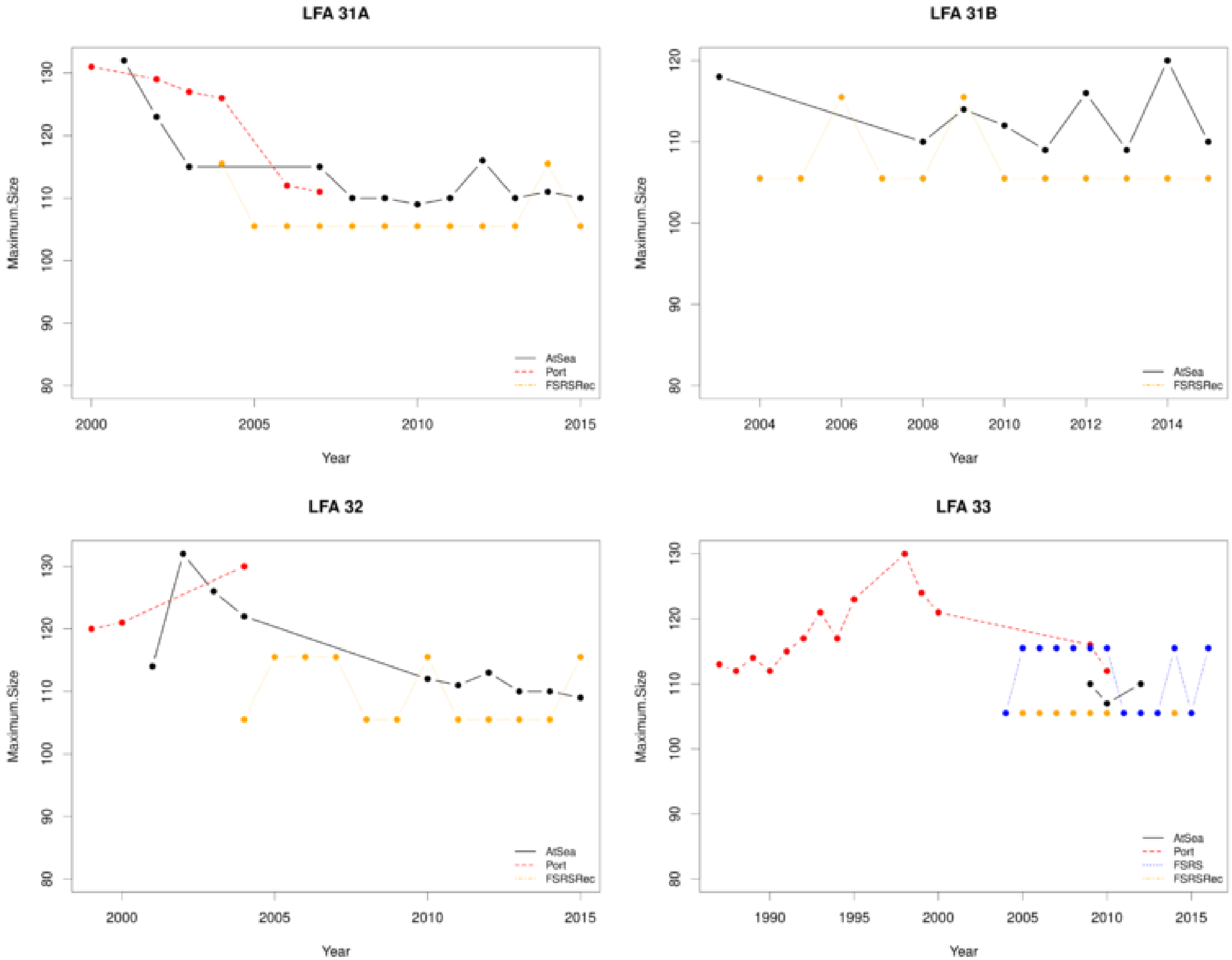


Figure 37: Estimated maximum carapace length (upper 95th quantile) of lobster samples taken from at sea samples, port samples, and/ or the FSRS recruitment trap project. Maximum sizes from FSRS recruitment or commercial traps represent the center of the size bin converted to mm from the gauge used to measure carapace length of Lobster. FSRS results with maximum sizes in the largest size bin were not included in these figures. Data were only from mid-season samples.

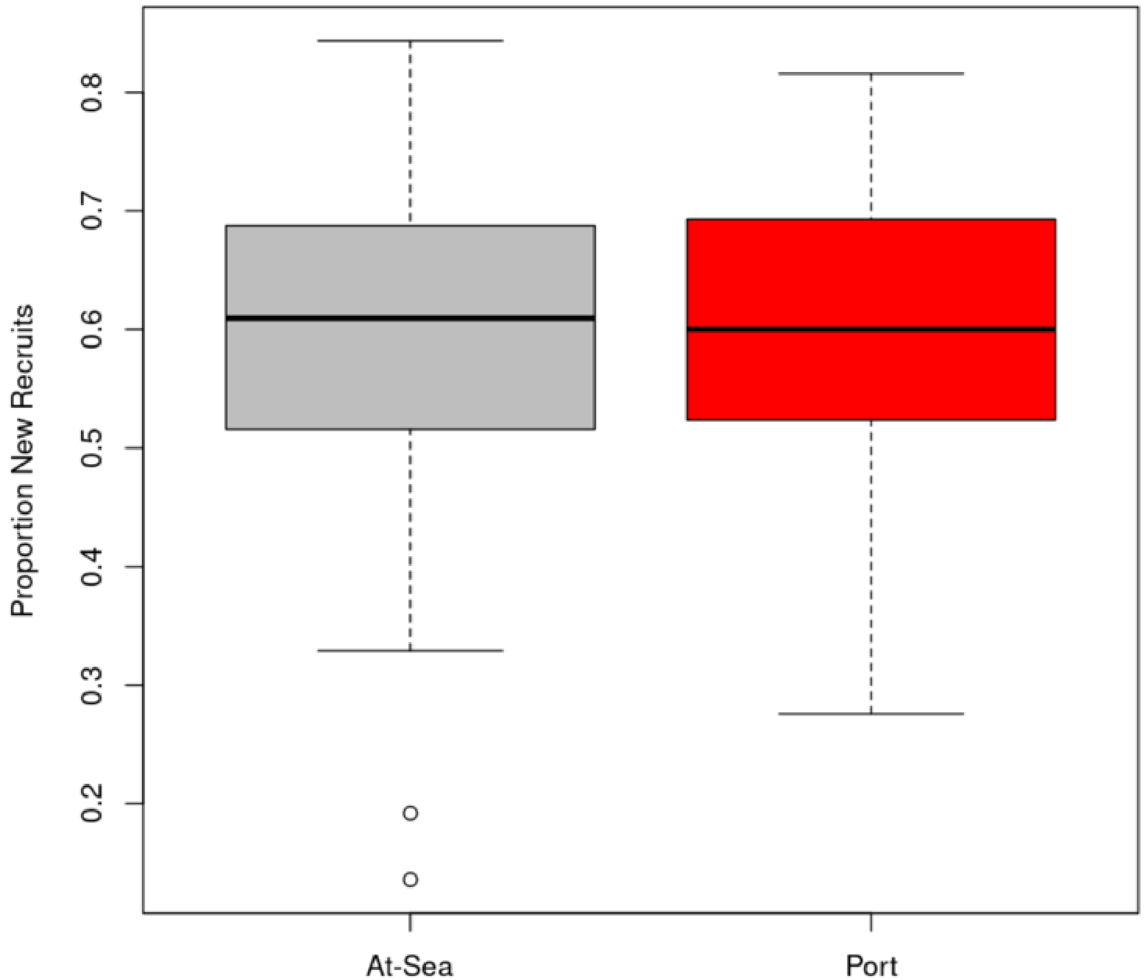


Figure 38: Boxplot of the combined estimates of the proportion of new recruits (size ranging from MLS - MLS + 11mm) sizes by data source.

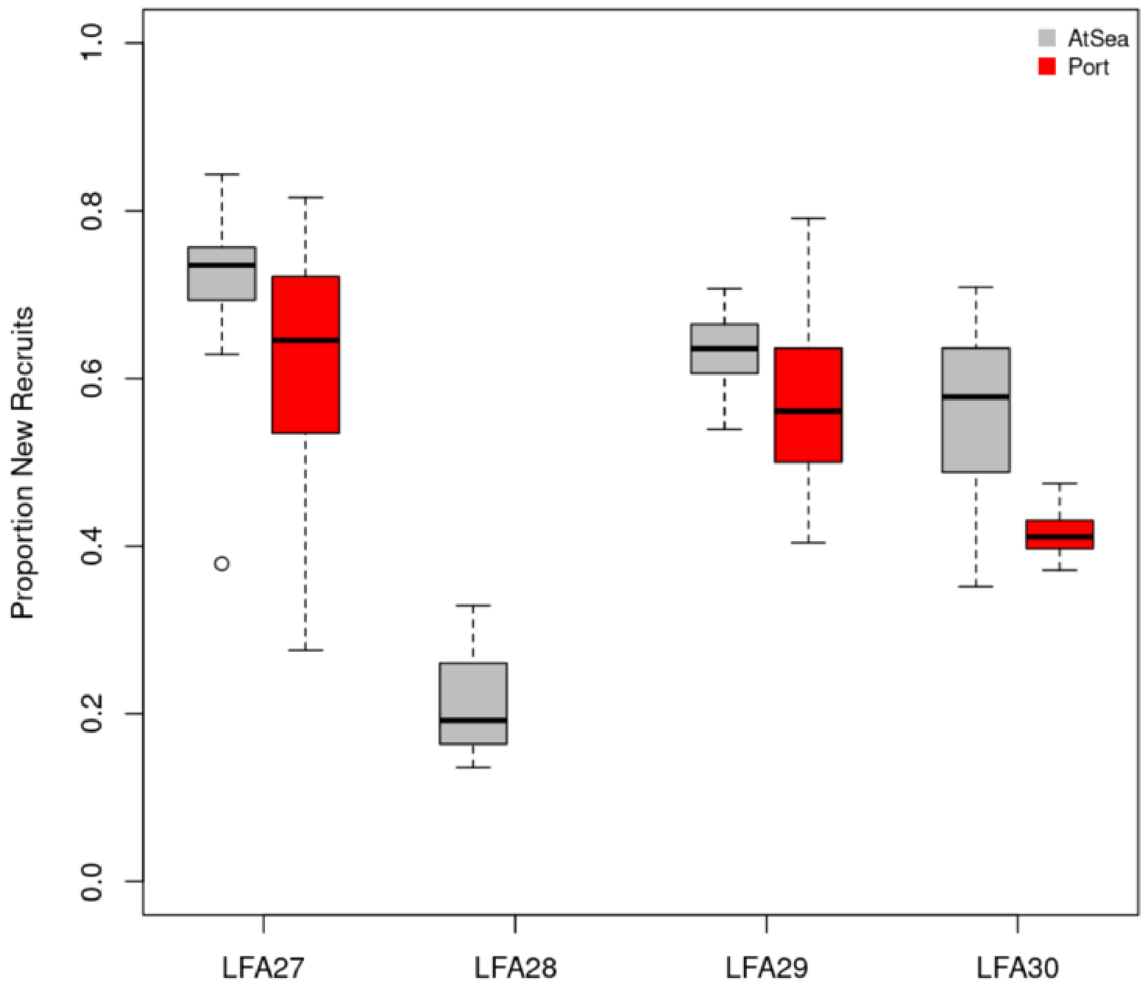


Figure 39: Boxplot of the annual estimates of proportion of total numbers landed represented by new recruits (MLS : MLS + 11 mm) by data source for LFA 27–30. FSRS recruitment traps not included in this analysis.

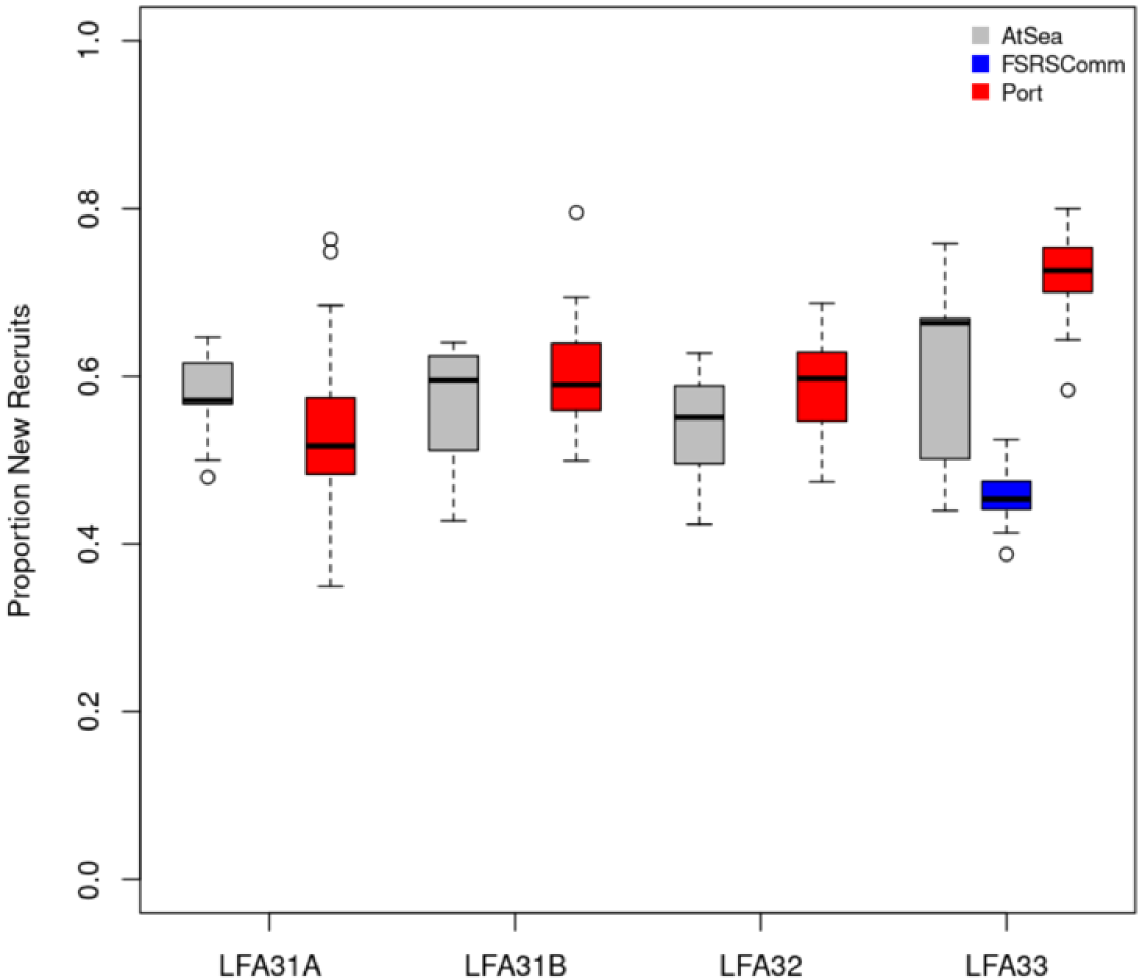


Figure 40: Boxplot of the annual estimates of proportion of total numbers landed represented by new recruits (MLS : MLS + 11 mm) by data source for LFA 31A–33. FSRS recruitment traps not included in this analysis.

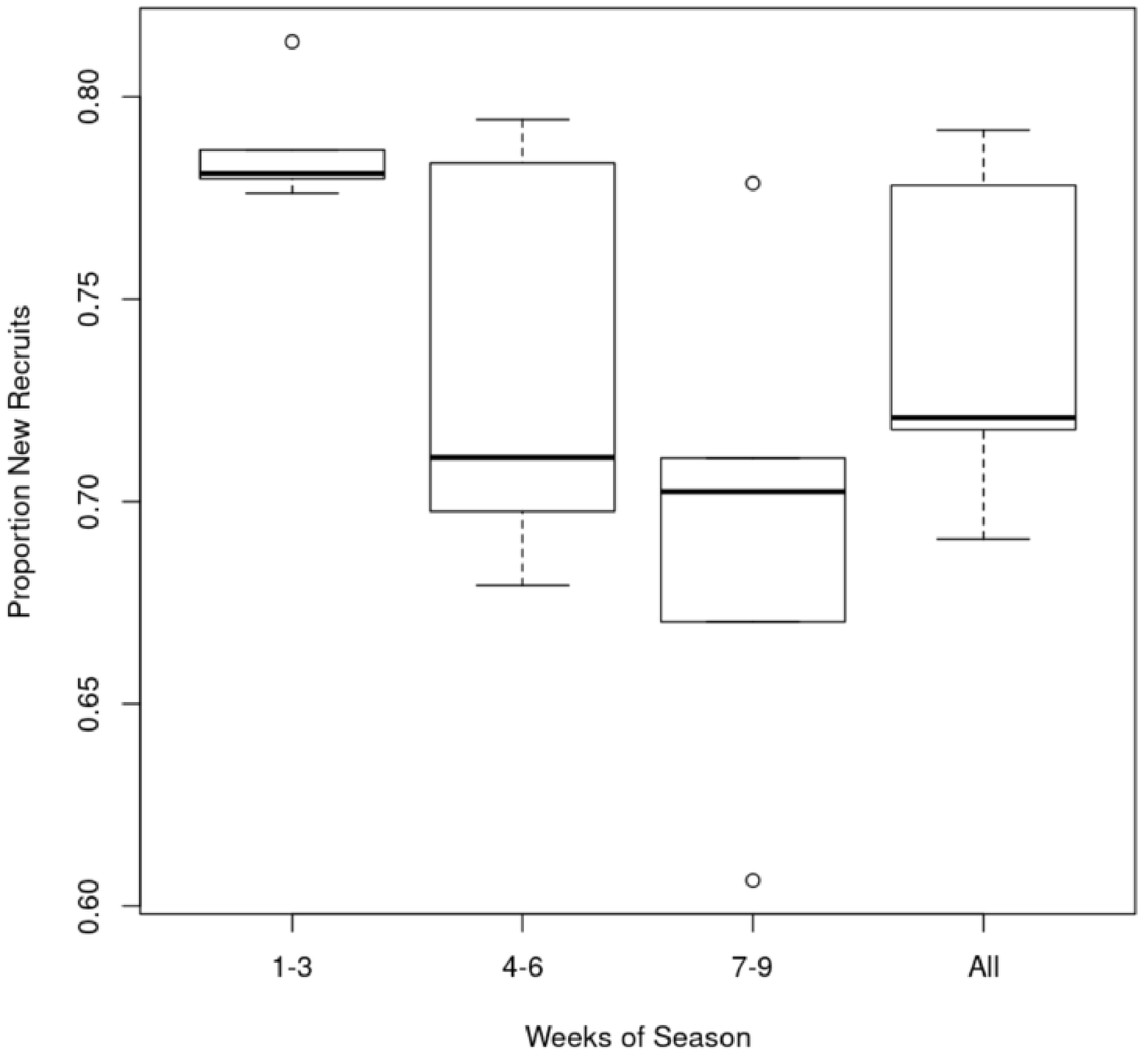


Figure 41: Boxplots of estimated proportion of total numbers landed represented by new recruits (MLS : MLS + 11 mm) from sea sampling dates (weeks of season) observed from LFA 27 during the 2011–2015 seasons.

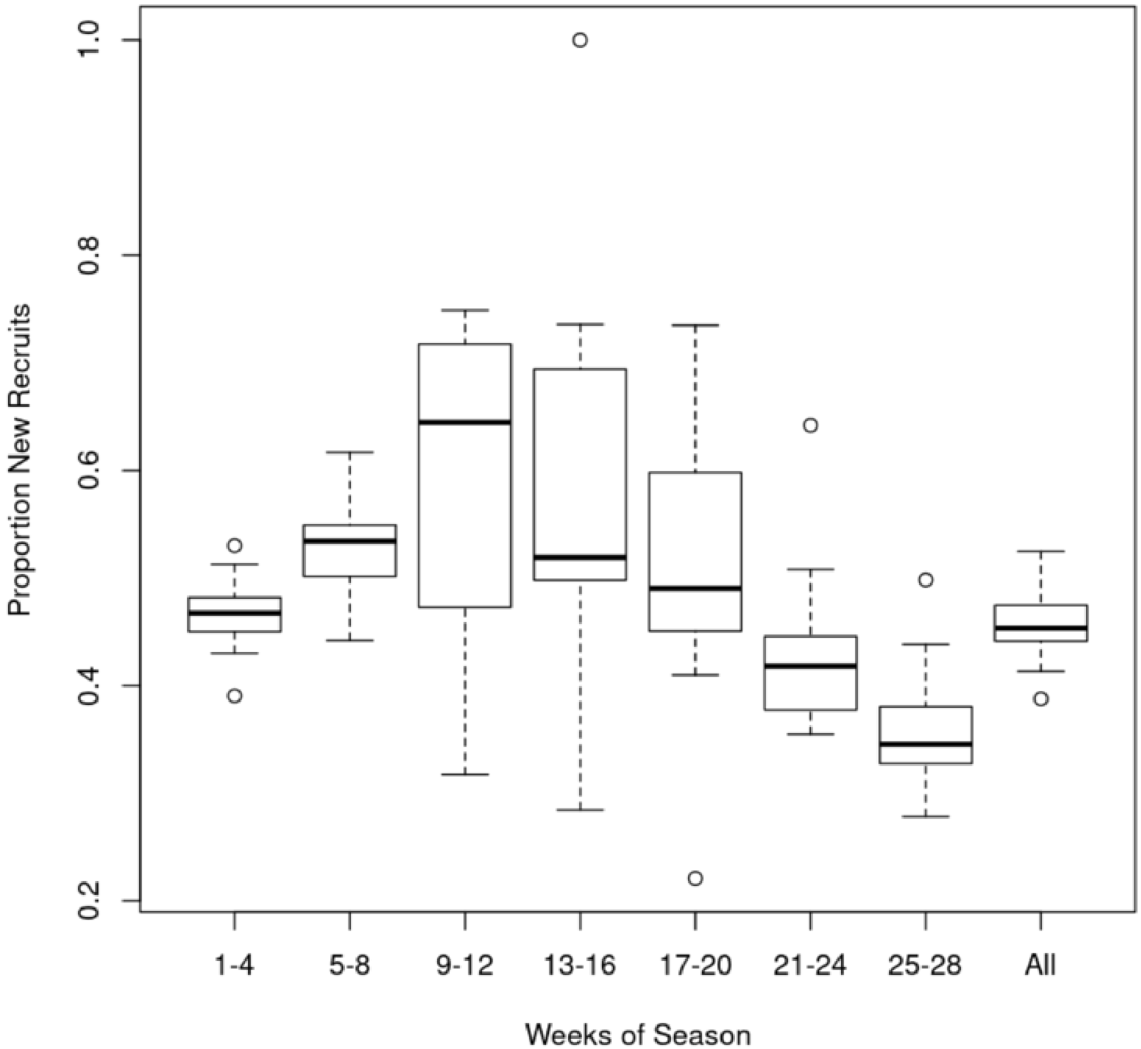


Figure 42: Boxplots of estimated proportion of total numbers landed represented by new recruits (MLS : MLS + 11 mm) from FSRS commercial sample dates (weeks of season) observed from LFA 33 during the 2004–2016 seasons.

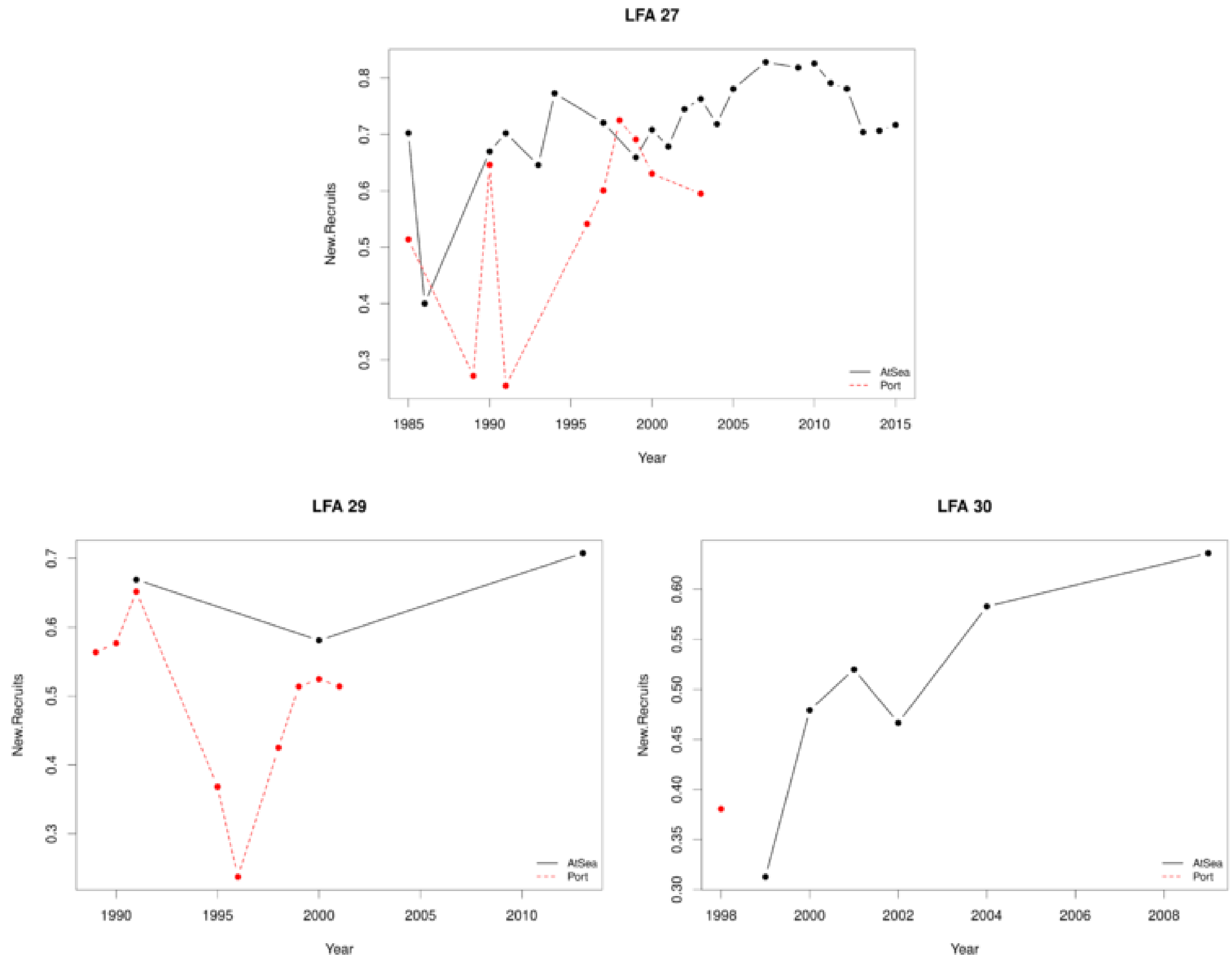


Figure 43: Time series of the proportion of total numbers landed represented by new recruits (MLS : MLS +11 mm) taken from at sea samples, and /or port samples. Data was limited to mid-season samples.

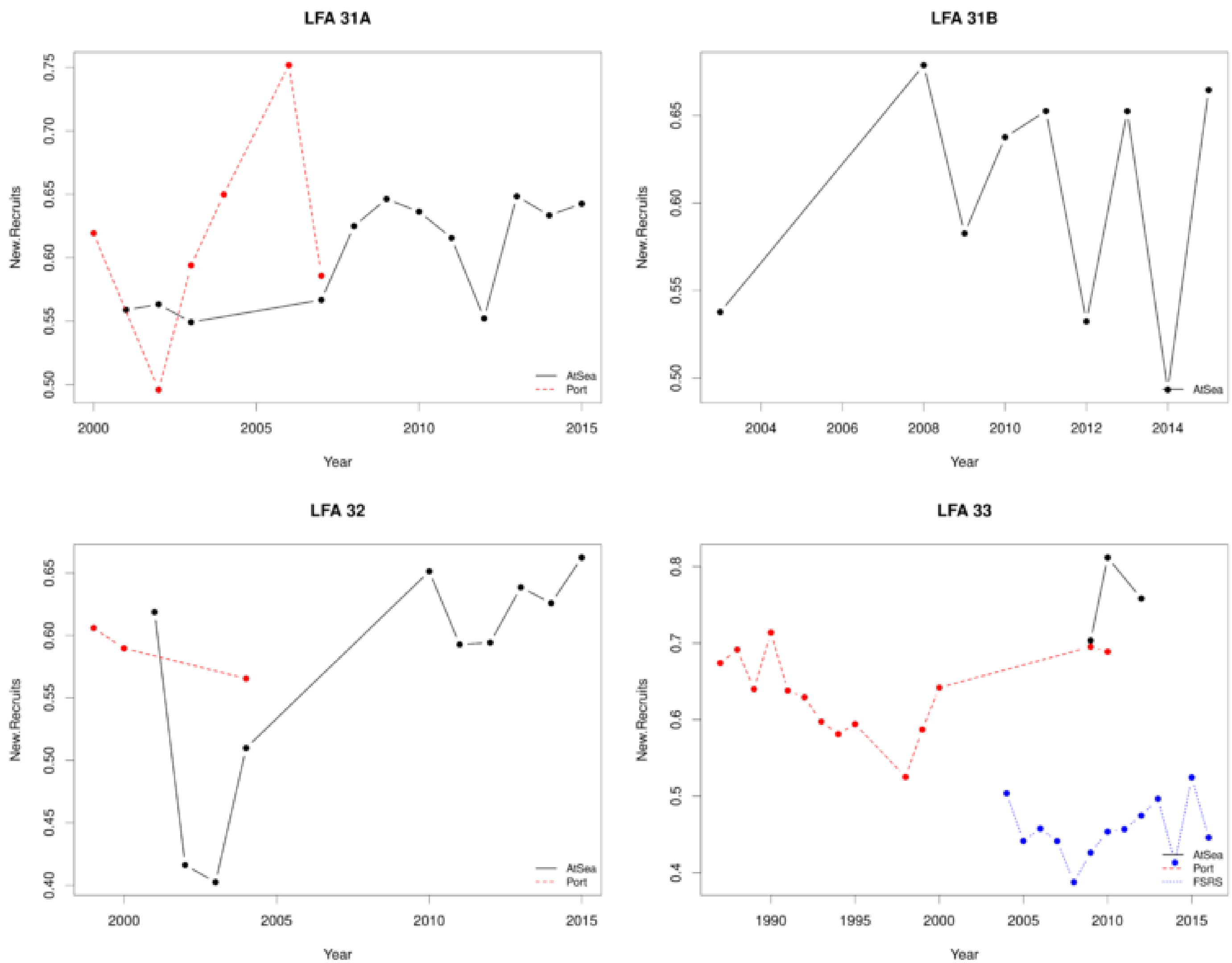


Figure 44: Time series of the proportion of total numbers landed represented by new recruits (MLS : MLS + 11 mm) taken from at sea samples, and /or port samples. Data was limited to mid-season samples.

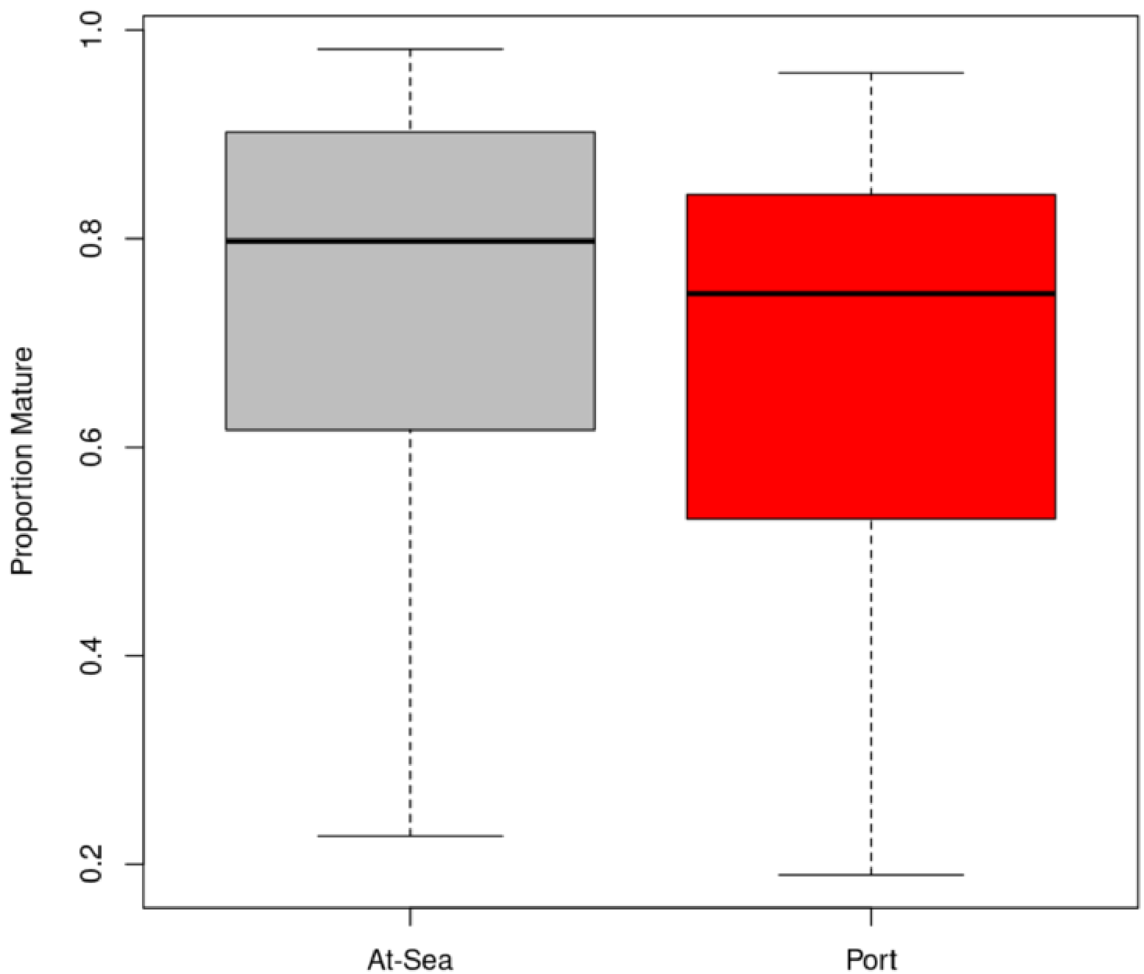


Figure 45: Boxplot of the estimates of proportion mature lobster in the landings, separated by data source.

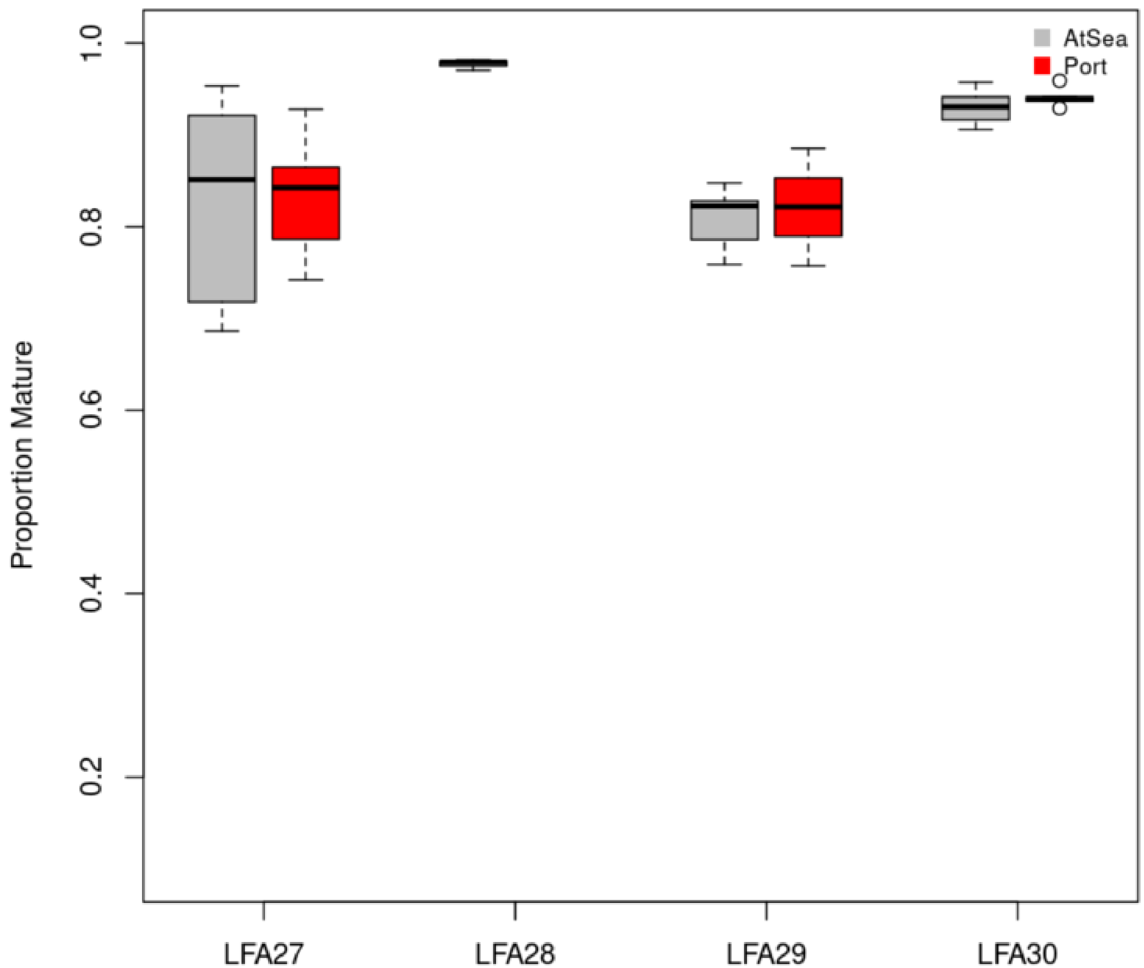


Figure 46: Boxplot of the annual estimates of proportion mature lobster in the landings separated by data source for LFA 27–30. FSRS data sets not included in this analysis.

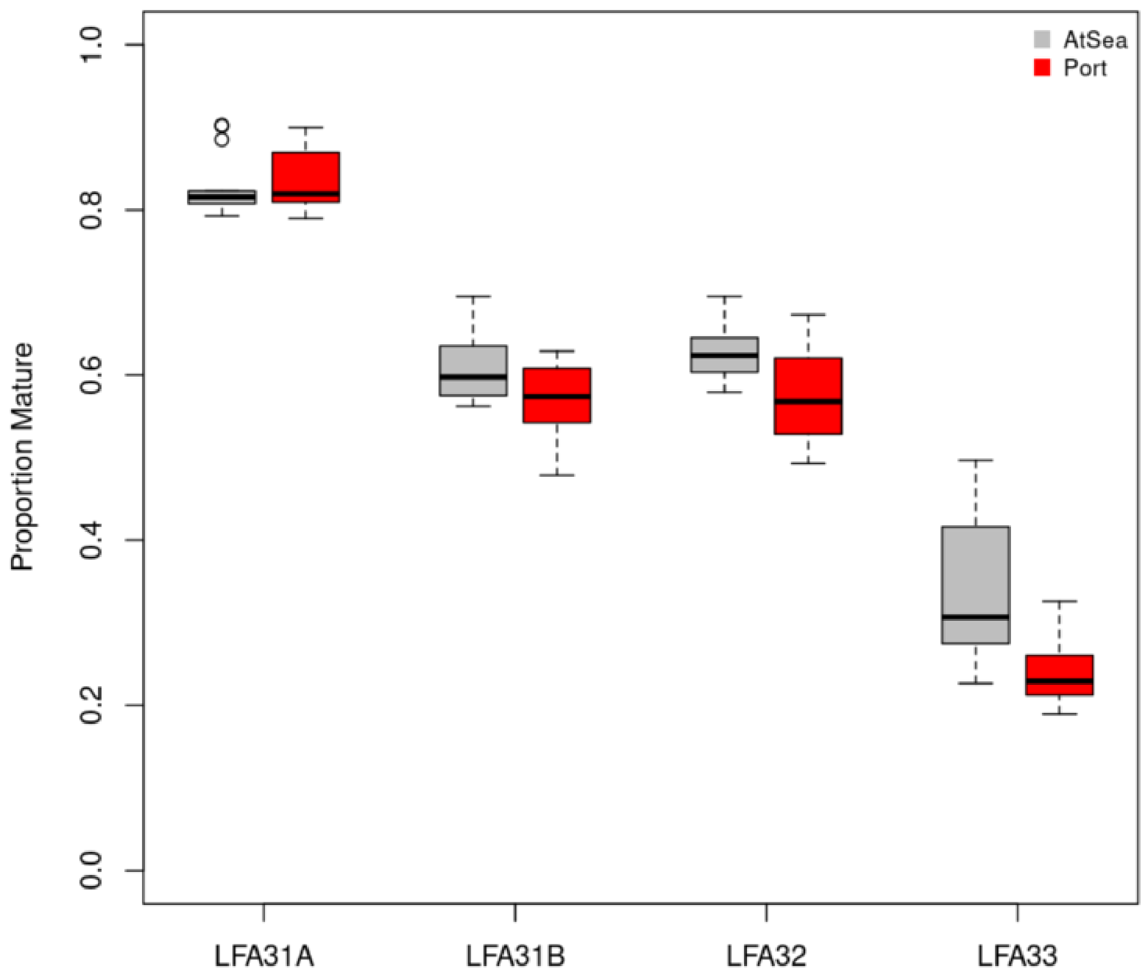


Figure 47: Boxplot of the annual estimates of proportion mature lobster in the landings, separated by data source for LFA 31A–33. FSRS data set not included in this analysis.

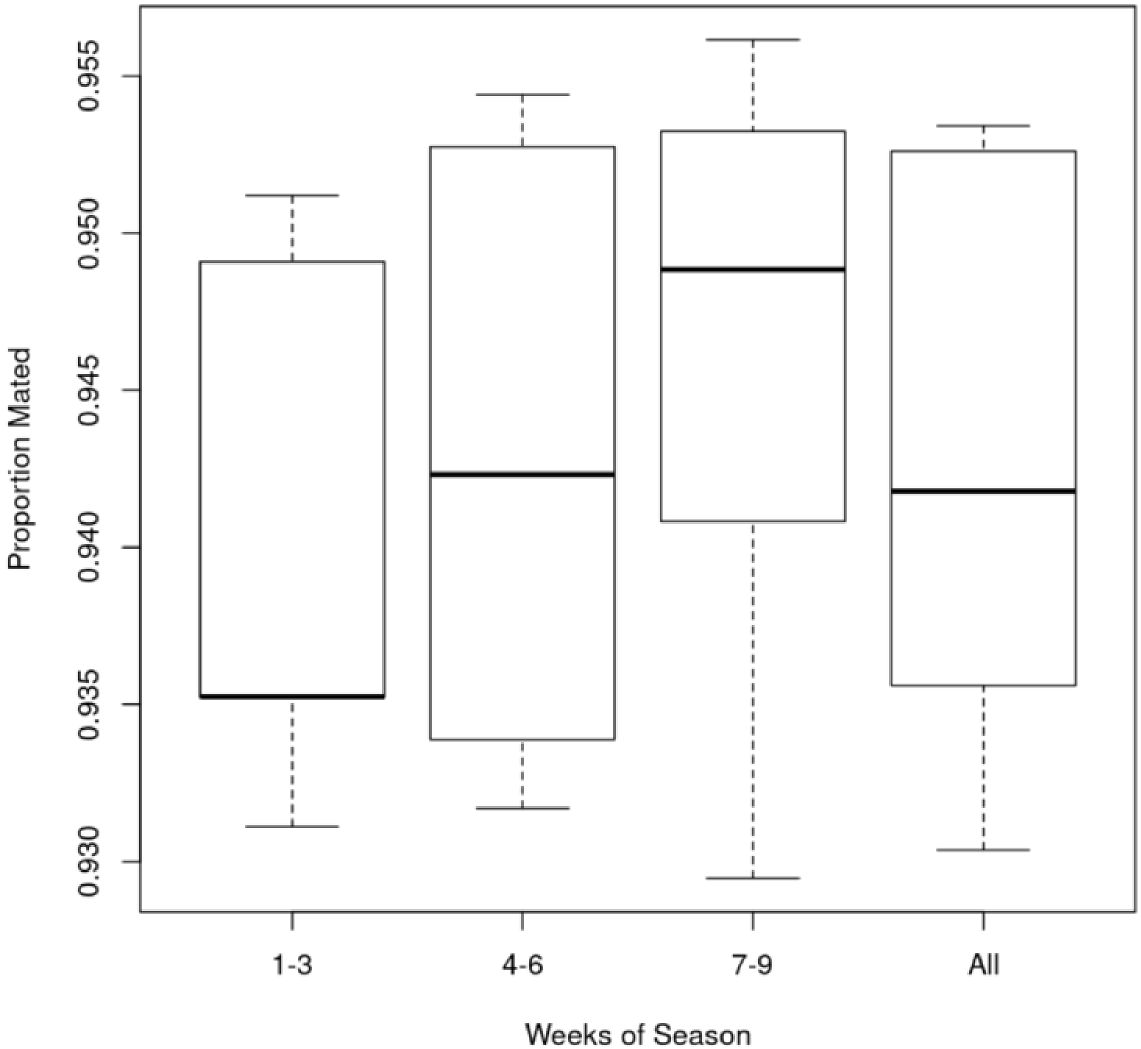


Figure 48: Boxplots of estimated proportion of the proportion mature lobster in the landings from sea sampling dates (weeks of season) observed from LFA 27 during the 2011–2015 seasons.

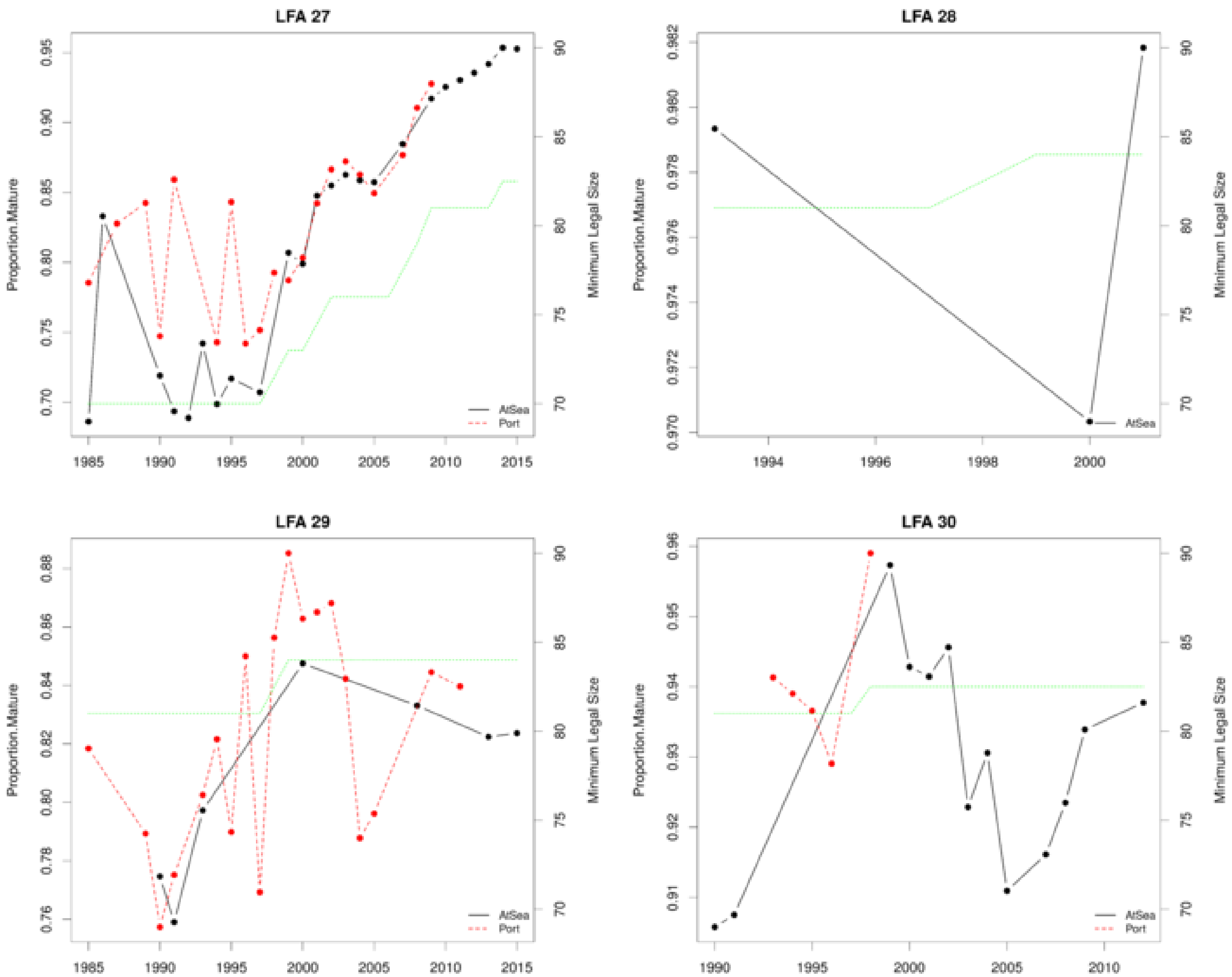


Figure 49: Time series of the proportion mature lobster in the landings from at sea samples, and /or port samples. Time series of changes in MLS are shown in green.

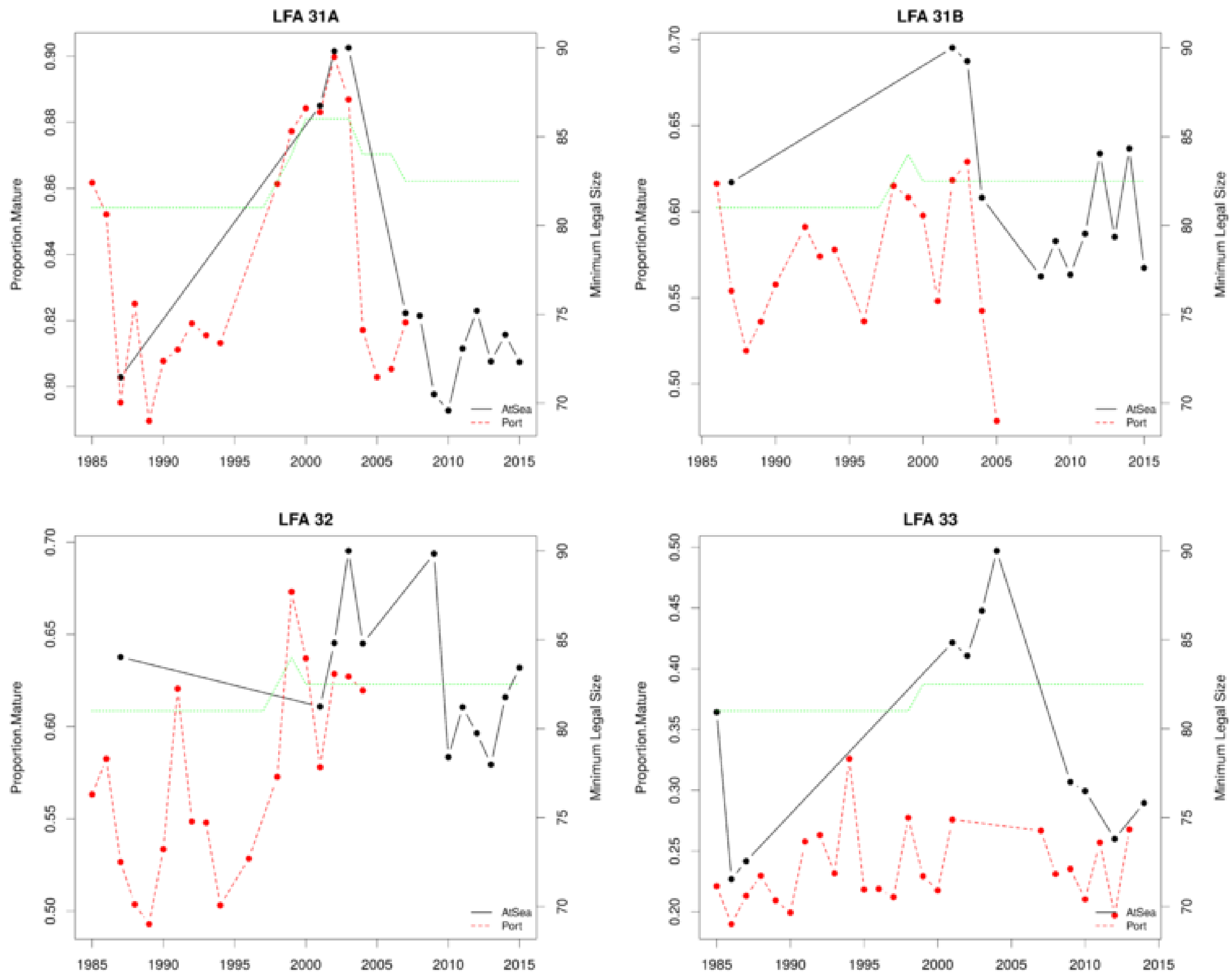


Figure 50: Time series of the proportion mature lobster in the landings at sea samples, and /or port samples. Time series of changes in MLS are shown in green.

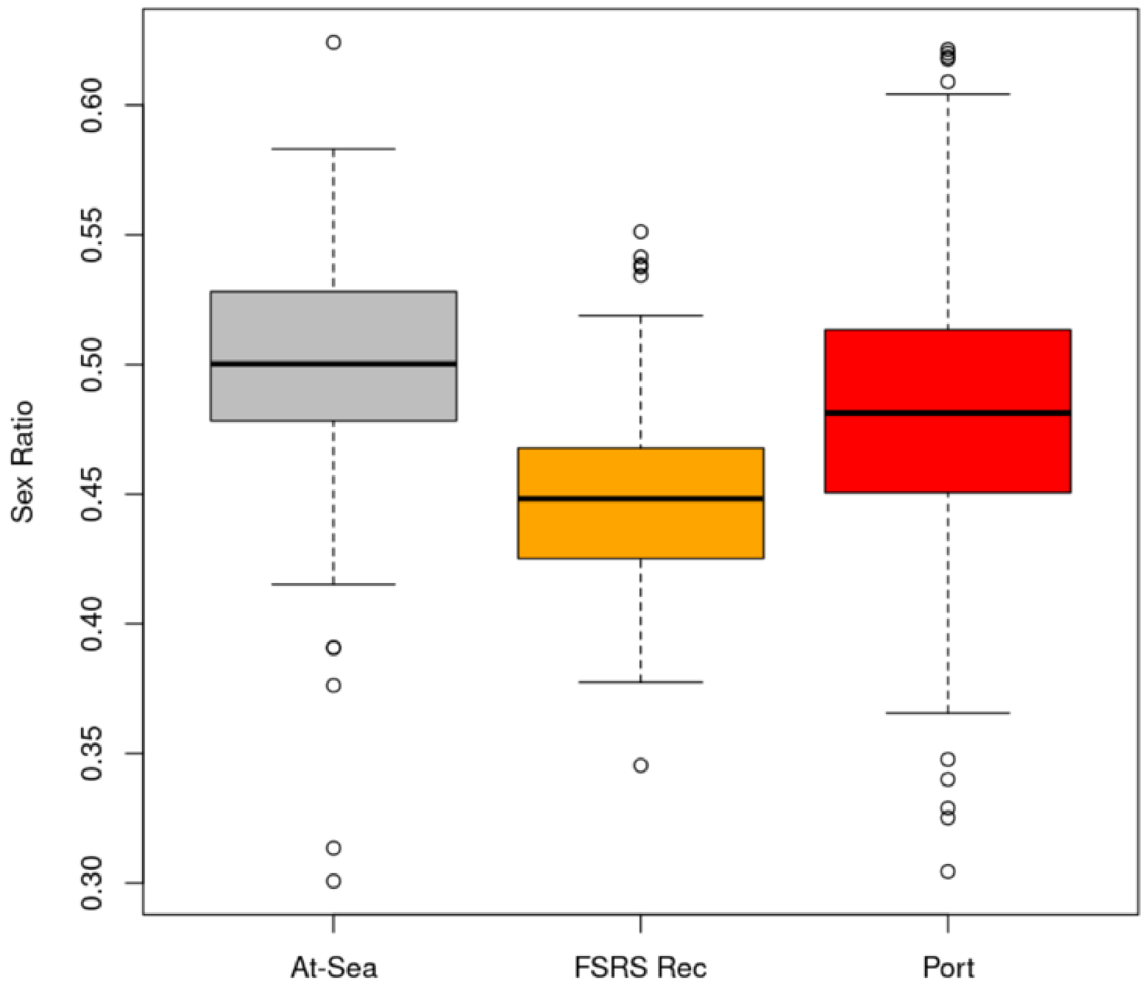


Figure 51: Boxplot of the estimates of sex ratio (proportion of female) Lobster separated by data source.

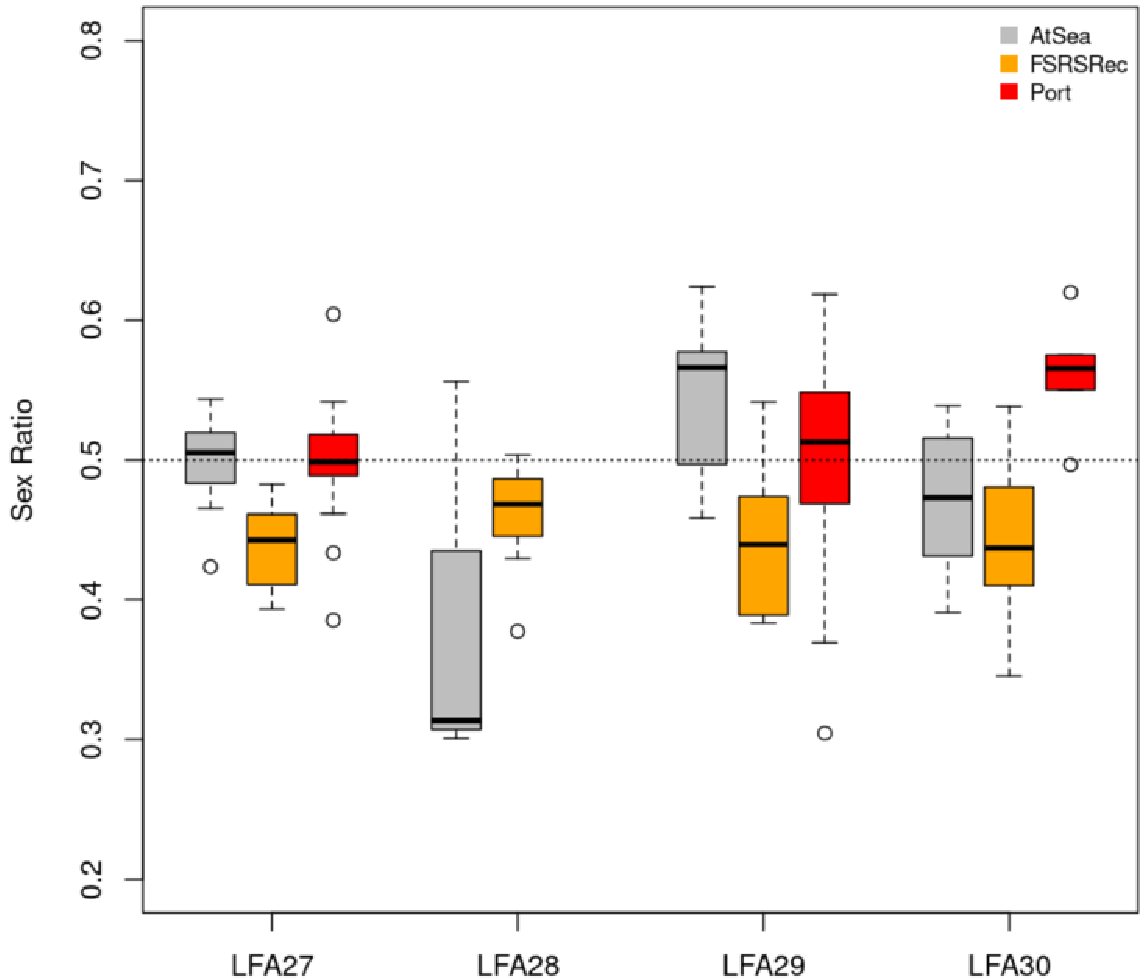


Figure 52: Boxplot of the annual estimates of sex ratio (proportion of female) Lobster sampled by data source for LFA 27–30.

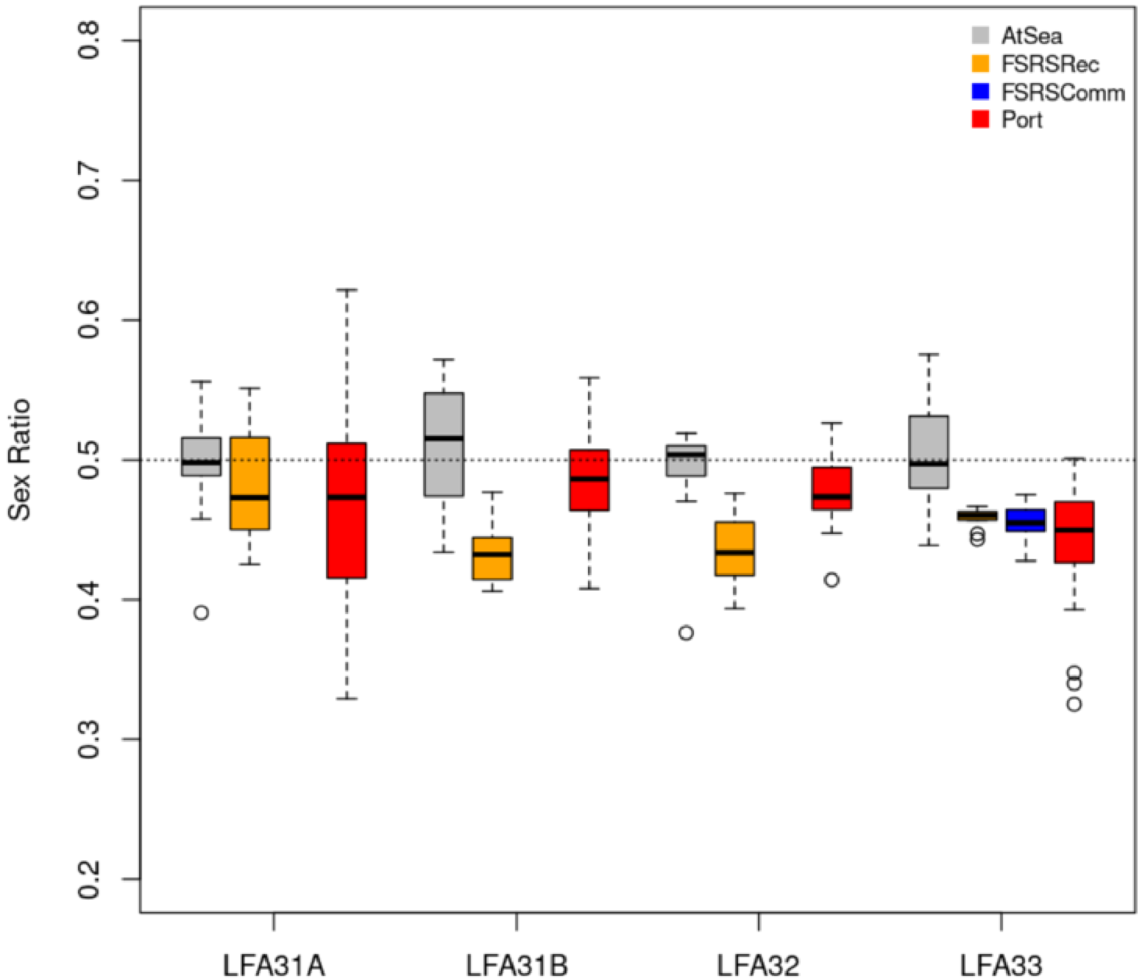


Figure 53: Boxplot of the annual estimates of sex ratio (proportion of female) Lobster sampled by data source for LFA 31A–33.

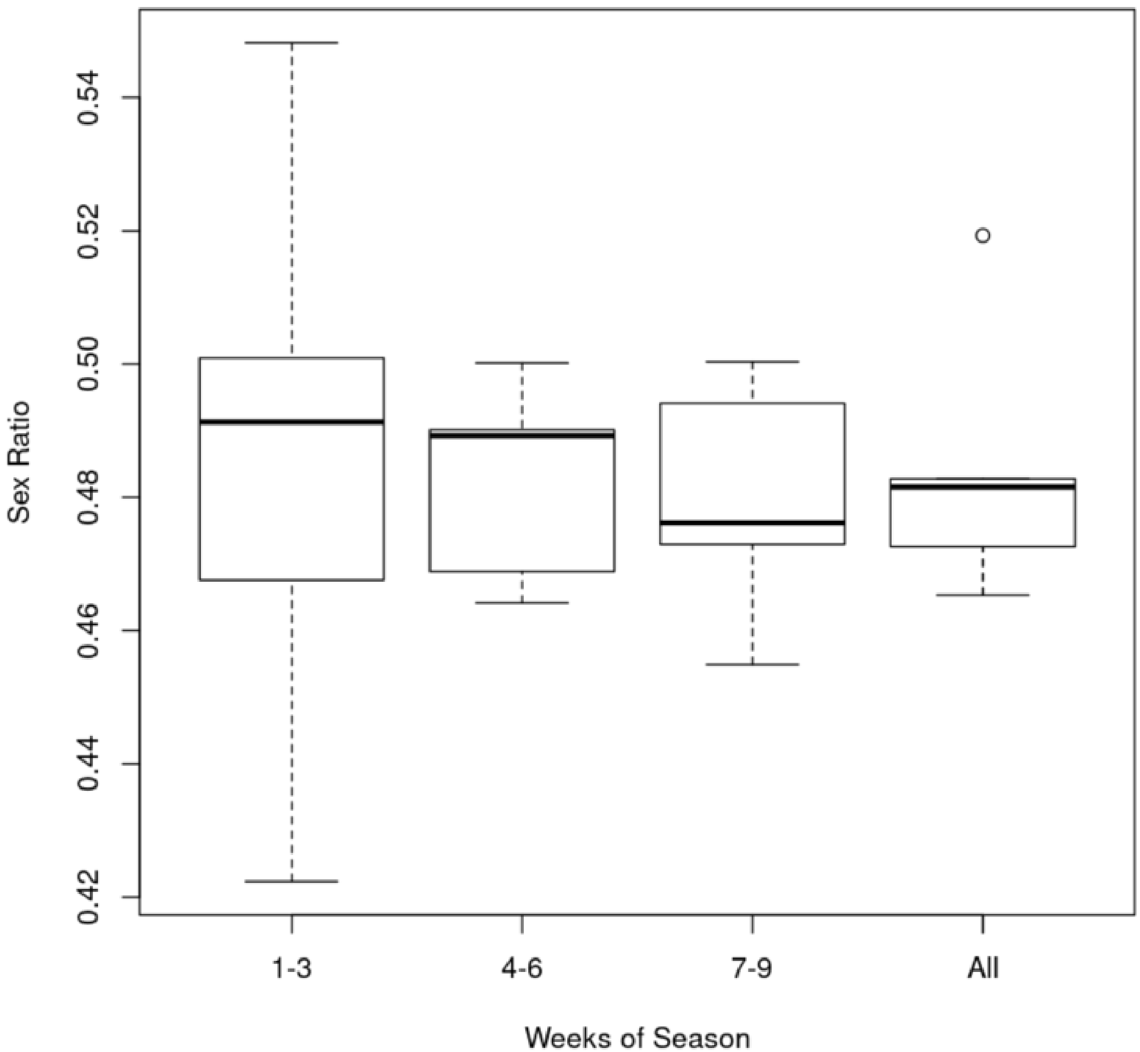


Figure 54: Boxplots of estimated sex ratio (proportion of females) from sea sampling dates (weeks of season) observed from LFA 27 during the 2011–2015 seasons.

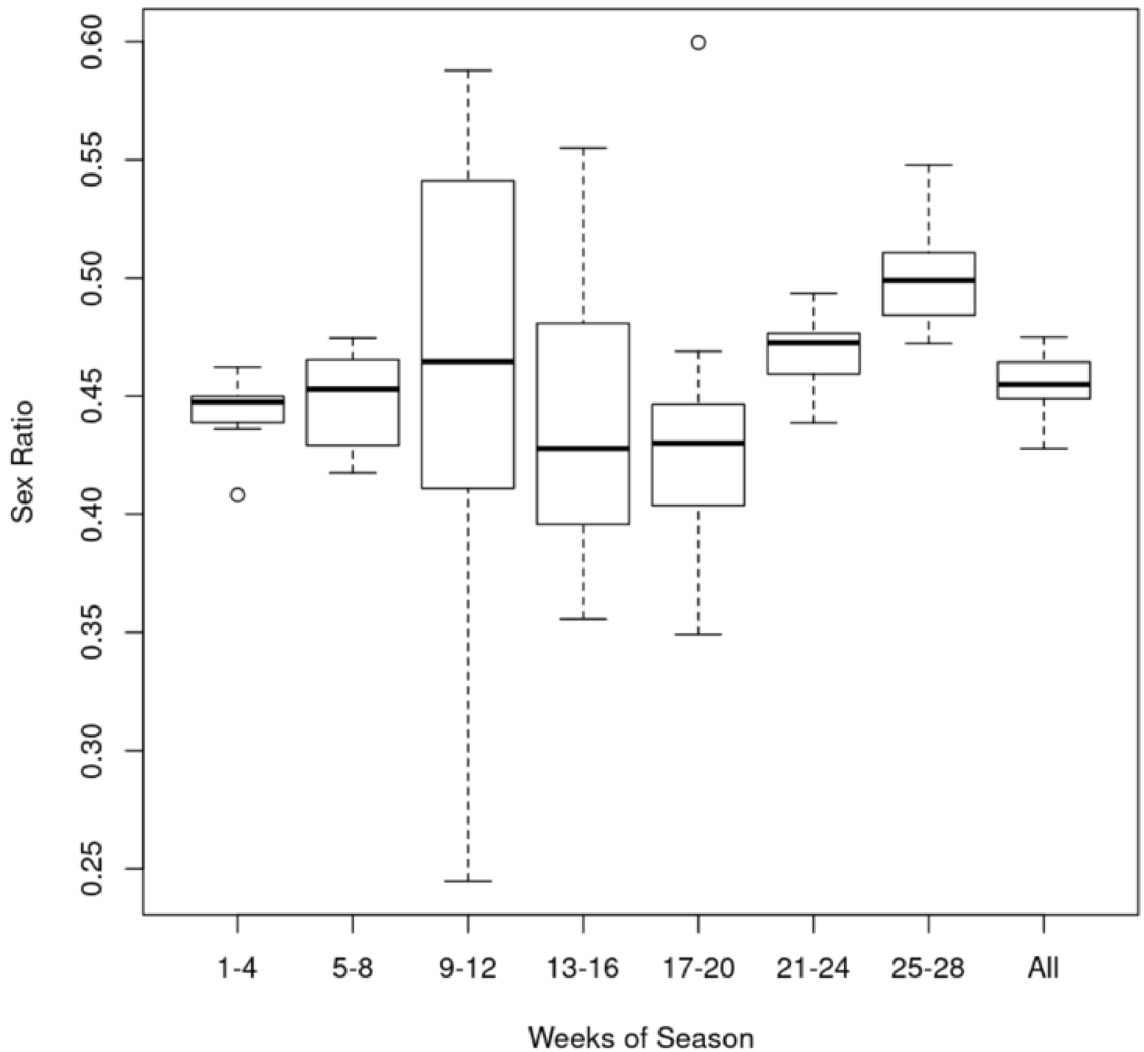


Figure 55: Boxplots of estimated sex ratio (proportion of females) from FSRS commercial sampling dates (weeks of season) observed from LFA 33 during the 2004–2016 seasons.

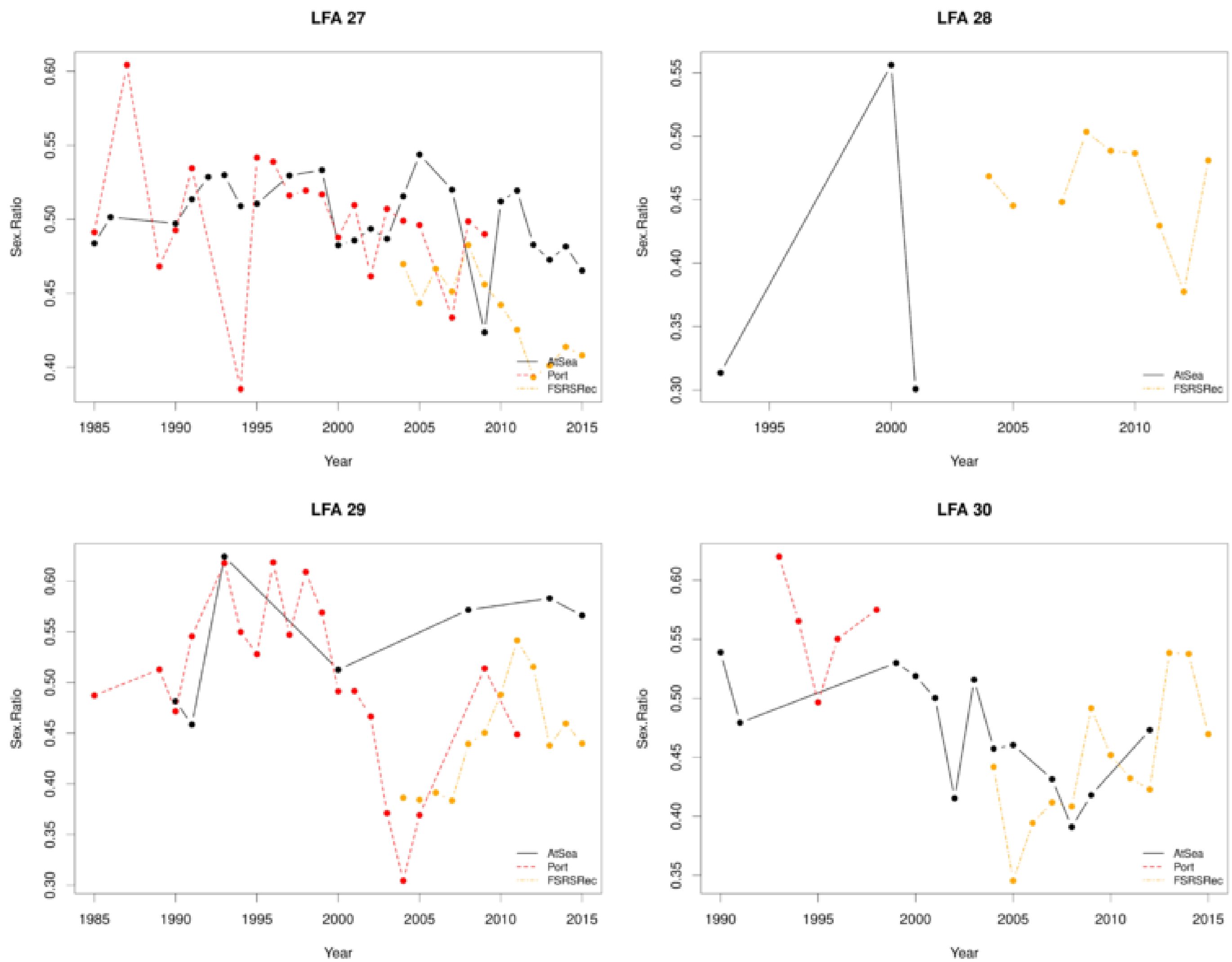


Figure 56: Time series of the sex ratio (proportion female) Lobster by data source across LFAs.

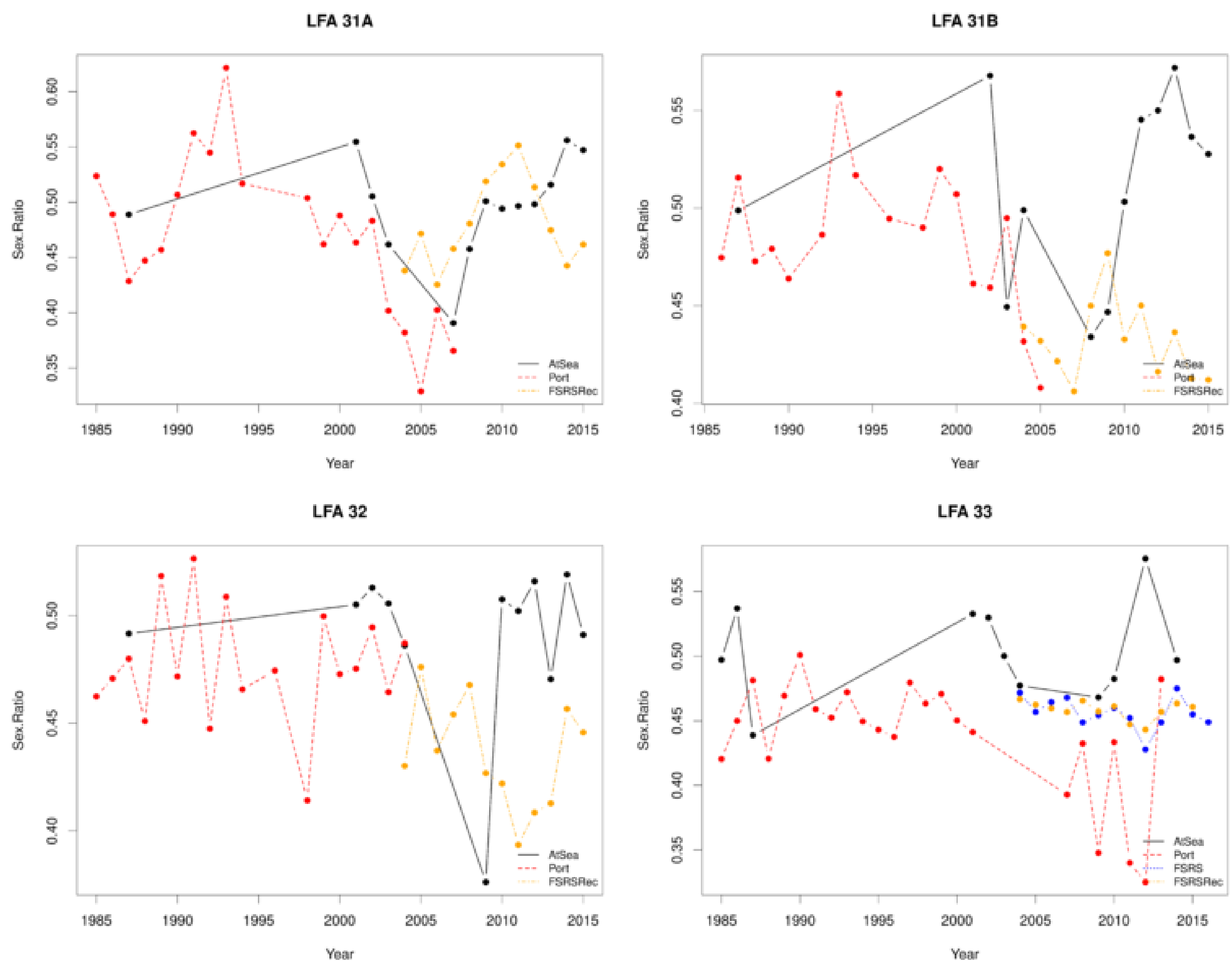


Figure 57: Time series of the sex ratio (proportion female) Lobster by data source across LFAs.

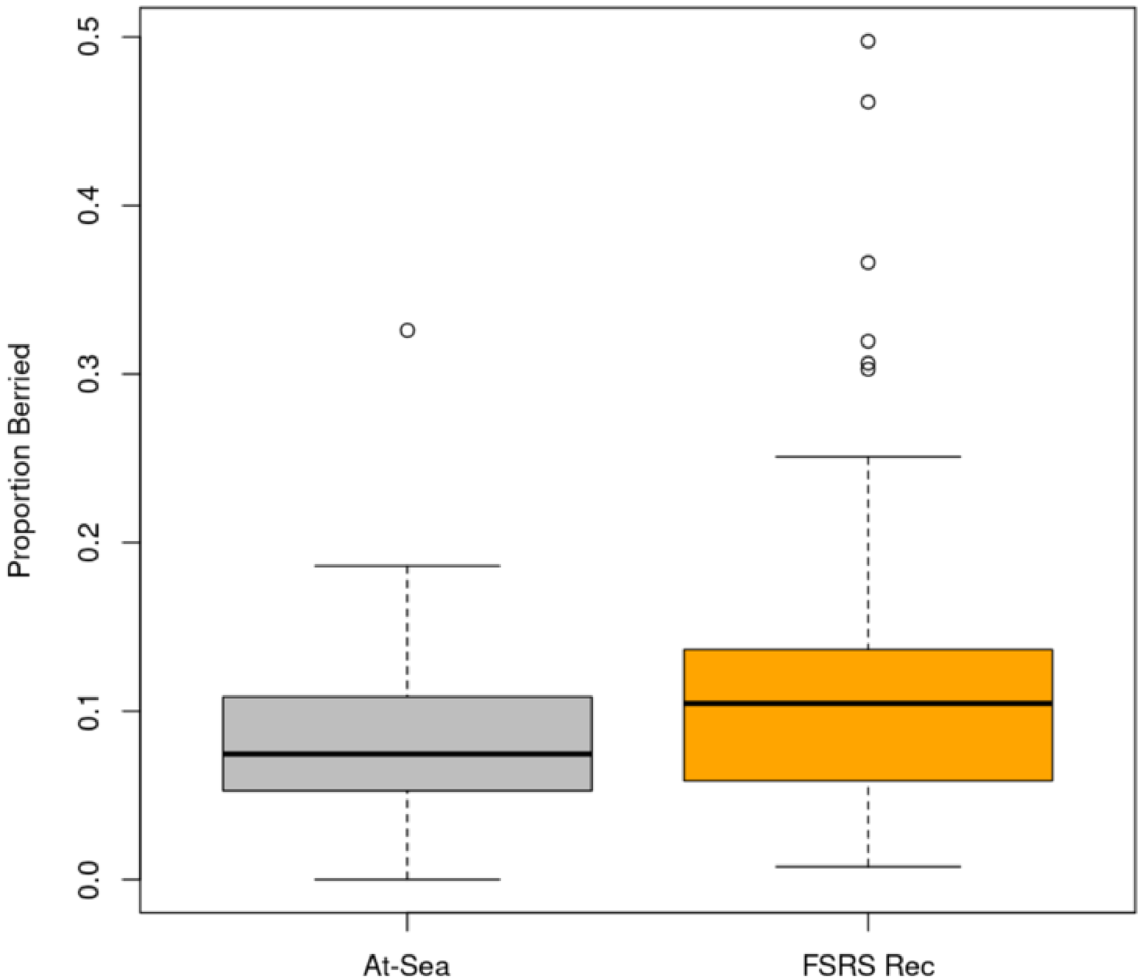


Figure 58: Boxplot of the estimates of proportion of berried female Lobster sampled by data source across all LFAs.

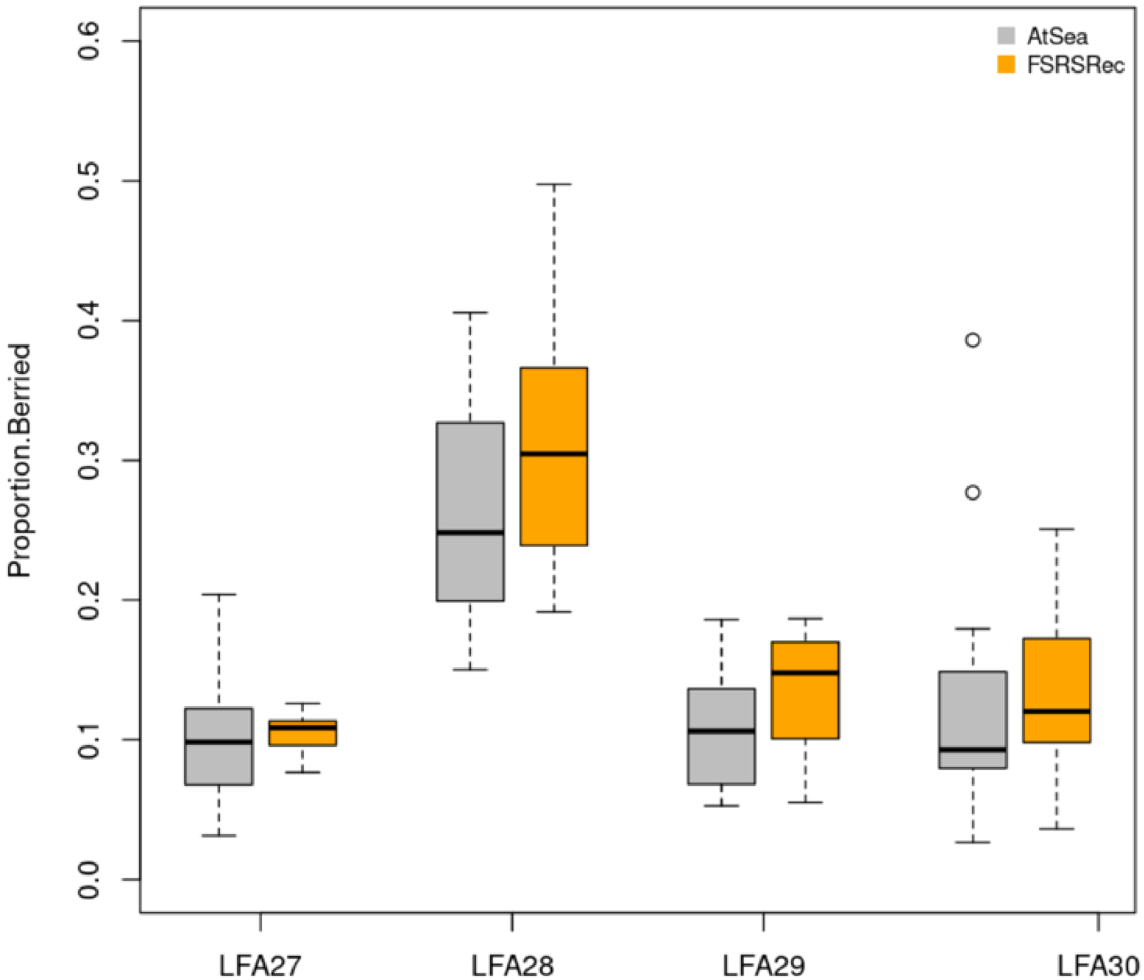


Figure 59: Boxplot of the time series of proportion of berried female Lobster sampled by data source for LFA 27–30.

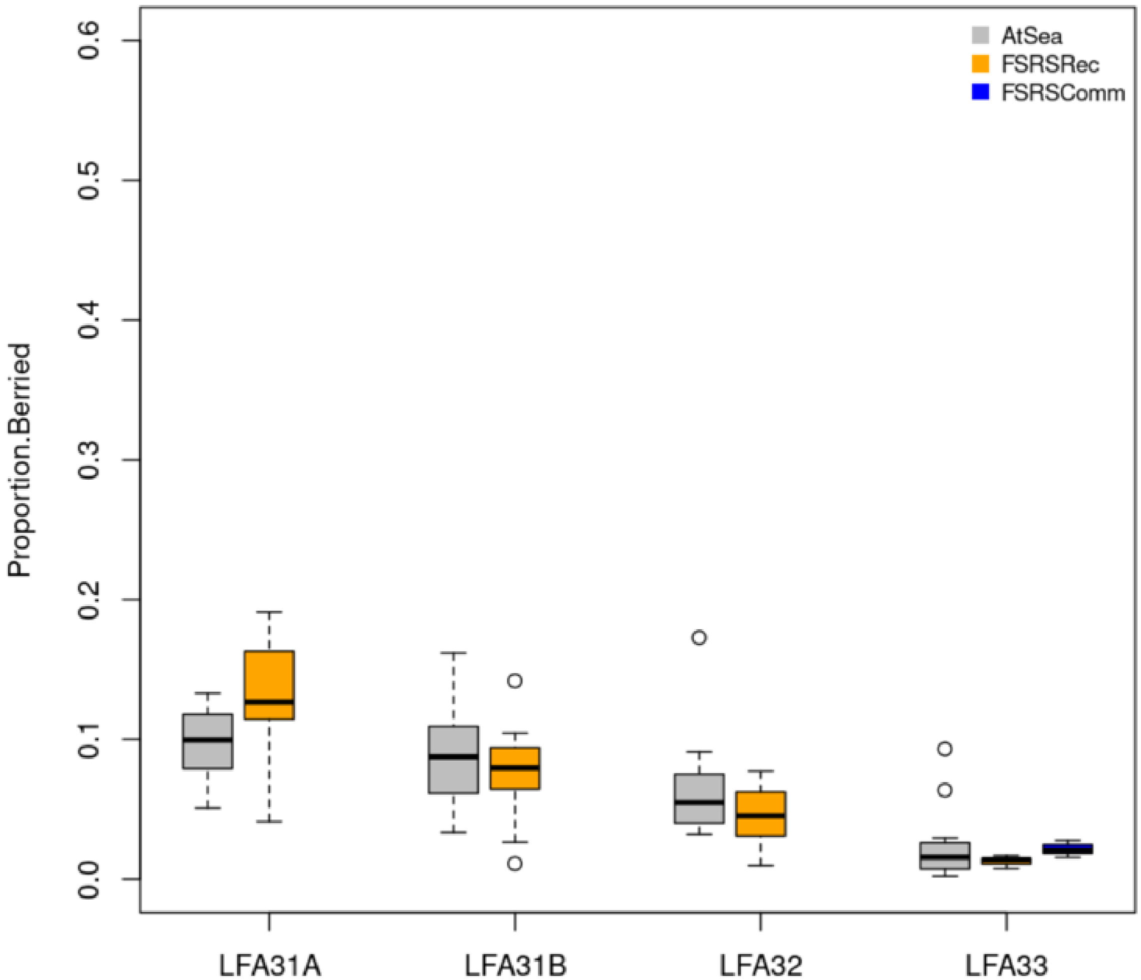


Figure 60: Boxplot of the time series of proportion of berried female Lobster sampled by data source for LFA 31A–33.

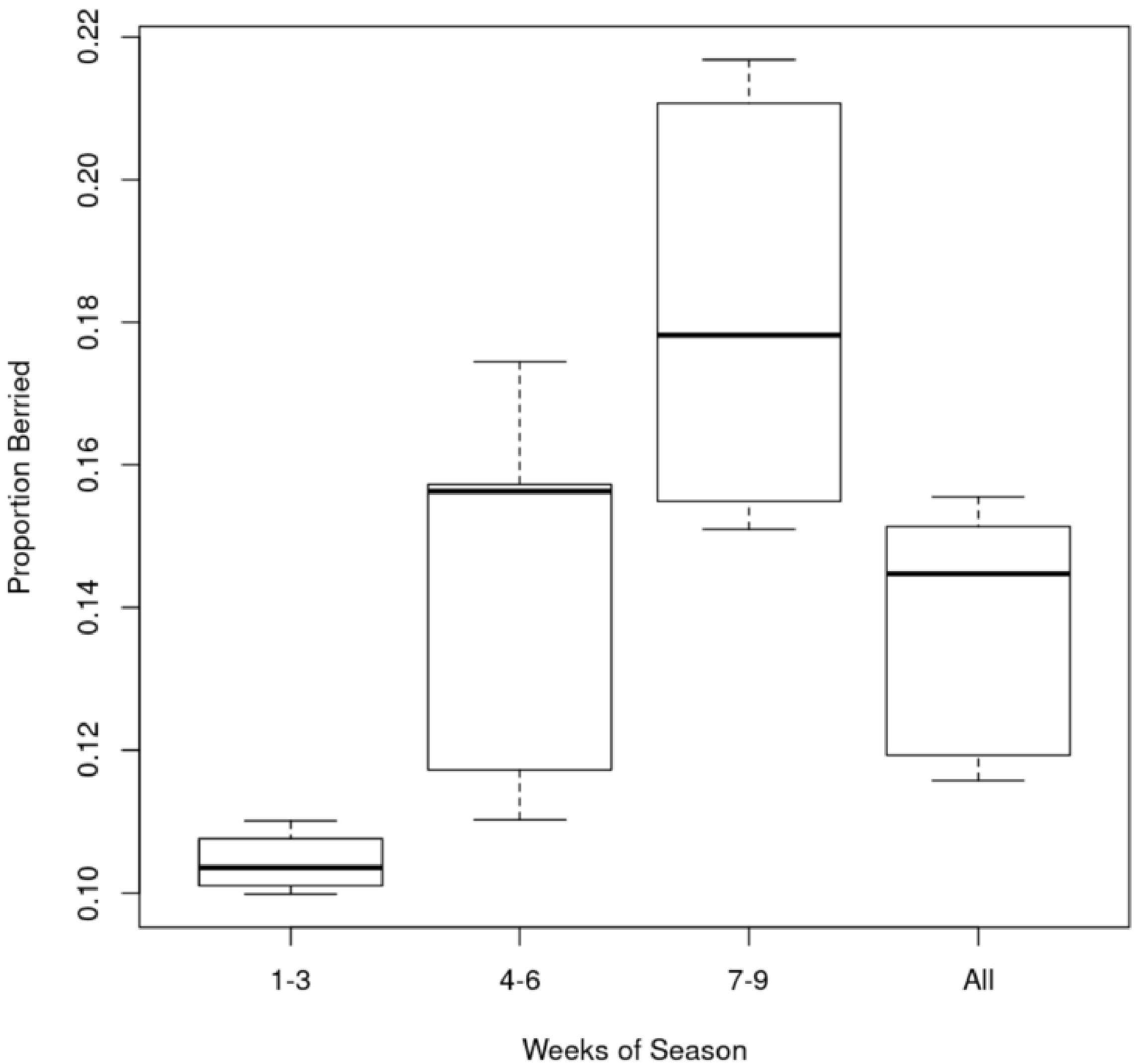


Figure 61: Boxplots of estimated proportion of berried females from sea sampling dates (weeks of season) observed from LFA 27 during the 2011–2015 seasons.

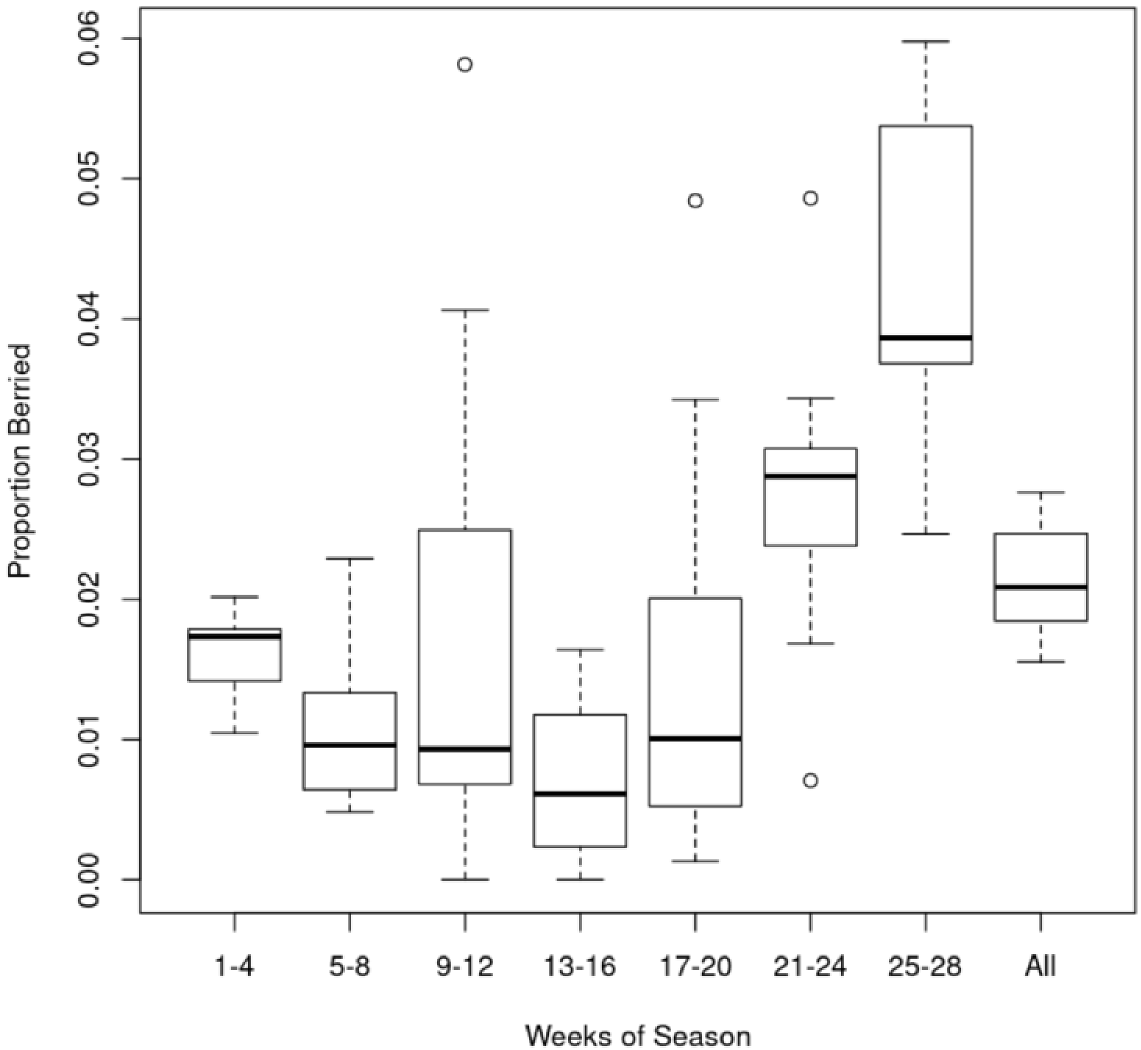


Figure 62: Boxplots of estimated proportion of berried females from FSRS commercial sampling dates (weeks of season) observed from LFA 33 during the 2004–2016 seasons.

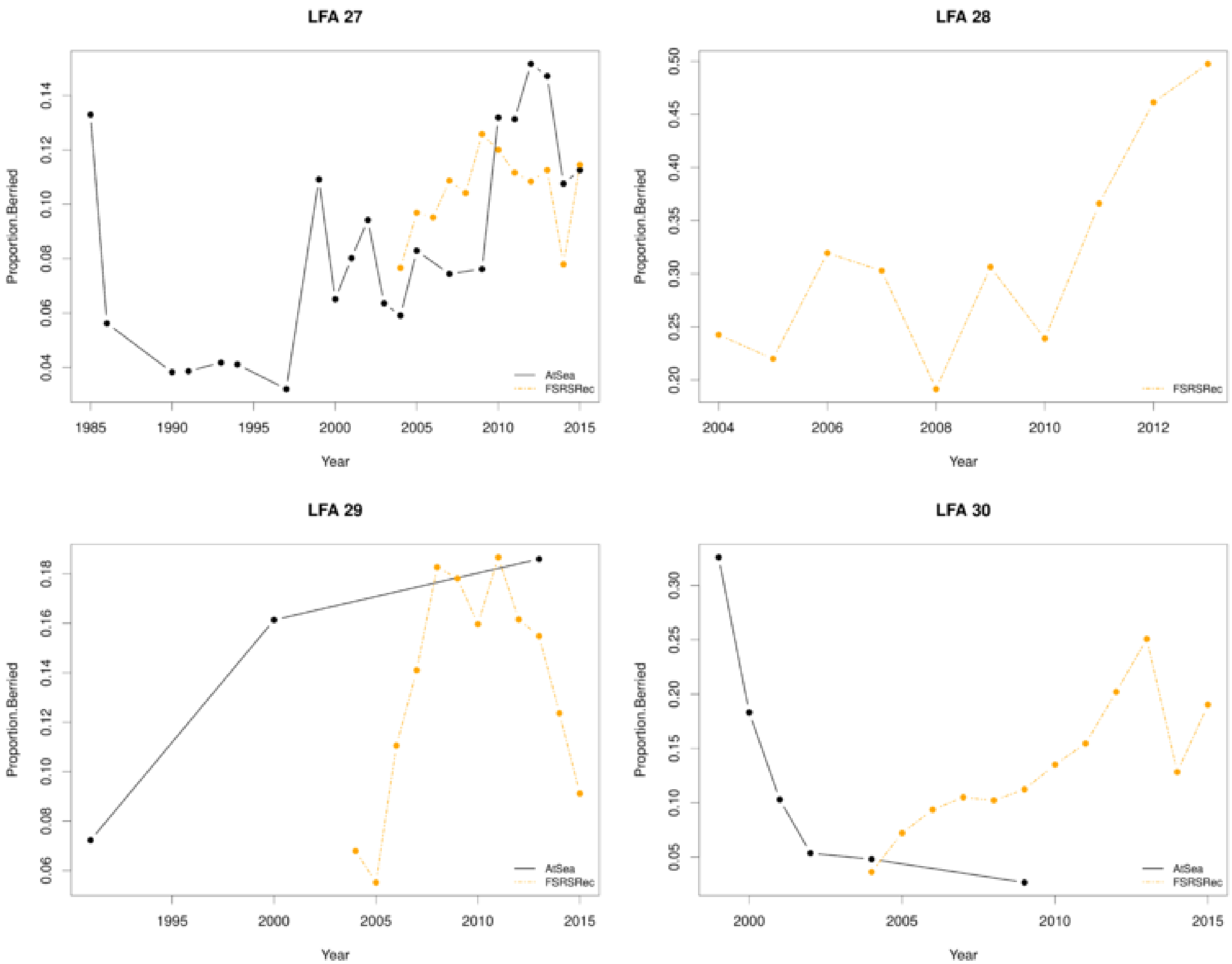


Figure 63: Time series of the proportion of berried female Lobster by data source across LFAs. Data was limited to mid-season samples.

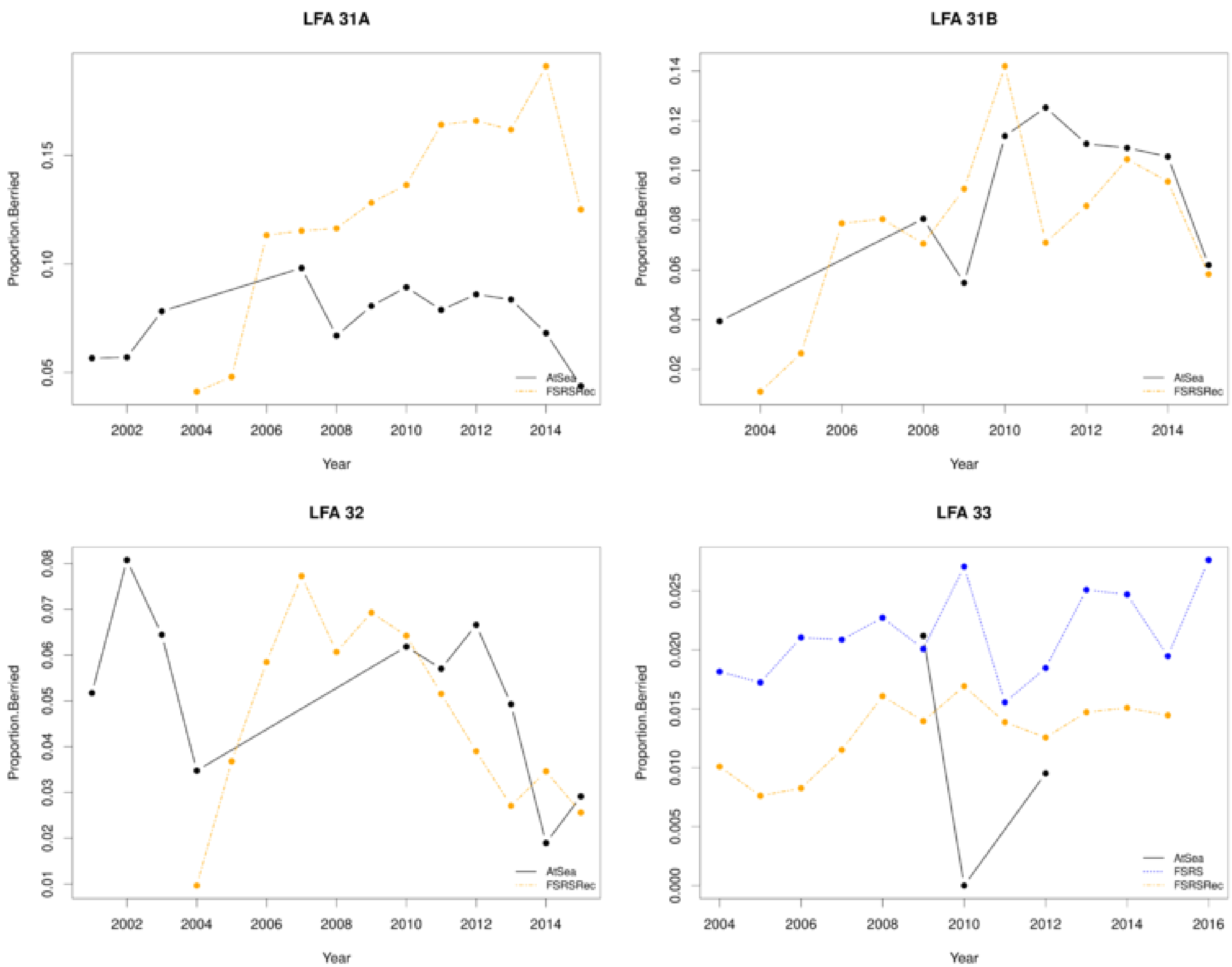


Figure 64: Time series of the proportion berried female Lobster by data source across LFAs. Data was limited to mid-season samples.

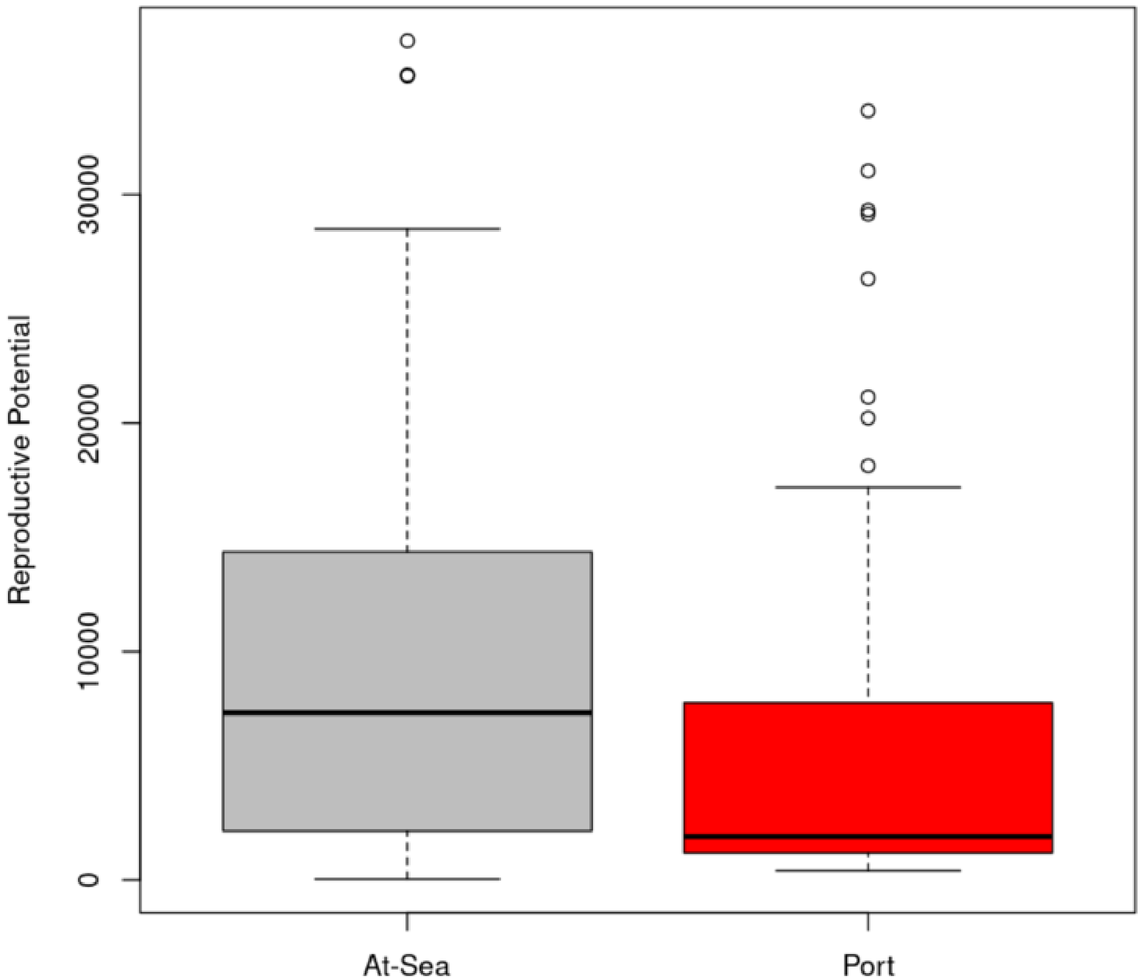


Figure 65: Boxplot of the estimates of reproductive potential by data source across all LFAs.

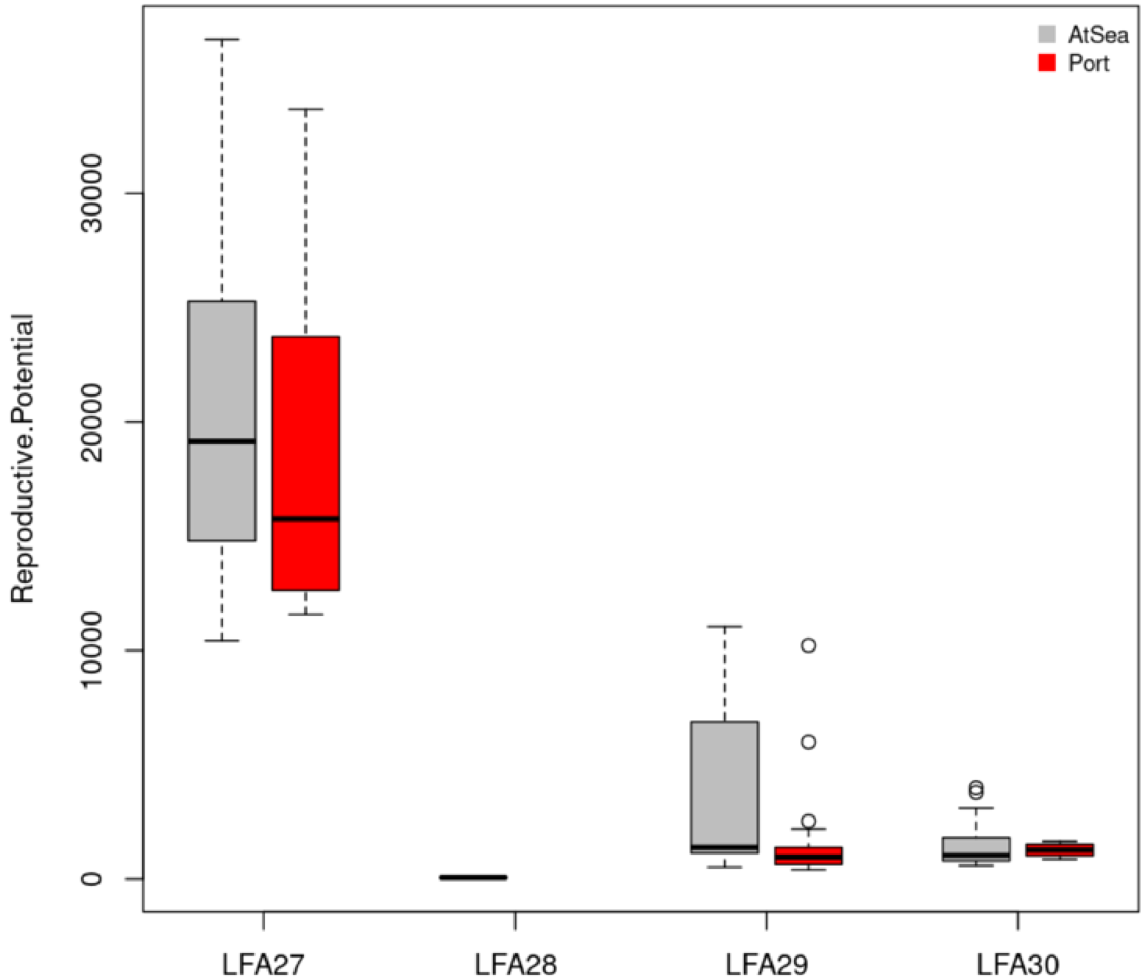


Figure 66: Boxplot of the time series of reproductive potential for Lobster sampled by data source for LFA 27–30.

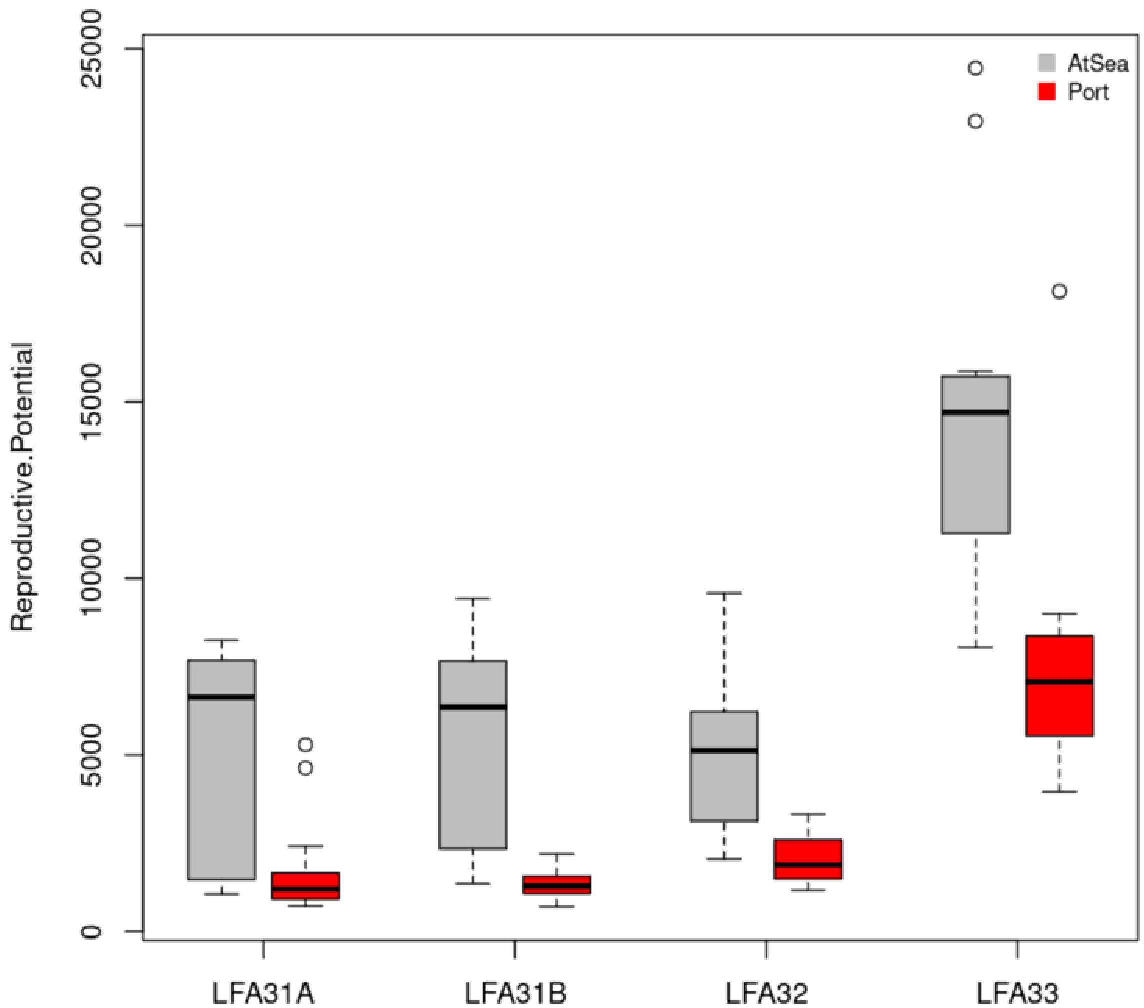


Figure 67: Boxplot of the time series of reproductive potential for Lobster sampled by data source for LFA 31A–33.

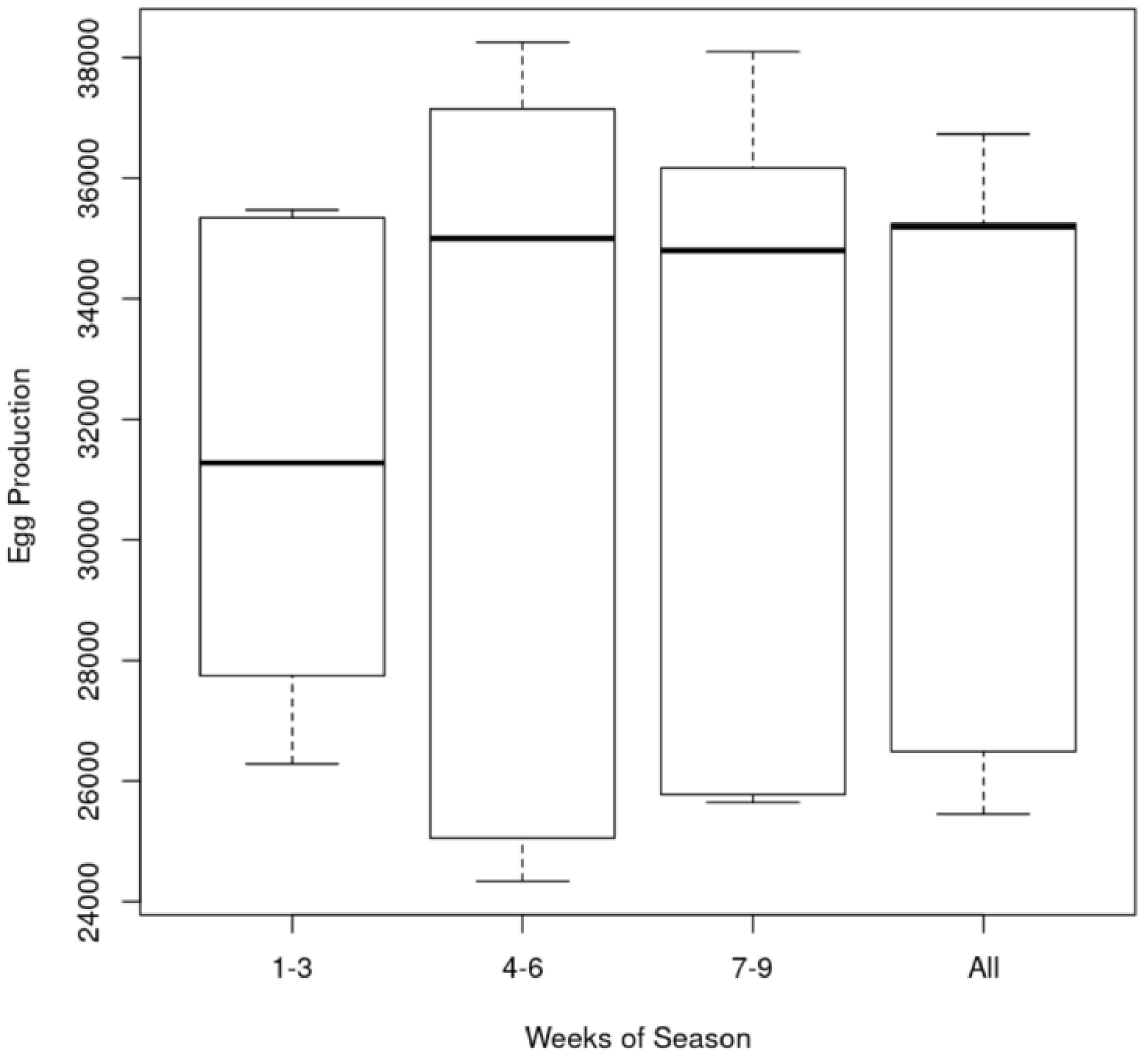


Figure 68: Boxplots of estimated reproductive potential from sea sampling dates (weeks of season) observed from LFA 27 during the 2011–2015 seasons.

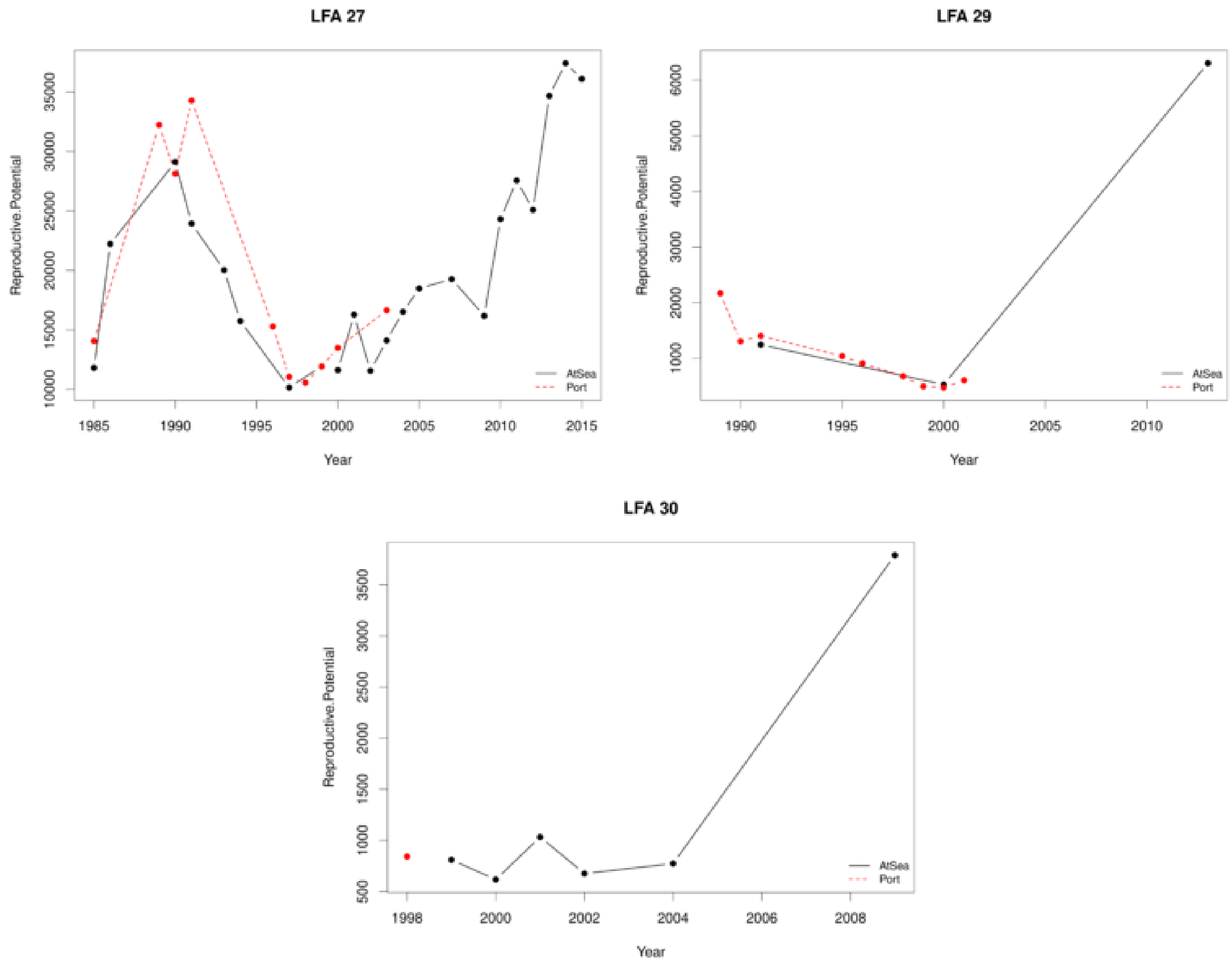


Figure 69: Time series of the reproductive potential by data source across LFAs. Data was limited to mid-season samples.

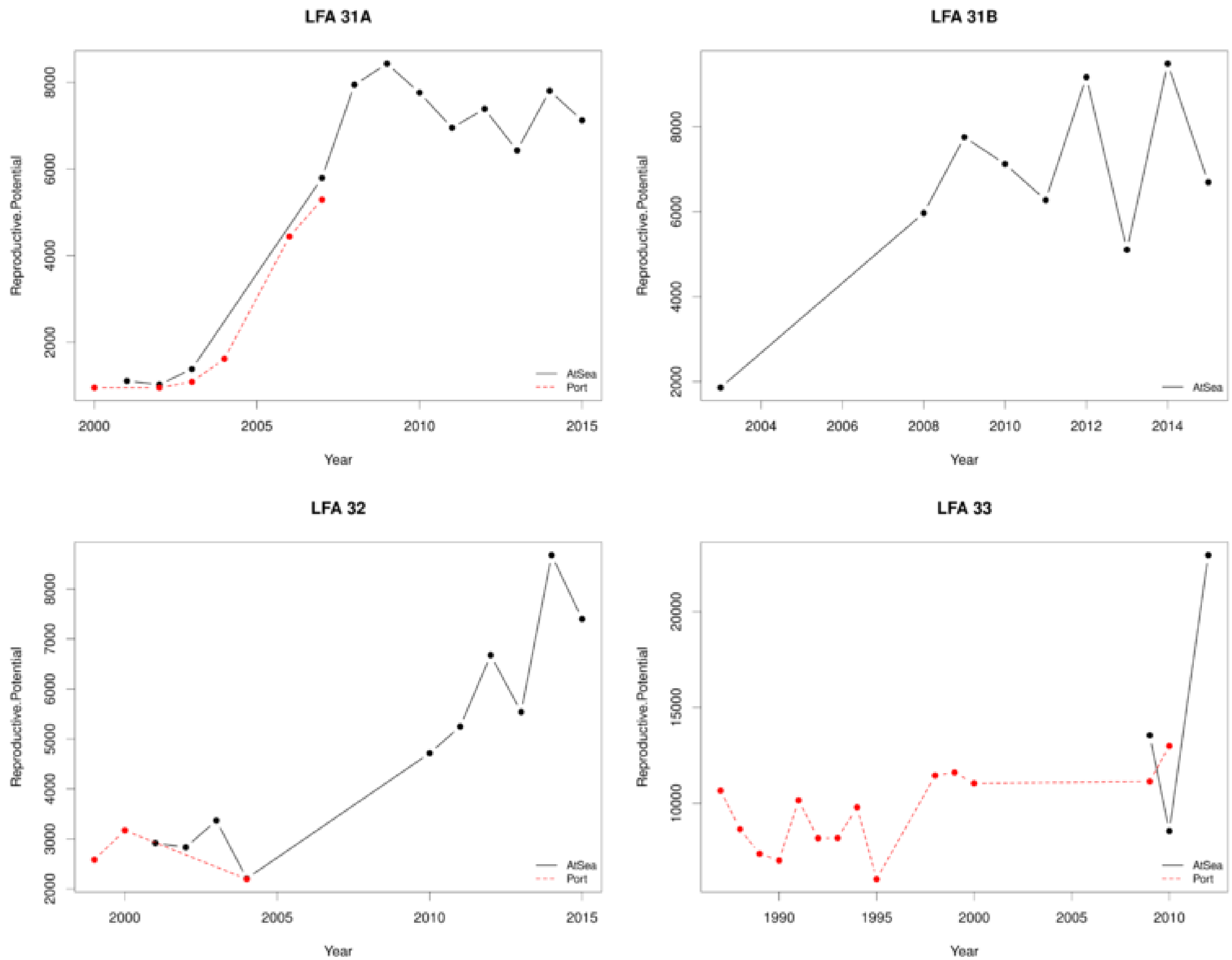


Figure 70: Time series of the reproductive potential by data source across LFAs. Data was limited to mid-season samples.

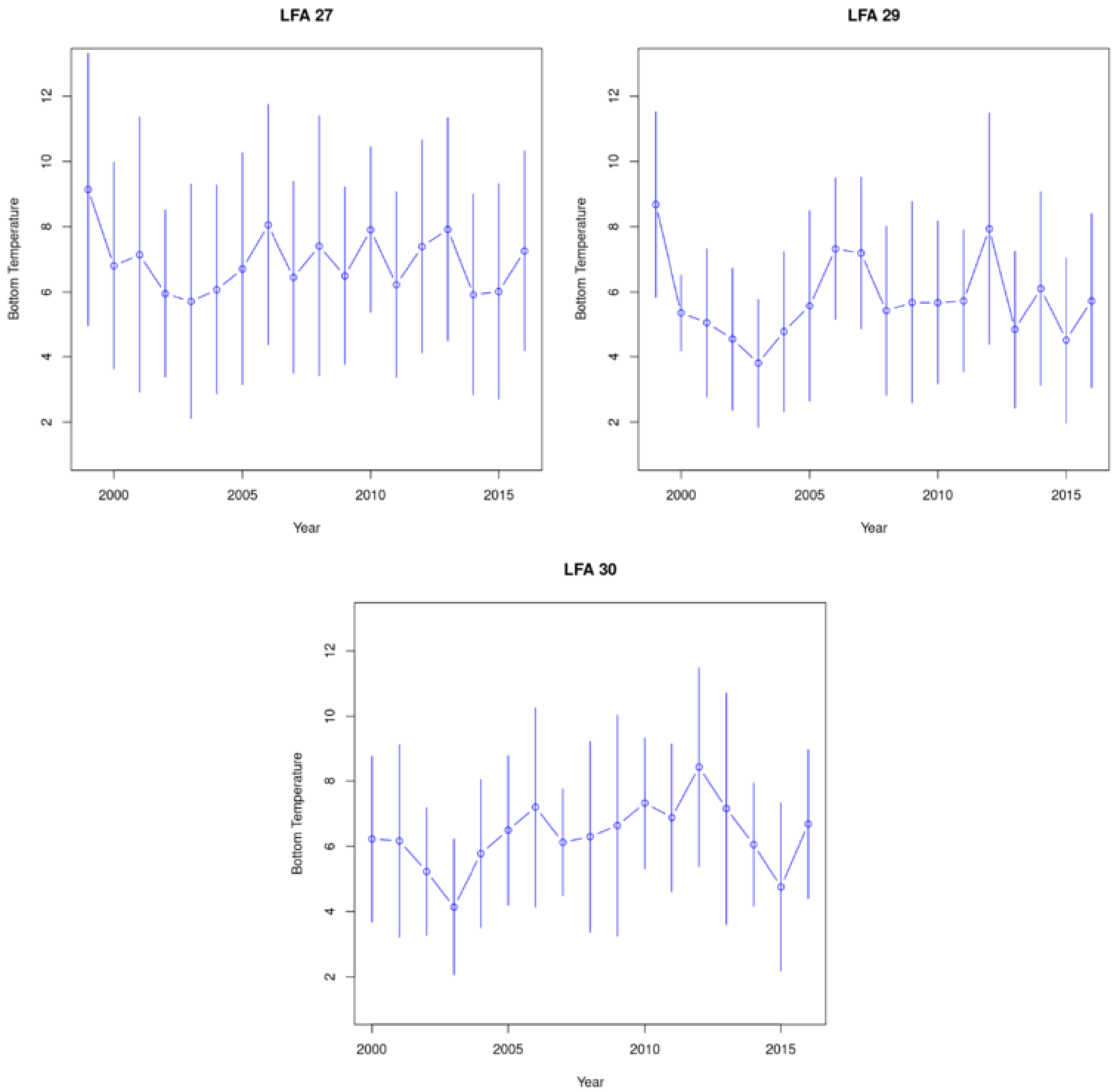


Figure 71: Time series of bottom temperatures across LFAs. Data represents the mean and standard deviation of the fishing season from the FSRS recruitment traps.

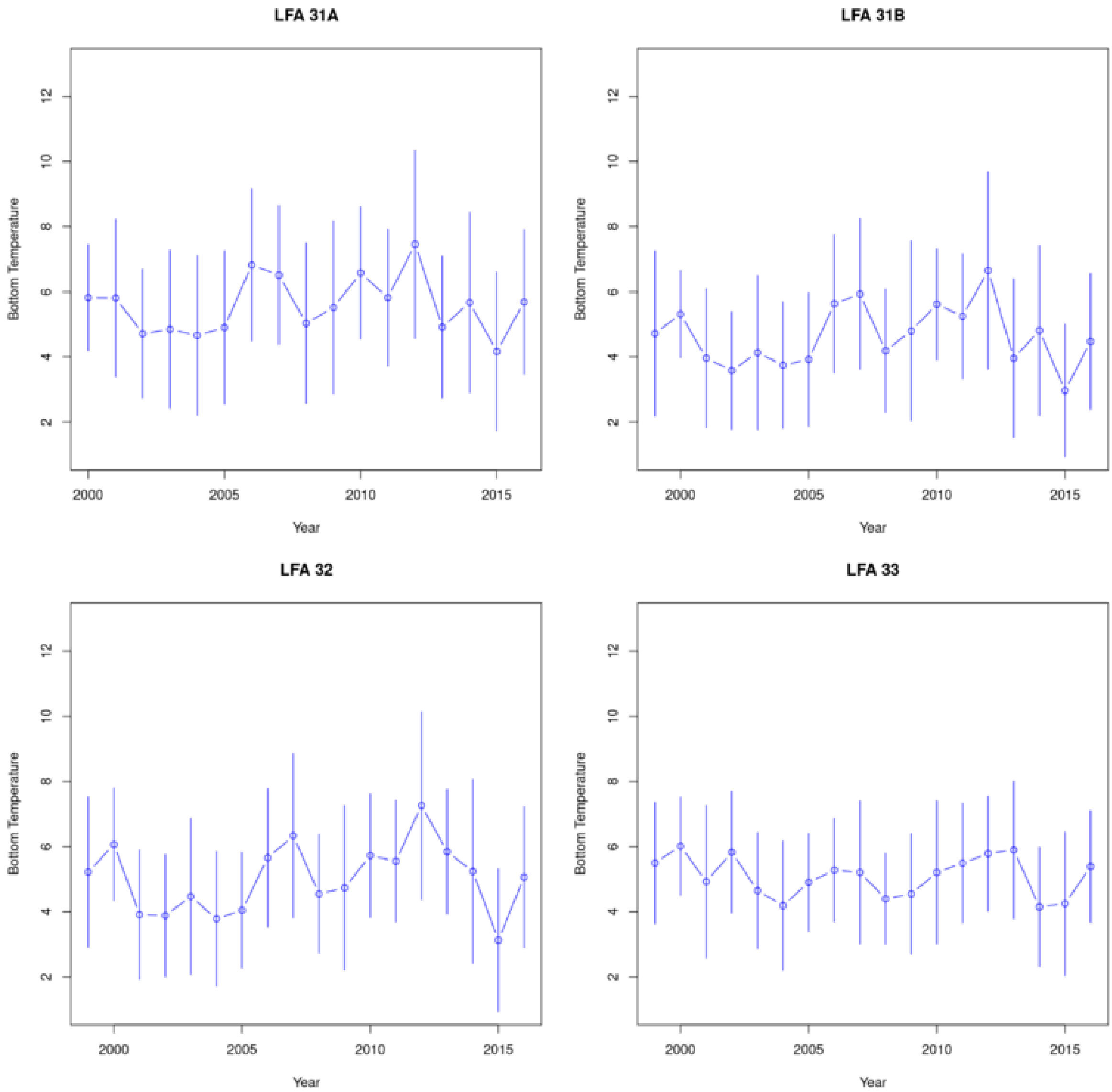


Figure 72: Time series of bottom temperatures across LFAs. Data represents the mean and standard deviation of the fishing season from the FSRS recruitment traps.

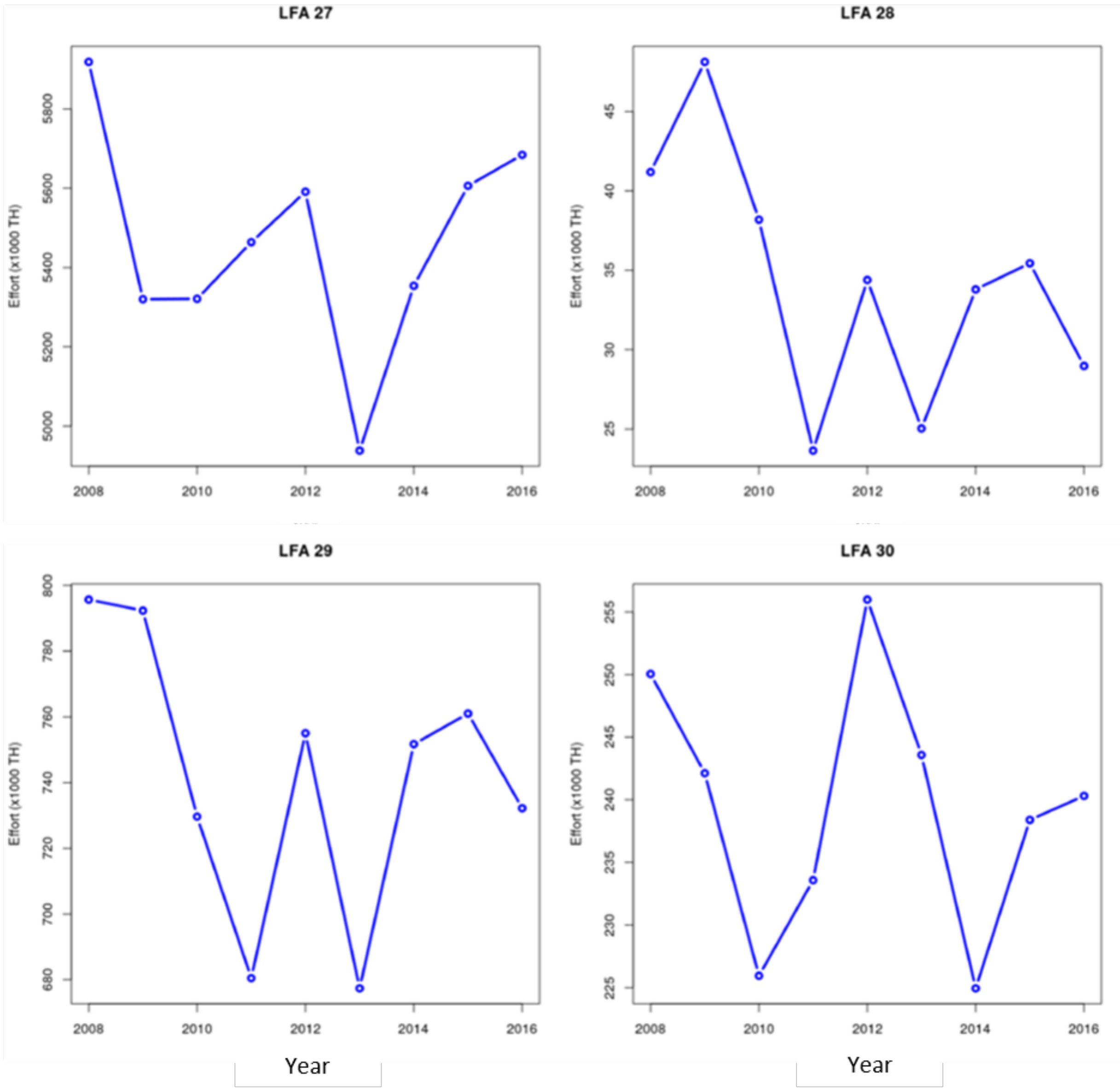


Figure 73: Time series of fishing effort in thousands of trap hauls across LFAs.

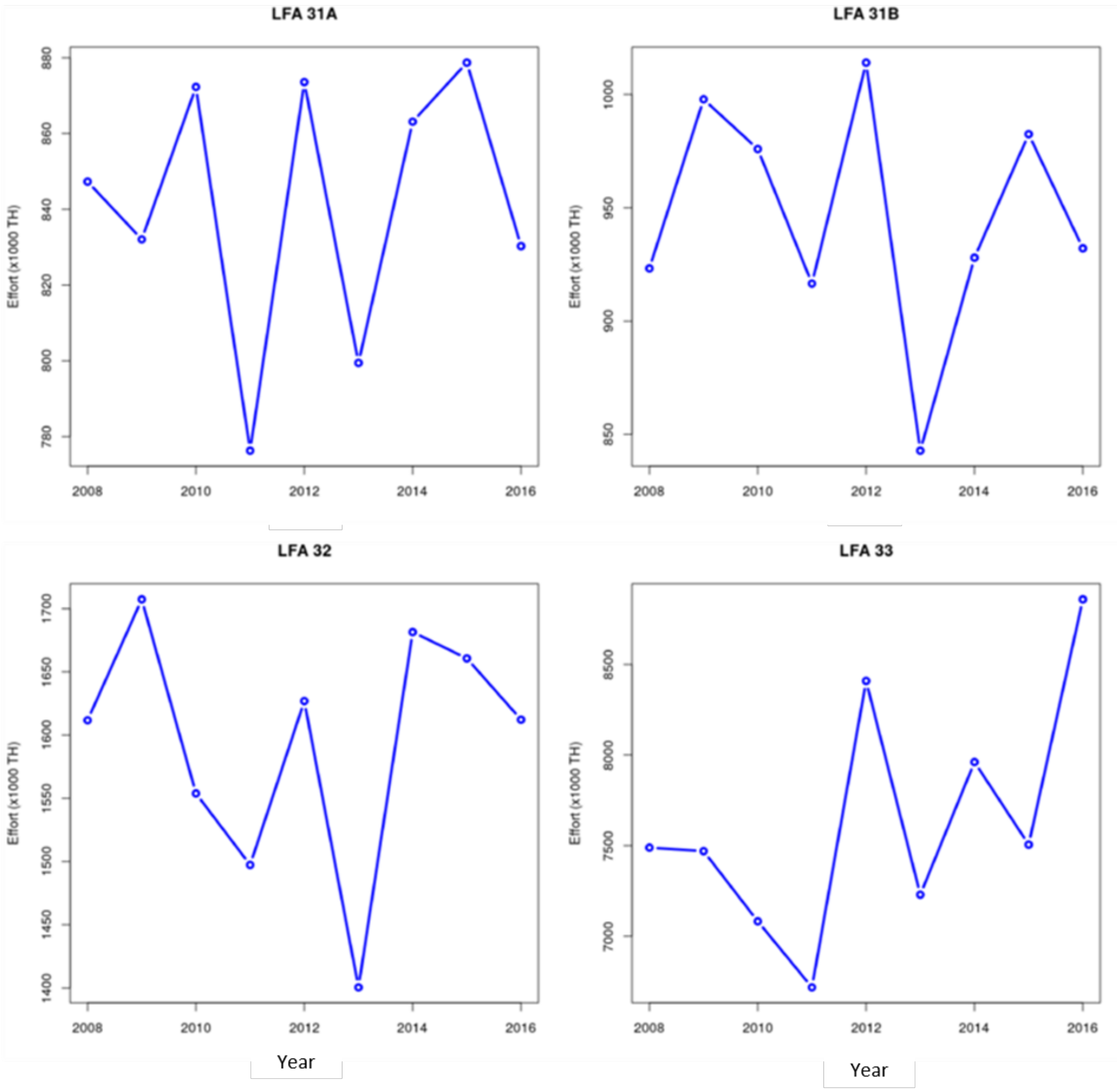


Figure 74: Time series of fishing effort in thousands of trap hauls across LFAs.

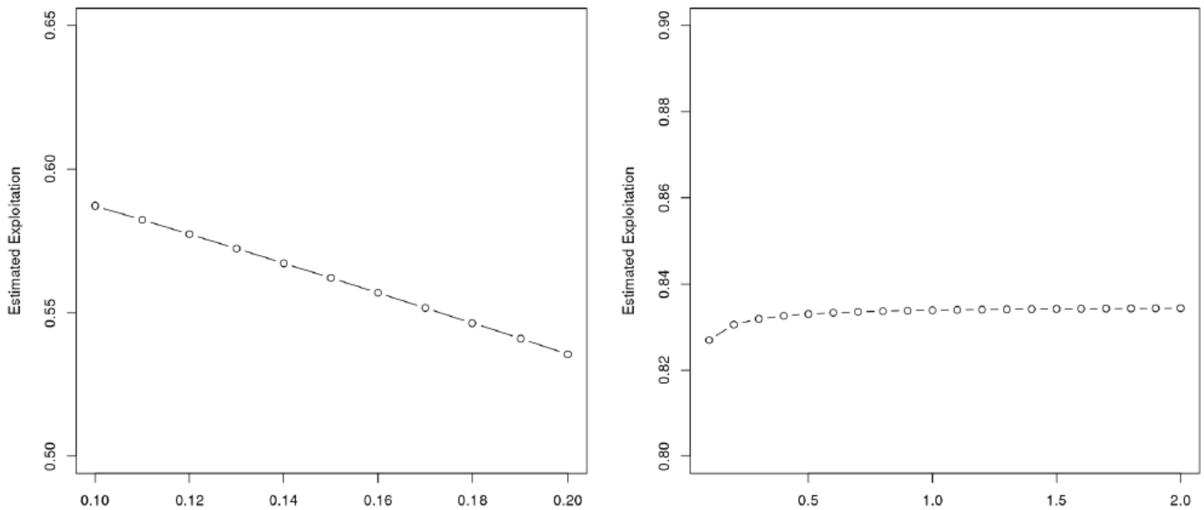


Figure 75: Sensitivity of cohort analysis to changing natural mortality (left) or changing fishing mortality on the oldest ages (right) on estimated exploitation rates. Size frequency data for sensitivity analyses were from LFA 33 sampled in 2015.

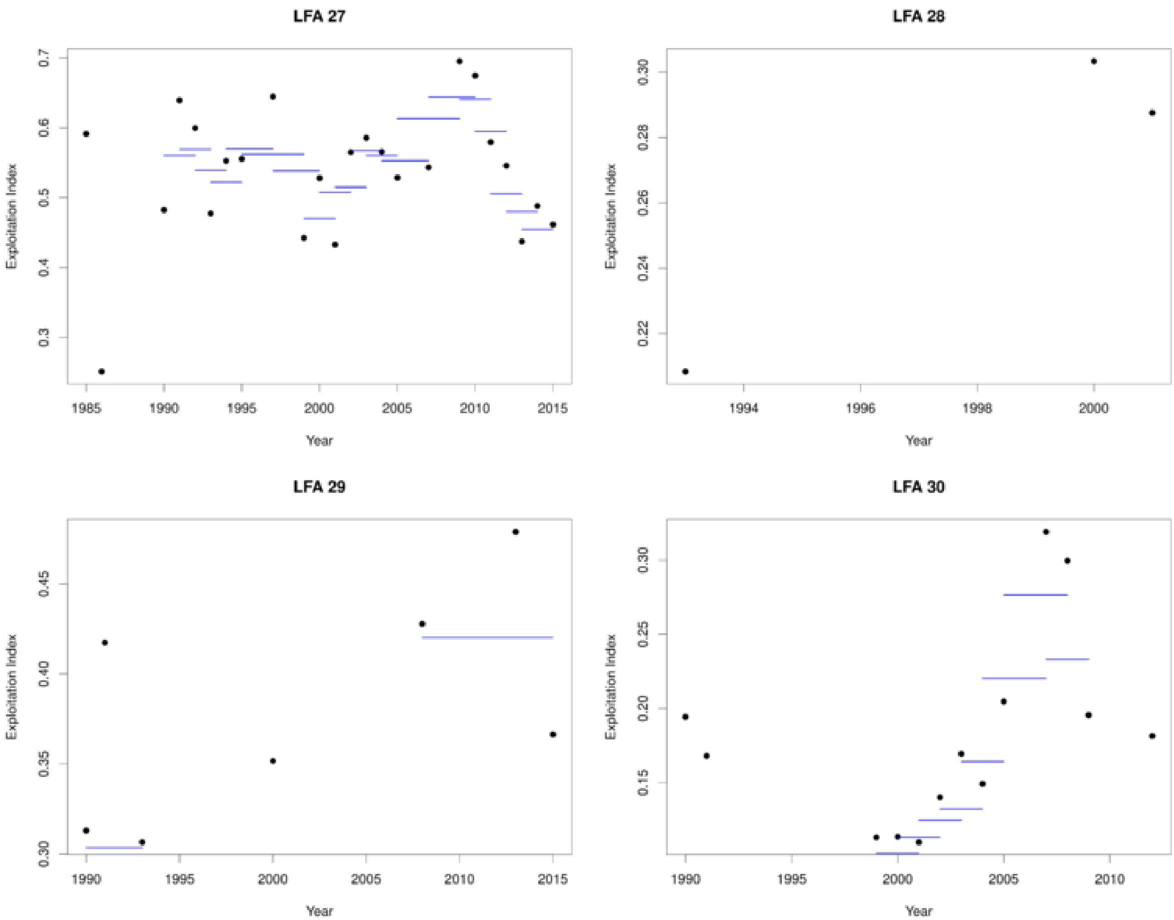


Figure 76: Estimates of exploitation from cohort analysis by year (black points) and by aggregate years (blue lines) within each LFA from at sea samples. The range of y-axes are not shared across plots.

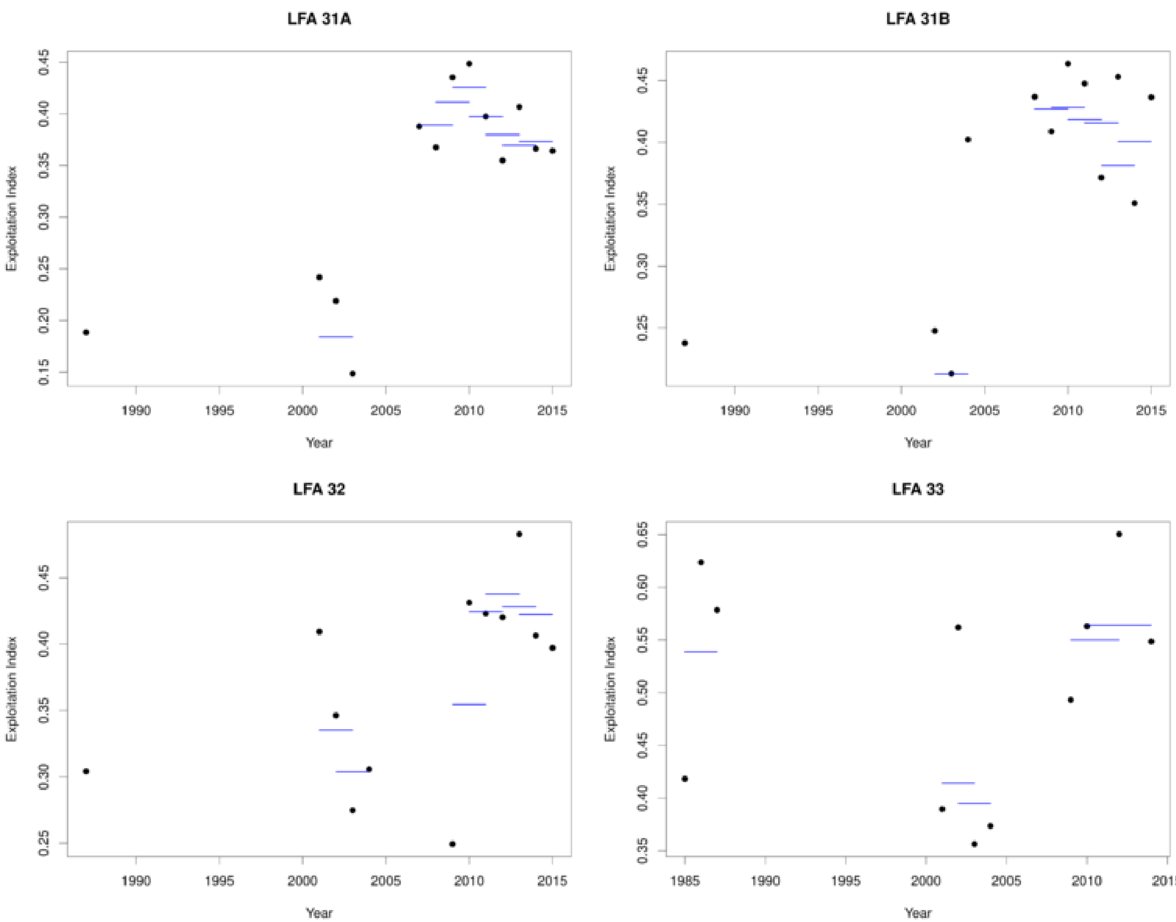


Figure 77: Estimates of exploitation from cohort analysis by year (black points) and by aggregate years (blue lines) within each LFA from at sea samples. The range of y-axes are not shared across plots.

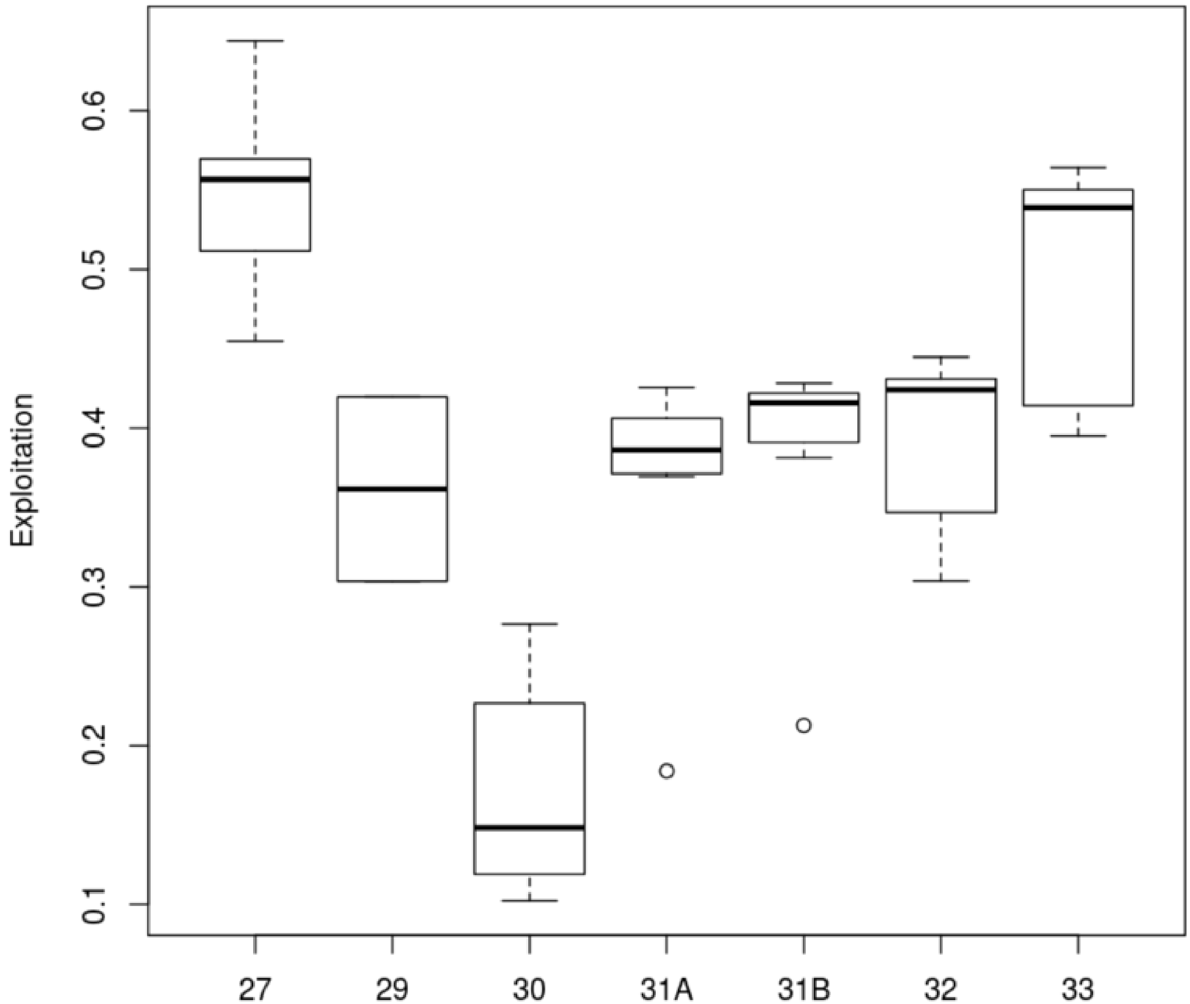


Figure 78: Boxplots of mean exploitation by LFA using the three year accumulated length frequencies from at sea sampled data.

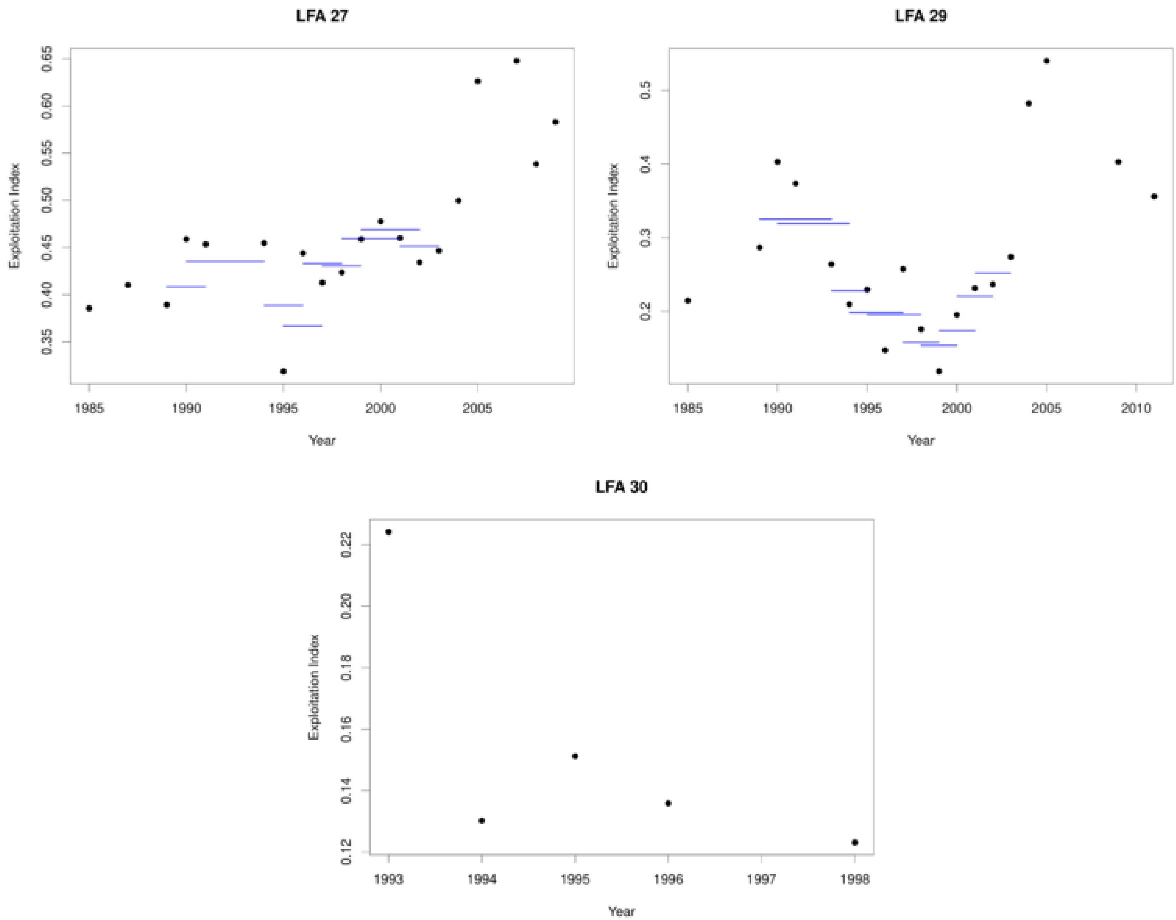


Figure 79: Estimates of exploitation from cohort analysis by year (black points) and by aggregate years (blue lines) within each LFA from port samples. The range of y-axes are not shared across plots.

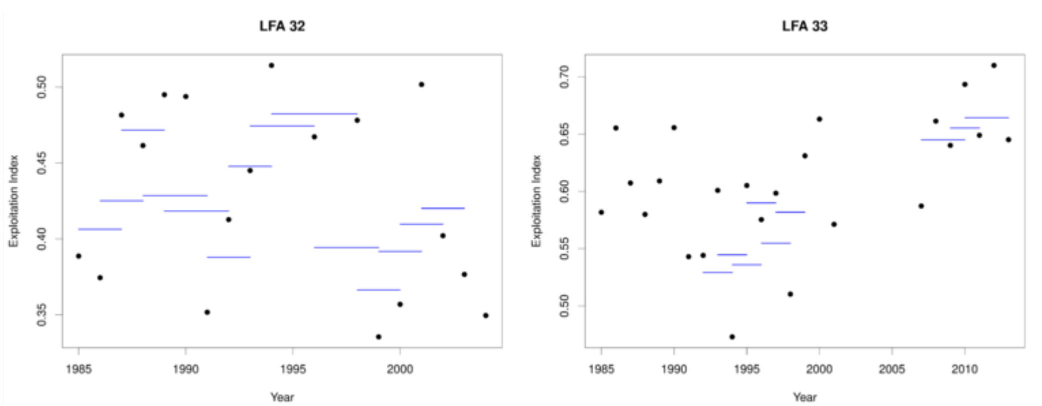


Figure 80: Estimates of exploitation from cohort analysis by year (black points) and by aggregate years (blue lines) within each LFA from port samples. The range of y-axes are not shared across plots.

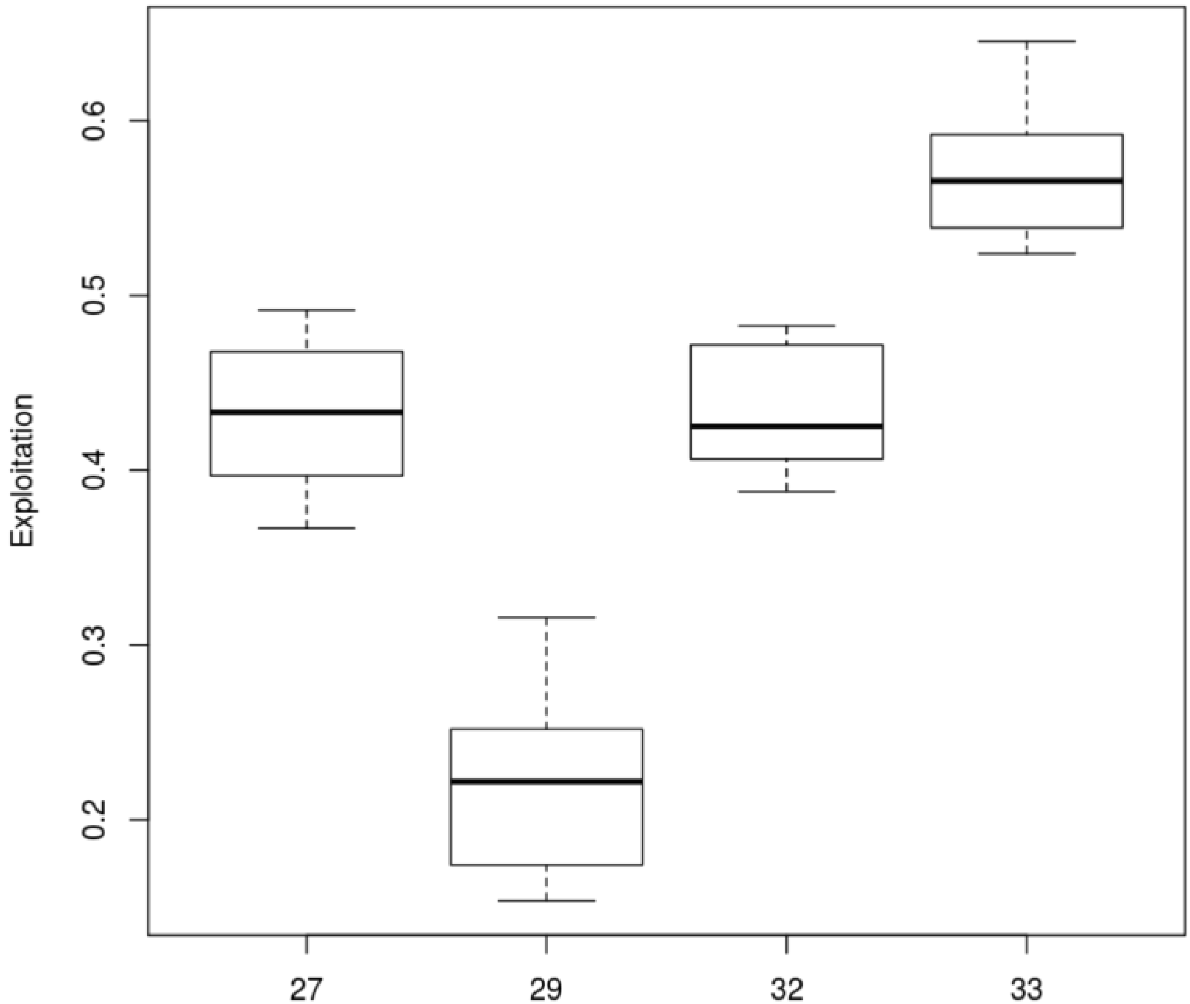


Figure 81: Boxplots of mean exploitation by LFA using the three year accumulated length frequencies from port sampled data.

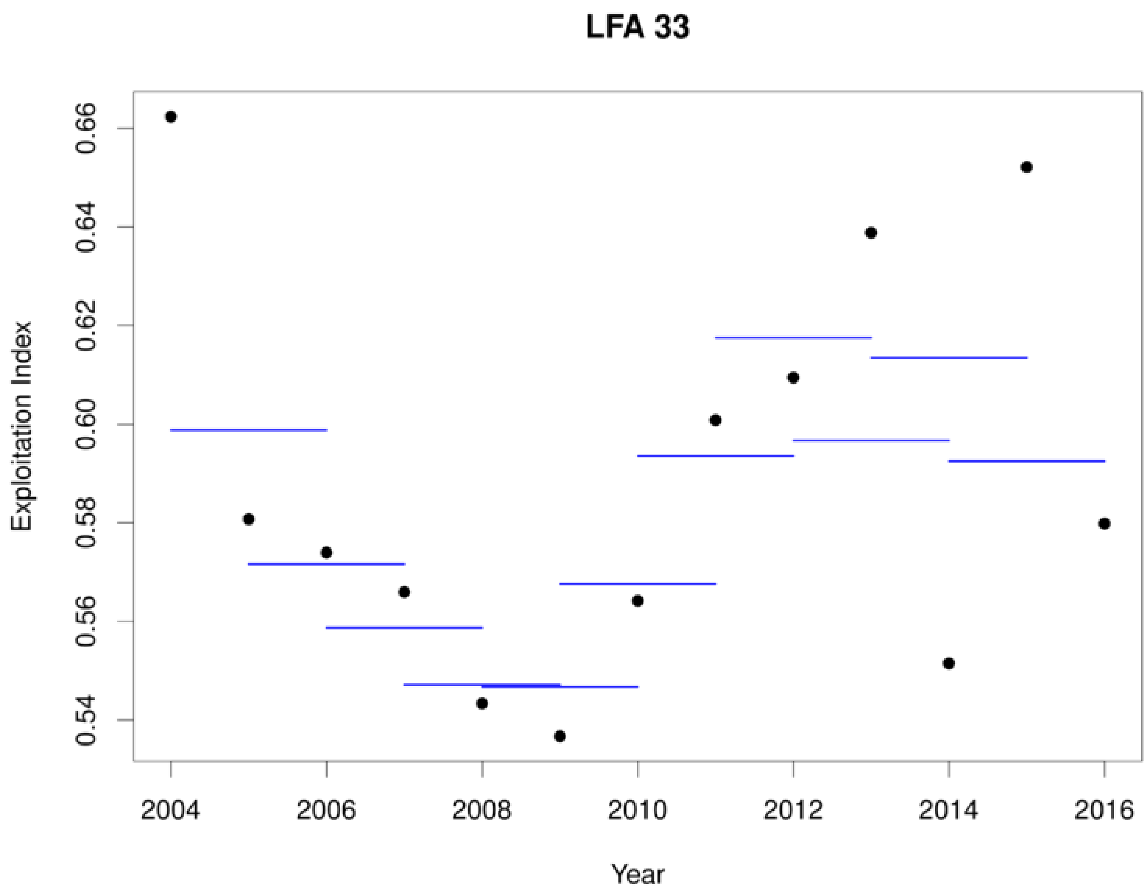


Figure 82: Estimates of exploitation from cohort analysis by year (black points) and by aggregate years (blue lines) from FSRS commercial trap data.

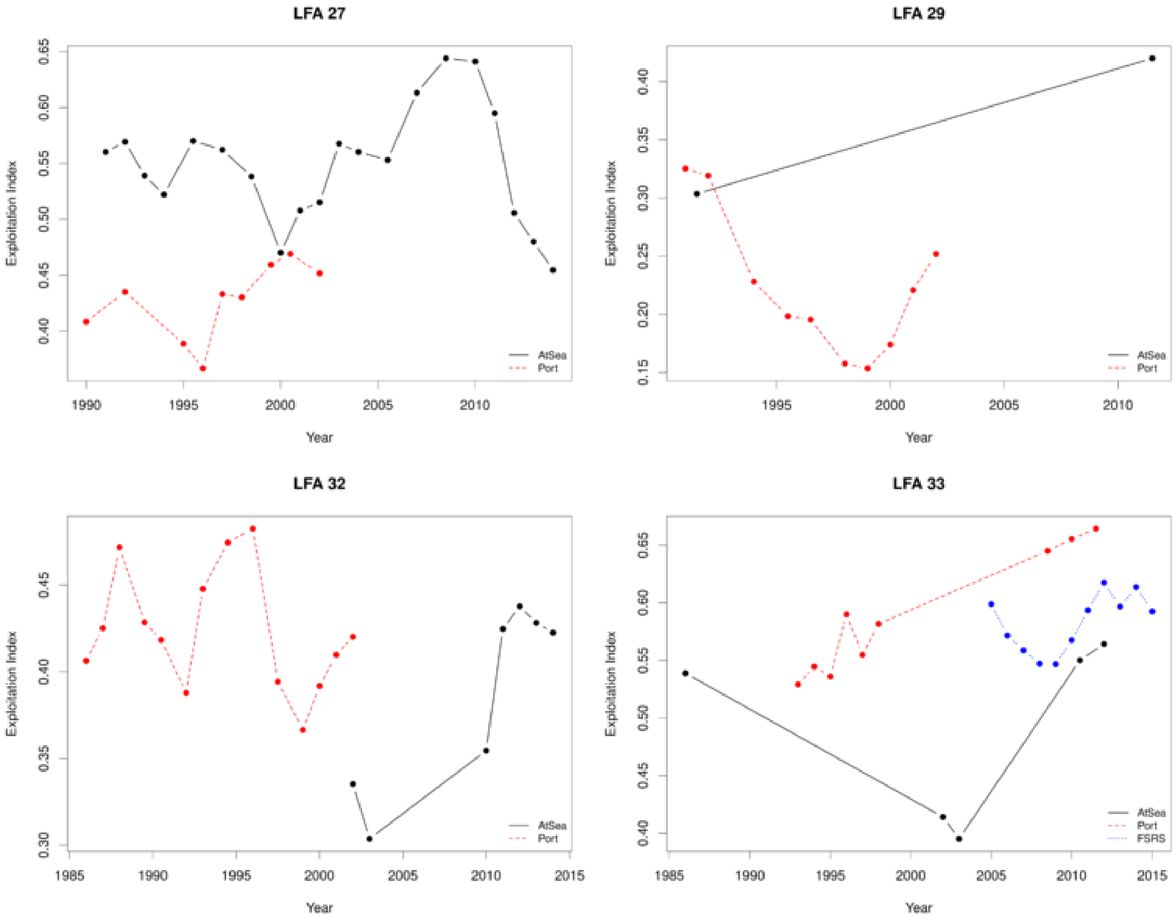


Figure 83: Estimates of three year aggregated exploitation (points represents the mean of the three years) from cohort analysis by year and data source. Black solid lines represent at sea collected data, red dashed lines represent port sampled data and blue dotted lines (LFA 33 only) represent FSRS commercial trap samples. The range of y-axes are not shared across plots.

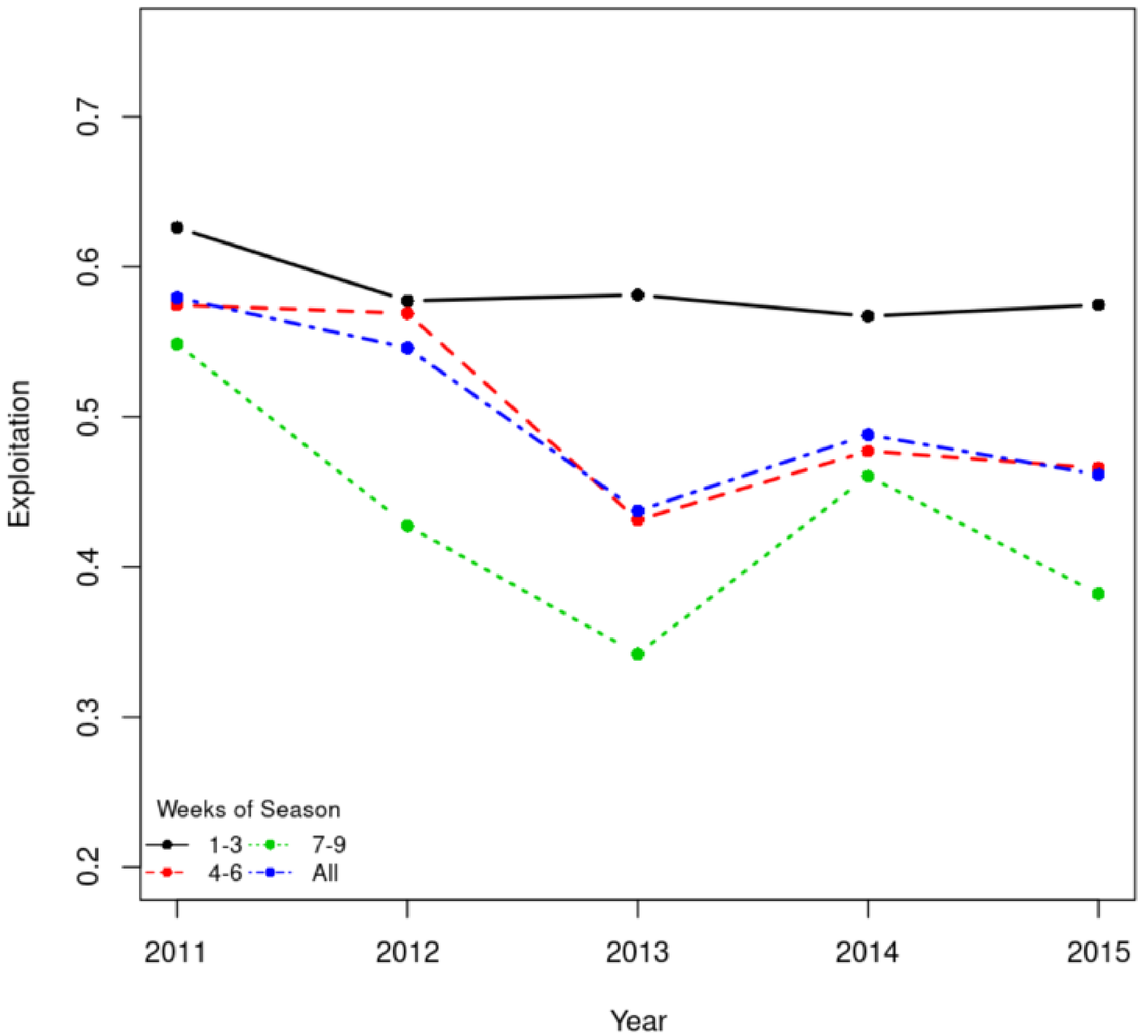


Figure 84: Impact of at sea sampling dates on estimated exploitation estimates from LFA 27 during the 2011–2015 seasons. Lines represent the landings weighted estimated exploitation from cohort analysis with size frequencies from each week of season block.

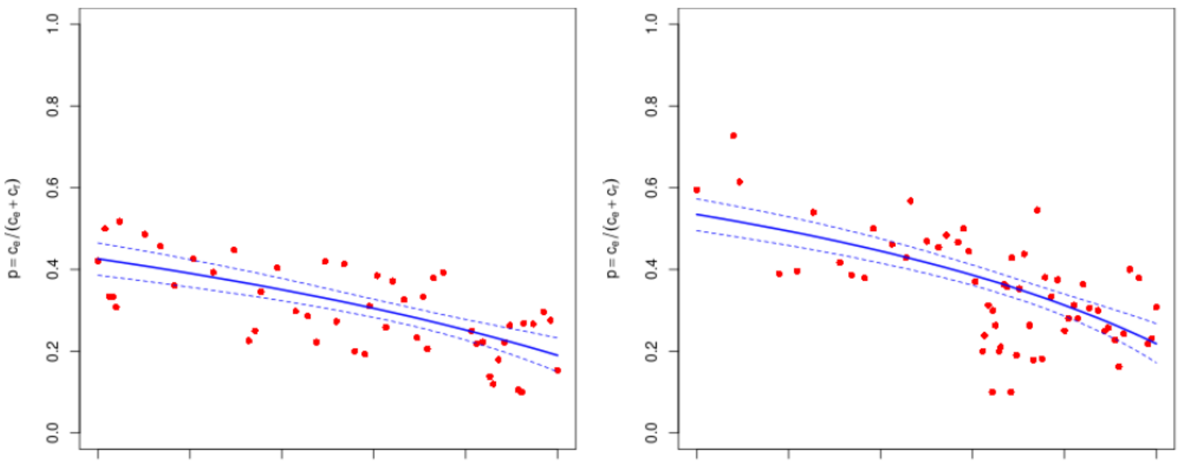


Figure 85: Example change in ratio of exploitable to total sample against cumulative scaled landings. Solid blue line represents CCIR median predictions whereas dashed blue lines represent 95% credible intervals. Left panel represents the results from LFA 27 south in 2007. Right panel represents results from LFA 33 east in 2009.

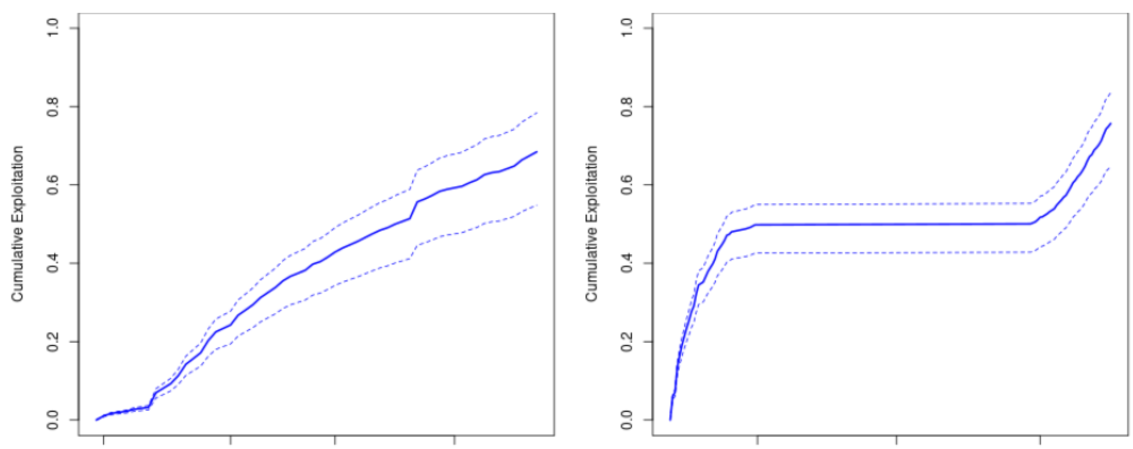


Figure 86: Within season CCIR estimated exploitation indices. Solid blue line represents CCIR median predicted exploitation whereas dashed blue lines represent 95% credible intervals. Left panel represents the results from LFA 27 south in 2007. Right panel represents results from LFA 33 east in 2009.

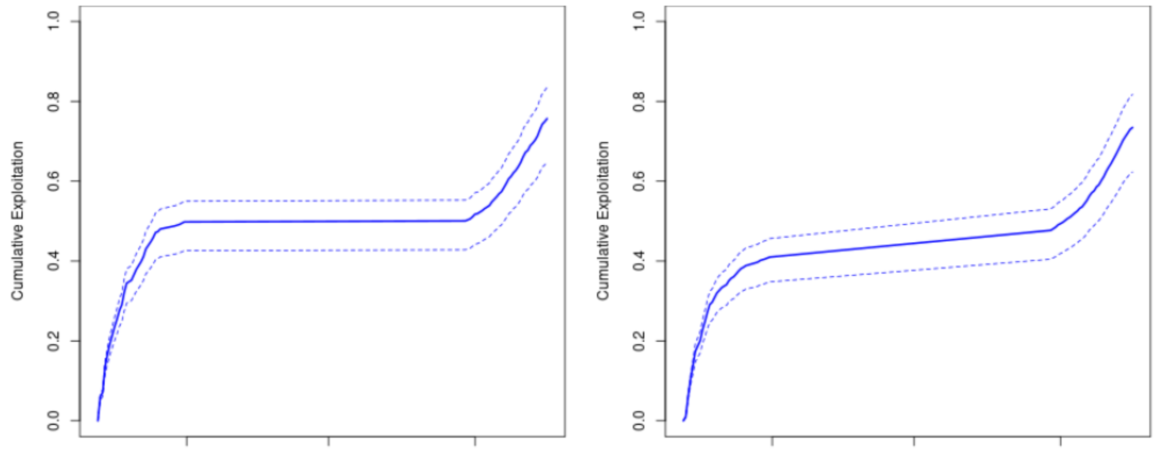


Figure 87: Comparison of within season CCIR estimated exploitation indices estimated using either the cumulative monitoring effort (left) or cumulative landings (right). Solid blue line represents CCIR median predicted exploitation whereas dashed blue lines represent 95% credible intervals. Both panels represent results from LFA 33 east in 2009.

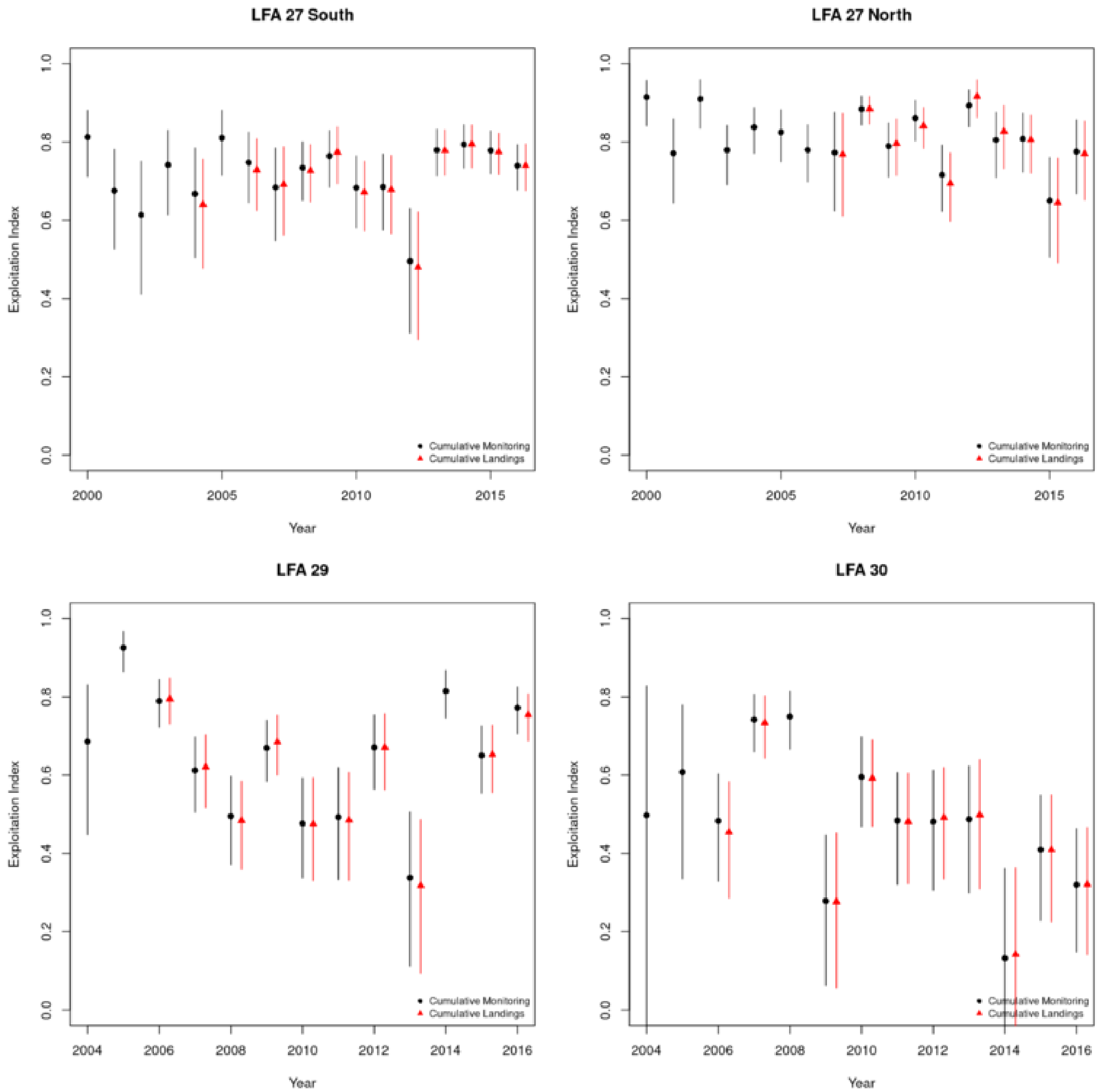


Figure 88: Comparison of predictor variables (cumulative monitoring - black or cumulative landings - red) on CCIR estimated end of season exploitation (points) with 95% credible intervals (vertical lines) by year within LFA 27 south and north, LFA 29 and LFA 30.

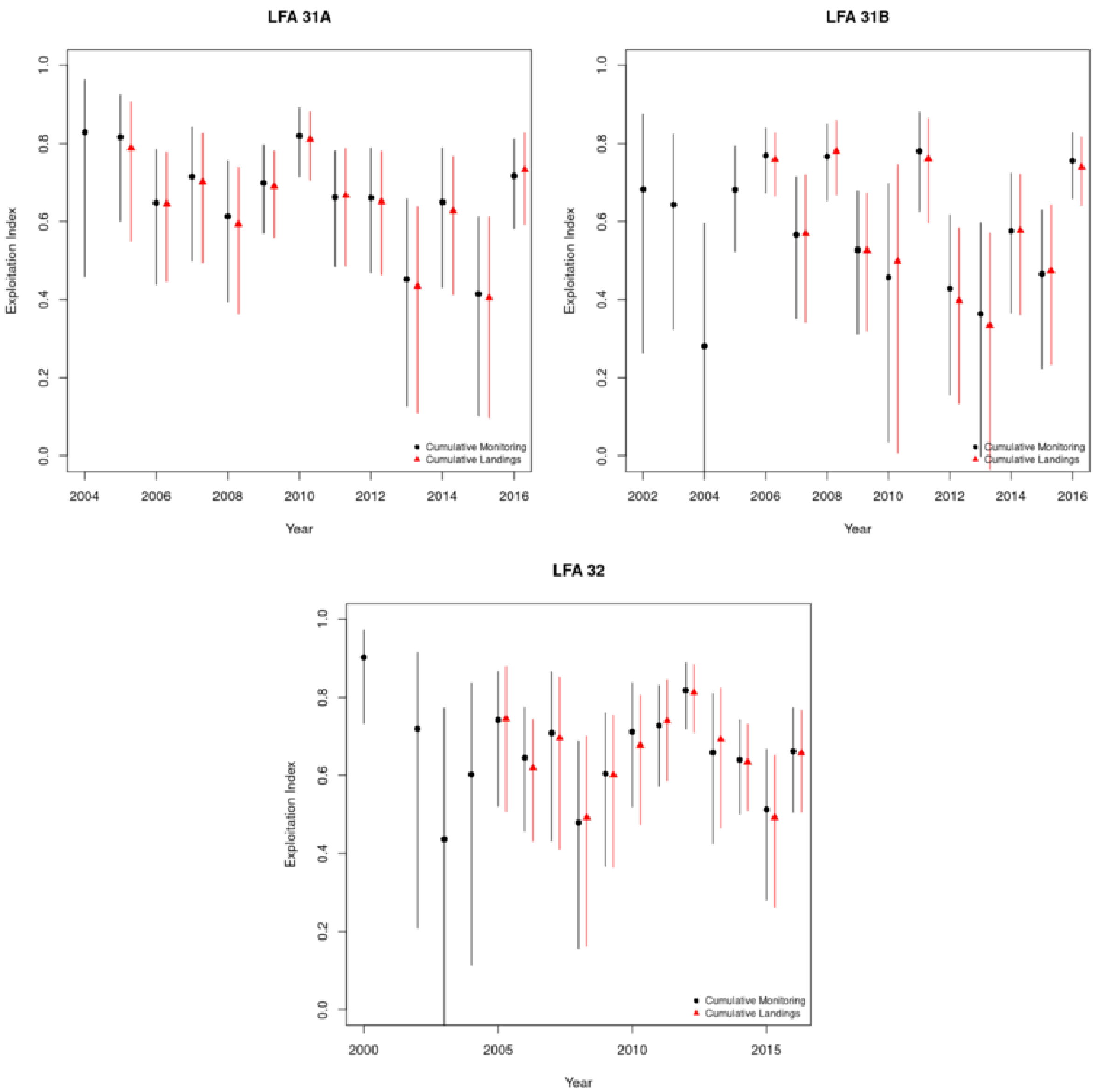


Figure 89: Comparison of predictor variables (cumulative monitoring - black or cumulative landings - red) on CCIR estimated end of season exploitation (points) with 95% credible intervals (vertical lines) by year within LFA 31A, LFA 31B and LFA 32.

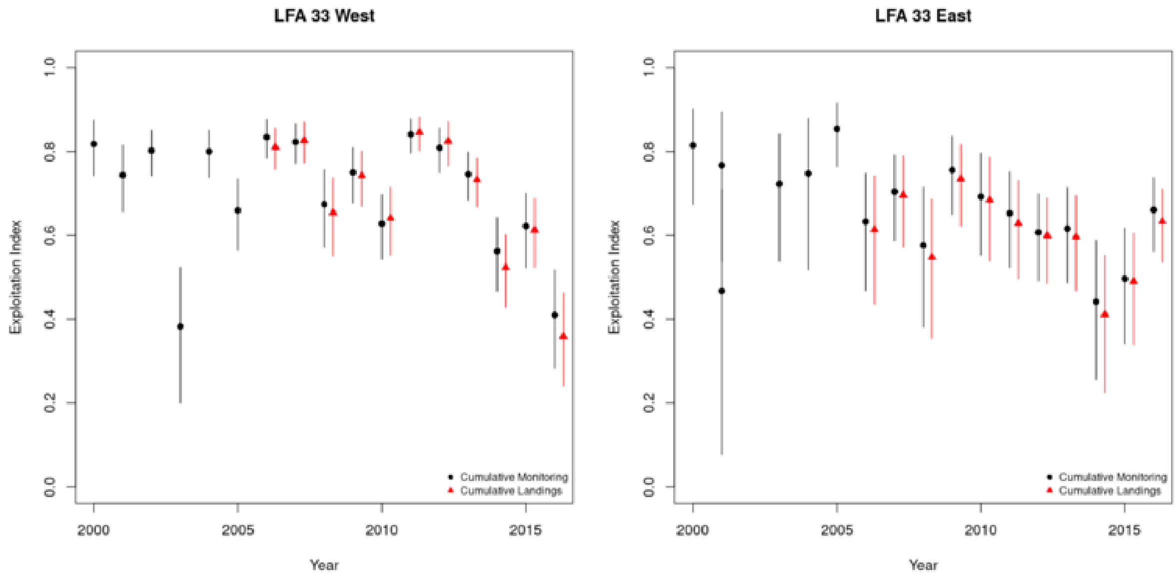


Figure 90: Comparison of predictor variables (cumulative monitoring - black or cumulative landings - red) on CCIR estimated end of season exploitation (points) with 95% credible intervals (vertical lines) by year within LFA 33 east and west.

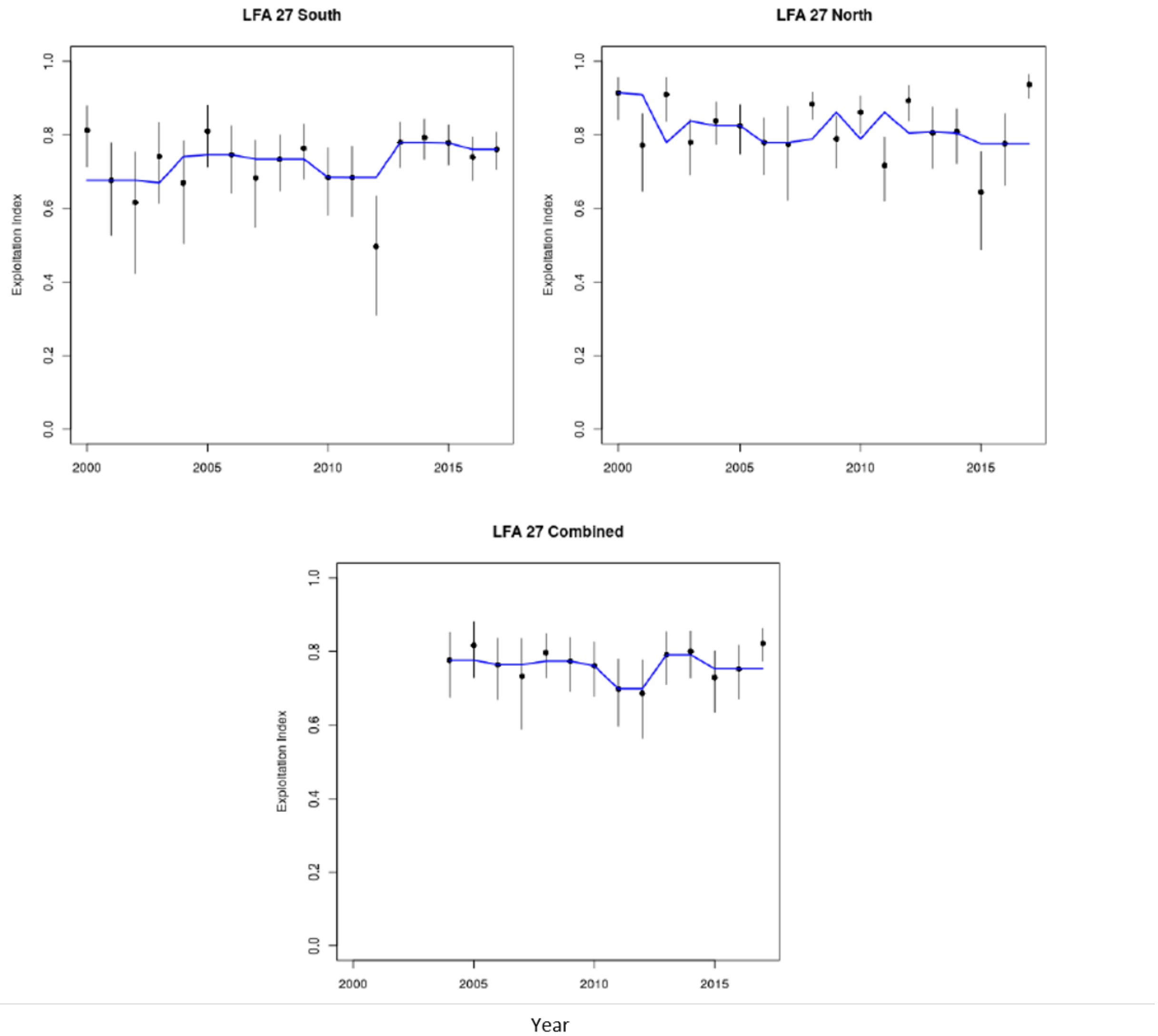


Figure 91: CCIR estimated end of season exploitation (points) with 95% credible intervals (vertical lines) by year within LFA 27 south, north or combined. The combined LFA 27 north and south represents the landings weighted annual exploitation. Within plots blue lines represent 3-year running median of exploitation estimates.

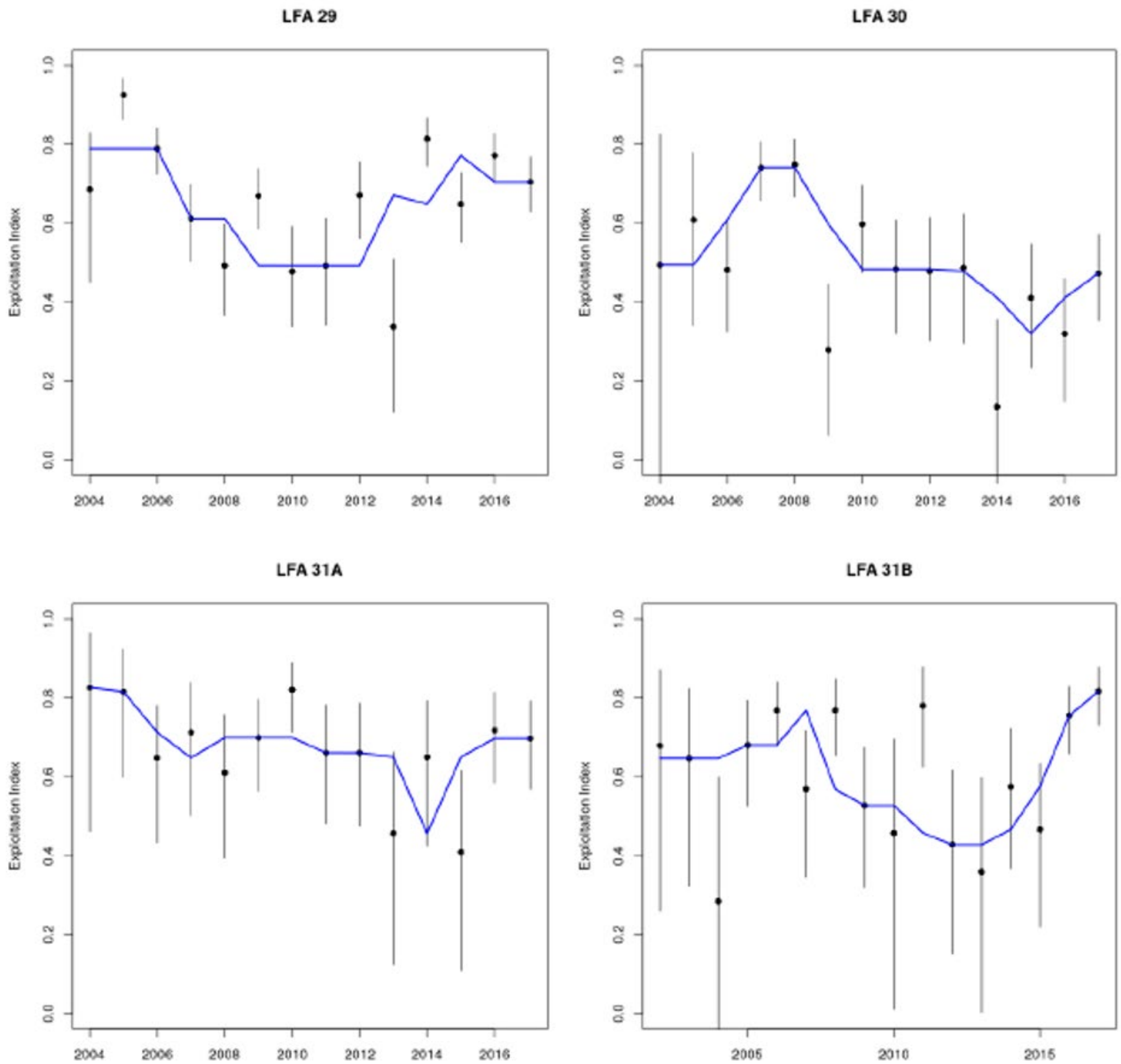


Figure 92: CCIR estimated end of season exploitation (points) with 95% credible intervals (vertical lines) by year within LFAs. Within plots blue lines represent 3-year running median of exploitation estimates.

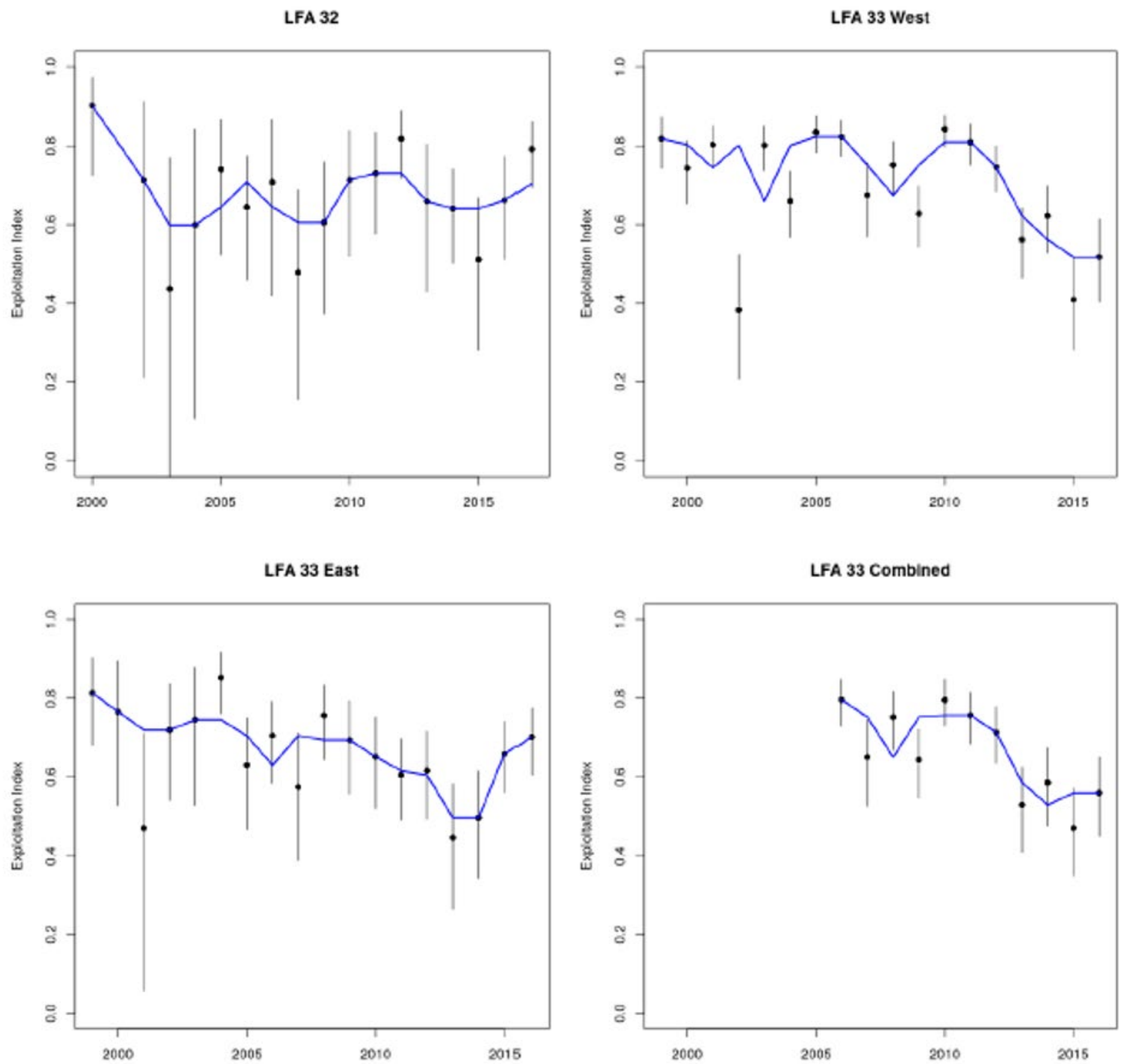


Figure 93: CCIR estimated end of season exploitation (points) with 95% credible intervals (vertical lines) by year within LFA 32, LFA 33 east, LFA 33 west and LFA 33 combined. The combined LFA 33 represents the landings weighted annual exploitation from the east and west combined. Within plots blue lines represent 3-year running median of exploitation estimates.

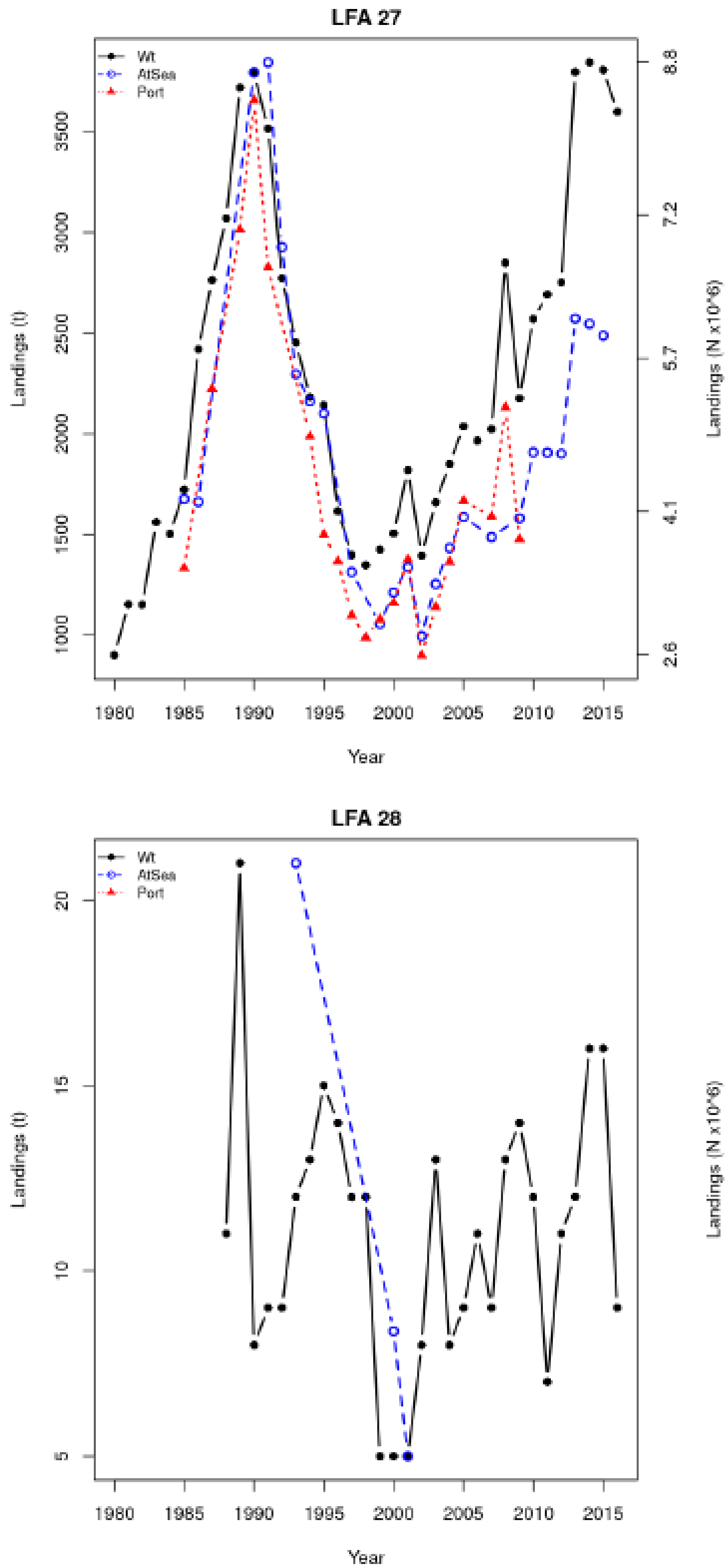


Figure 94: Time series of total landings in tons (black lines) and total landings in numbers estimated using length frequencies from At-Sea (blue) or Port samples (red).

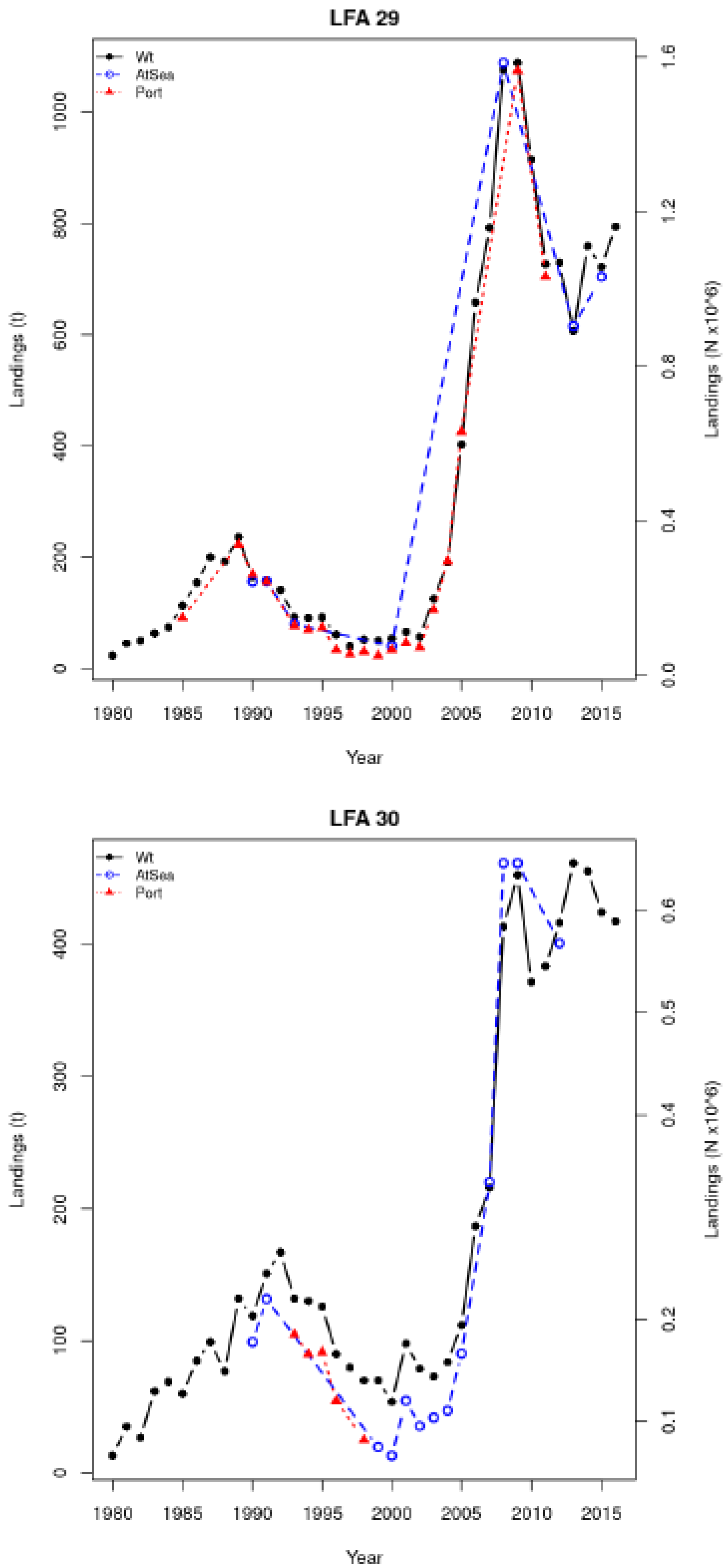


Figure 95: Time series of total landings in tons (black lines) and total landings in numbers estimated using length frequencies from At-Sea (blue) or Port samples (red).

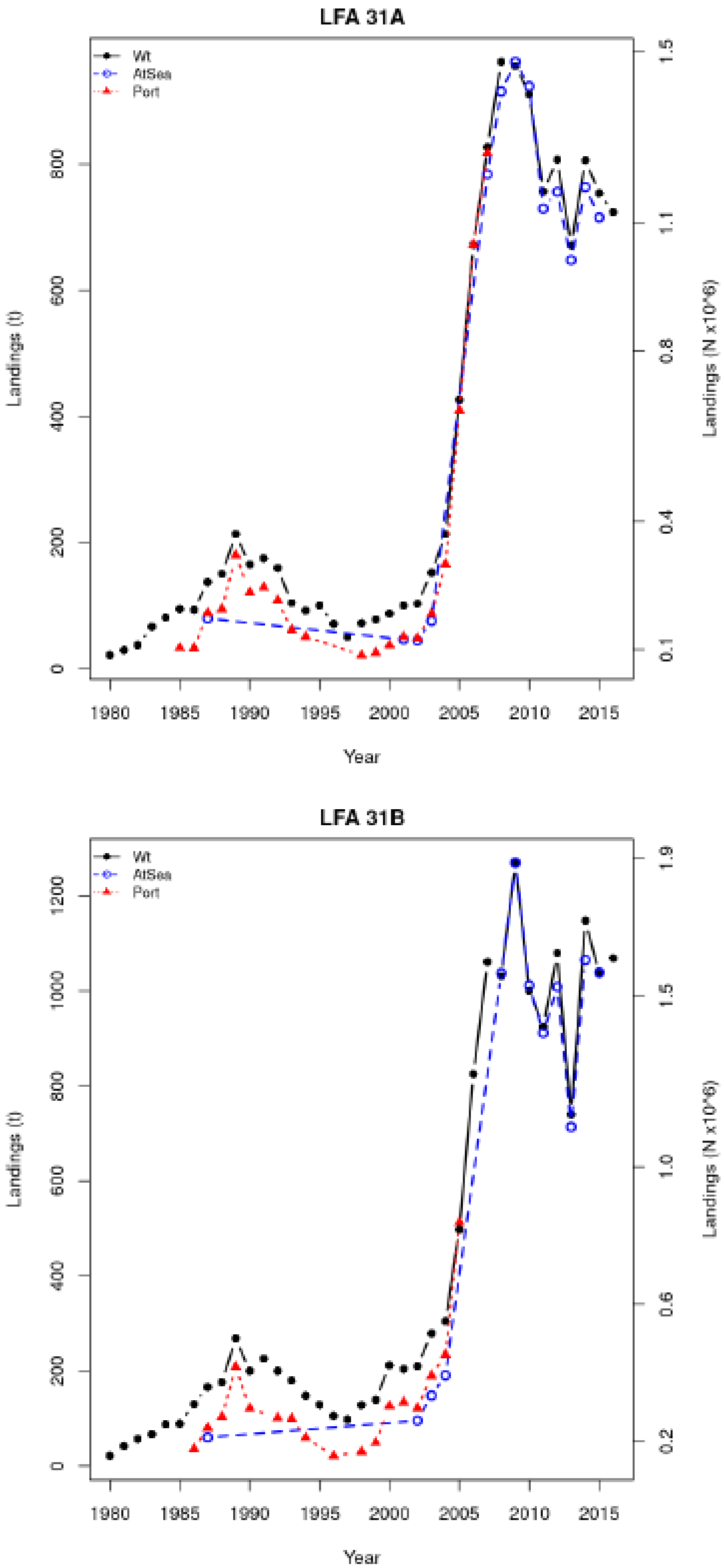


Figure 96: Time series of total landings in tons (black lines) and total landings in numbers estimated using length frequencies from At-Sea (blue) or Port samples (red).

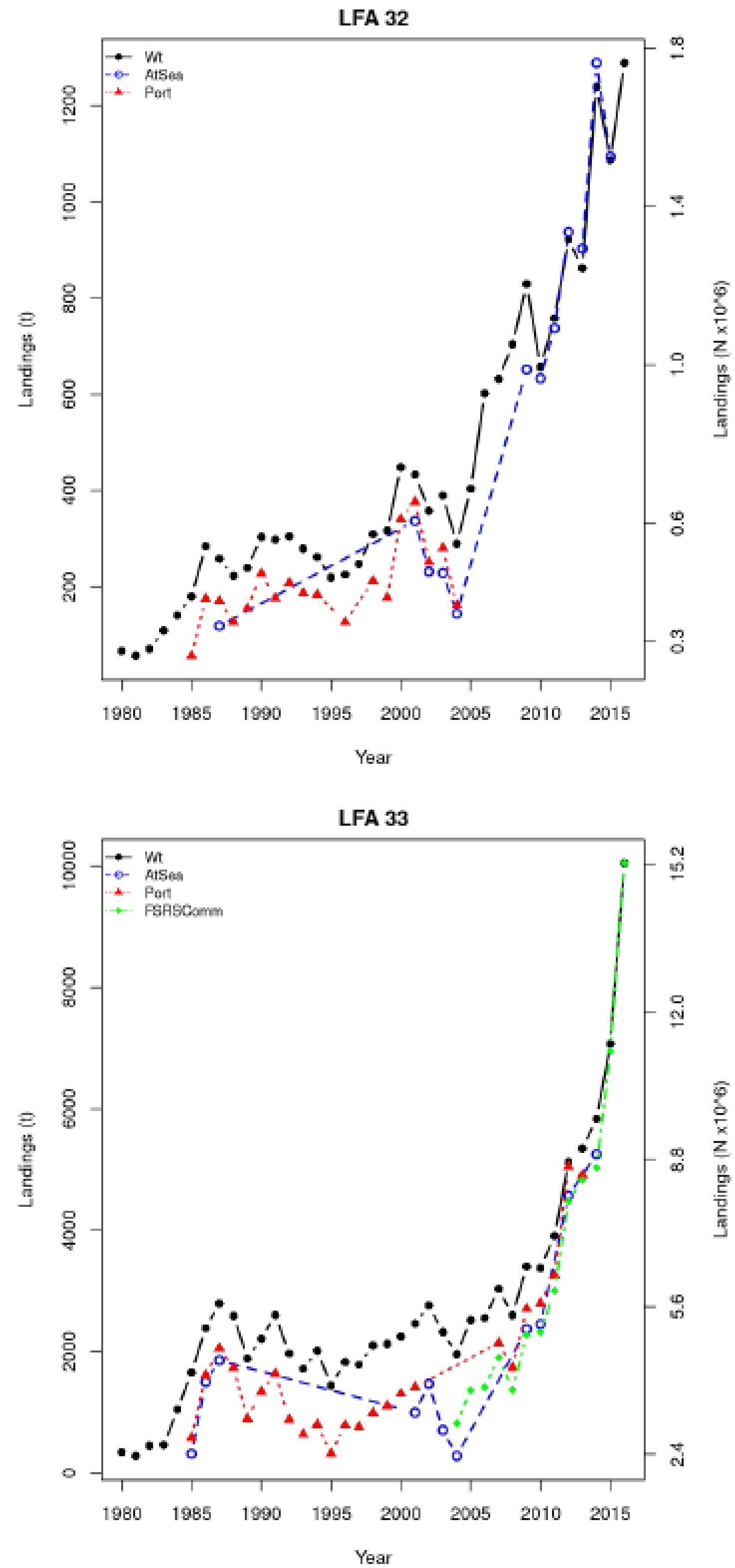


Figure 97: Time series of total landings in tons (black lines) and total landings in numbers estimated using length frequencies from At-Sea (blue) or Port samples (red), or FSRS commercial samples (green).

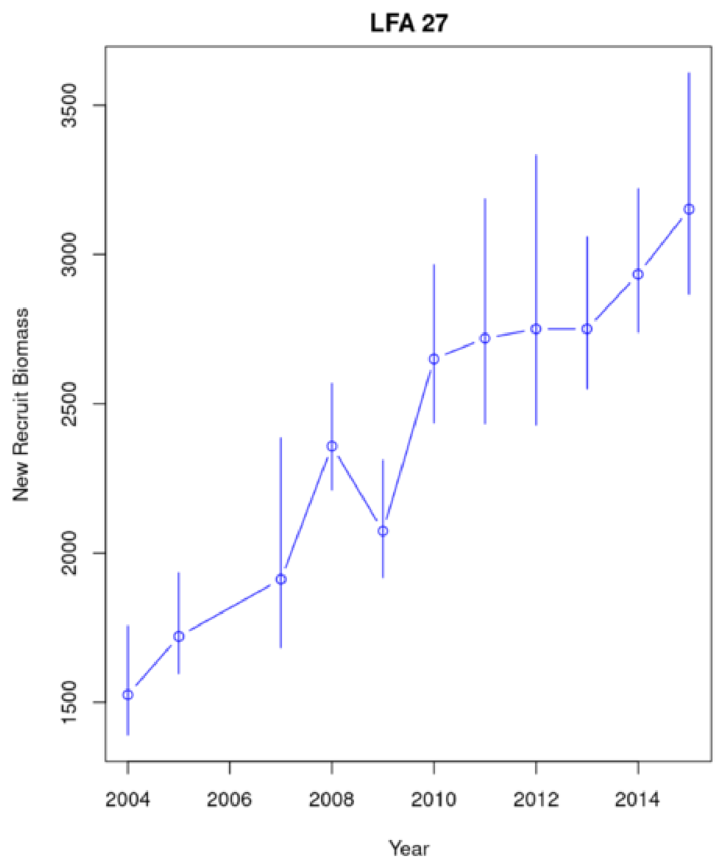


Figure 98: Time series of estimated recruitment biomass in tons with associated 95%error bounds.

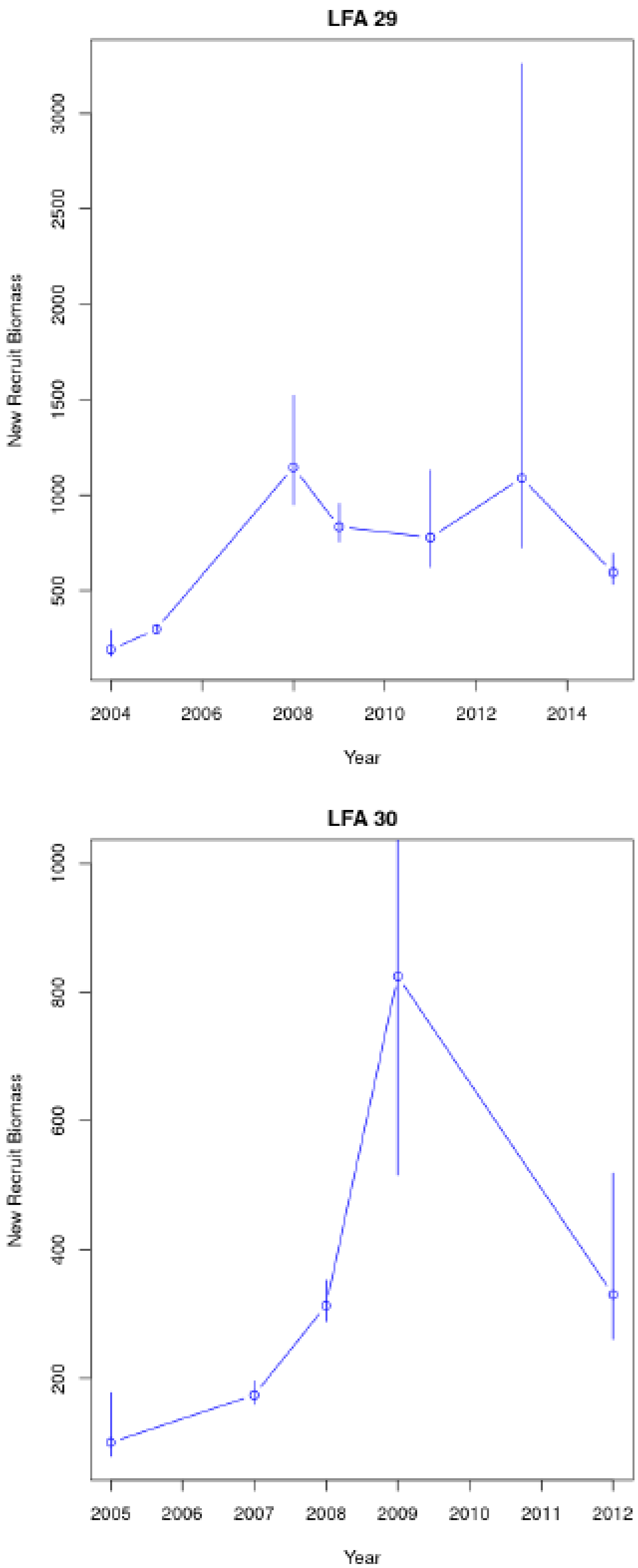


Figure 99: Time series of estimated recruitment biomass in tons with associated 95% error bounds. Upper bounds in LFA 30 in 2009 were not shown (4195 t). The full range of error was not shown as lower credible intervals on exploitation rates were not well defined.

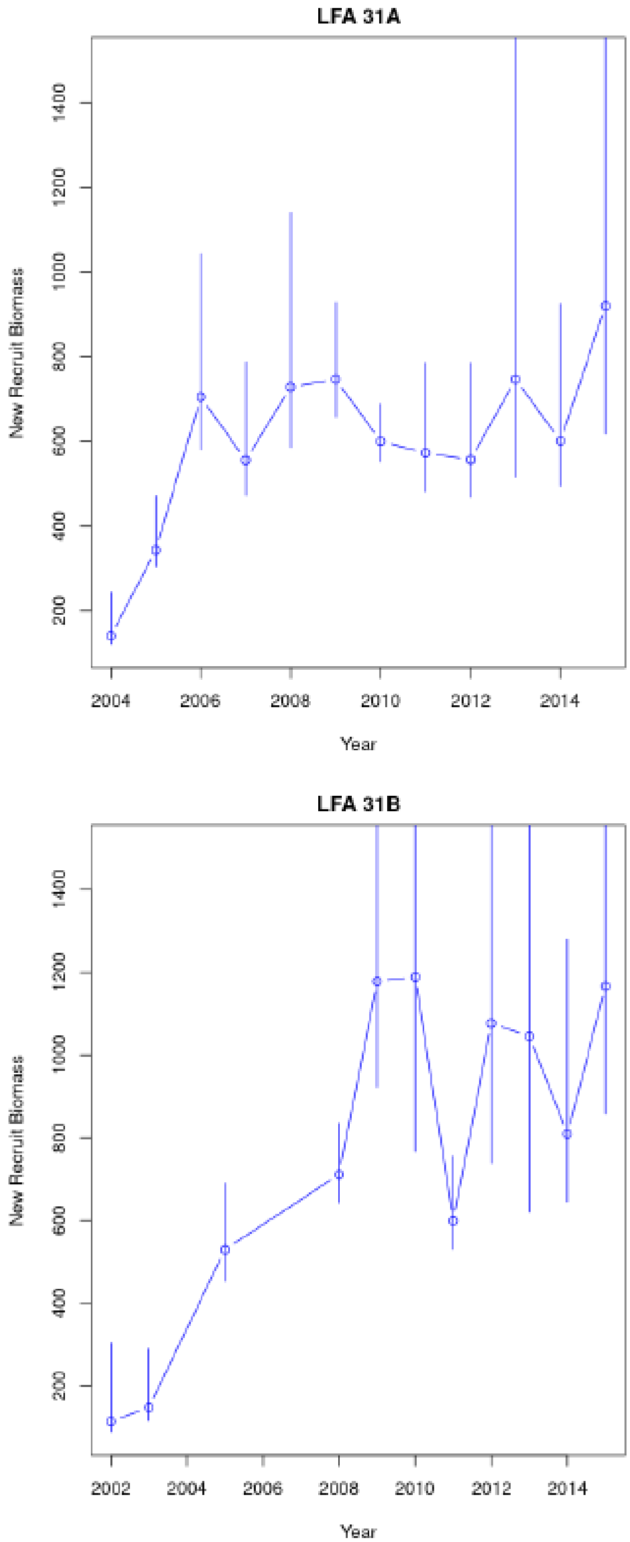


Figure 100: Time series of estimated recruitment biomass in tons with associated 95%error bounds. Upper bounds in LFA 31A for 2013 and 2015 were >2990t. Upper bounds for LFA 31B in 2010 and 2013 were >30000t. The full range of error was not shown as lower credible intervals on exploitation rates were not well defined.

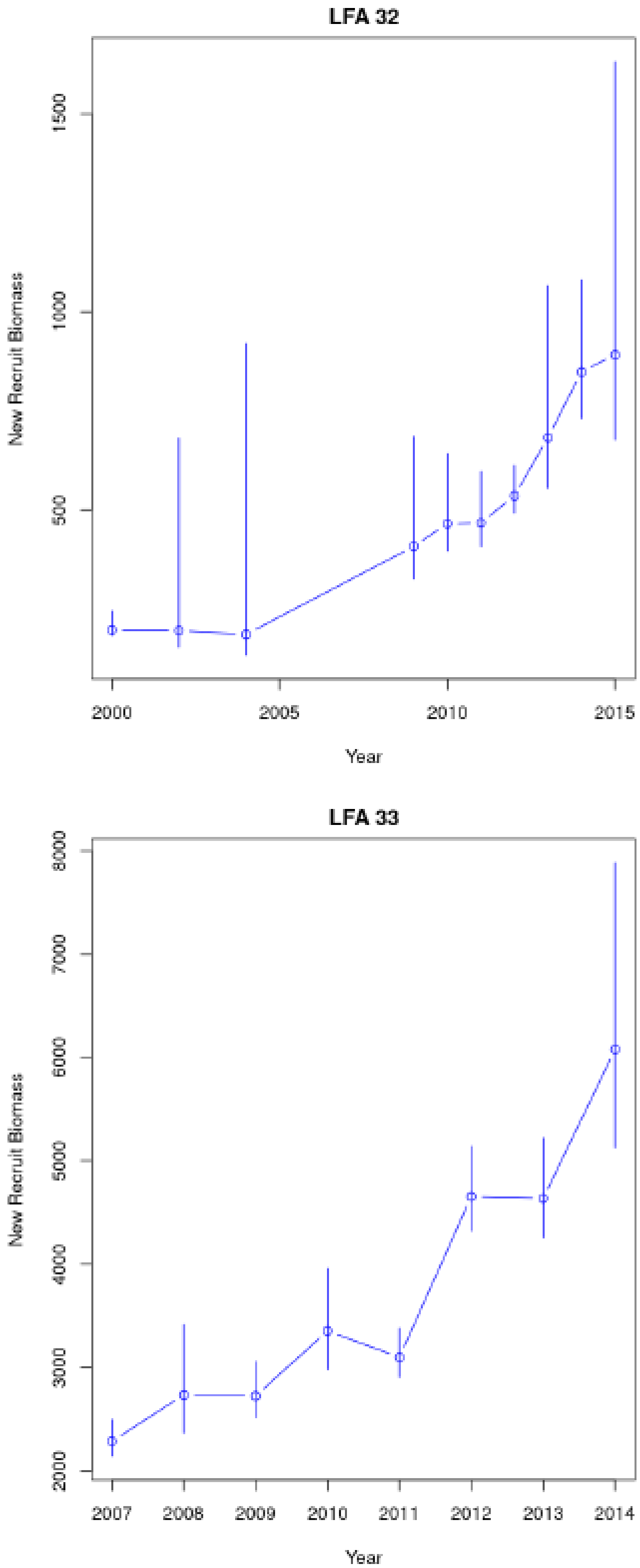


Figure 101: Time series of estimated recruitment biomass in tons with associated 95% error bounds.

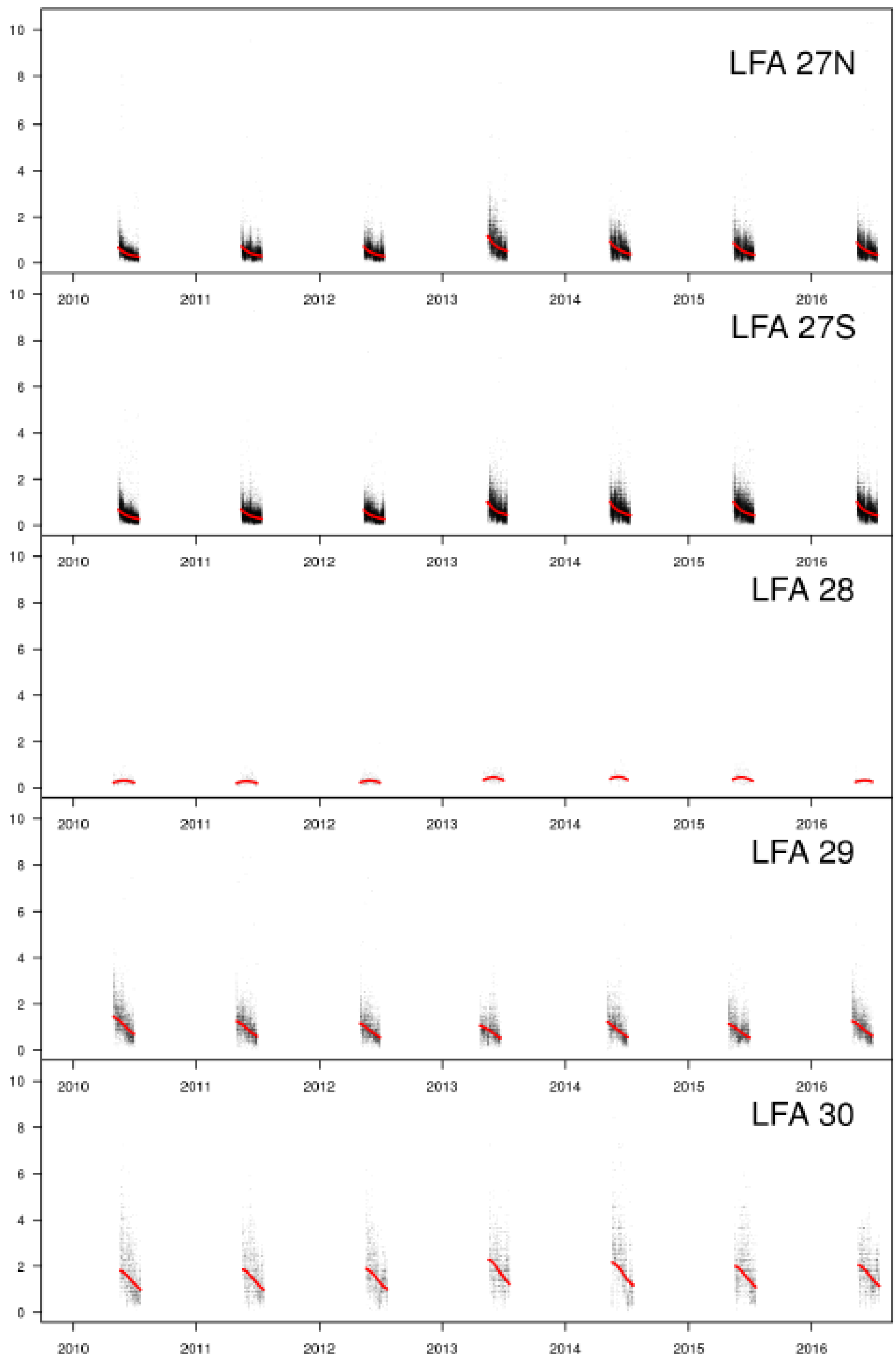


Figure 102: Predictions of Catch Per Unit Effort (kg/trap haul) from the model for each day (red line), overlaid on the raw data for LFAs 27–30.

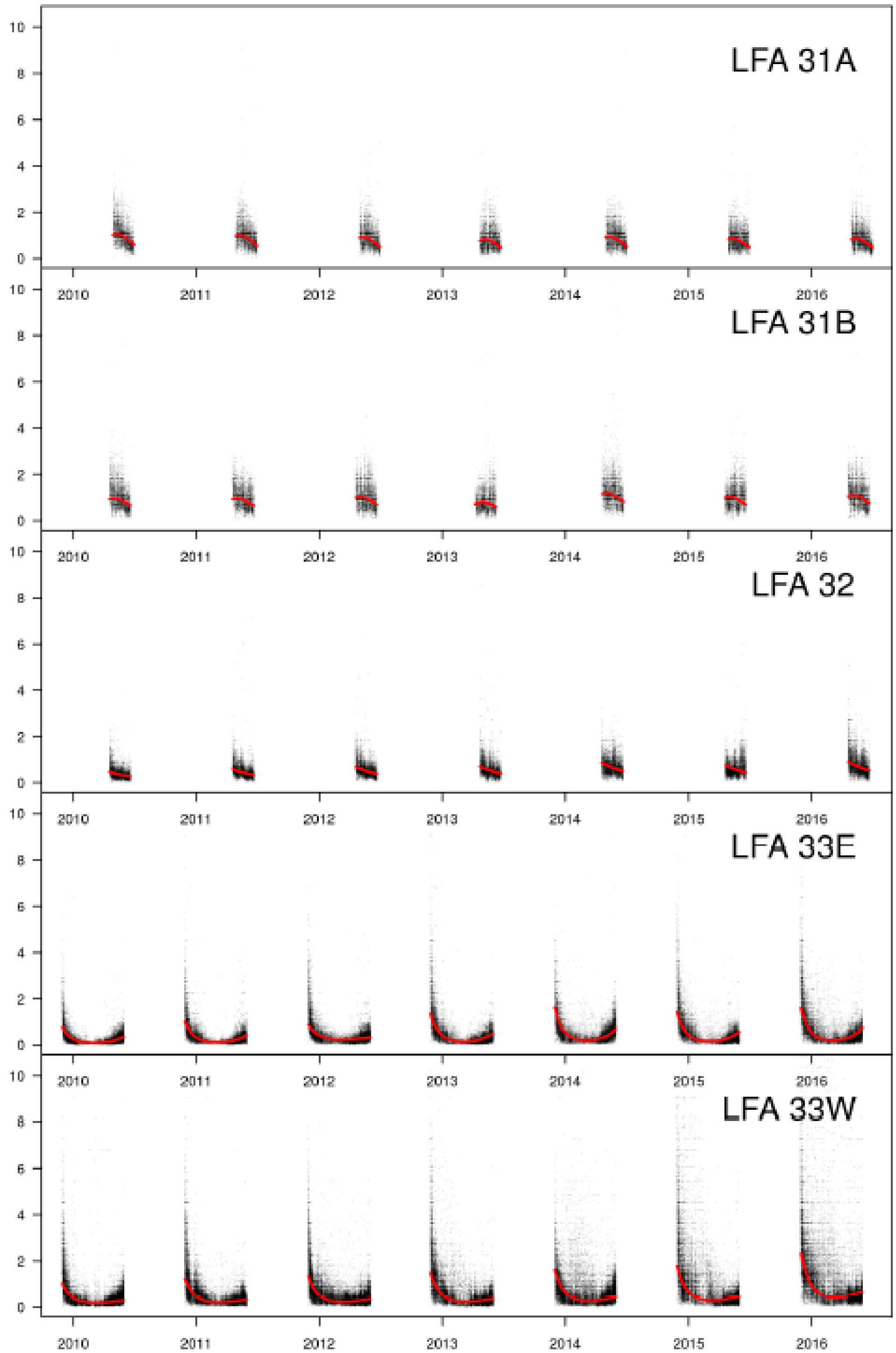


Figure 103: Predictions of Catch Per Unit Effort (kg/trap haul) from the model for each day (red line), overlaid on the raw data for LFAs 31–33.

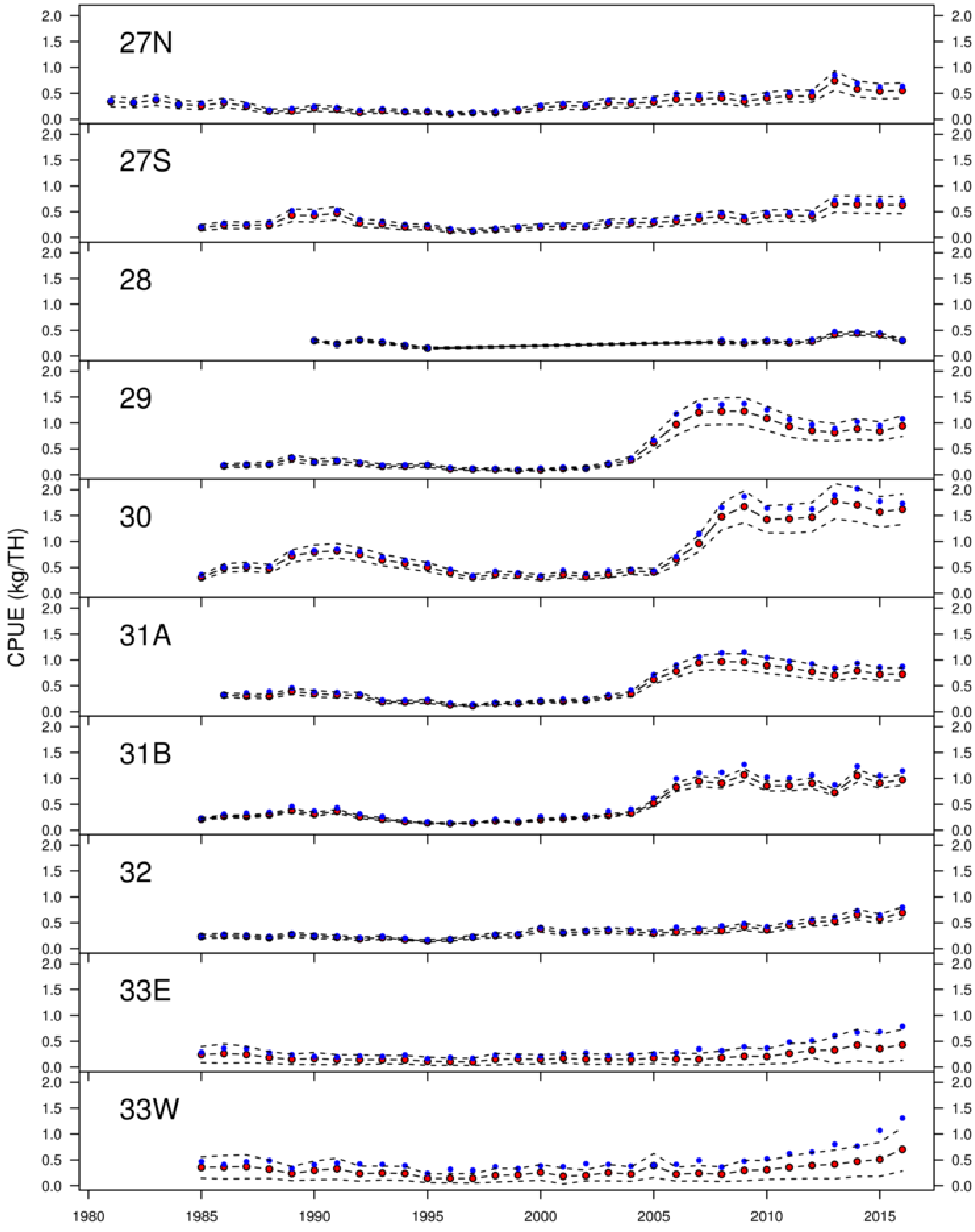


Figure 104: The predicted mean and standard deviation for seasonal and LFA Catch Per Unit Effort (CPUE) indices from the CPUE model (red dots, dashed line). Unmodelled mean CPUE for each season and LFA (blue dots).

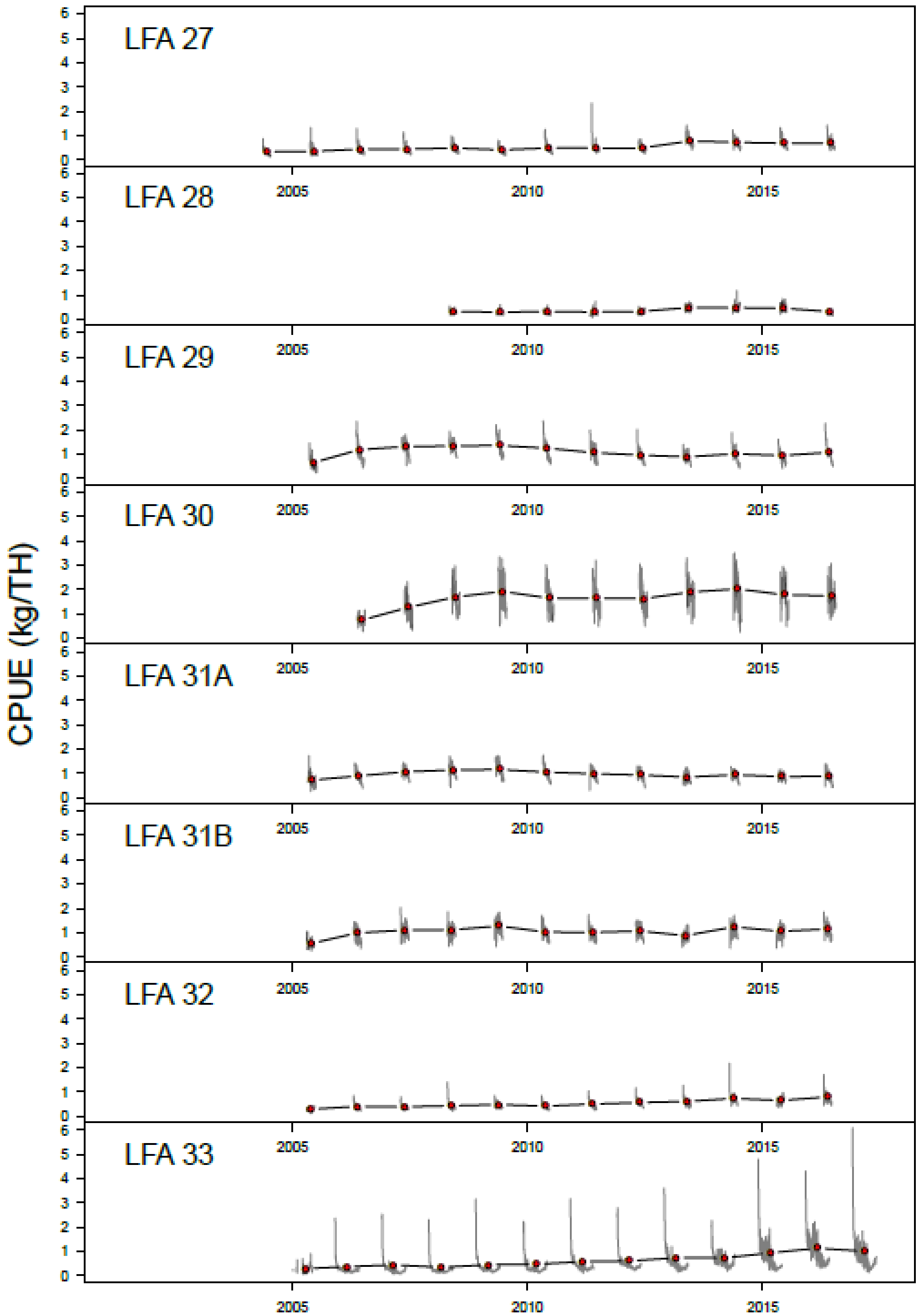


Figure 105: Daily (grey line) and Annual (red dot) mean Catch Per Unit Effort (kg/Trap Haul) for each LFA.

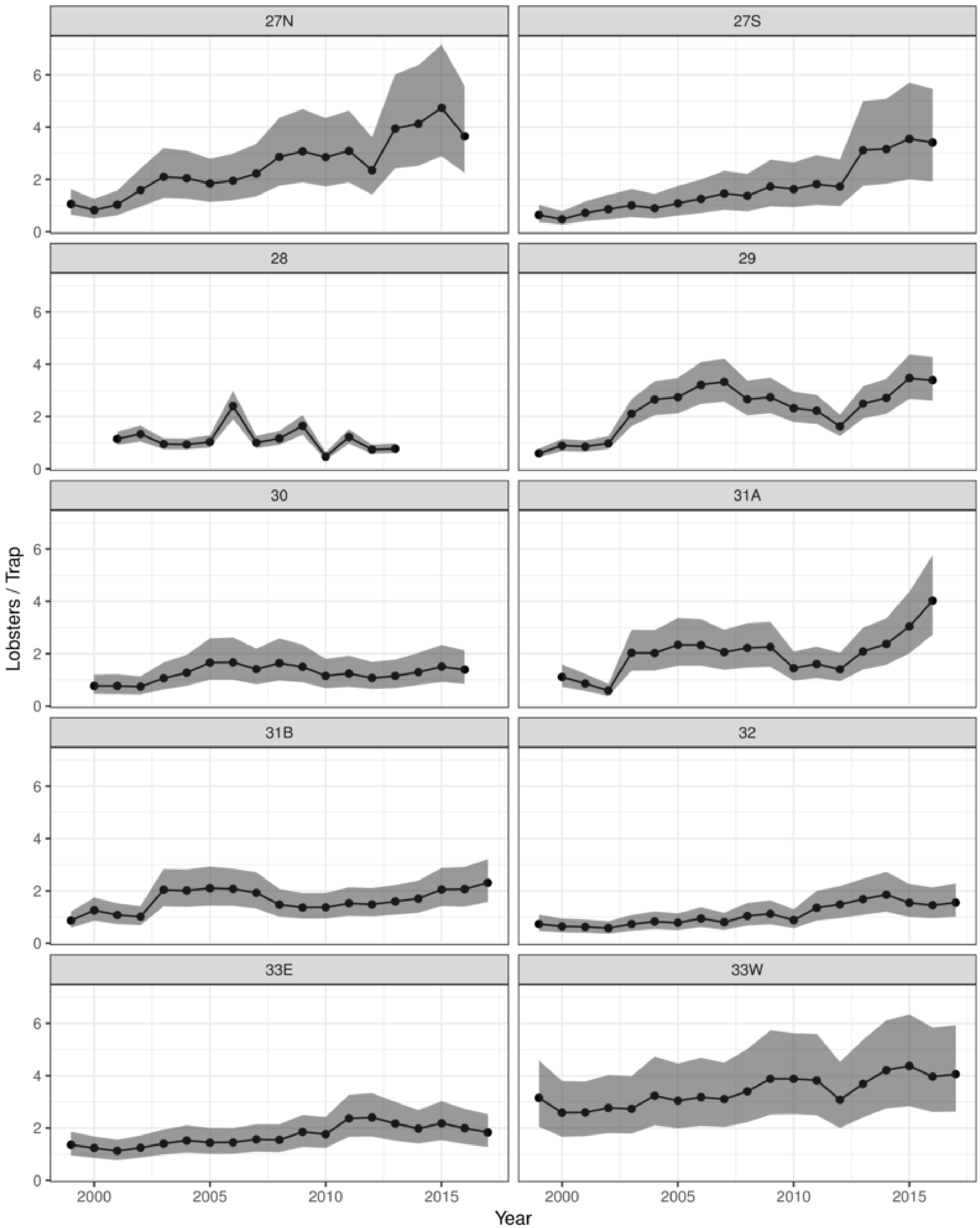


Figure 106: Annual index of sublegal-sized (<82.5 mm) Lobster from the FSRS model with 95% credible intervals for each LFA.

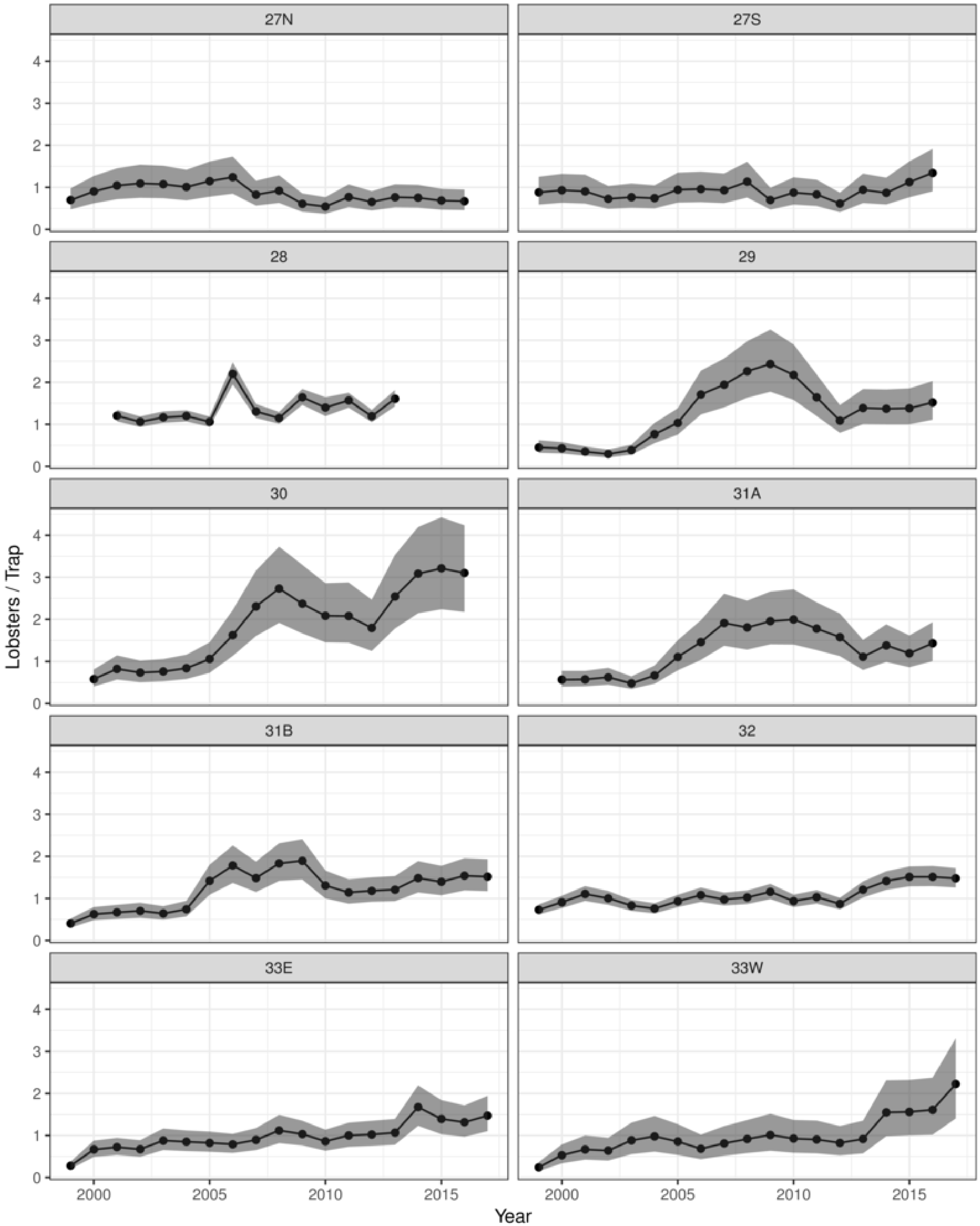


Figure 107: Annual index of legal-sized (>82.5 mm) Lobster from the FSRS model with 95% credible intervals for each LFA.

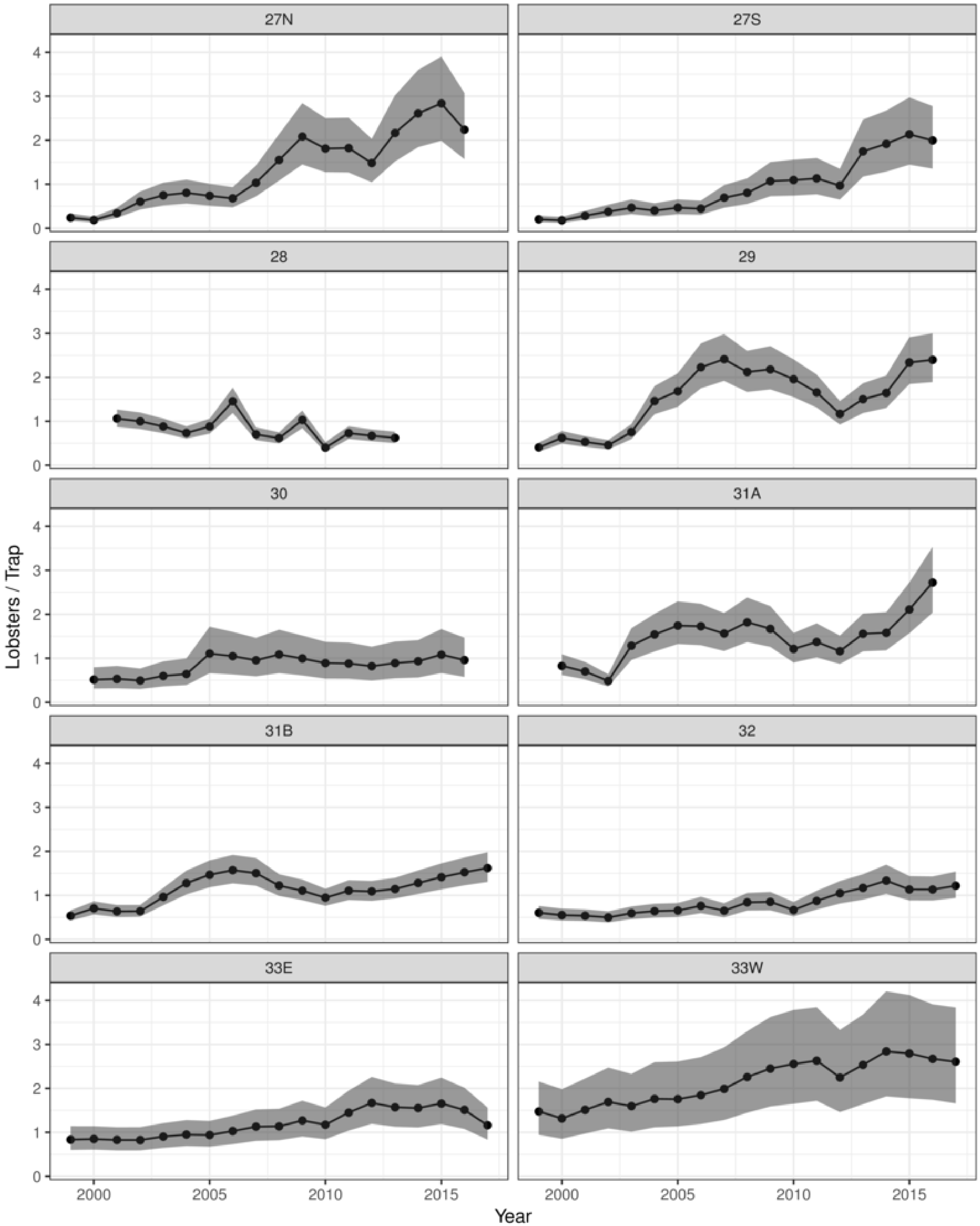


Figure 108: Annual index of recruit-sized (75–82.5 mm) Lobster from the FSRS model with 95% credible intervals for each LFA.

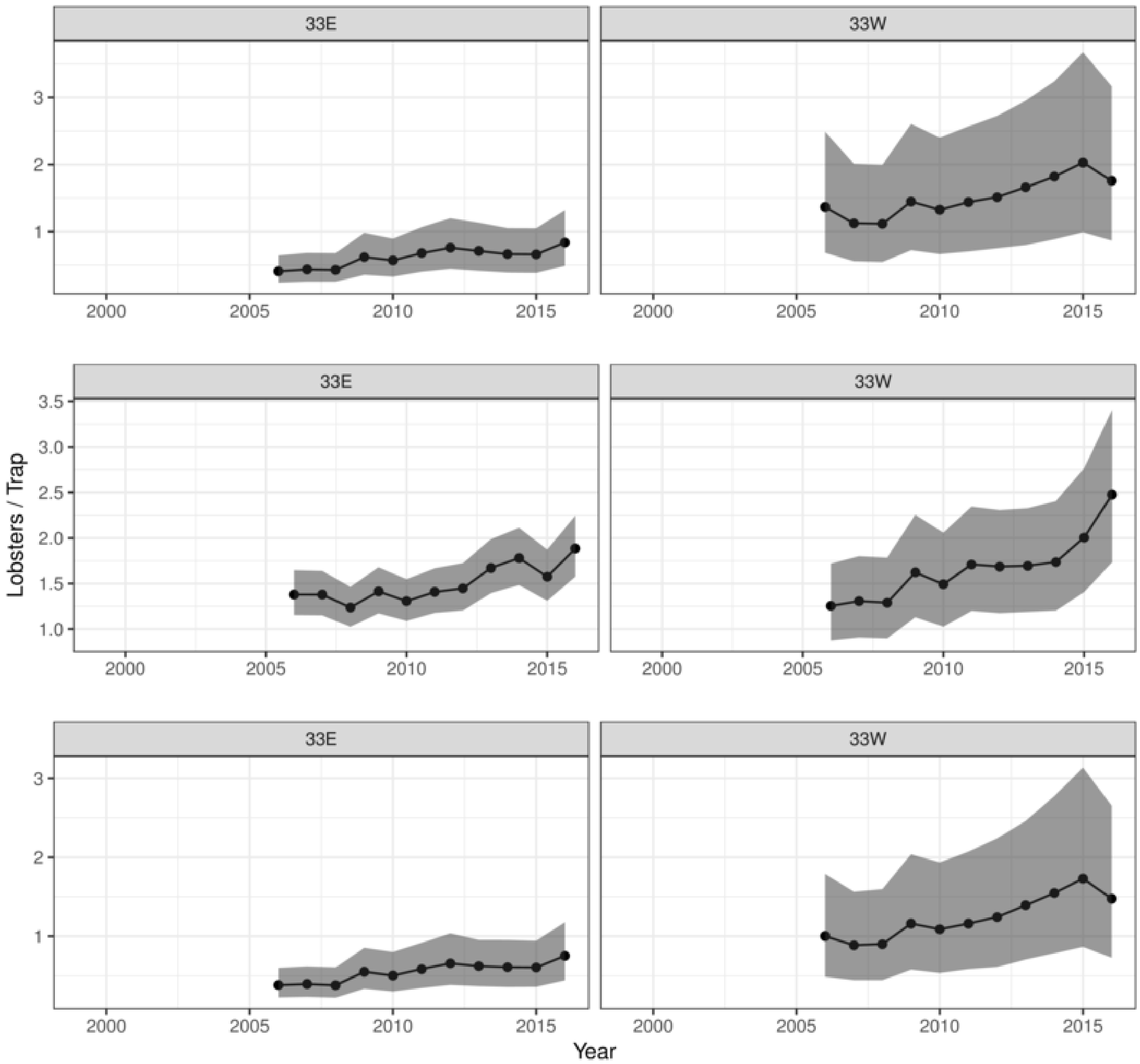


Figure 109: Model predictions from the FSRS commercial sampling program in LFA 33. Top to bottom: sublegal sized (<82.5 mm) , legal sized (>82.5 mm) and recruit sized (75–82.5 mm).

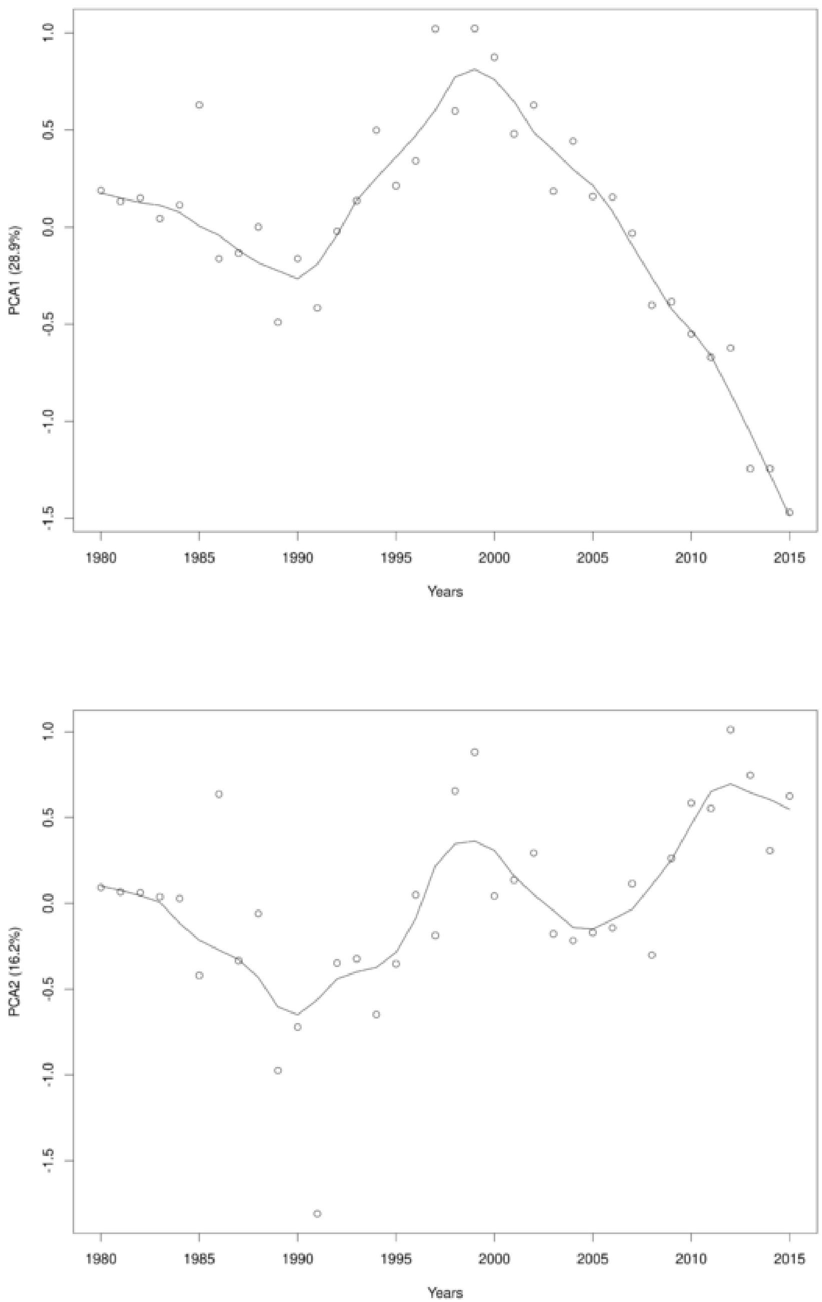


Figure 110: The first two principle components of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 27. Solid line represents a loess smooth.

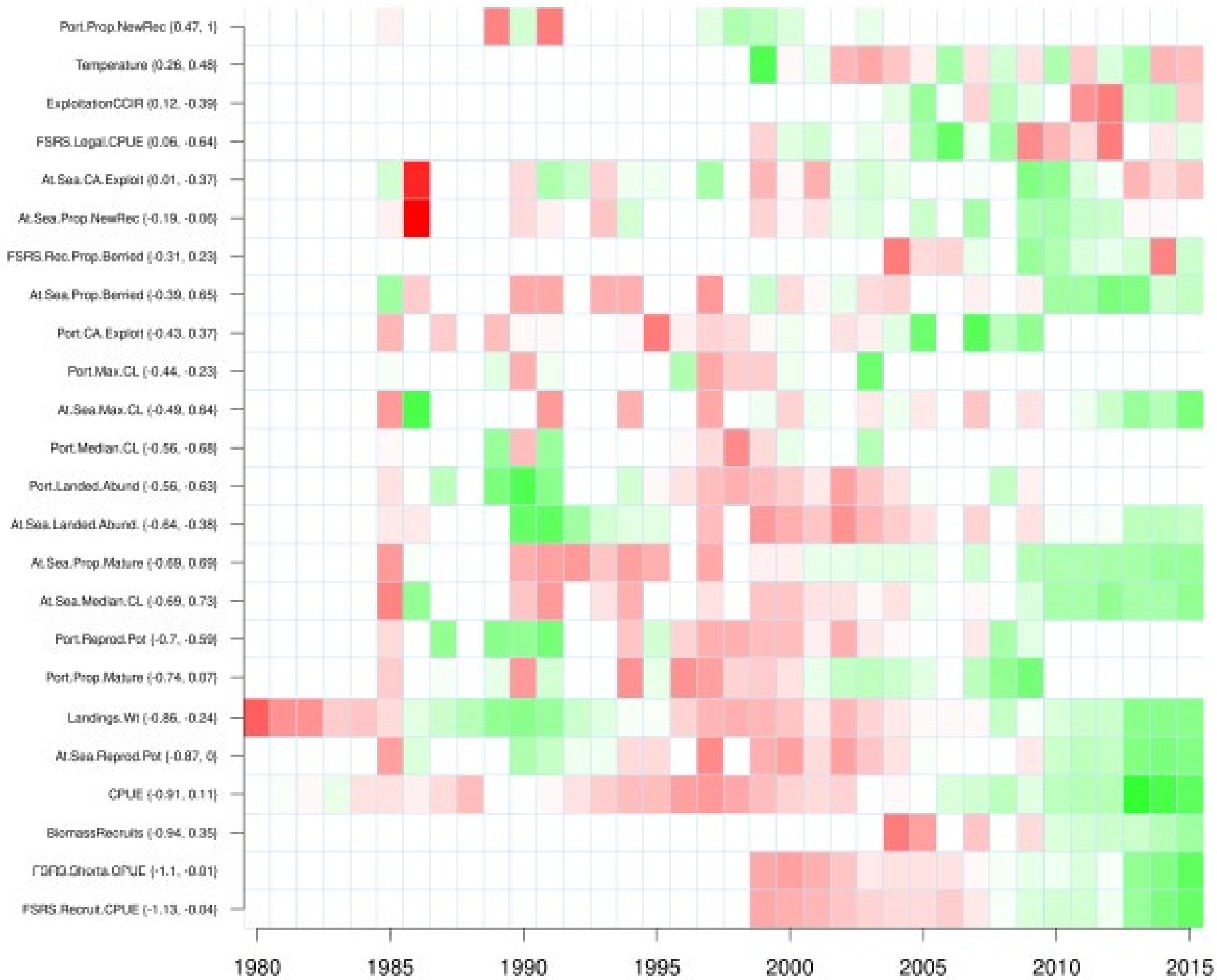


Figure 111: Time series of anomalies of the first principle component of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 27. The values in brackets beside indicator names represent component scores for PC1 and PC2 respectively.

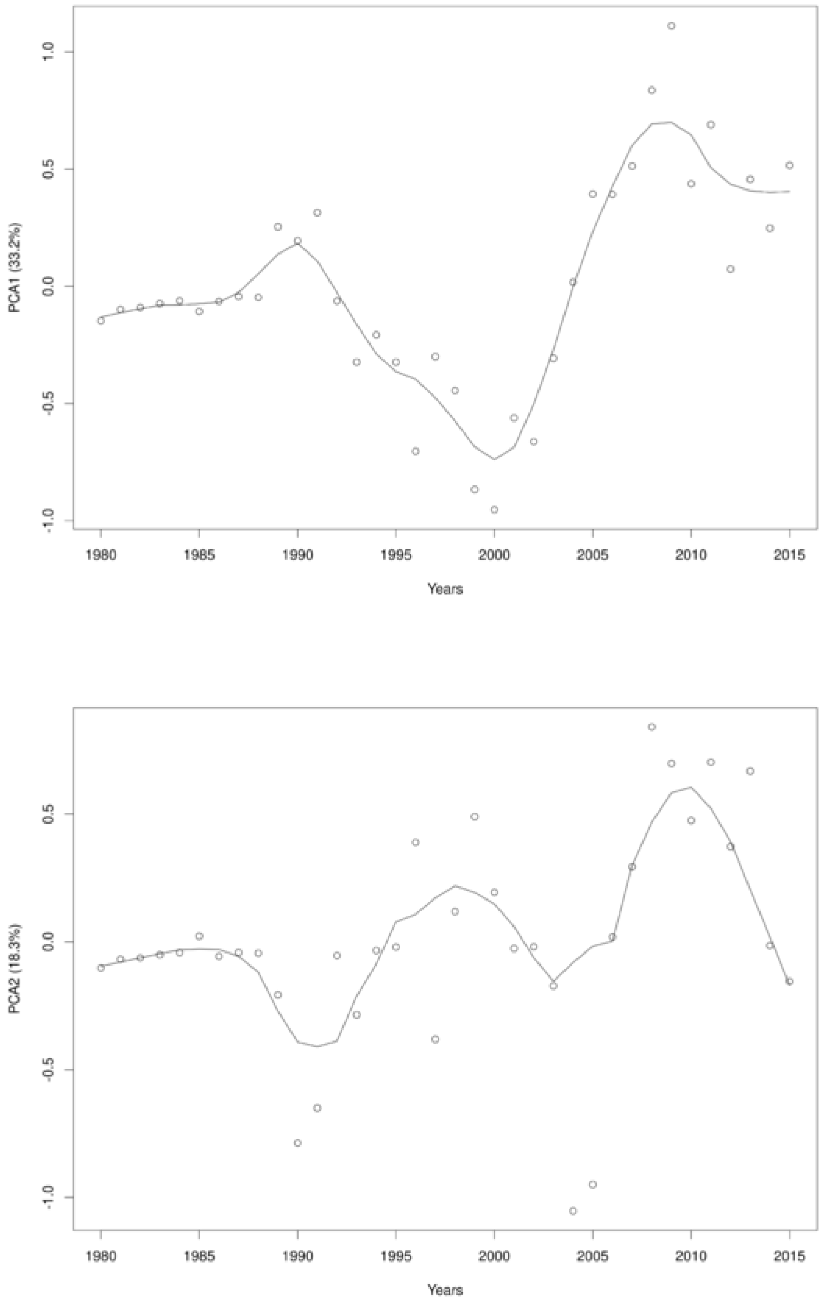


Figure 112: The first two principle components of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 29. Solid line represents a loess smooth.

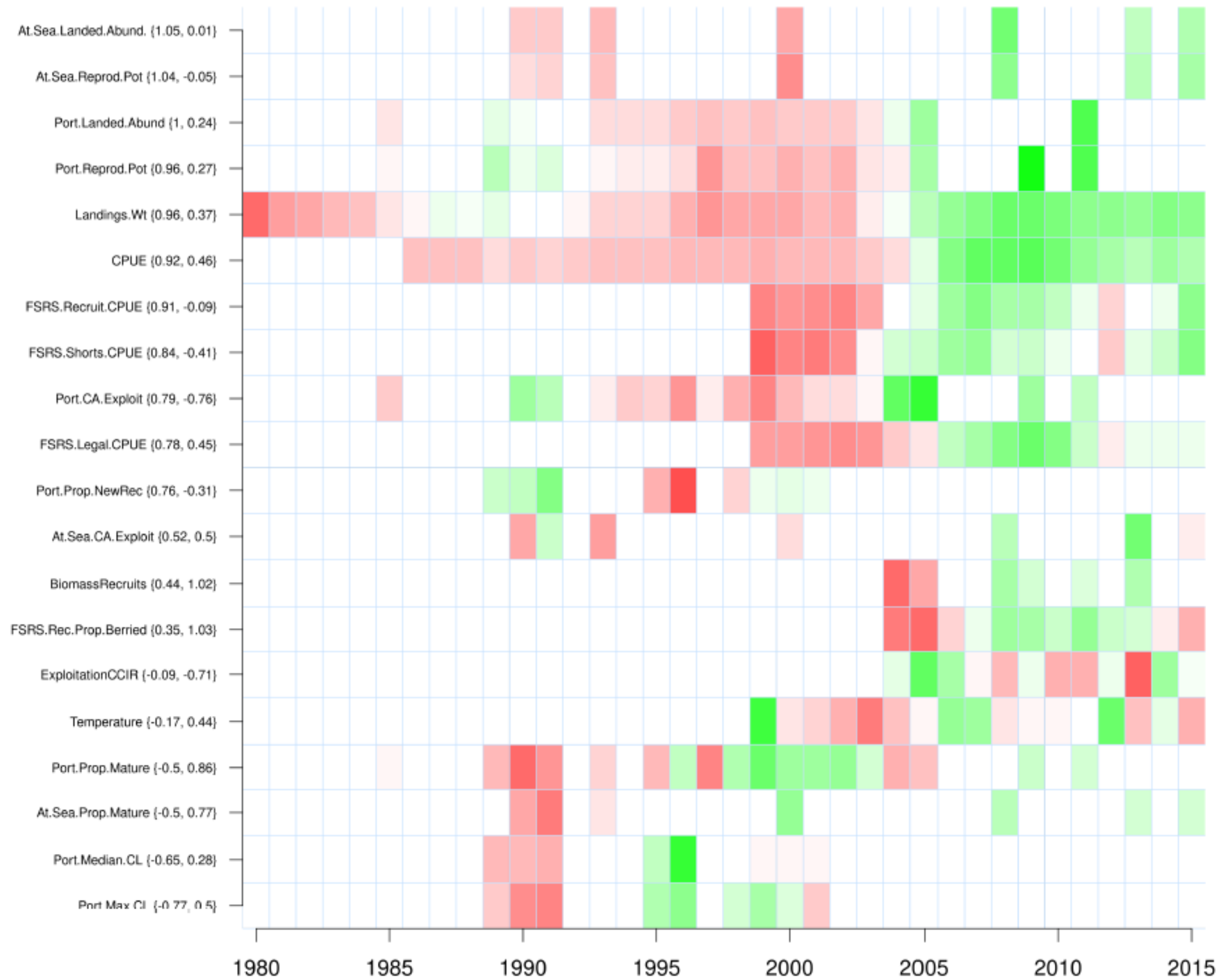


Figure 113: Time series of anomalies of the first principle component of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 29. The values in brackets beside indicator names represent component scores for PC1 and PC2 respectively.

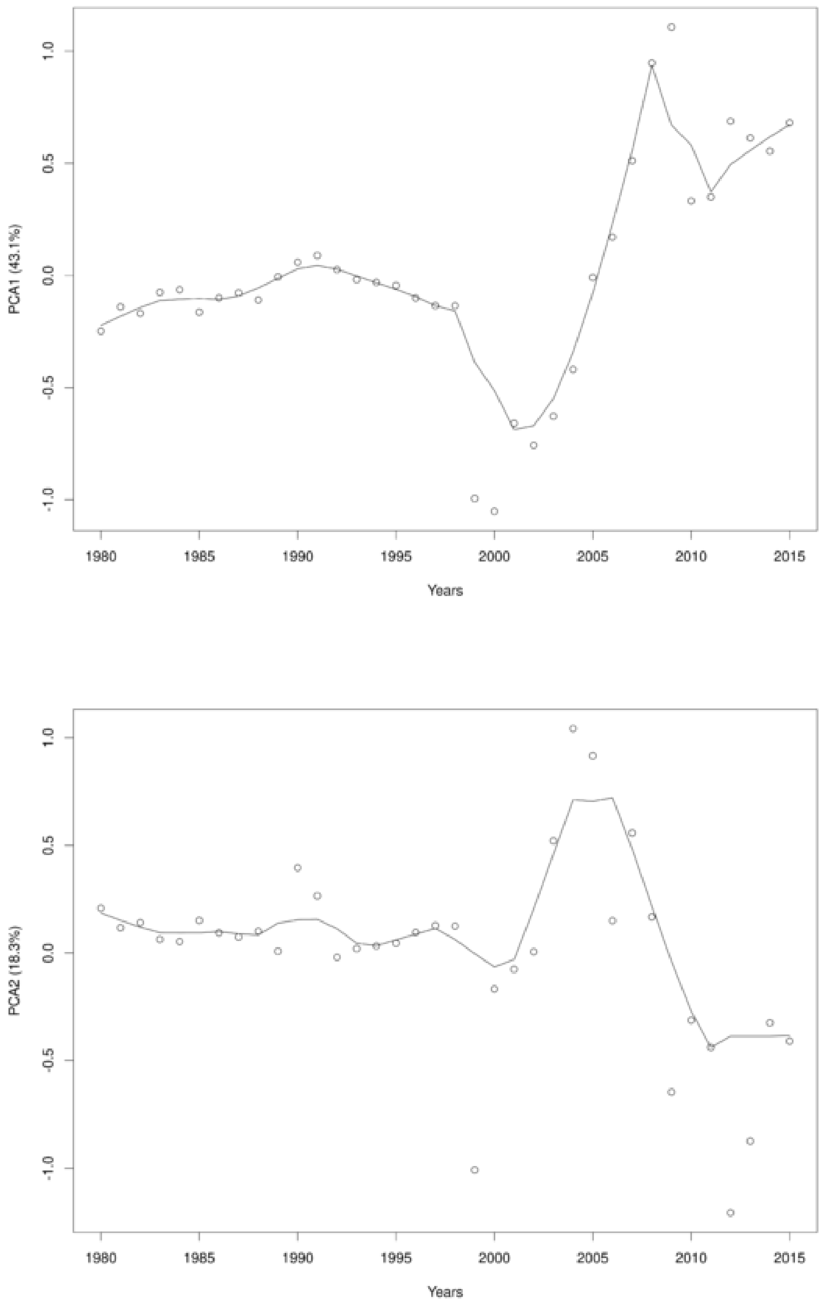


Figure 114: The first two principle components of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 30. Solid line represents a loess smooth.

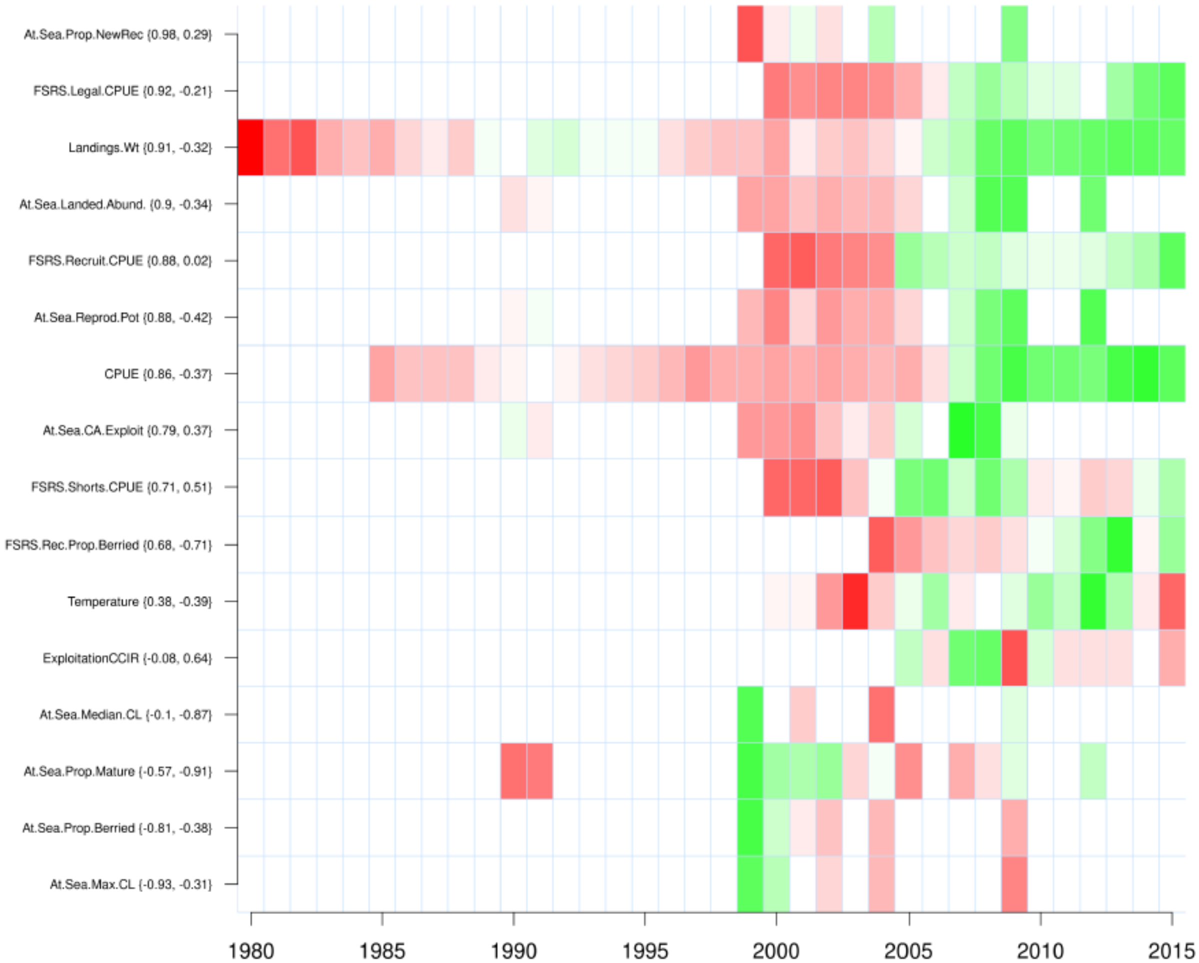


Figure 115: Time series of anomalies of the first principle component of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 30. The values in brackets beside indicator names represent component scores for PC1 and PC2 respectively.

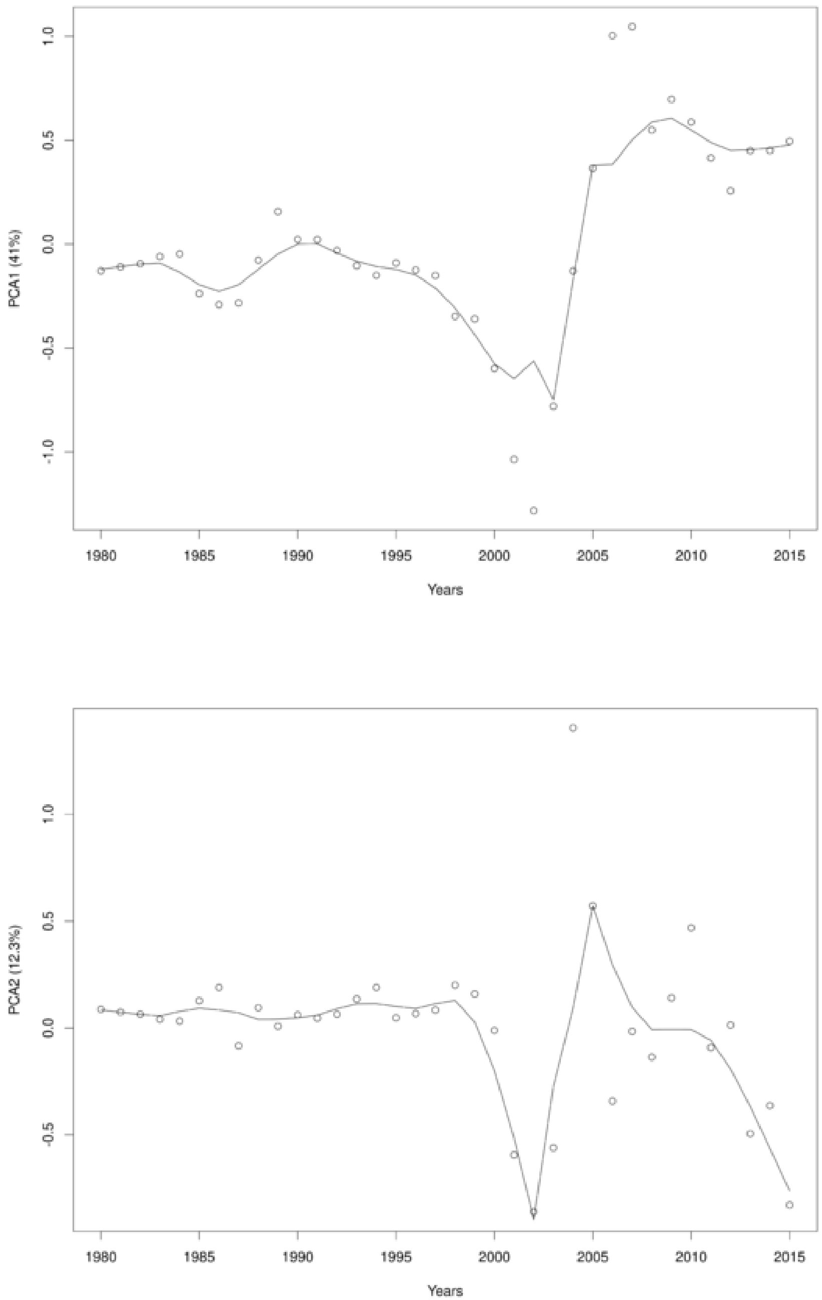


Figure 116: The first two principle components of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 31A. Solid line represents a loess smooth.

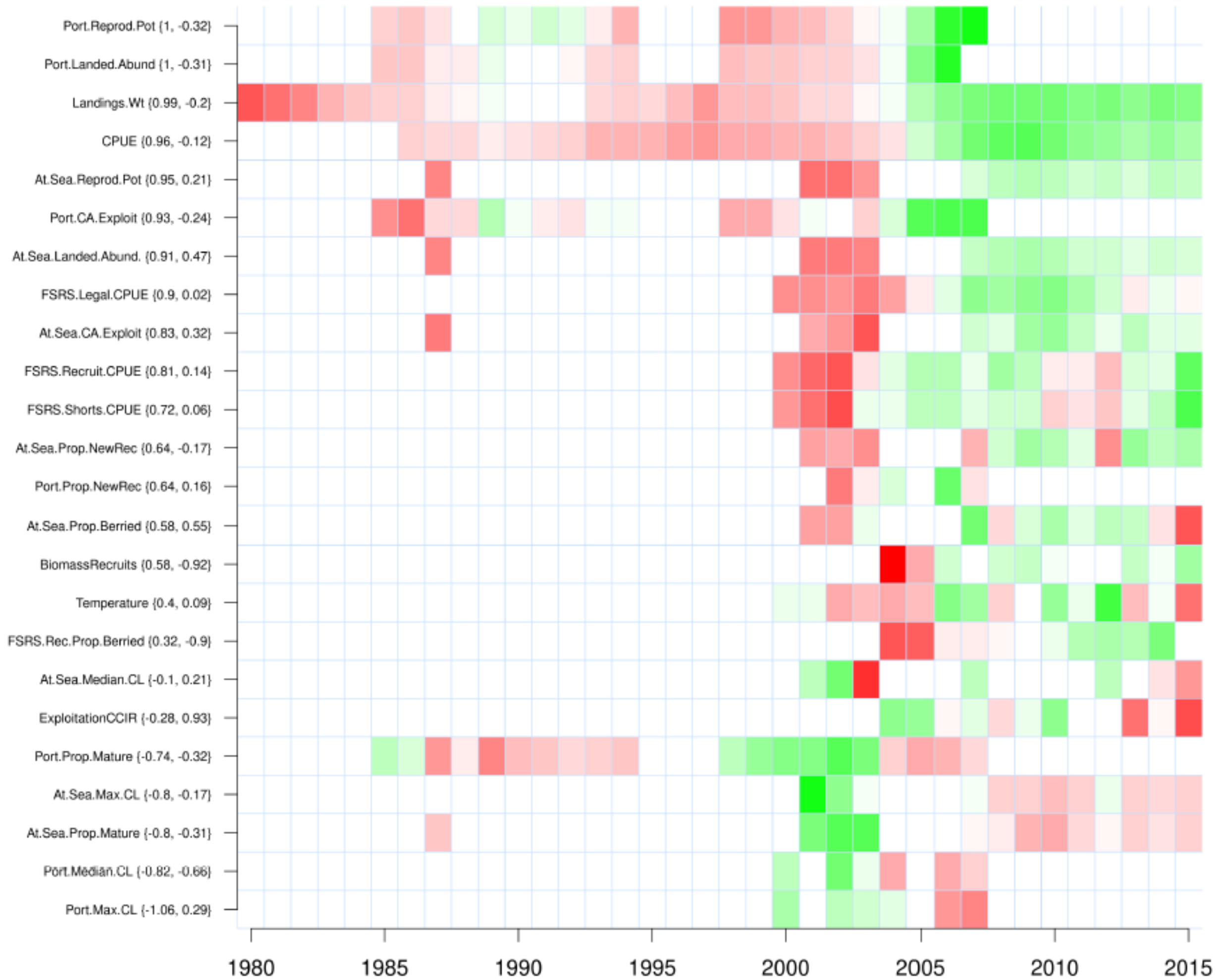
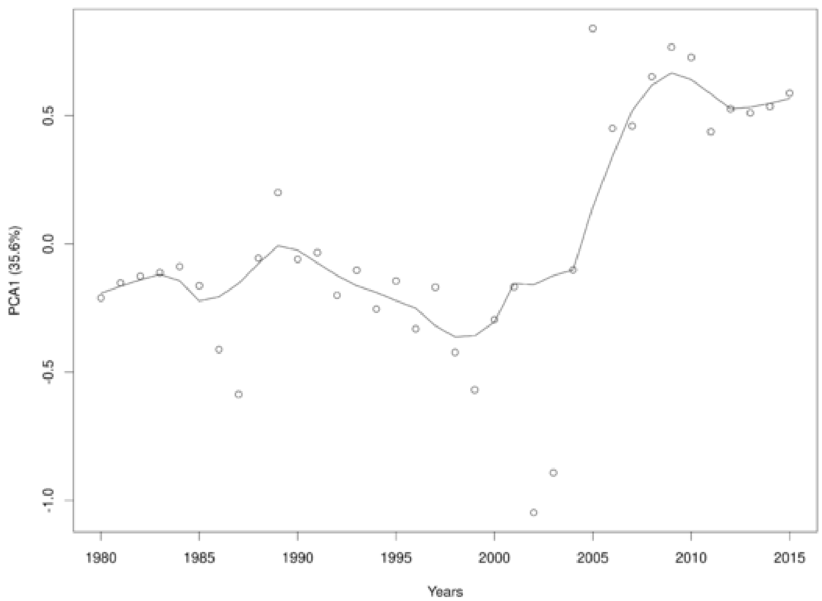


Figure 117: Time series of anomalies of the first principle component of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 31A. The values in brackets beside indicator names represent component scores for PC1 and PC2 respectively.



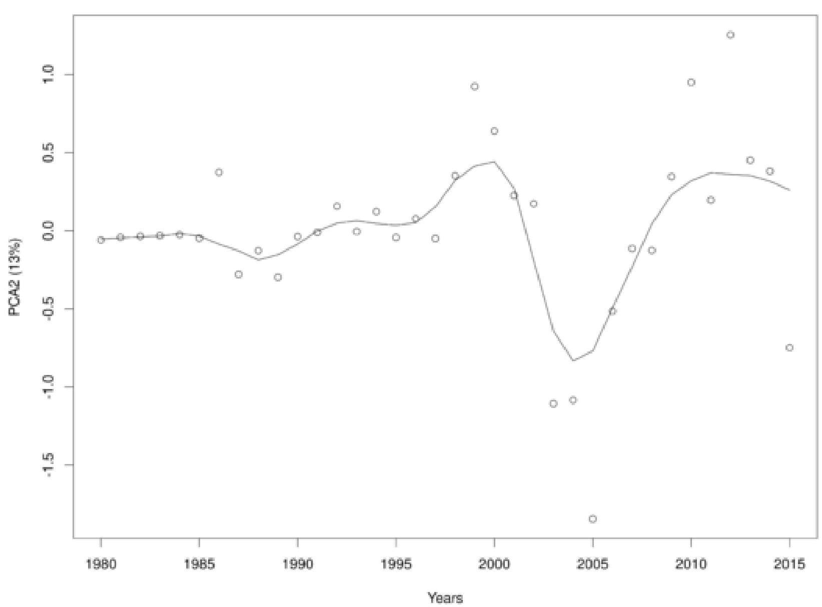


Figure 118: The first two principle components of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 31B. Solid line represents a loess smooth.

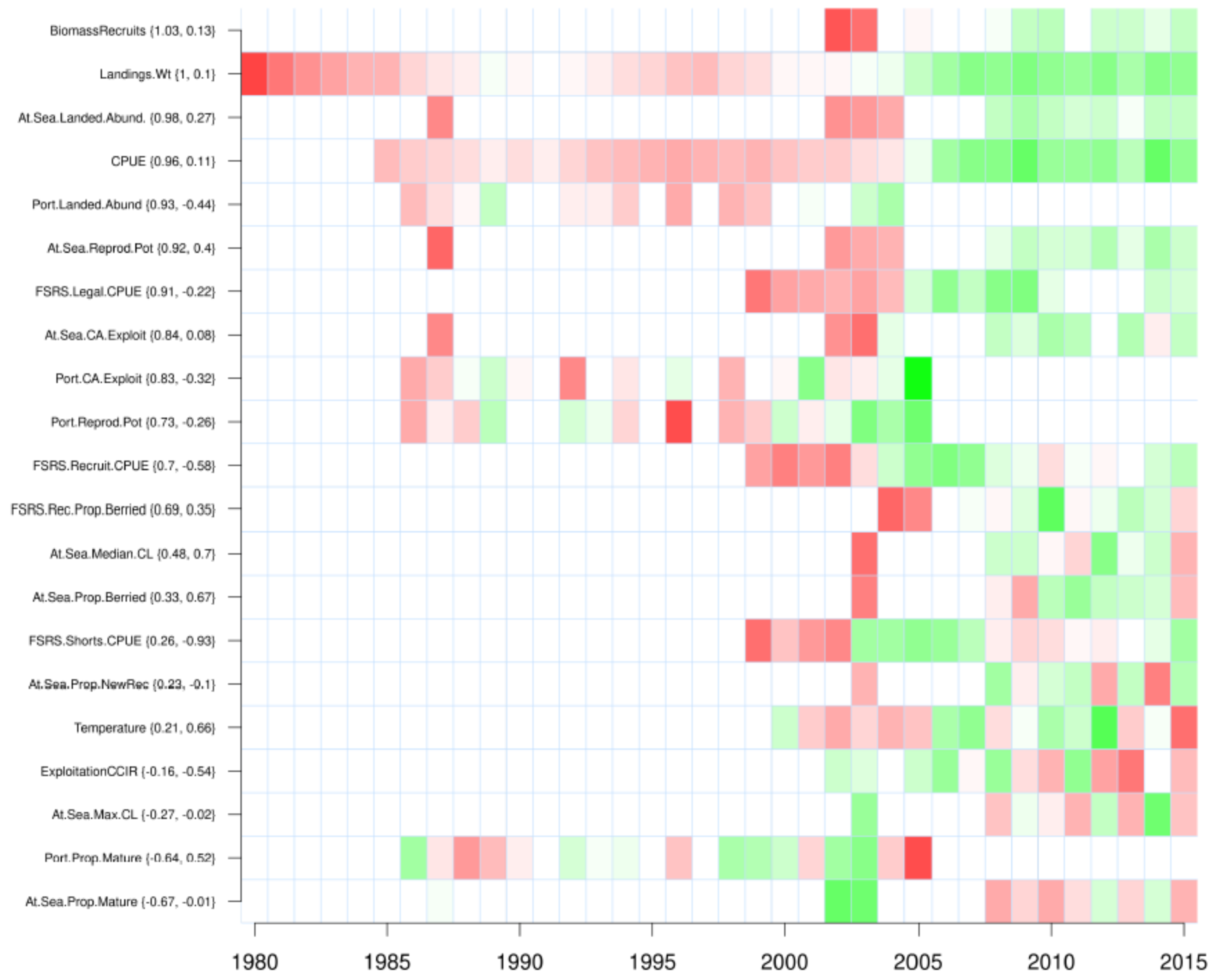


Figure 119: Time series of anomalies of the first principle component of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 31B. The values in brackets beside indicator names represent component scores for PC1 and PC2 respectively.

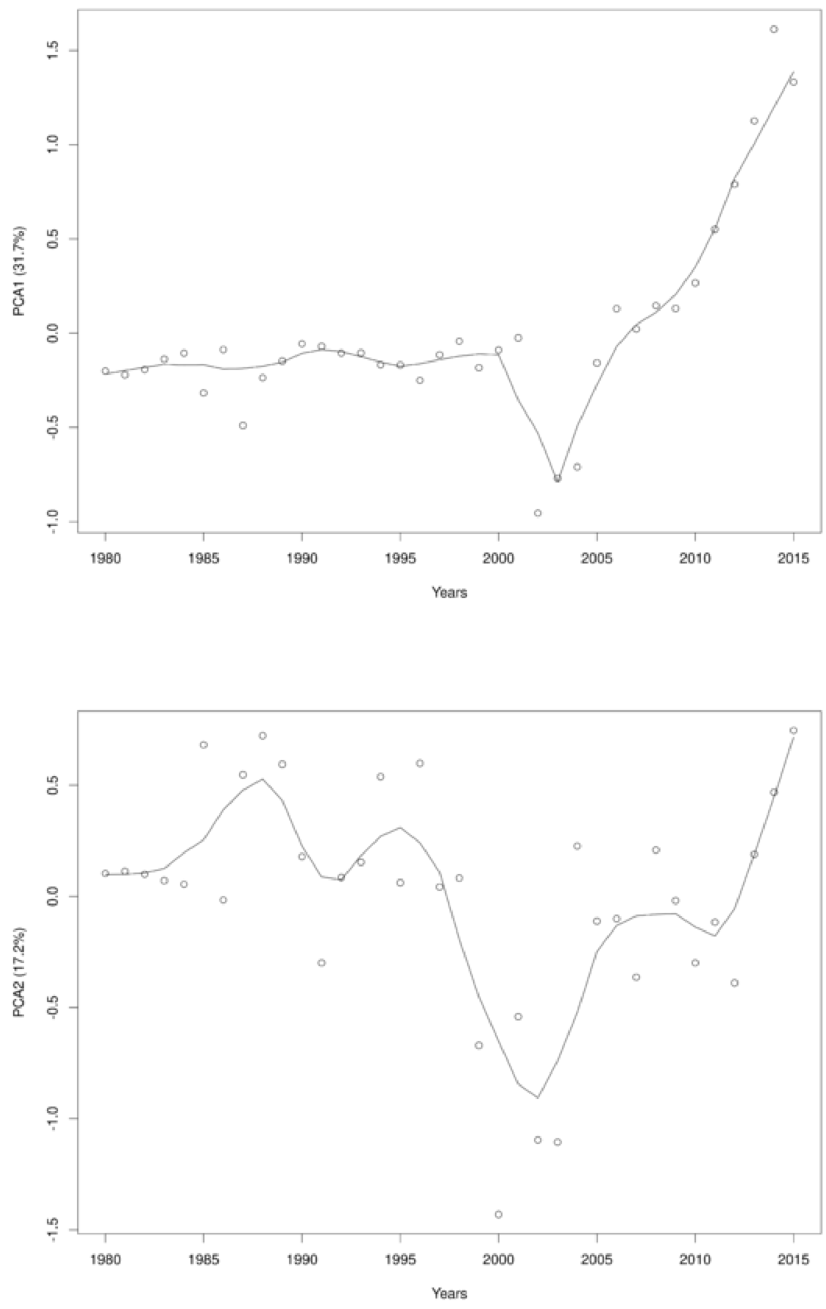


Figure 120: The first two principle components of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 32. Solid line represents a loess smooth.

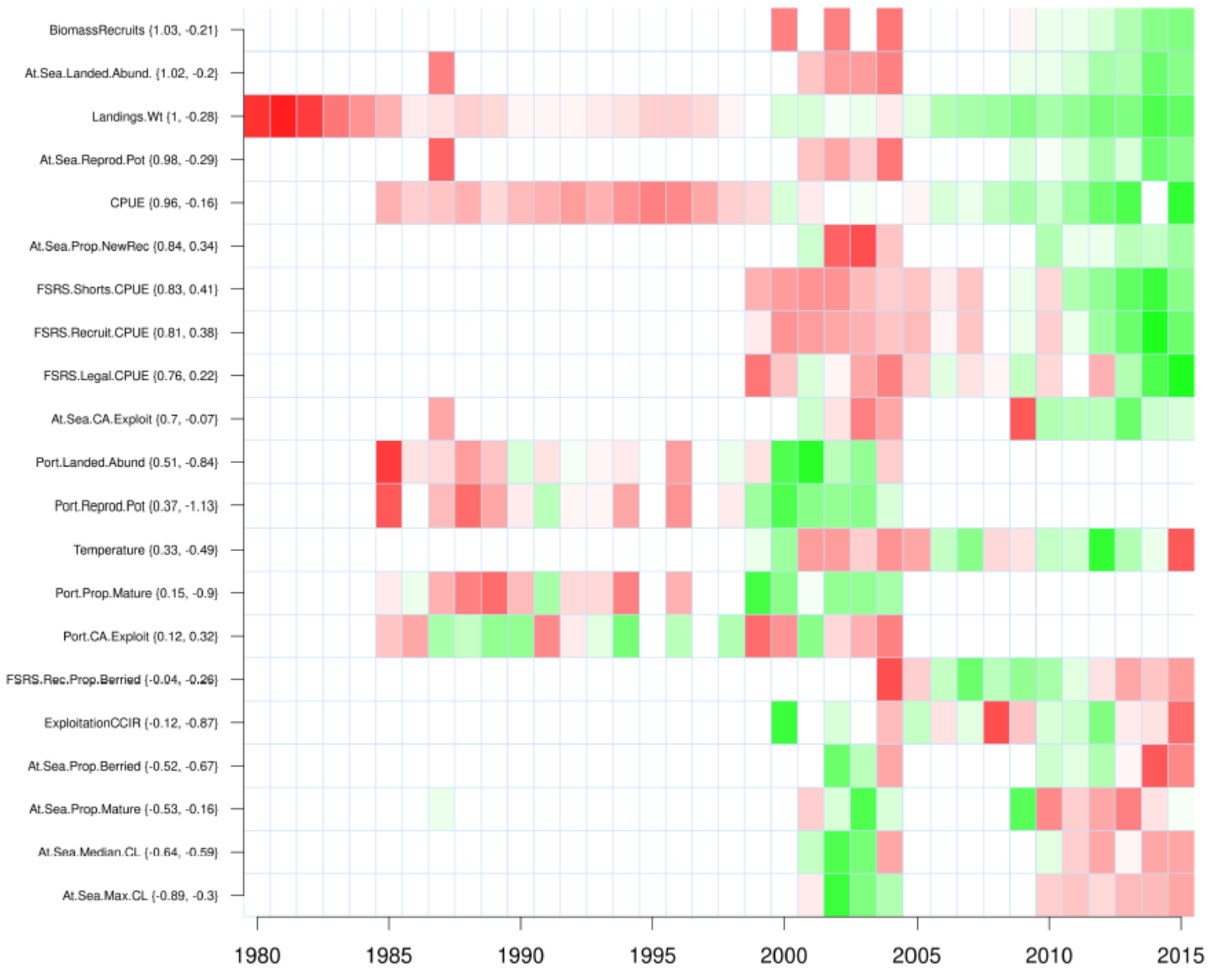
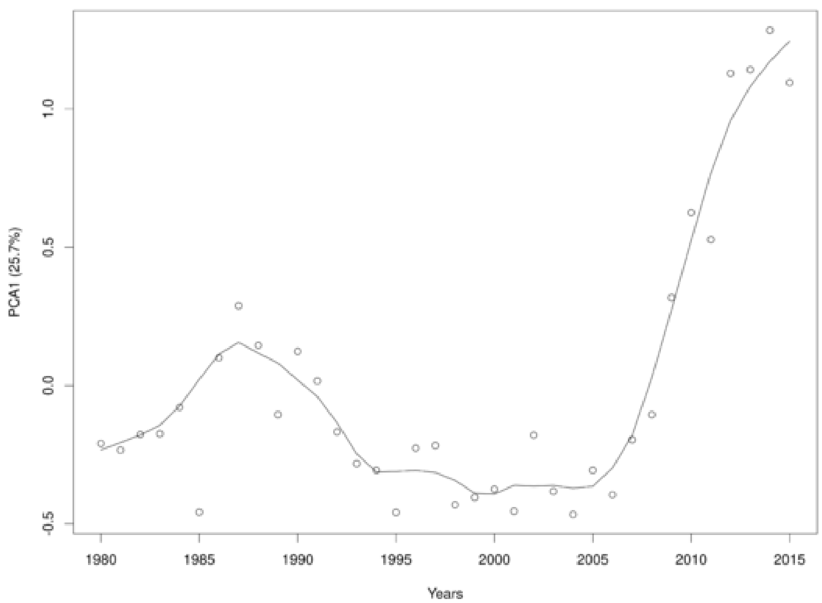


Figure 121: Time series of anomalies of the first principle component of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 32. The values in bracketsbeside indicator names represent component scores for PC1 and PC2 respectively.



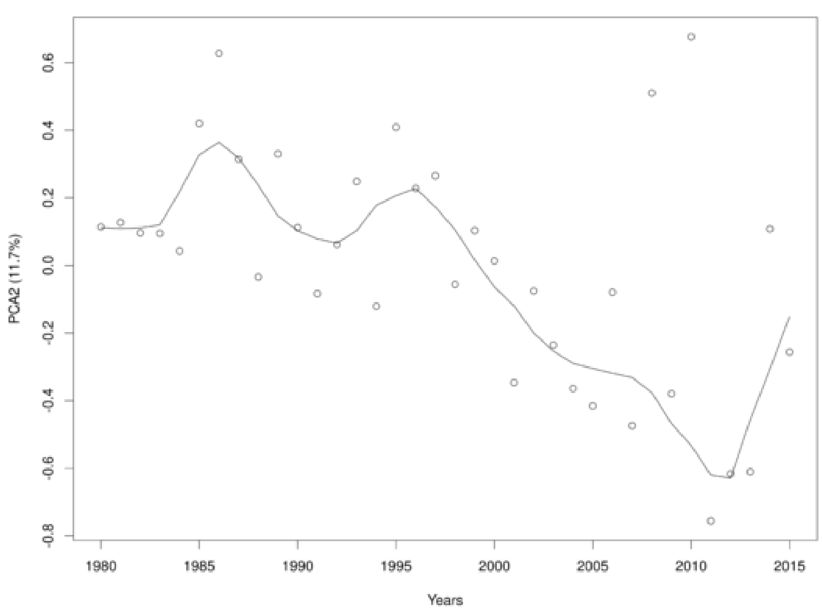


Figure 122: The first two principle components of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 33. Solid line represents a loess smooth.

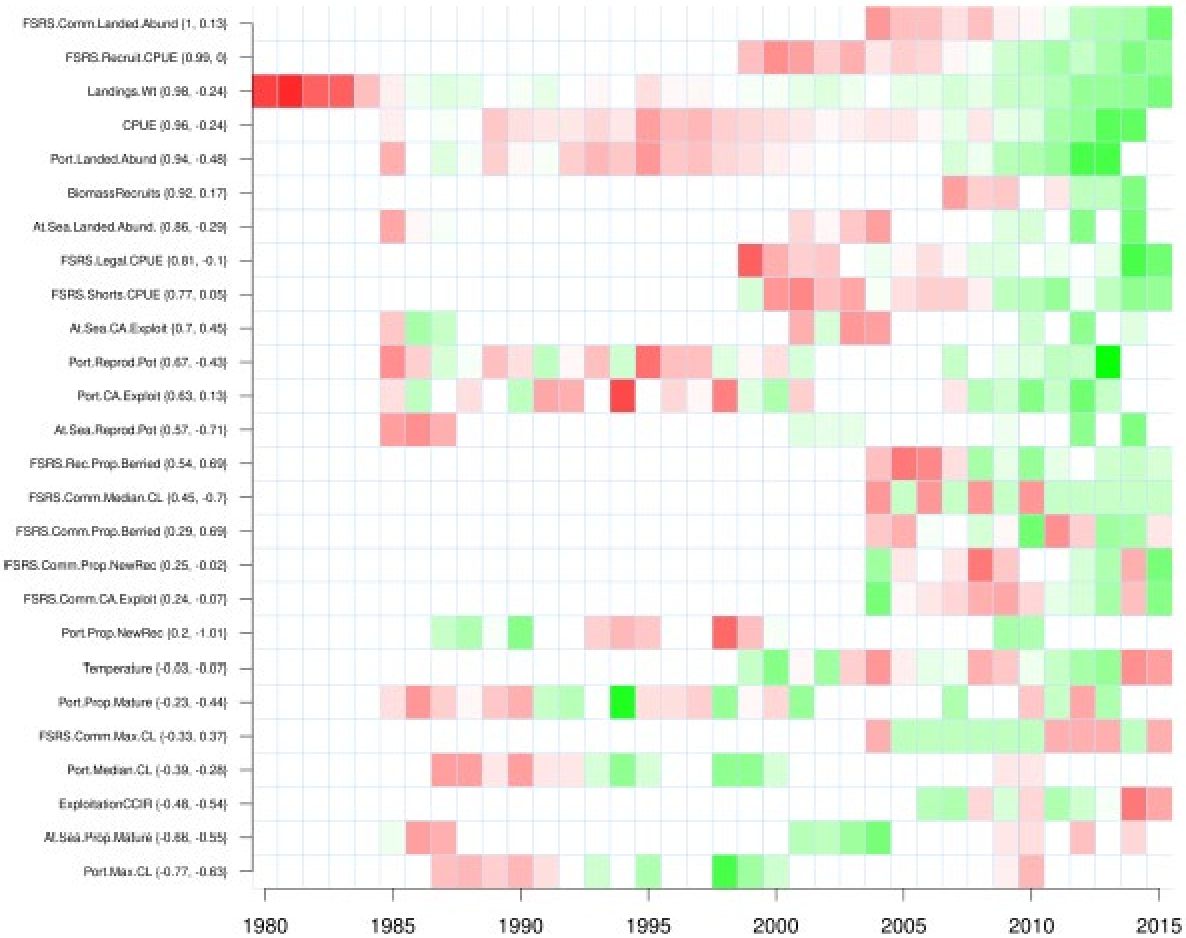


Figure 123: Time series of anomalies of the first principle component of a multivariate ordination of indicators representing the lobster stock and fishery in LFA 33. The values in brackets beside indicator names represent component scores for PC1 and PC2 respectively.

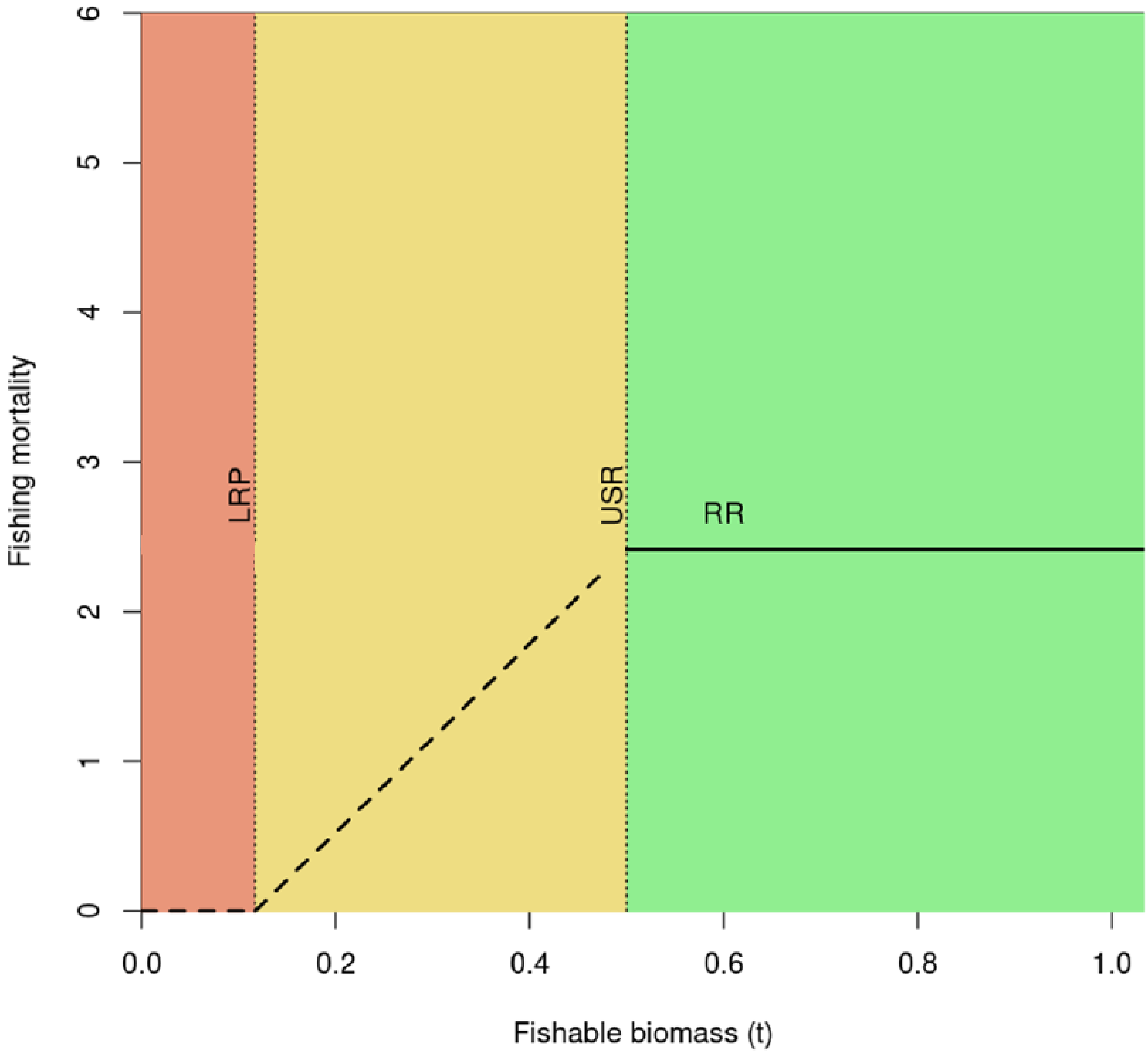


Figure 124: Example precautionary approach phase plot delimiting the healthy zone (green) above upper stock reference (USR) the cautious zone (yellow), between the USR and the limit reference point (LRP) and critical zone (red), below the LRP. The removal reference (RR) is shown as a solid black line in all three zones, however in practice the RR should be reduced in the cautious zone (black dashed) to allow stock rebuilding and set to 0 in the critical zone.

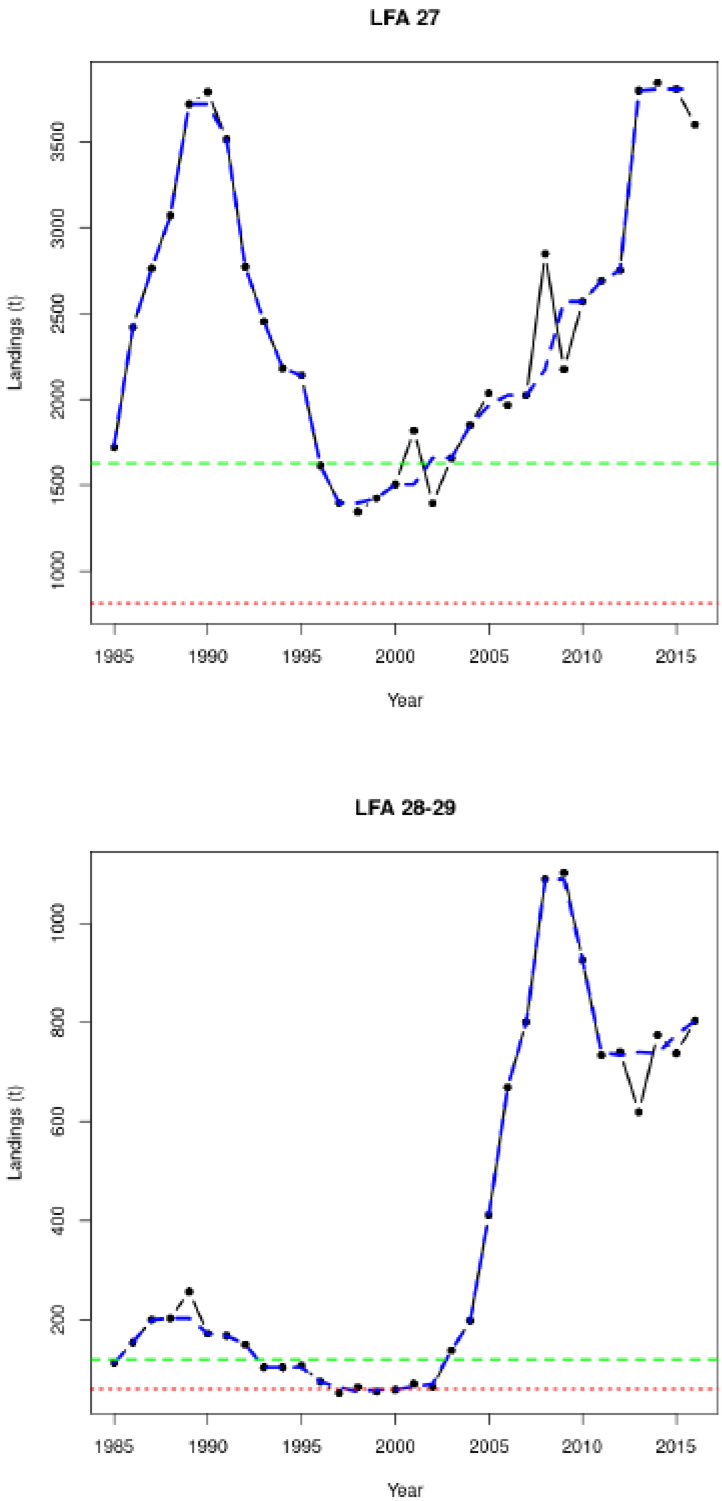
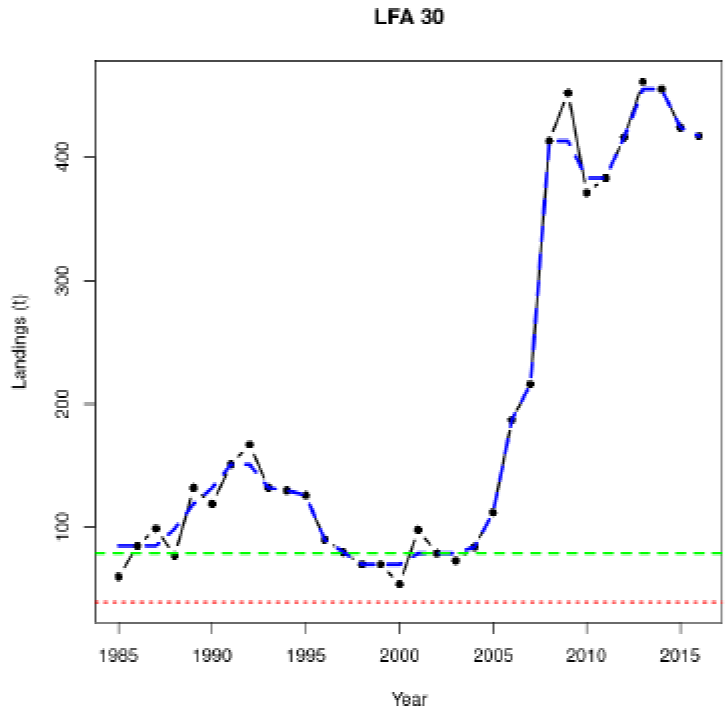


Figure 125: Time series of landings (black), three year running median of landings (blue) with currently approved upper stock (dashed green line) and limit reference (dotted red line) points by LFA.



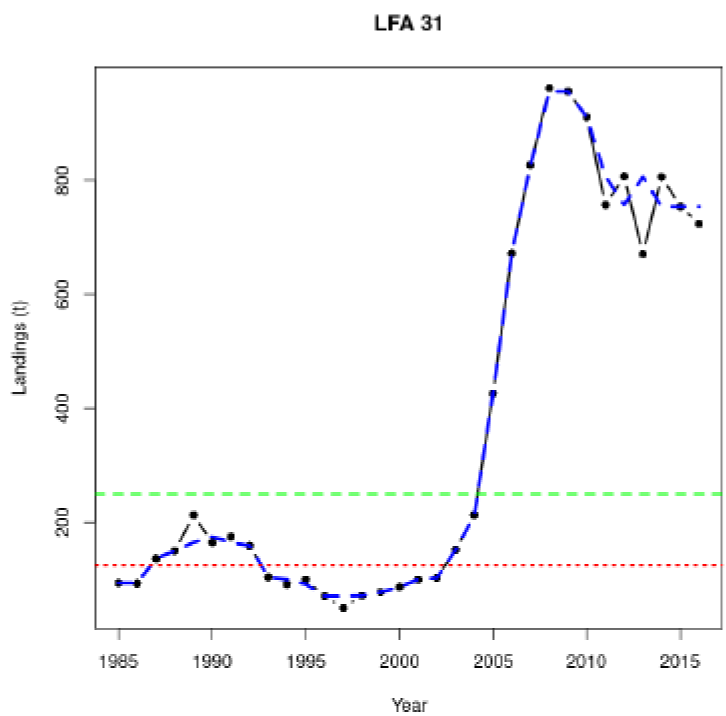
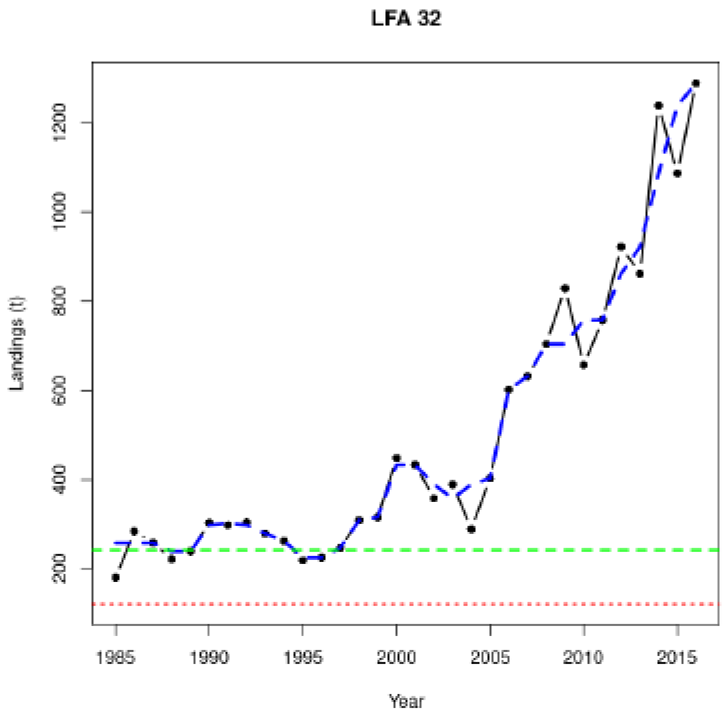


Figure 126: Time series of landings (black), three year running median of landings (blue) with currently approved upper stock (dashed green line) and limit reference (dotted red line) points by LFA.



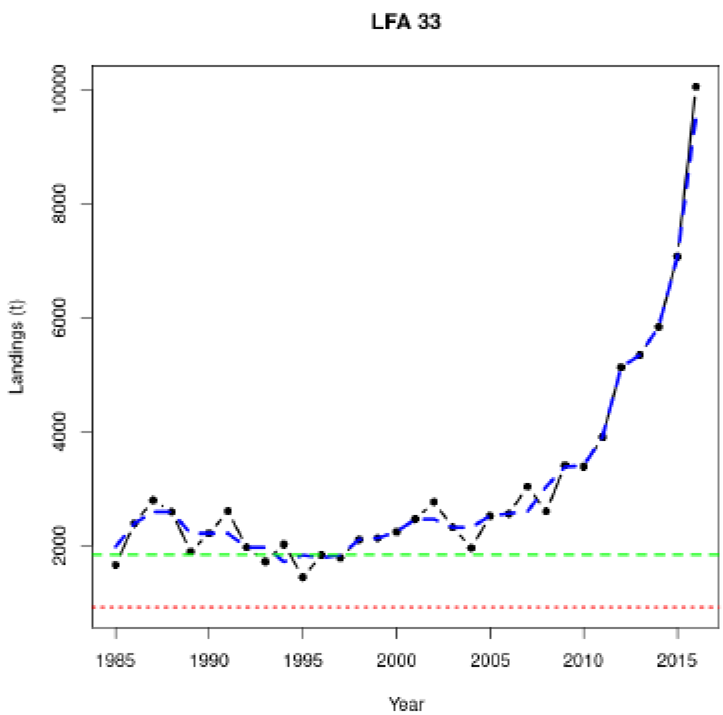
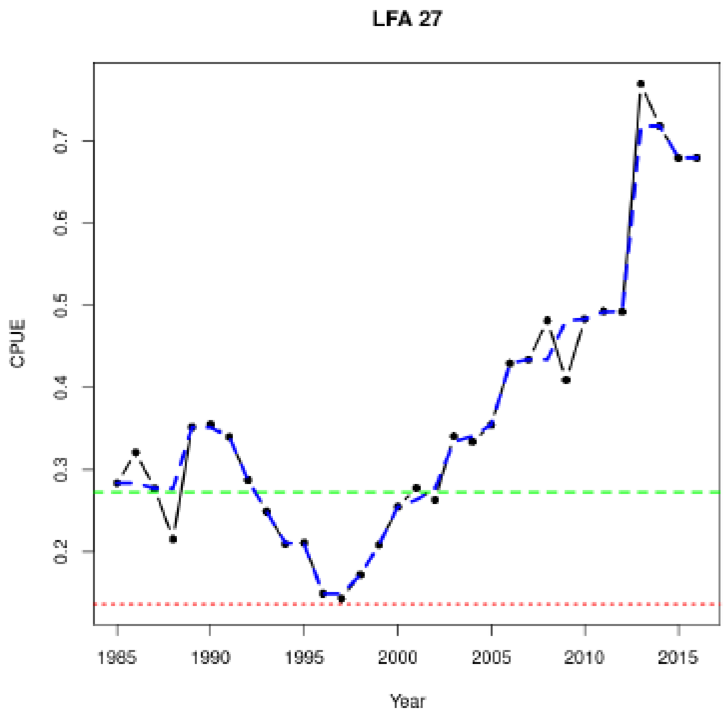


Figure 127: Time series of landings (black), three year running median of landings (blue) with currently approved upper stock (dashed green line) and limit reference (dotted red line) points by LFA.



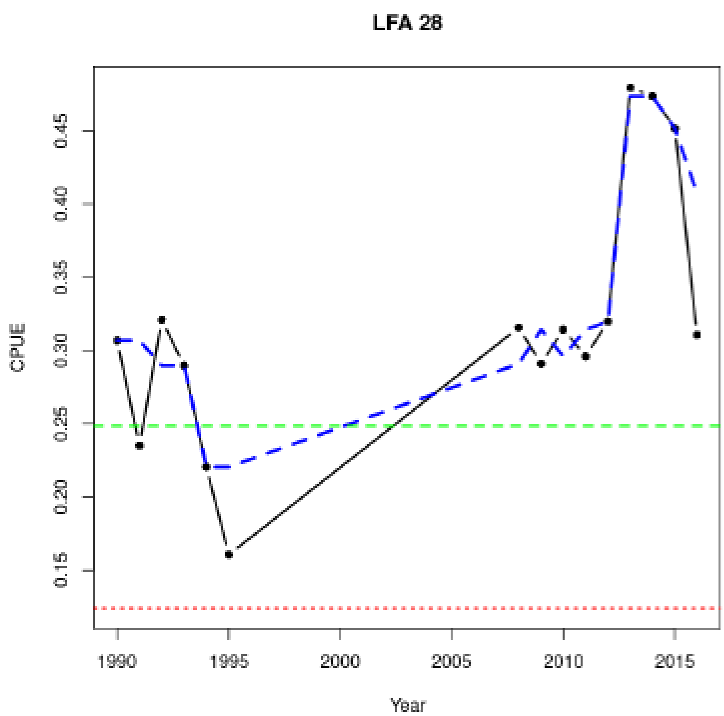
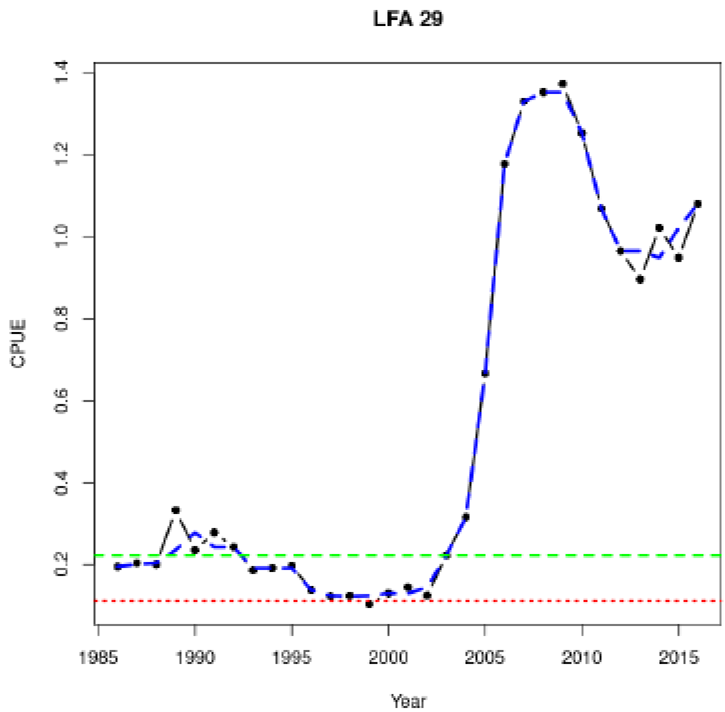


Figure 128: Time series of commercial catch rates (black), three year running median (blue) with proposed upper stock (dashed green line) and limit reference (dotted red line) points by LFA.



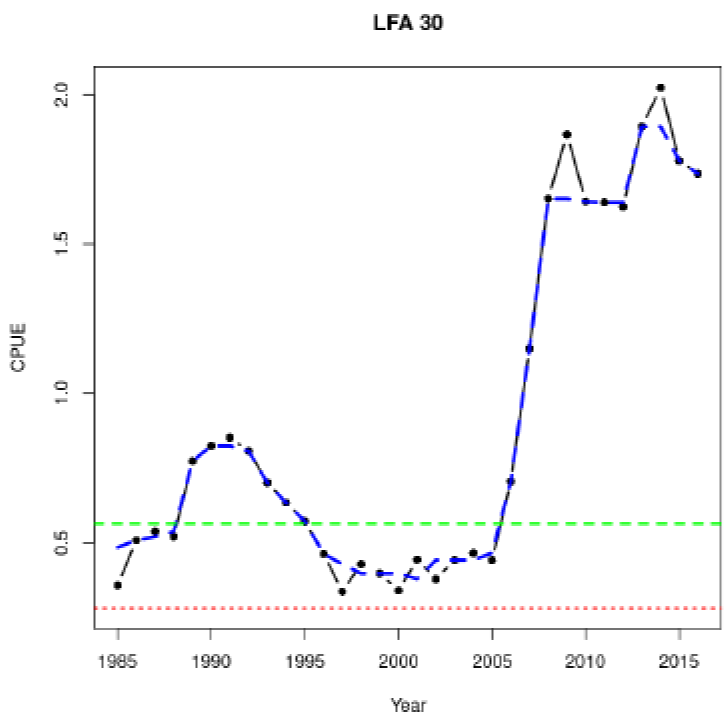
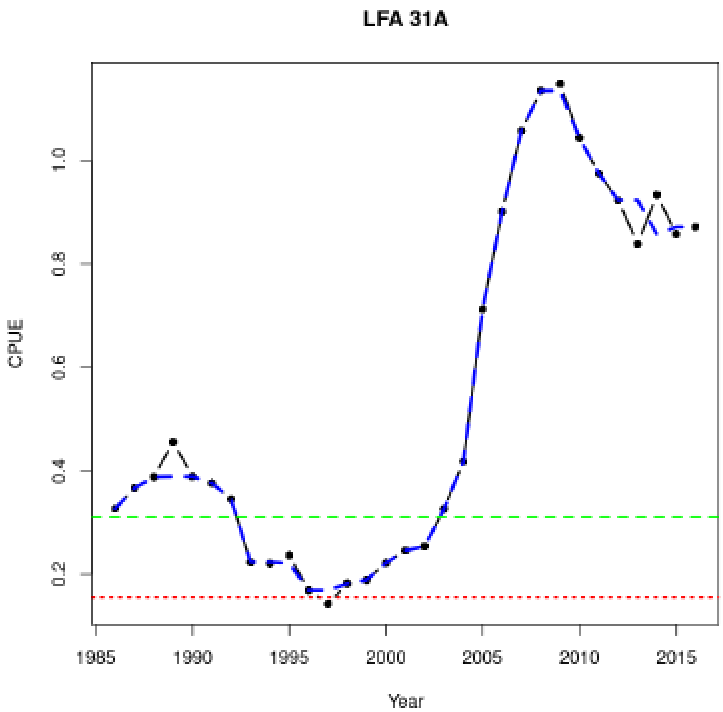


Figure 129: Time series of commercial catch rates (black), three year running median (blue) with proposed upper stock (dashed green line) and limit reference (dotted red line) points by LFA.



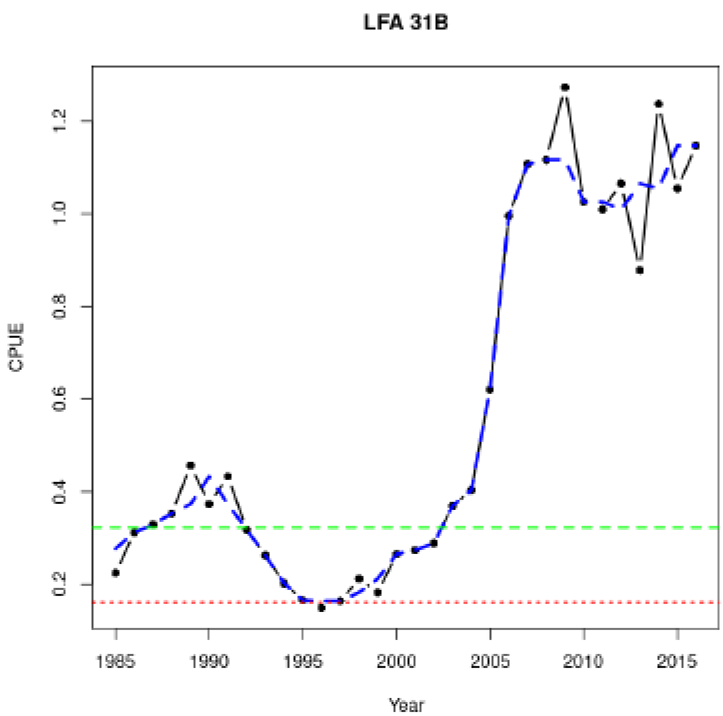


Figure 130: Time series of commercial catch rates (black), three year running median (blue) with proposed upper stock (dashed green line) and limit reference (dotted red line) points by LFA.

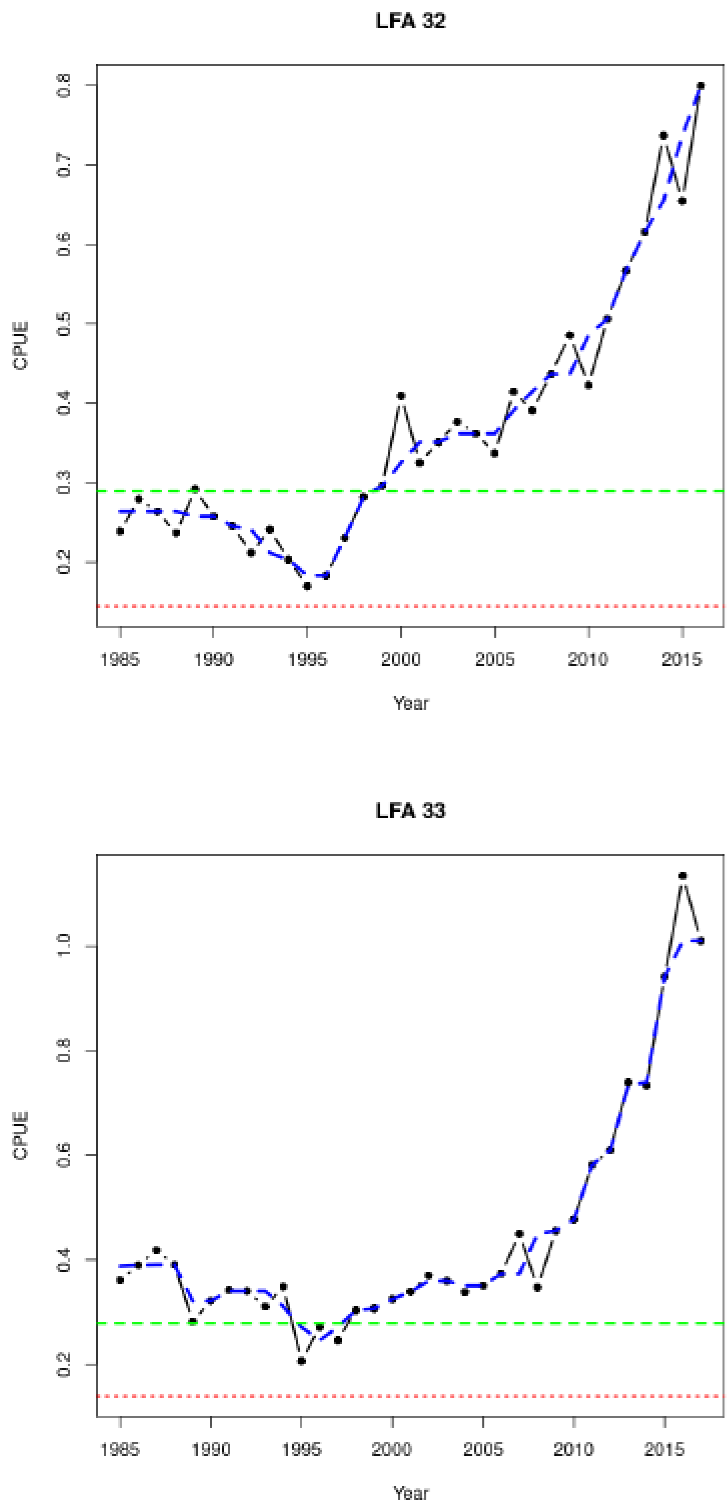


Figure 131: Time series of commercial catch rates (black), three year running median (blue) with proposed upper stock (dashed green line) and limit reference (dotted red line) points by LFA.

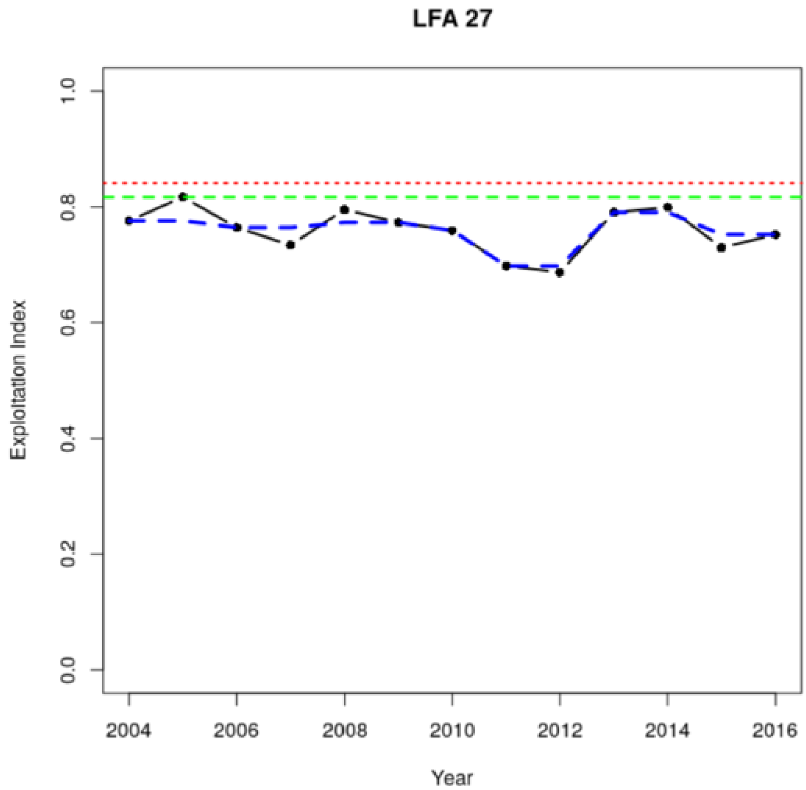


Figure 132: Time series of CCIR exploitation indices (black), three year running median (blue) with removal references (RRc = dashed green line; RR_{75} = dotted red line).

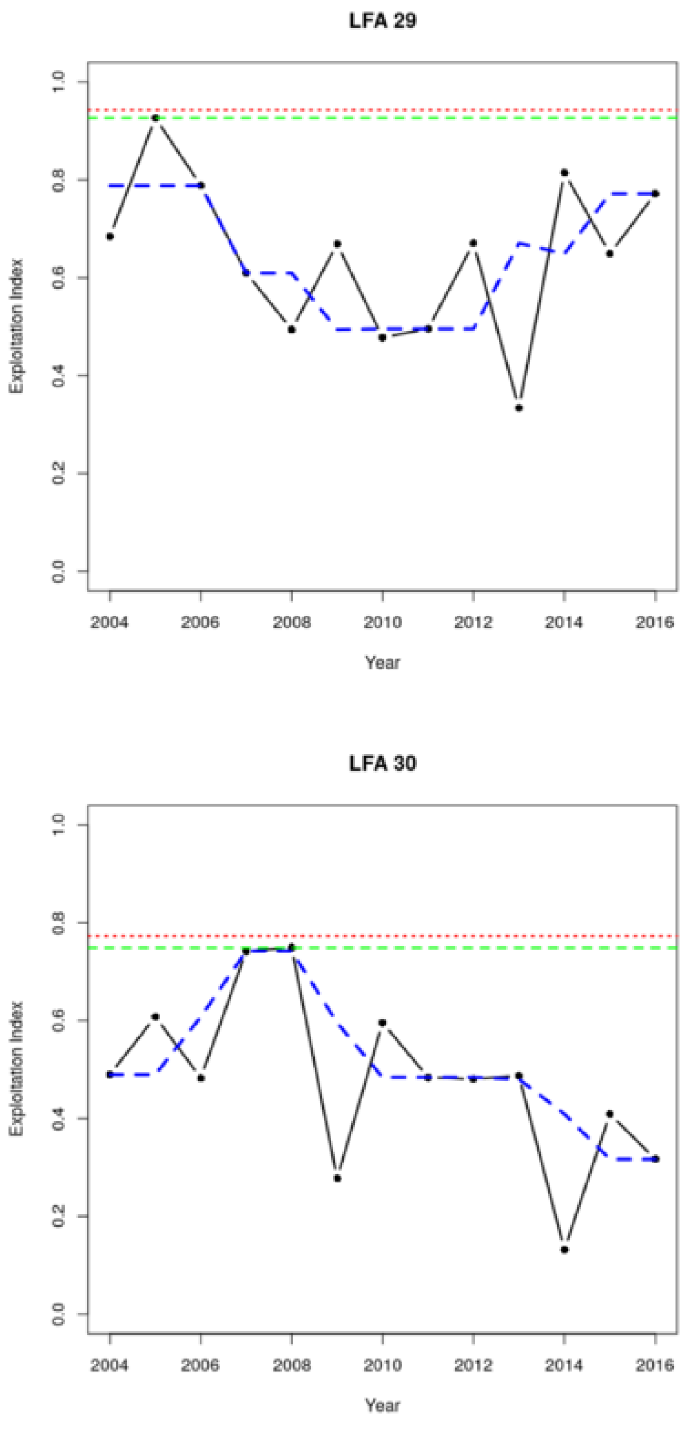
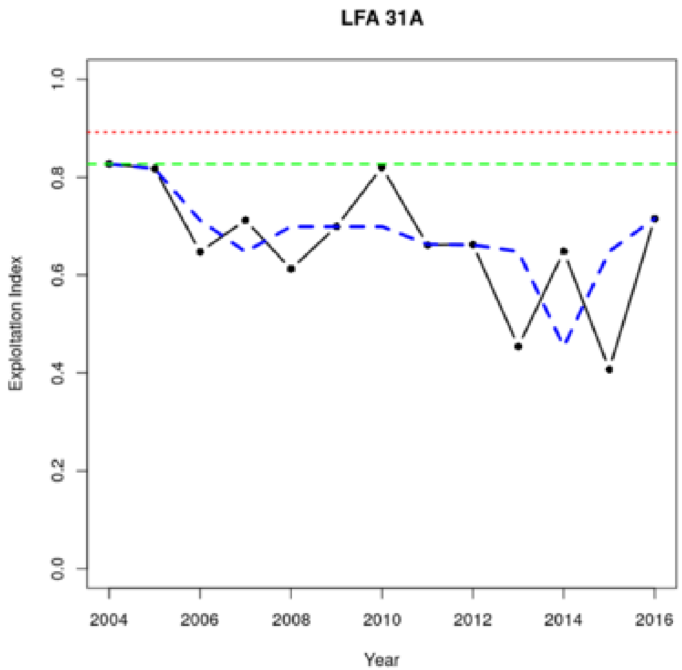


Figure 133: Time series of CCIR exploitation indices (black), three year running median (blue) with removal references (RRc = dashed green line; RR_{75} = dotted red line).



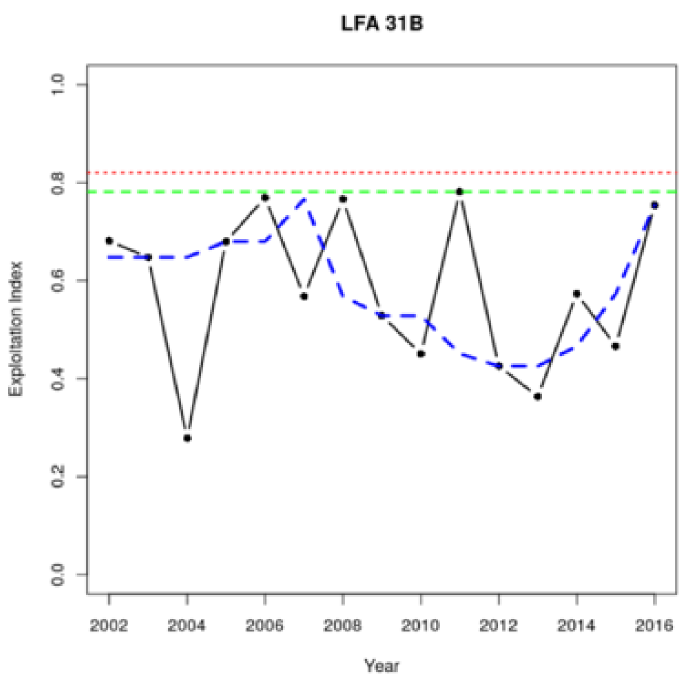
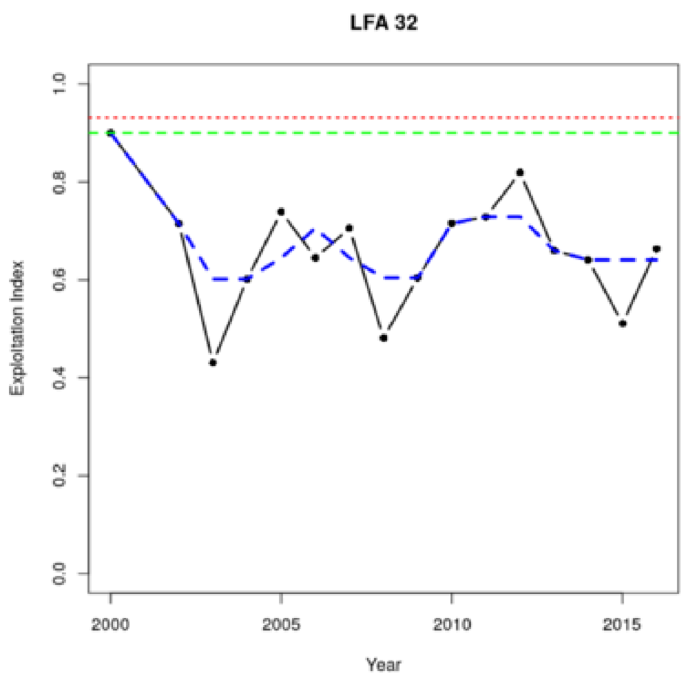


Figure 134: Time series of CCIR exploitation indices (black), three year running median (blue) with removal references (RRc = dashed green line; RR_{75} = dotted red line).



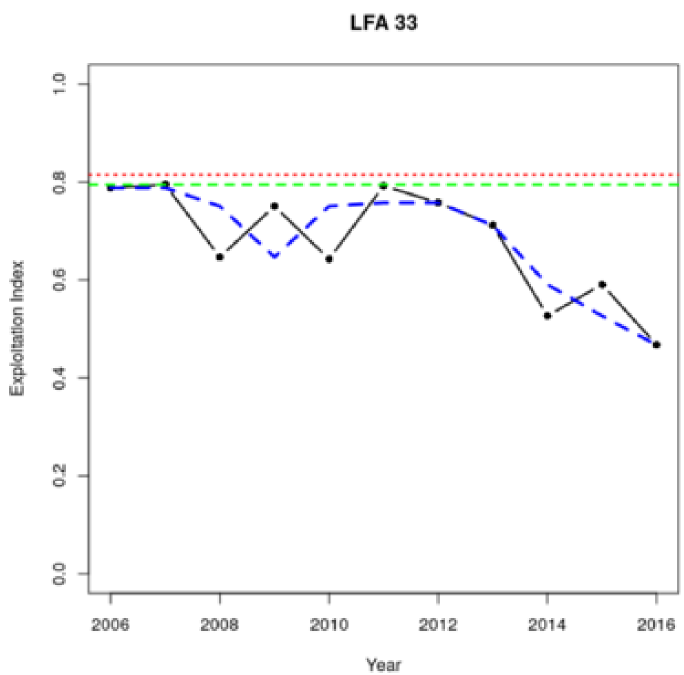


Figure 135: Time series of CCIR exploitation indices (black), three year running median (blue) with removal references (RRc = dashed green line; RR_{75} = dotted red line).

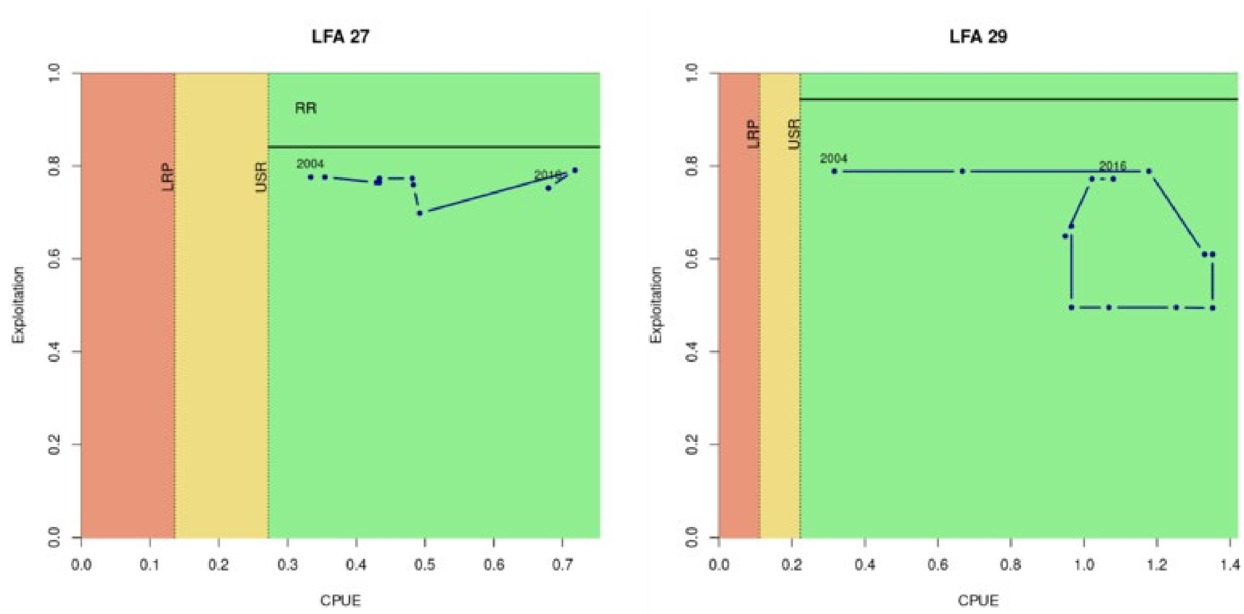


Figure 136: Phase plot using the three year running median of CPUE and three year running median of CCIR exploitation index compared against the proposed upper stock and limit reference points based on commercial catch rates. The removal reference proposed represented the 75th quantile break of the posterior distribution for the maximum exploitation index respectively.

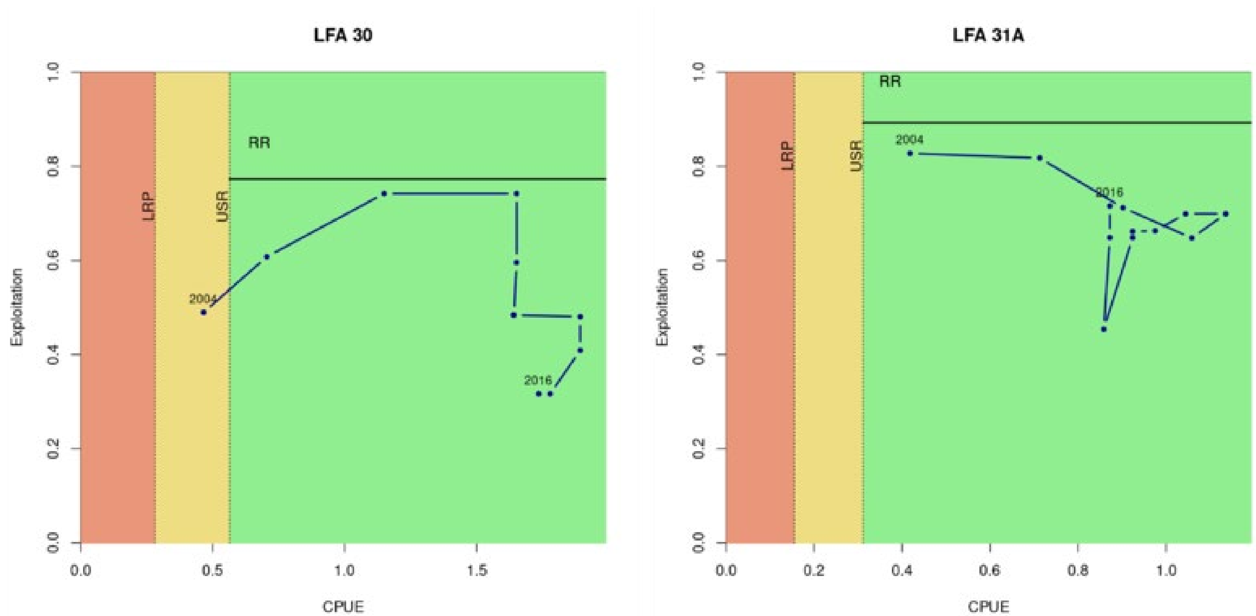


Figure 137: Phase plot using the three year running median of CPUE and three year running median of CCIR exploitation index compared against the proposed upper stock and limit reference points based on commercial catch rates. The removal reference proposed represented the 75th quantile break of the posterior distribution for the maximum exploitation index respectively.

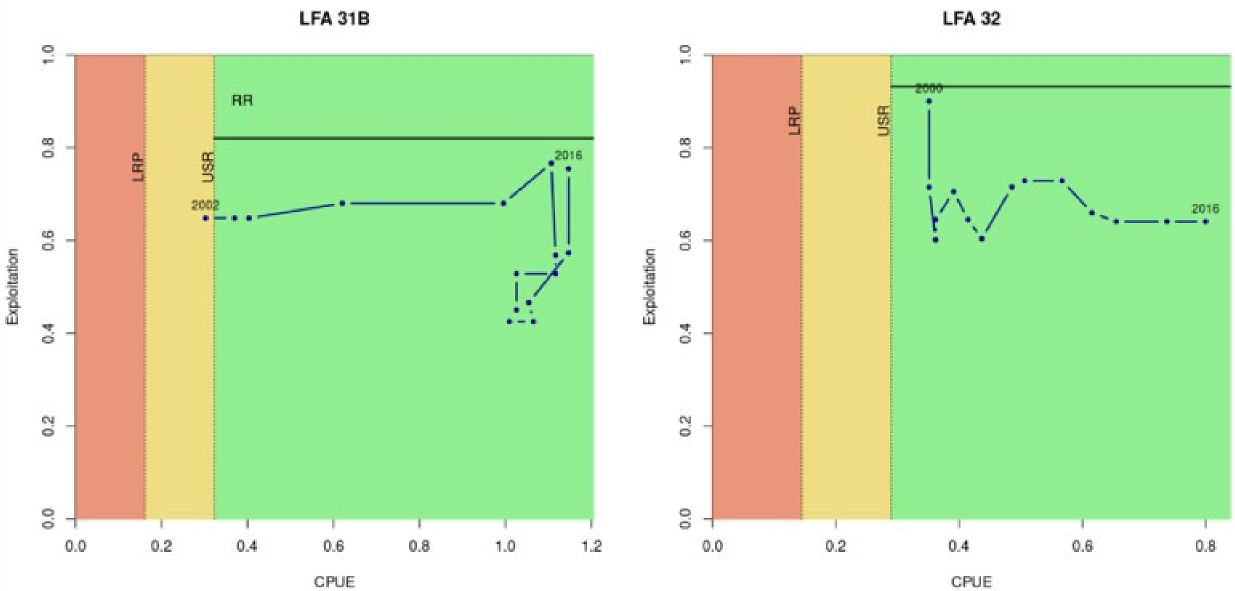


Figure 138: Phase plot using the three year running median of CPUE and three year running median of CCIR exploitation index compared against the proposed upper stock and limit reference points based on commercial catch rates. The removal reference proposed represented the 75th quantile break of the posterior distribution for the maximum exploitation index respectively.

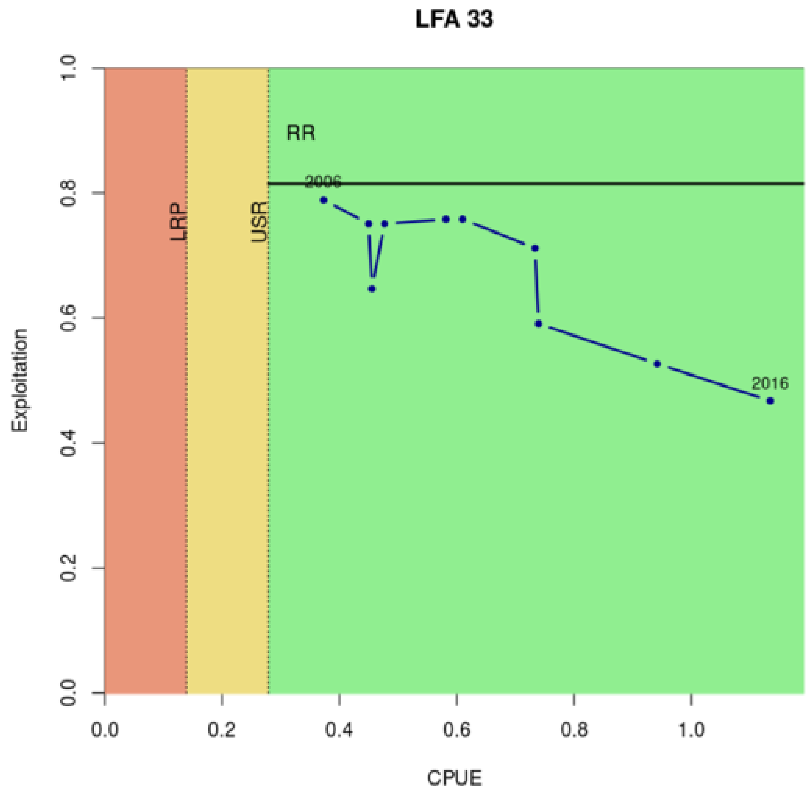


Figure 139: Phase plot using the three year running median of CPUE and three year running median of CCIR exploitation index compared against the proposed upper stock and limit reference points based on commercial catch rates. The removal reference proposed represented the 75th quantile break of the posterior distribution for the maximum exploitation index respectively.

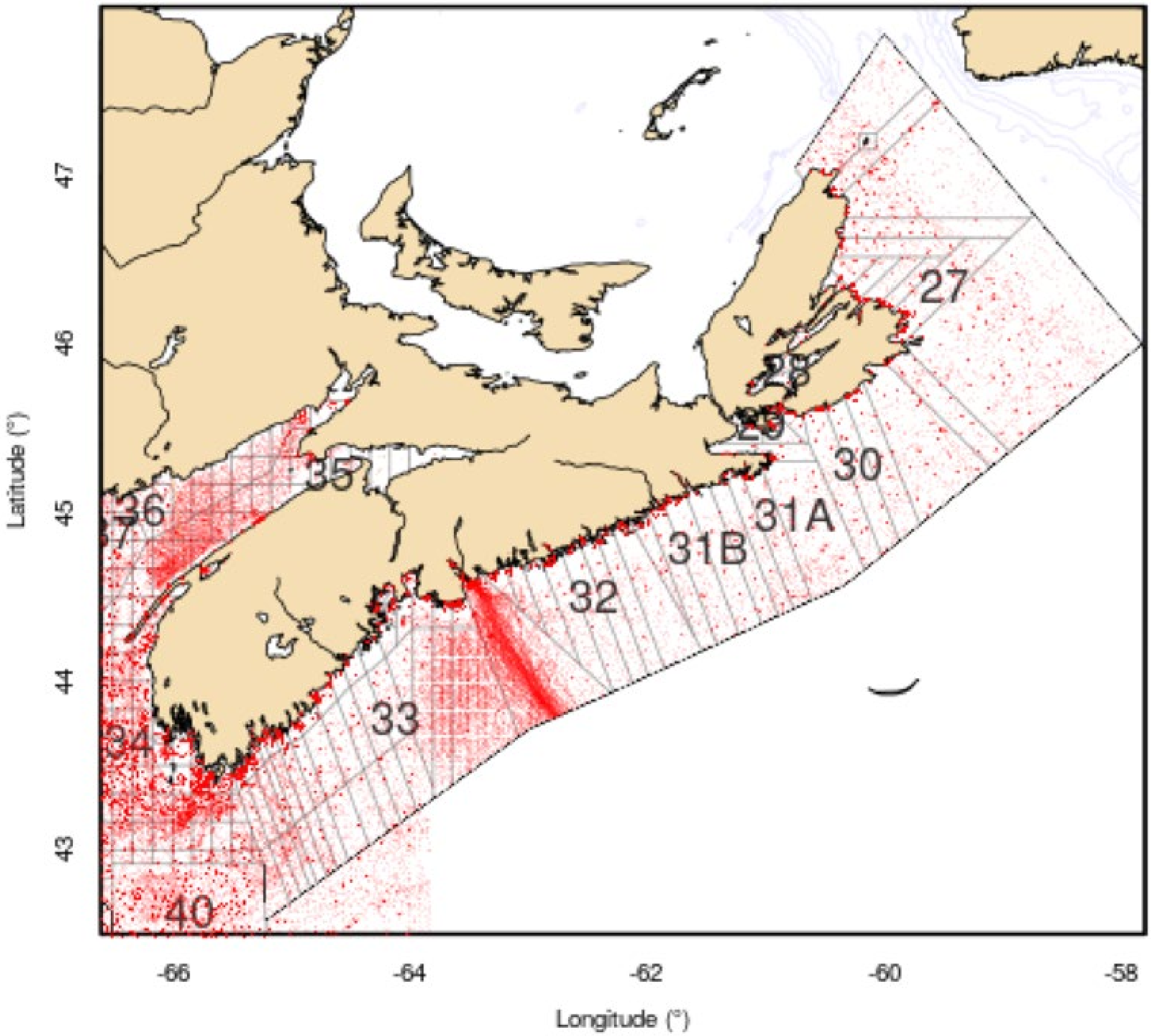


Figure 140: Locations of all temperature data used in the temperature model.

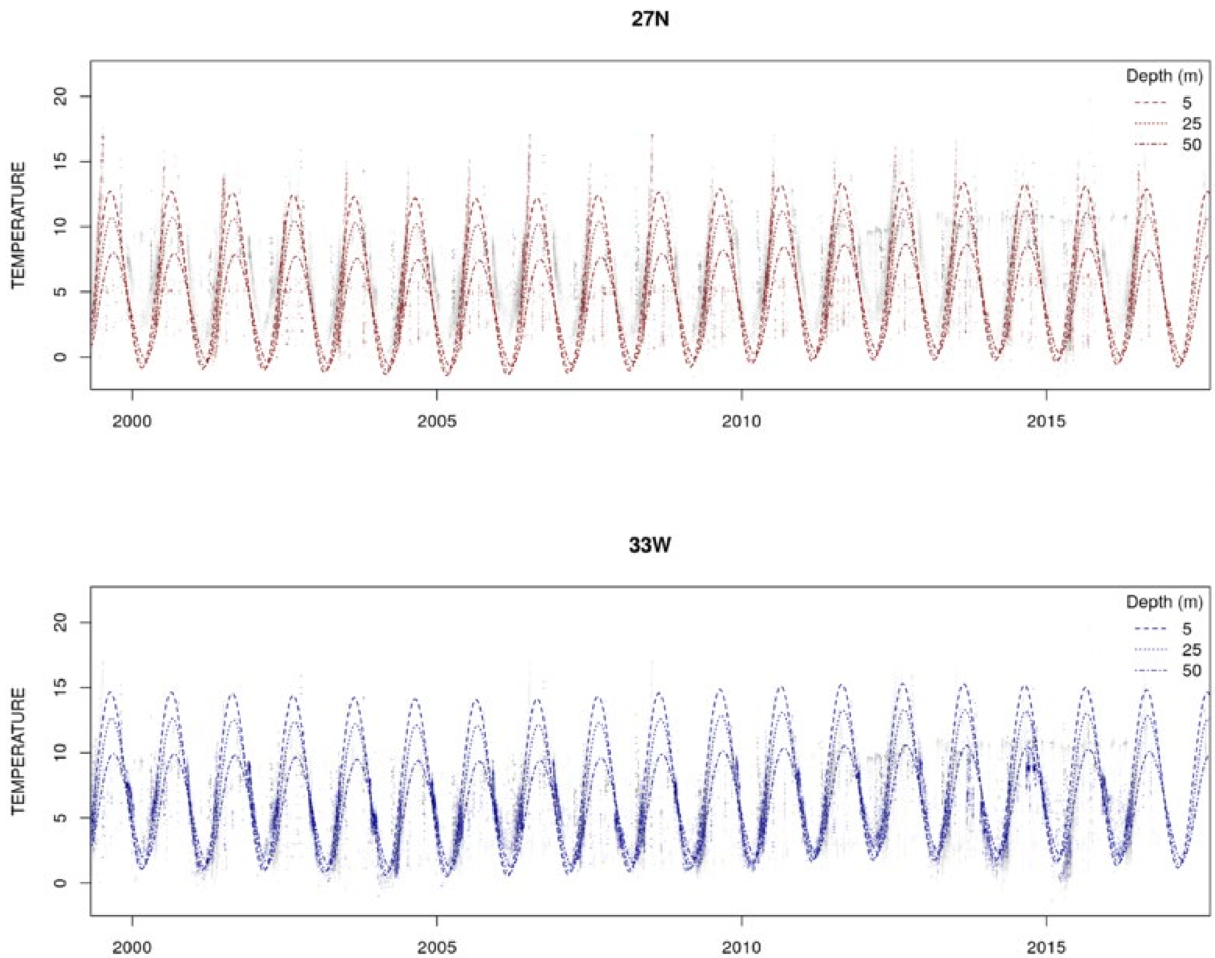


Figure 141: Time series of temperature data overlaid with predictions from the temperature model showing seasonal trends in LFA 27N (top, red) and LFA 33W (bottom, blue) at various depths.

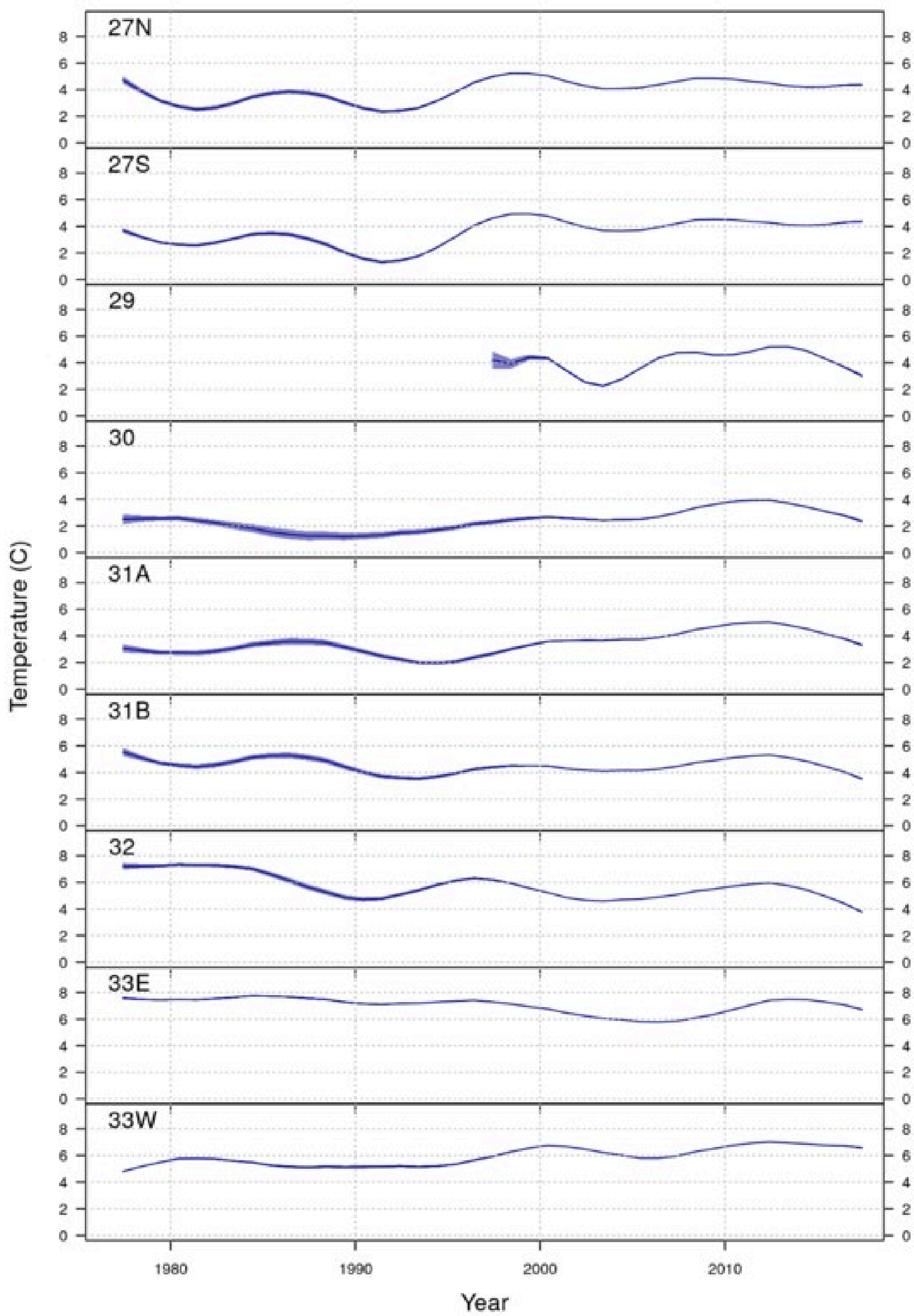


Figure 142: Predictions from the temperature model for June 1st at 25 m to show the annual trends in each LFA. Light blue band represents the standard error of the prediction.

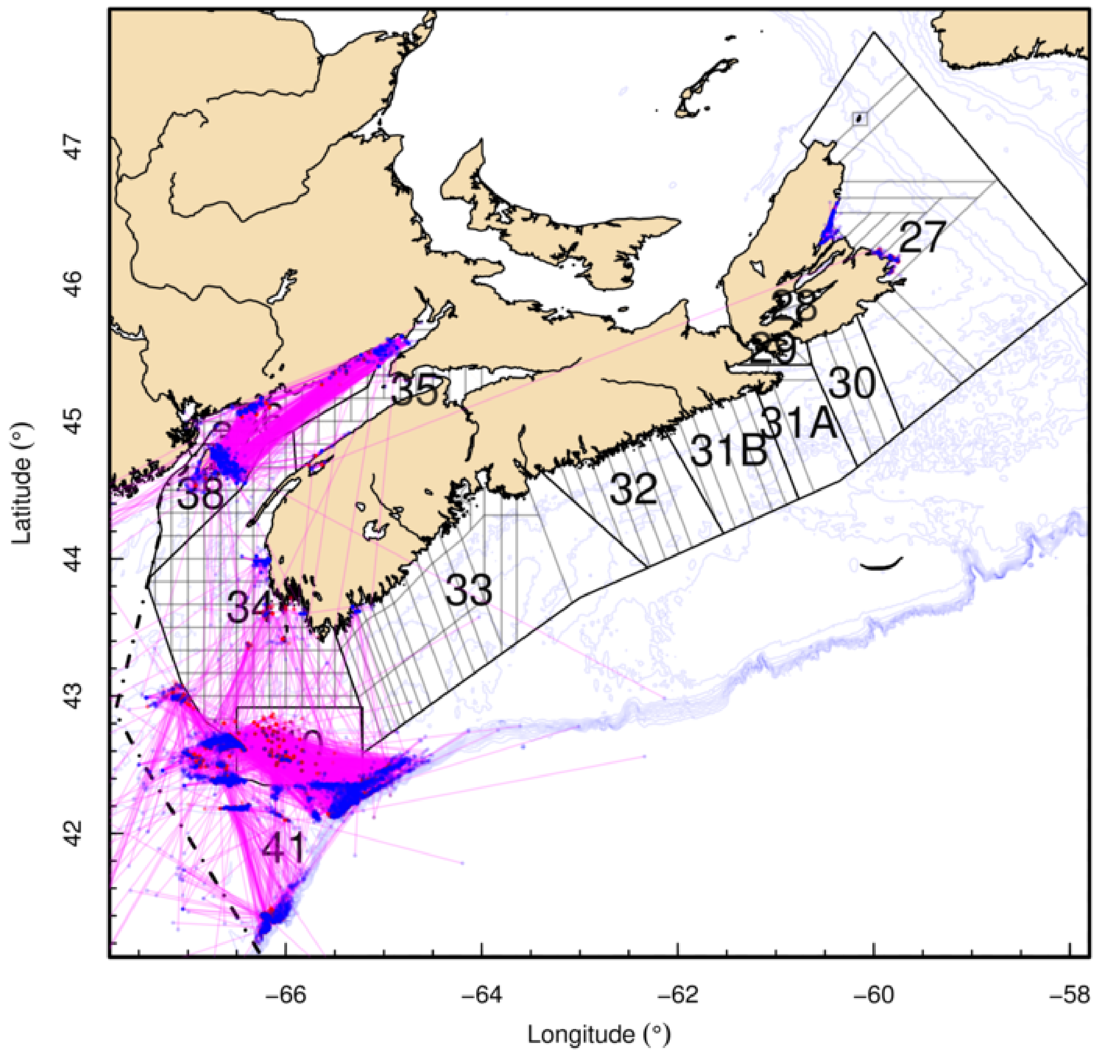


Figure 143: Locations of tagging mark-recapture data used for estimating moult probability and increment. Releases (red dots) are connected to their recaptures (blue dots) with a purple line.

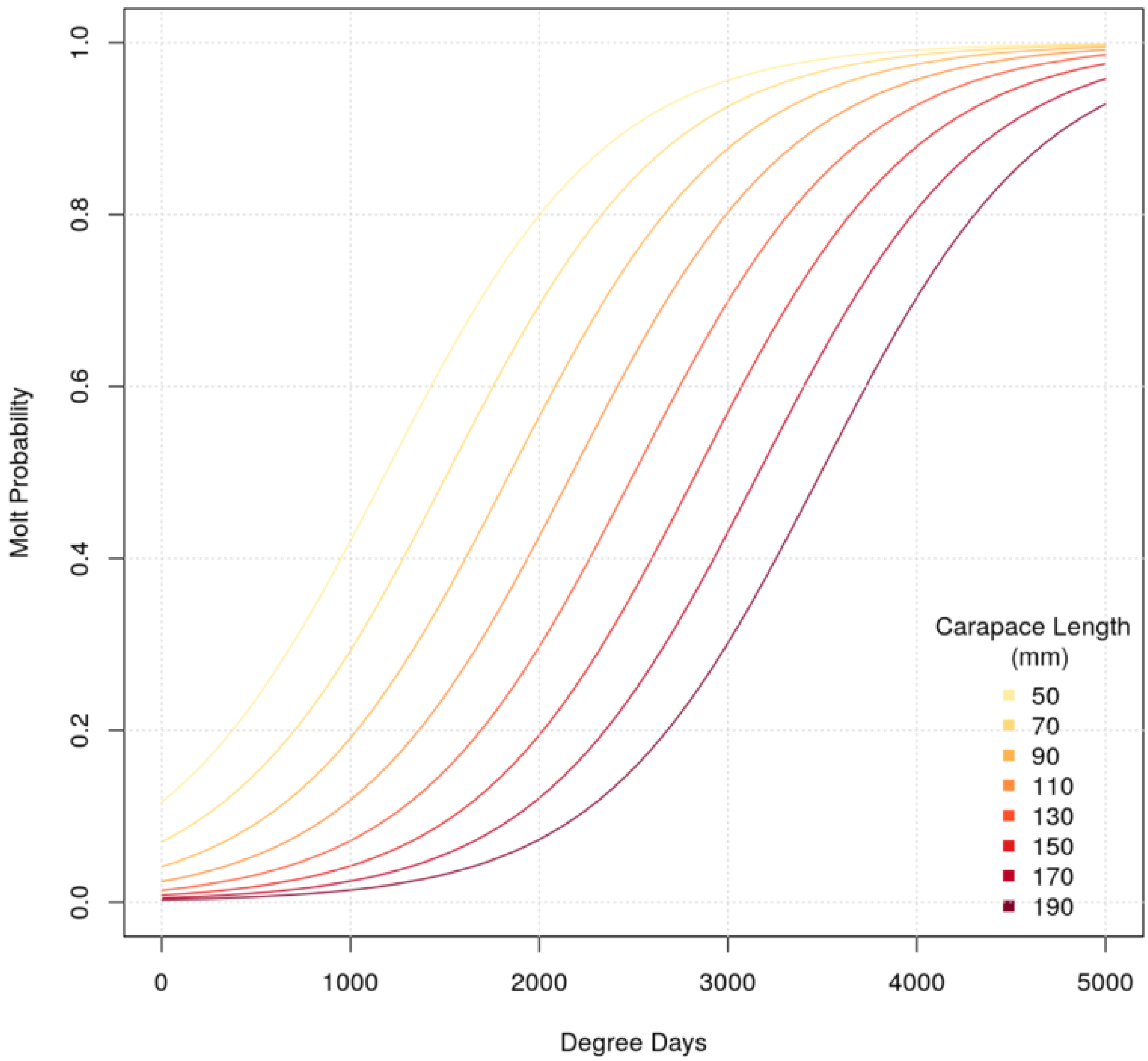


Figure 144: Predicted moult probabilities by number of degree days above 0_C since last moult or various initial carapace lengths from the moult probability model.

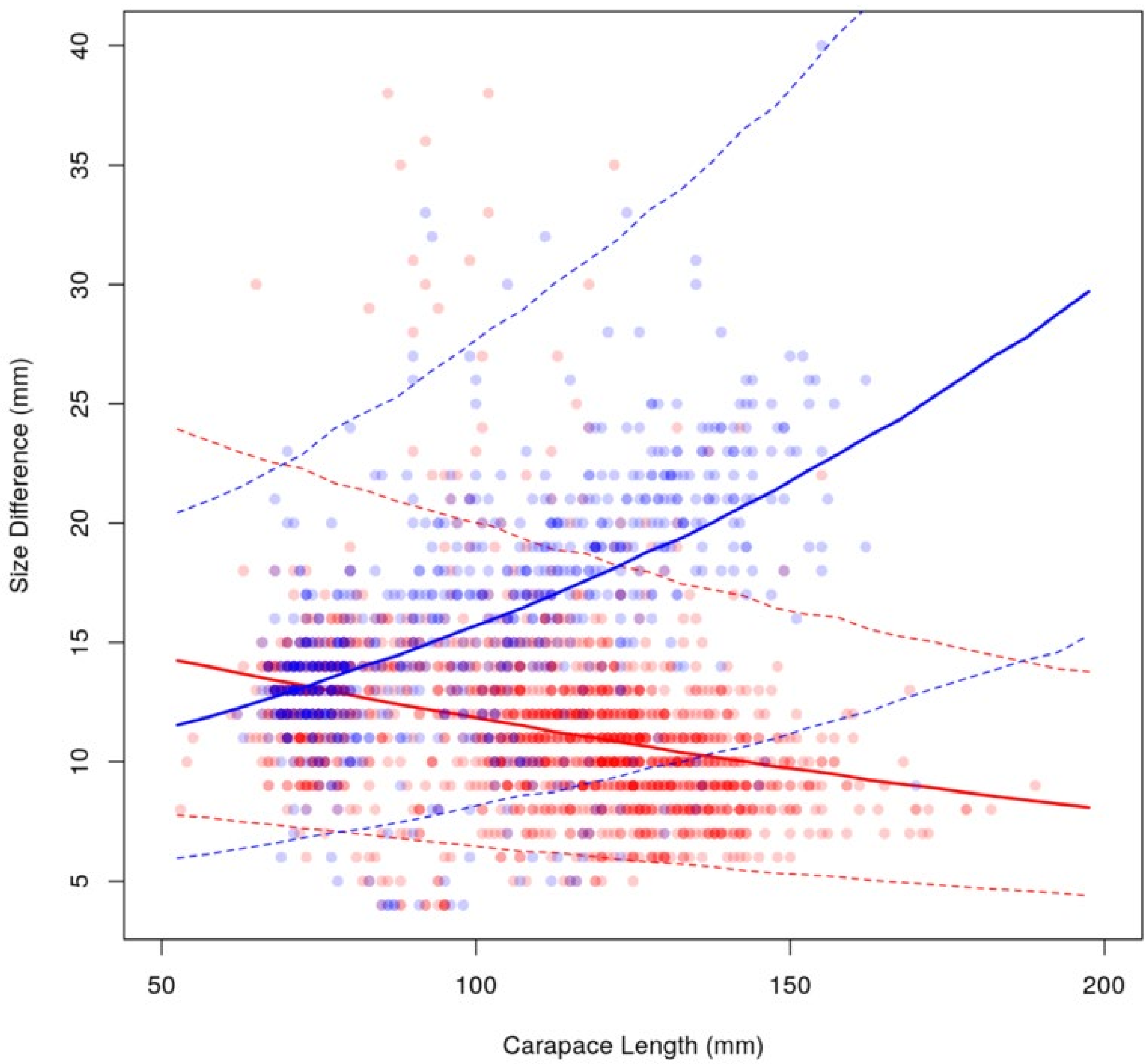


Figure 145: Moult increment as the size difference versus initial carapace length for males (blue) and females (red) from tagging data. Lines represent the fits and 95% credible interval of the moult increment model for each sex.

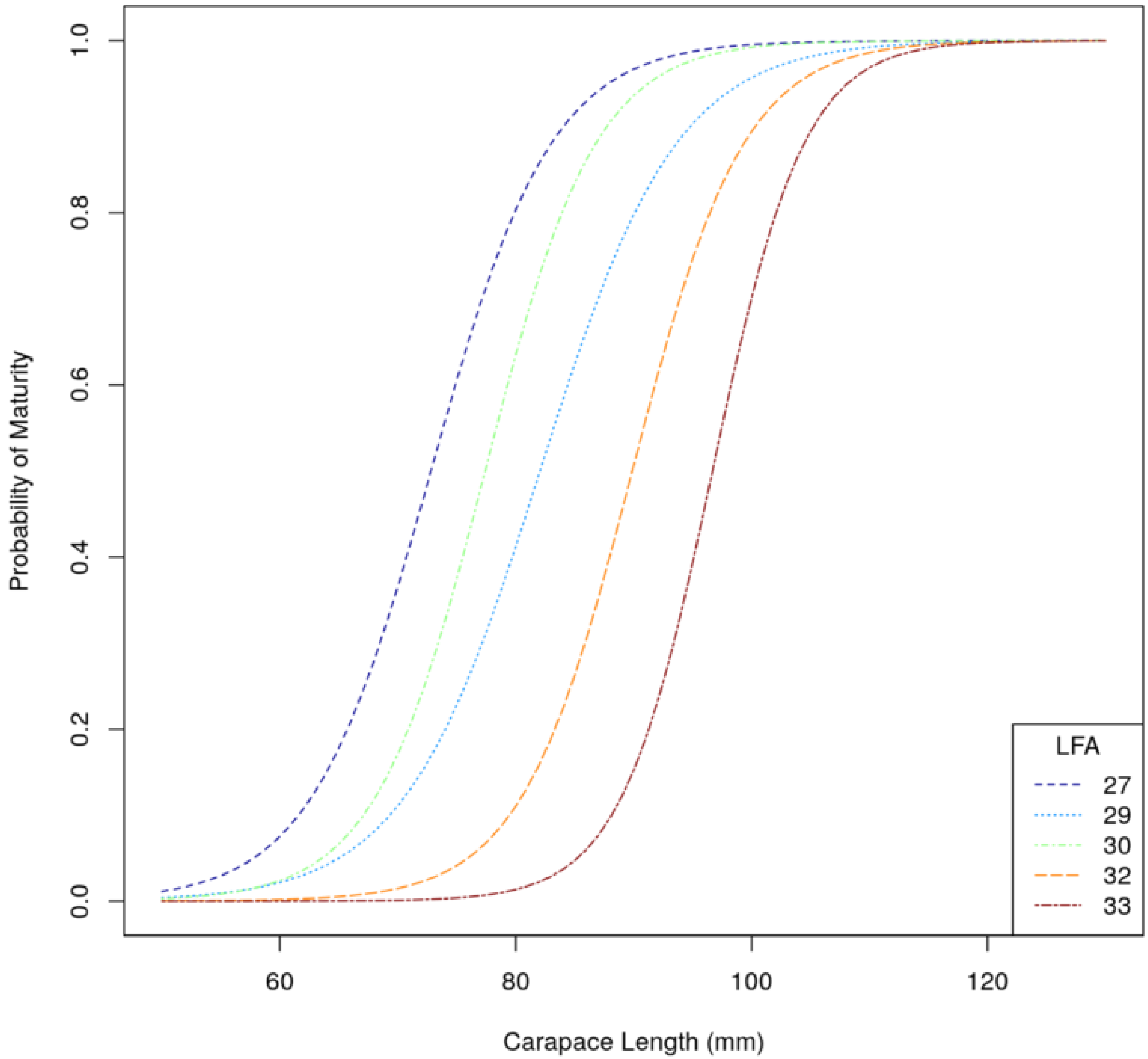


Figure 146: Size at maturity ogives applied for selected LFAs.

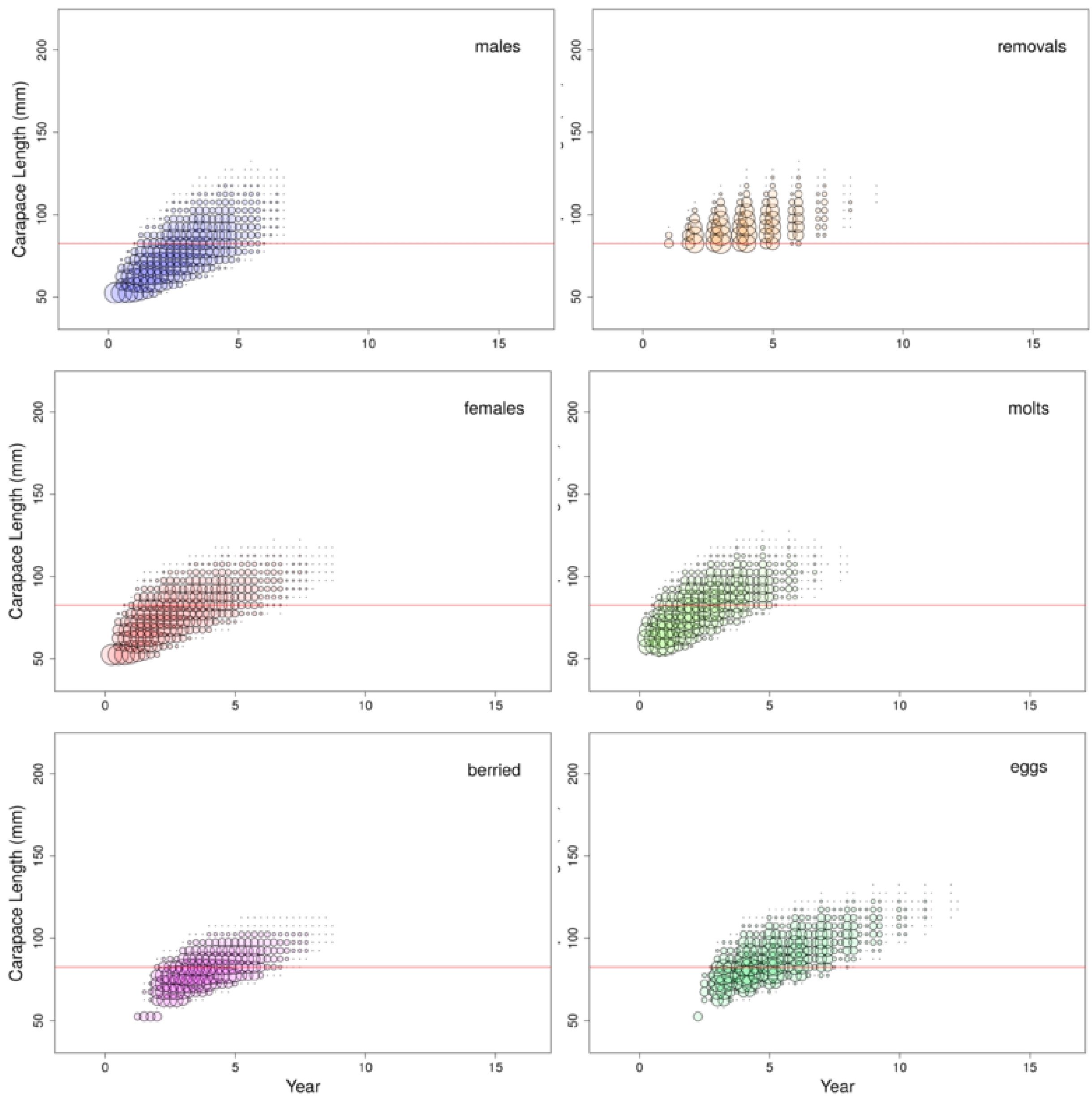


Figure 147: Bubble plots showing the simulated population under the current management regime for LFA 27N. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

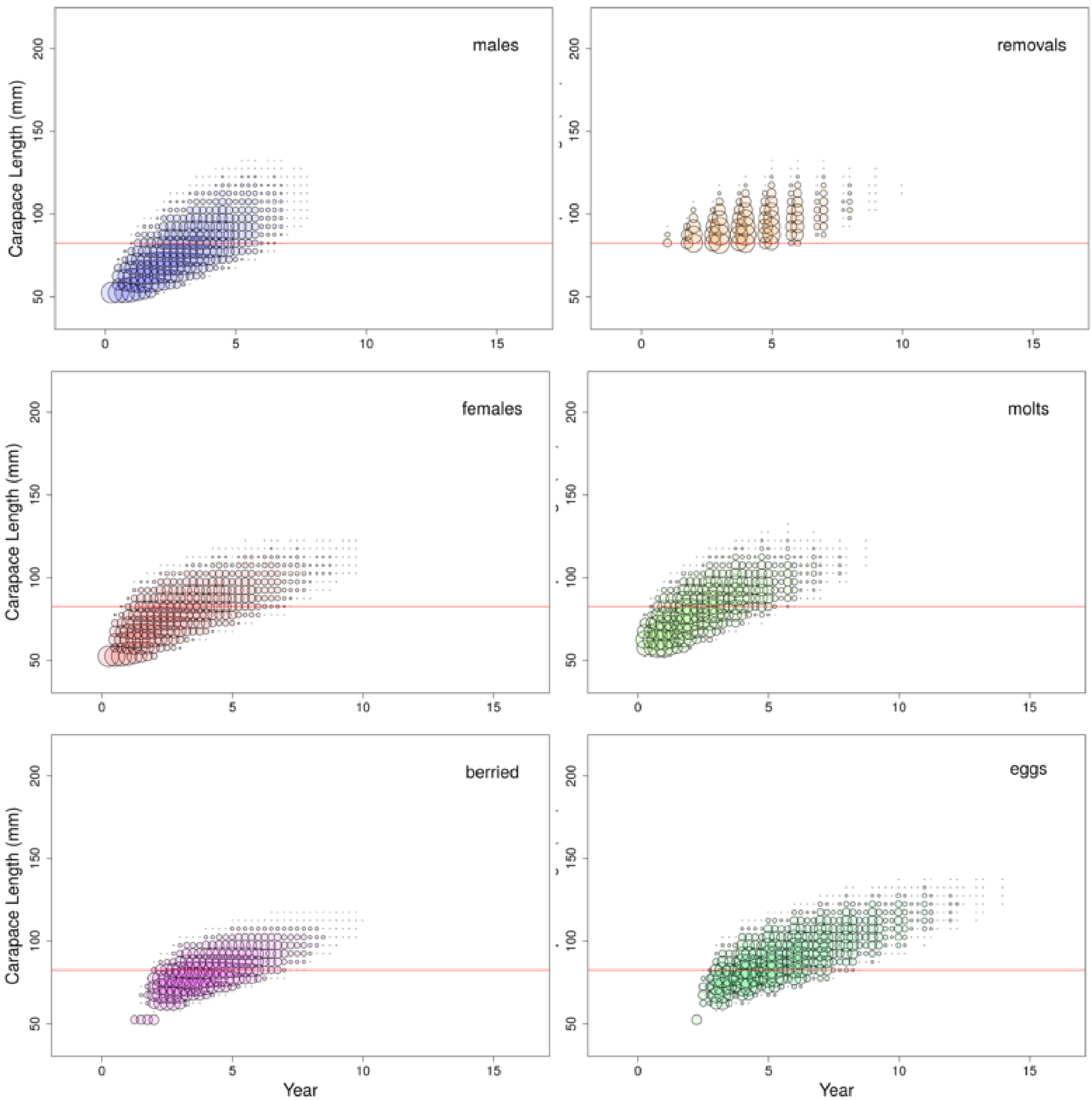


Figure 148: Bubble plot showing the simulated population under the current management regime for LFA 27S. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

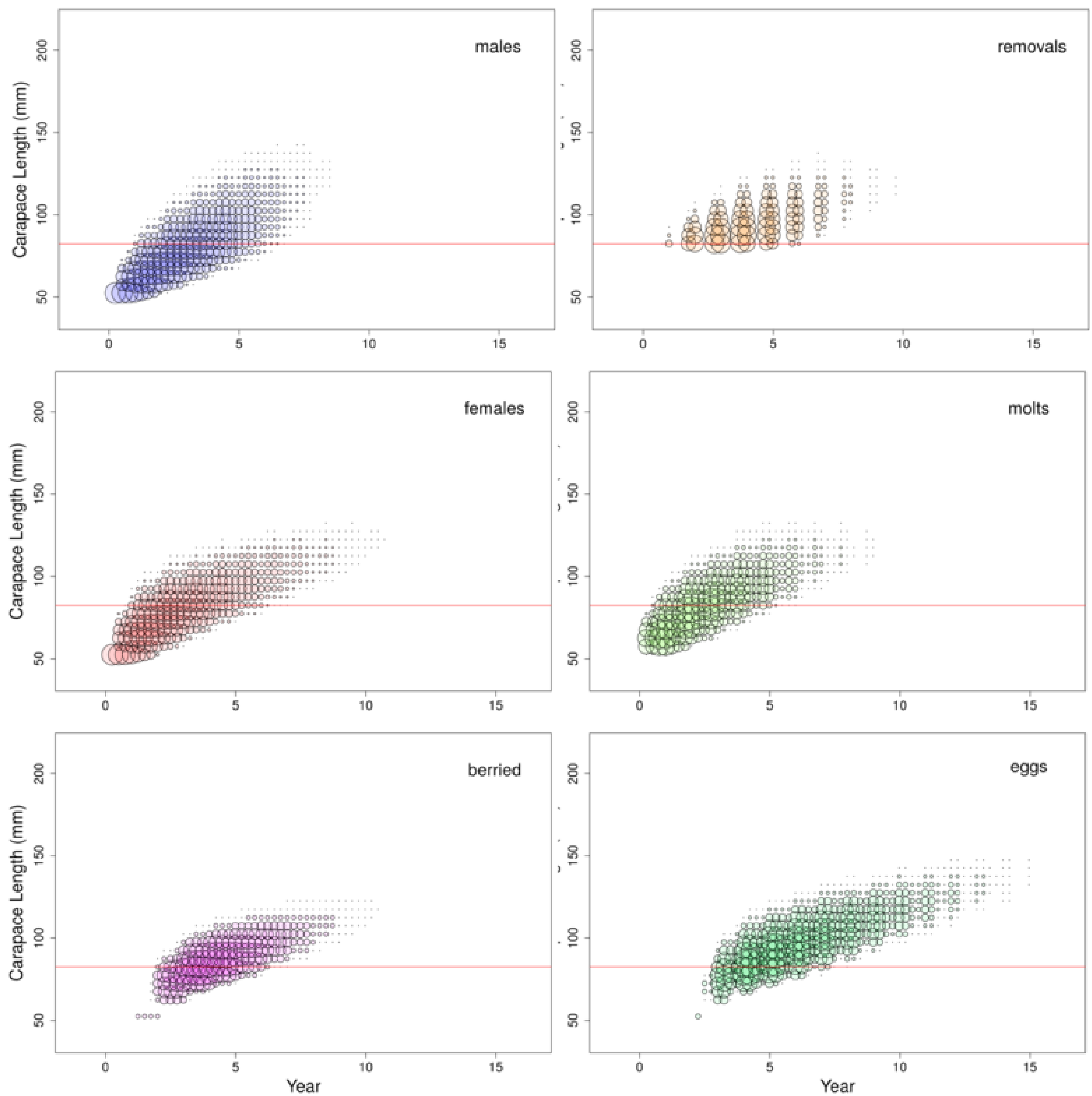


Figure 149: Bubble plot showing the simulated population under the current management regime for LFA 29. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

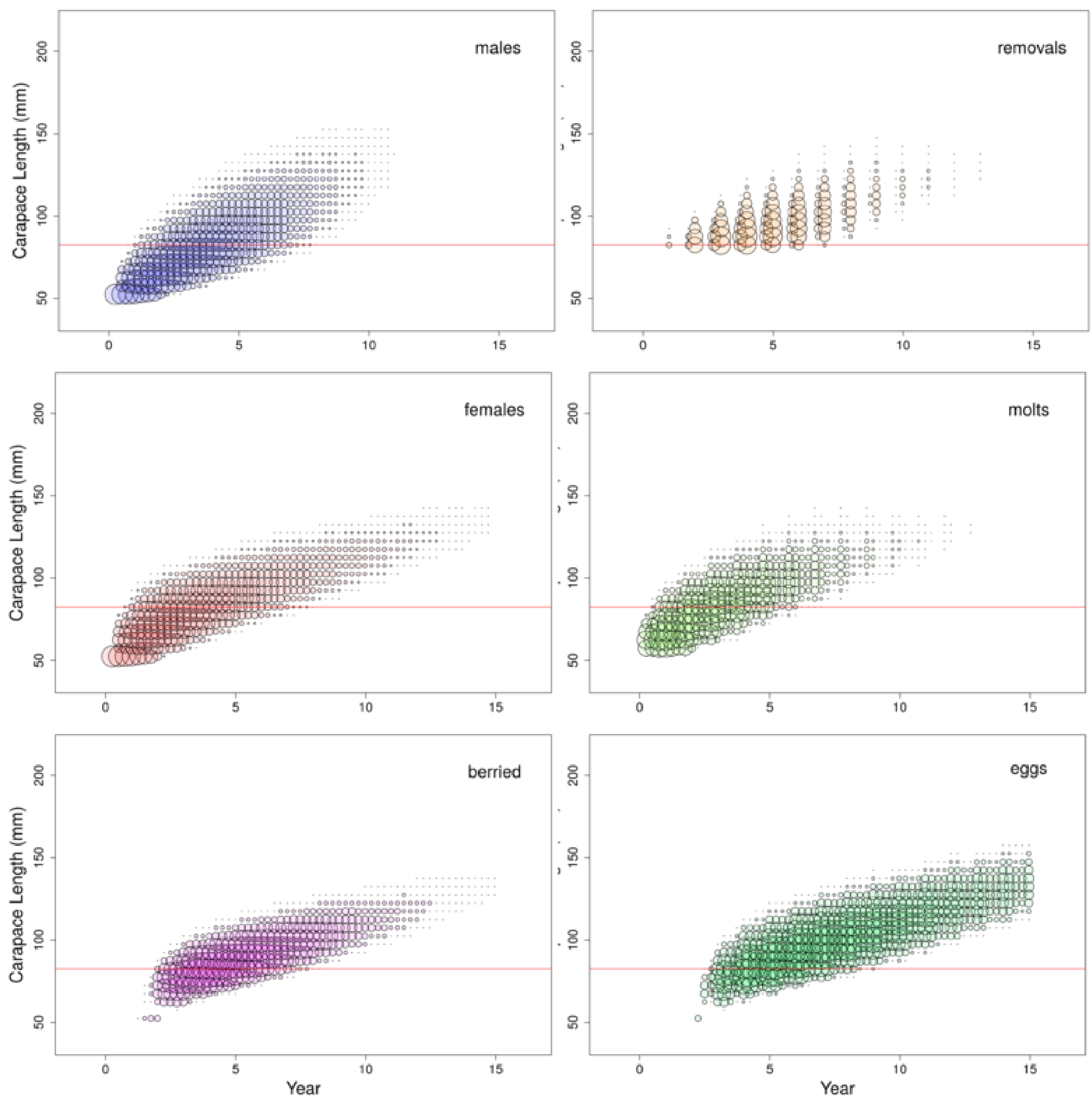


Figure 150: Bubble plot showing the simulated population under the current management regime for LFA 30. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

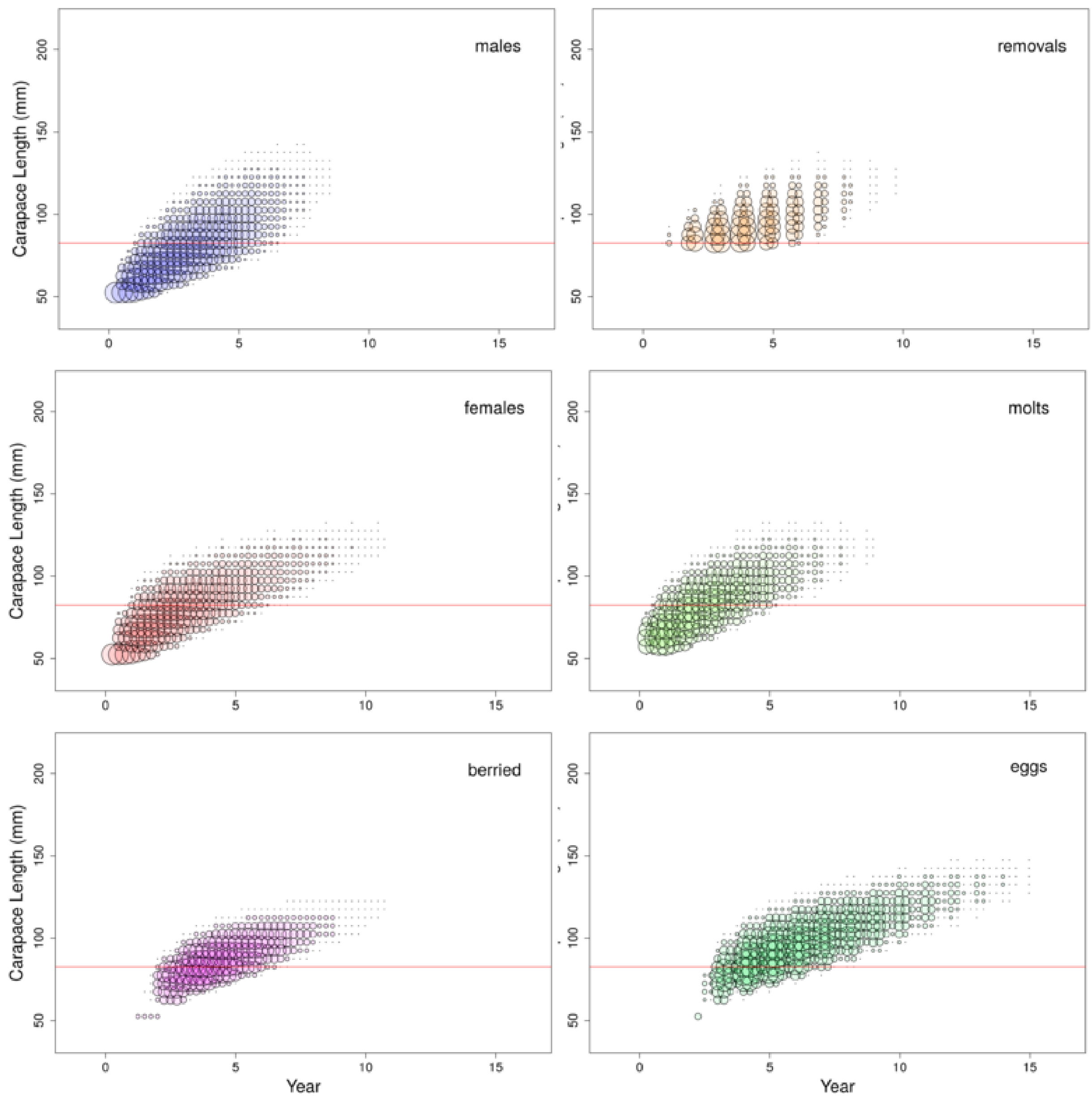


Figure 151: Bubble plot showing the simulated population under the current management regime for LFA 31A. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

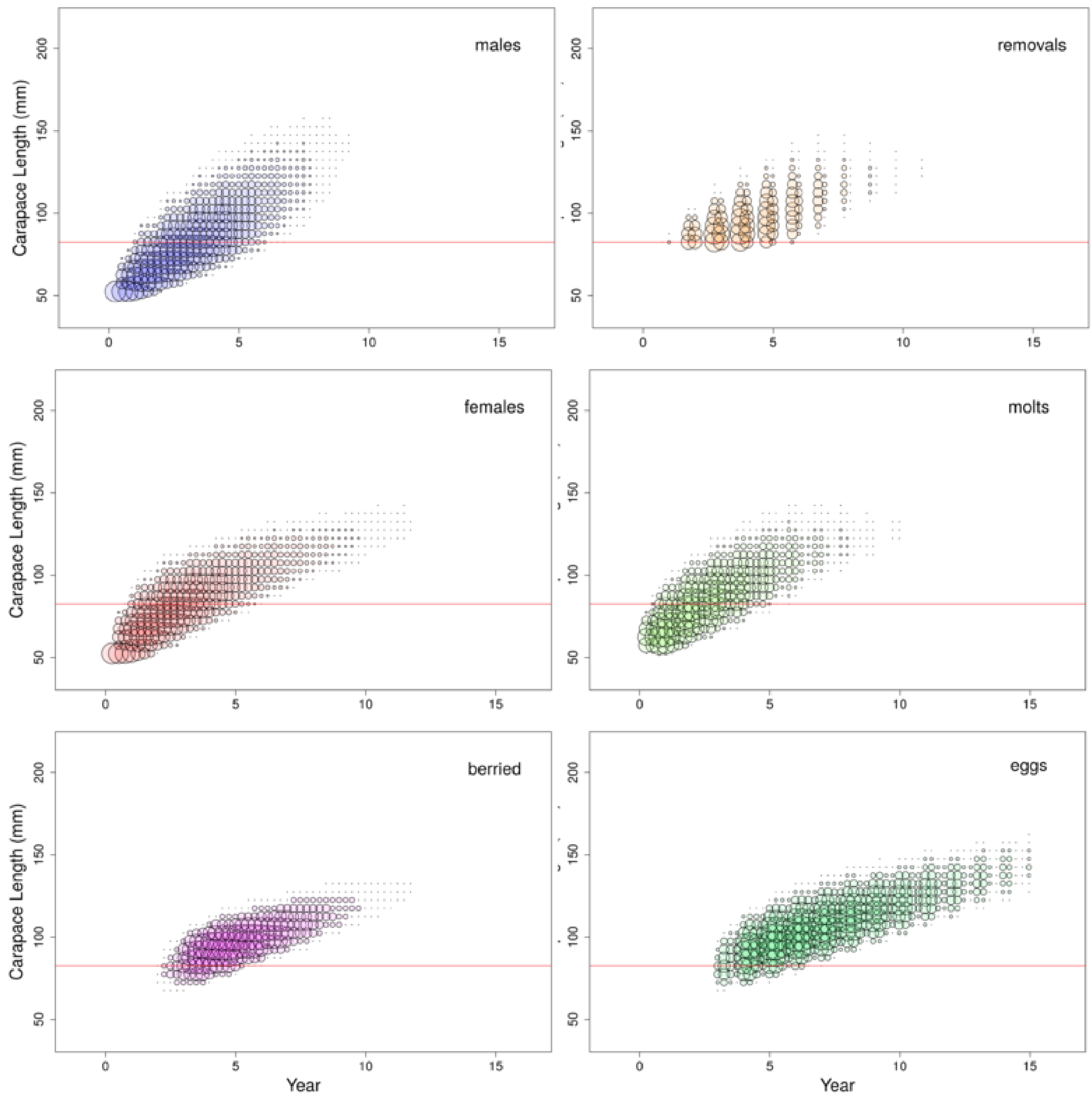


Figure 152: Bubble plot showing the simulated population under the current management regime for LFA 31B. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

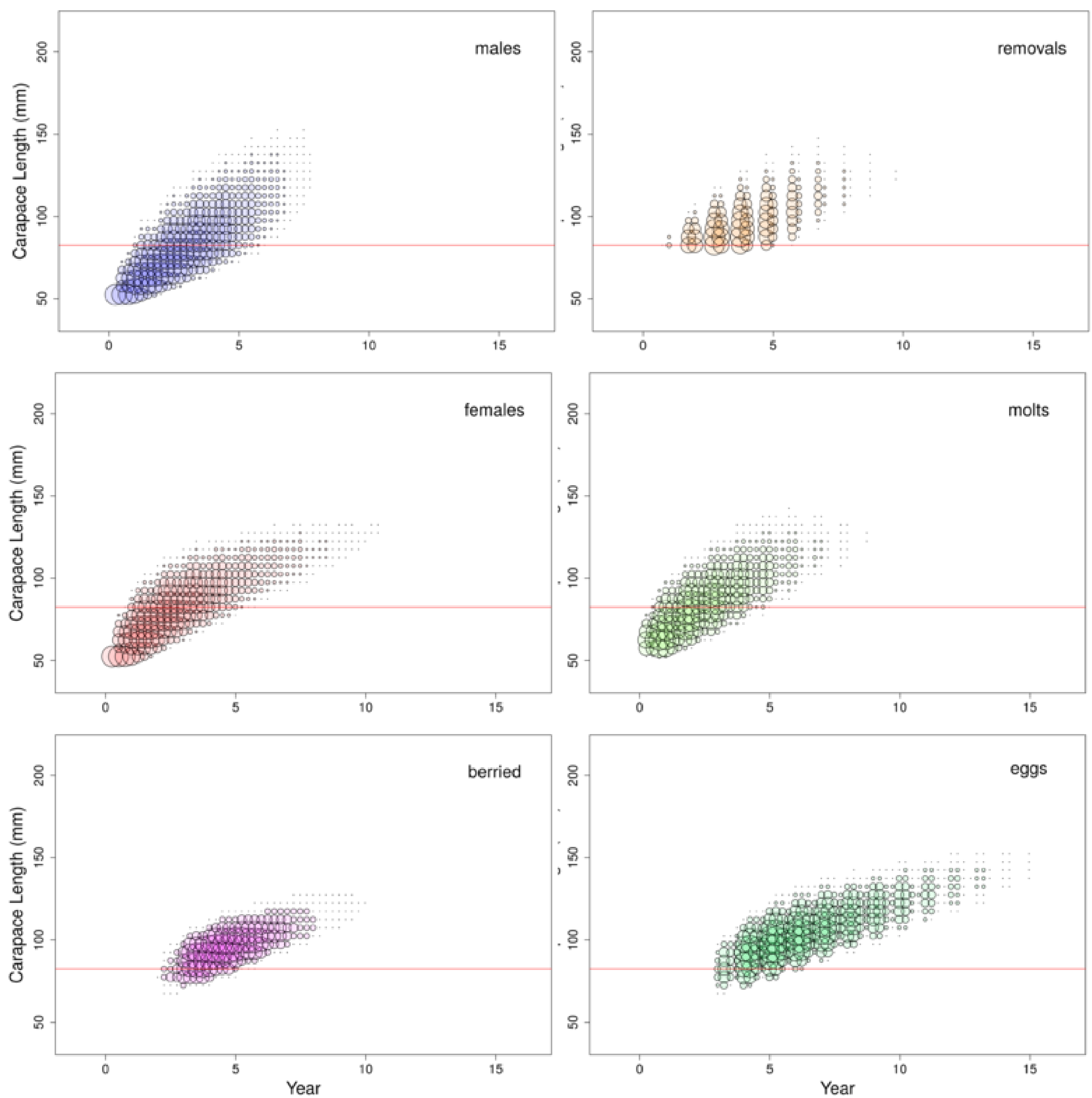


Figure 153: Bubble plot showing the simulated population under the current management regime for LFA 32. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

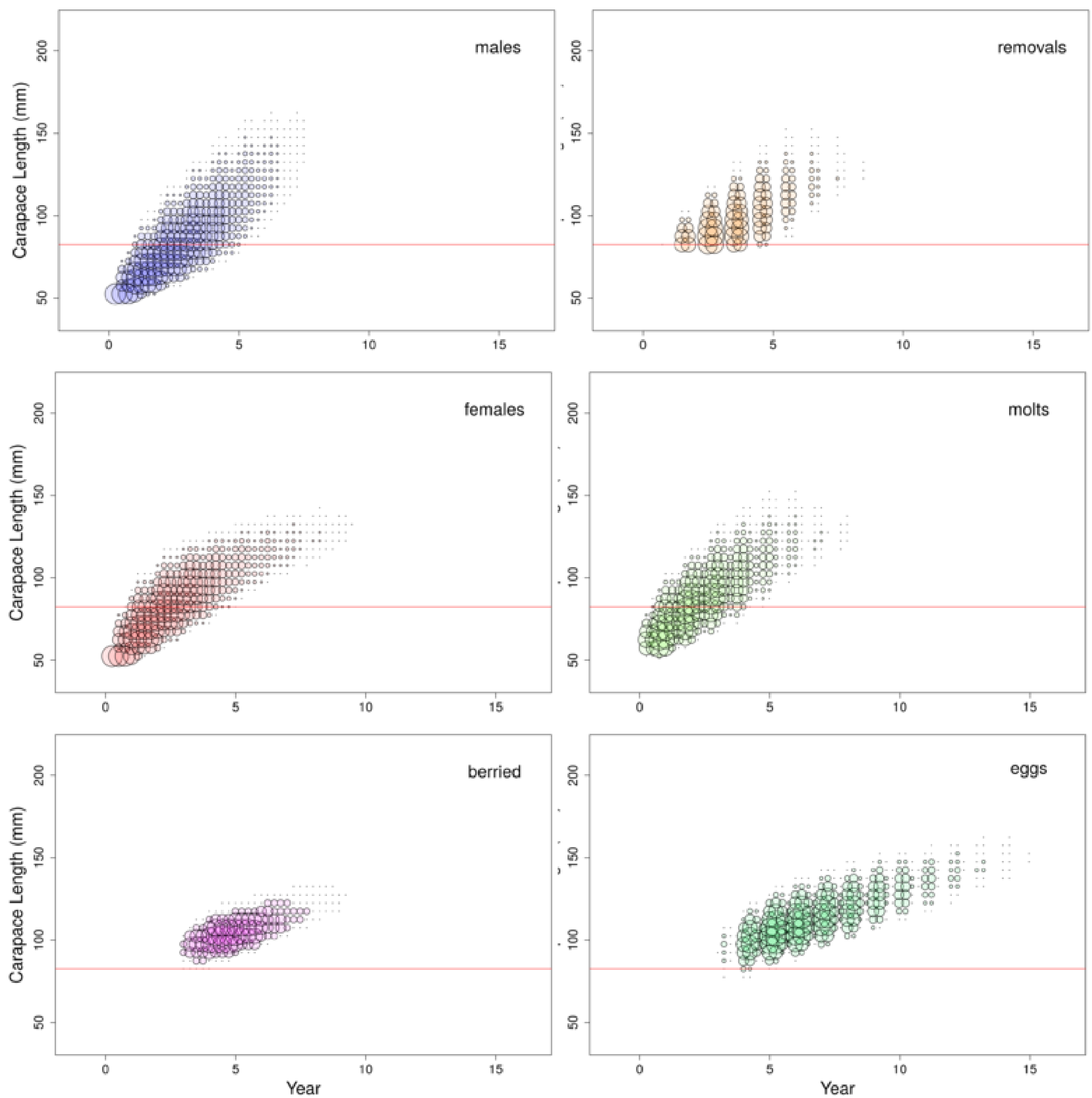


Figure 154: Bubble plot showing the simulated population under the current management regime for LFA 33E. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

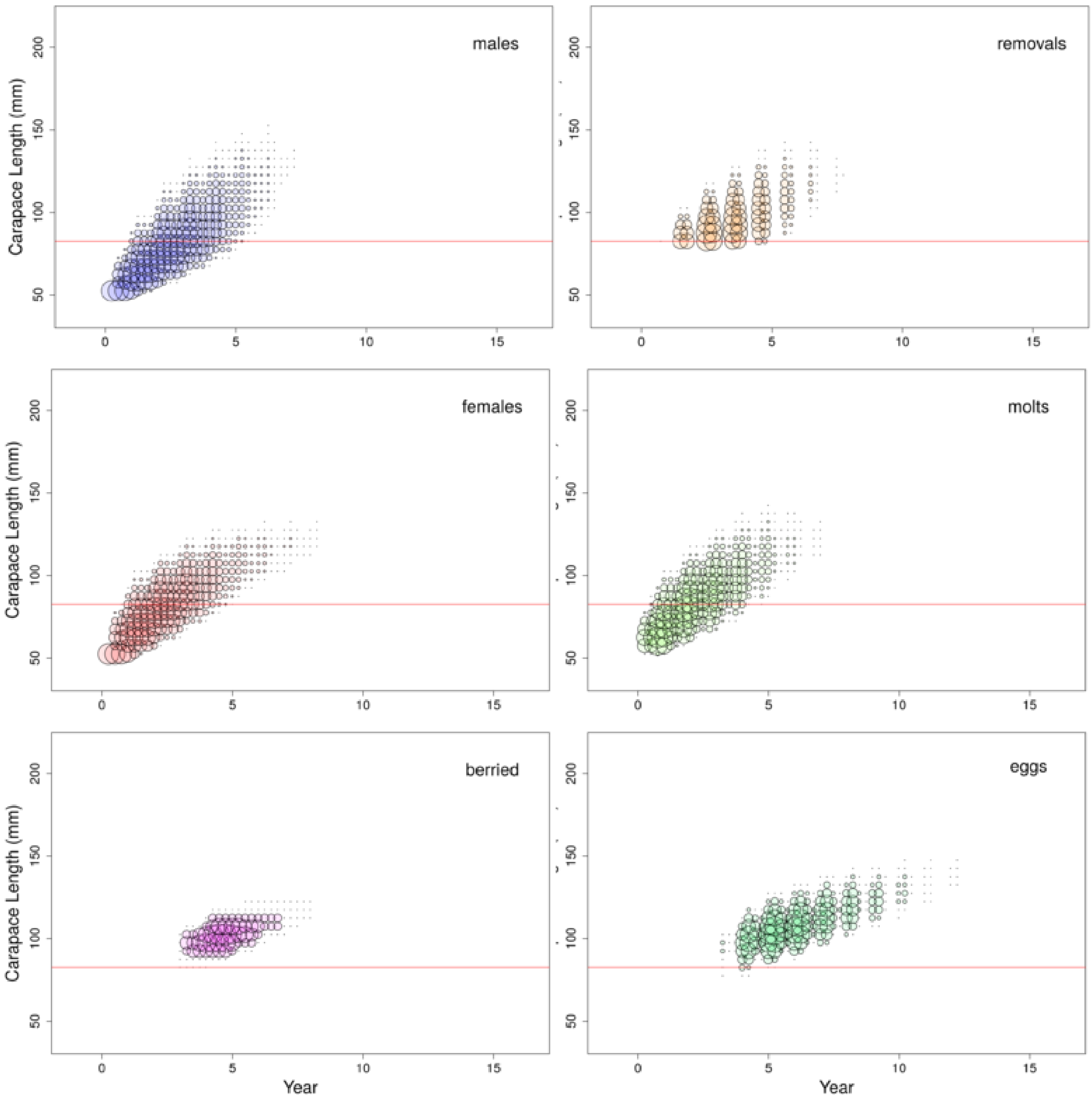


Figure 155: Bubble plot showing the simulated population under the current management regime for LFA 33W. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

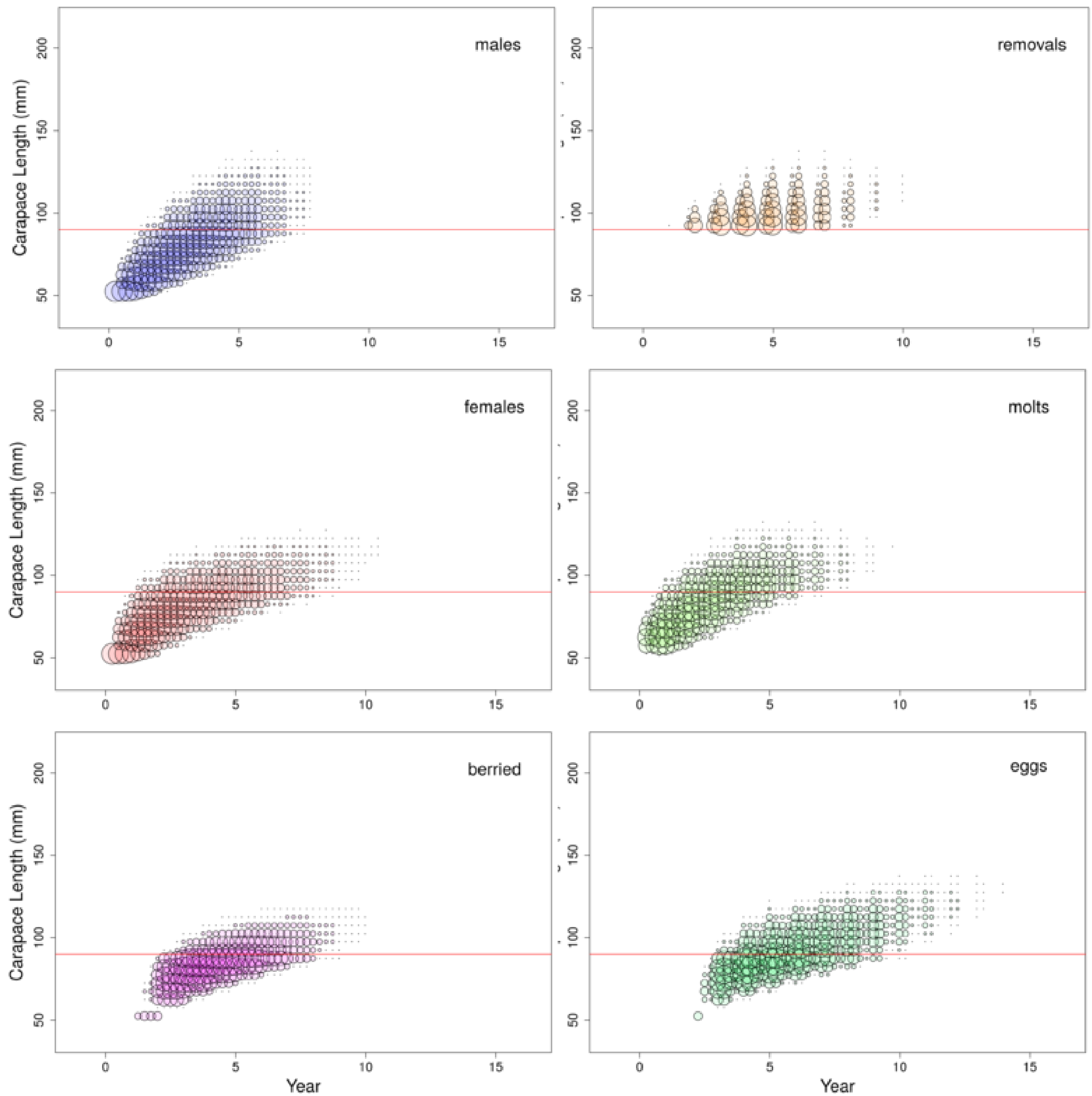


Figure 156: Bubble plots showing the simulated population where MLS was increased to 90mm for LFA 27N. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

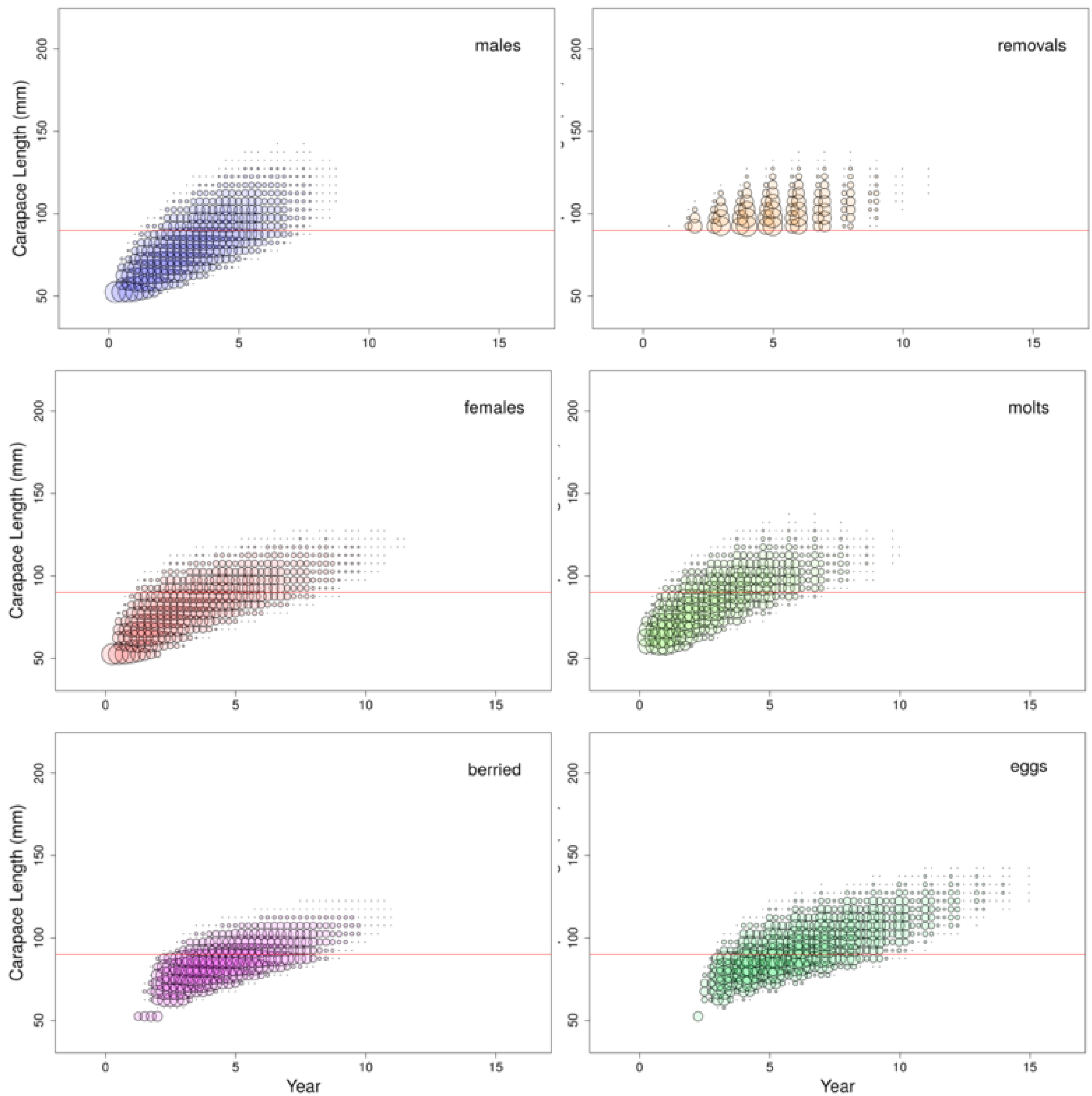


Figure 157: Bubble plot showing the simulated population where MLS was increased to 90mm for LFA 27S. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

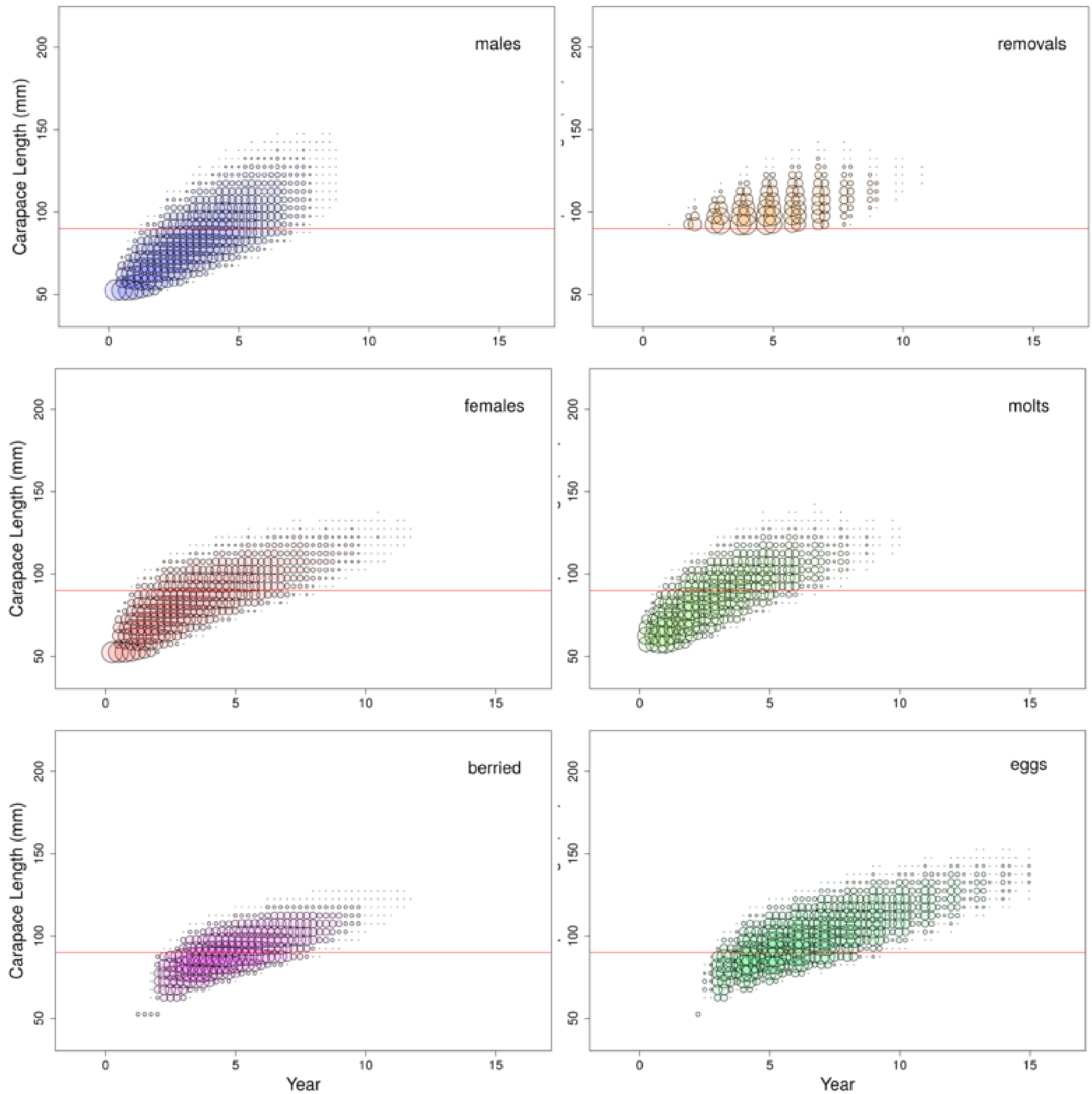


Figure 158: Bubble plot showing the simulated population where MLS was increased to 90mm for LFA 29. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

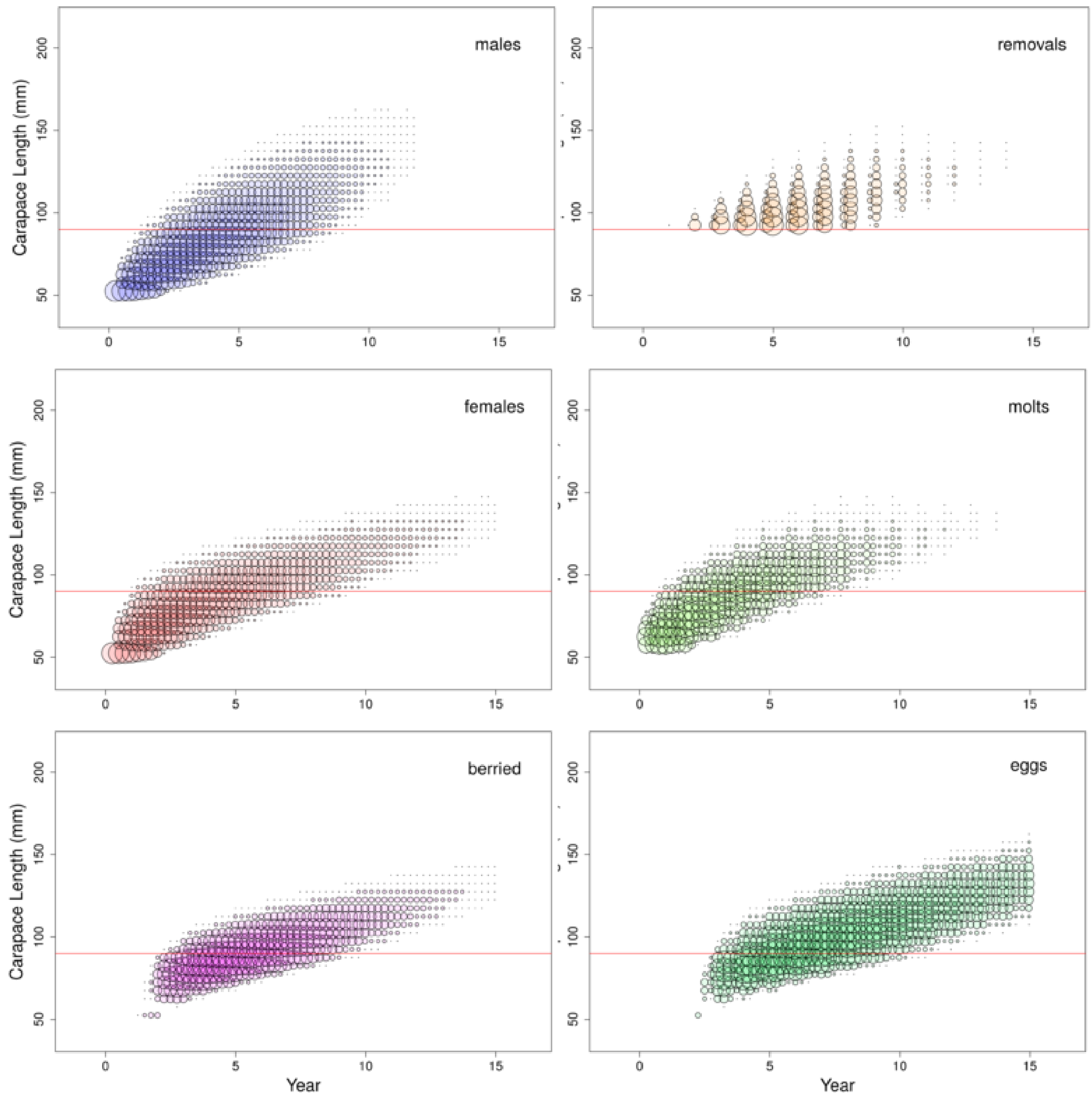


Figure 159: Bubble plot showing the simulated population where MLS was increased to 90mm for LFA 30. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

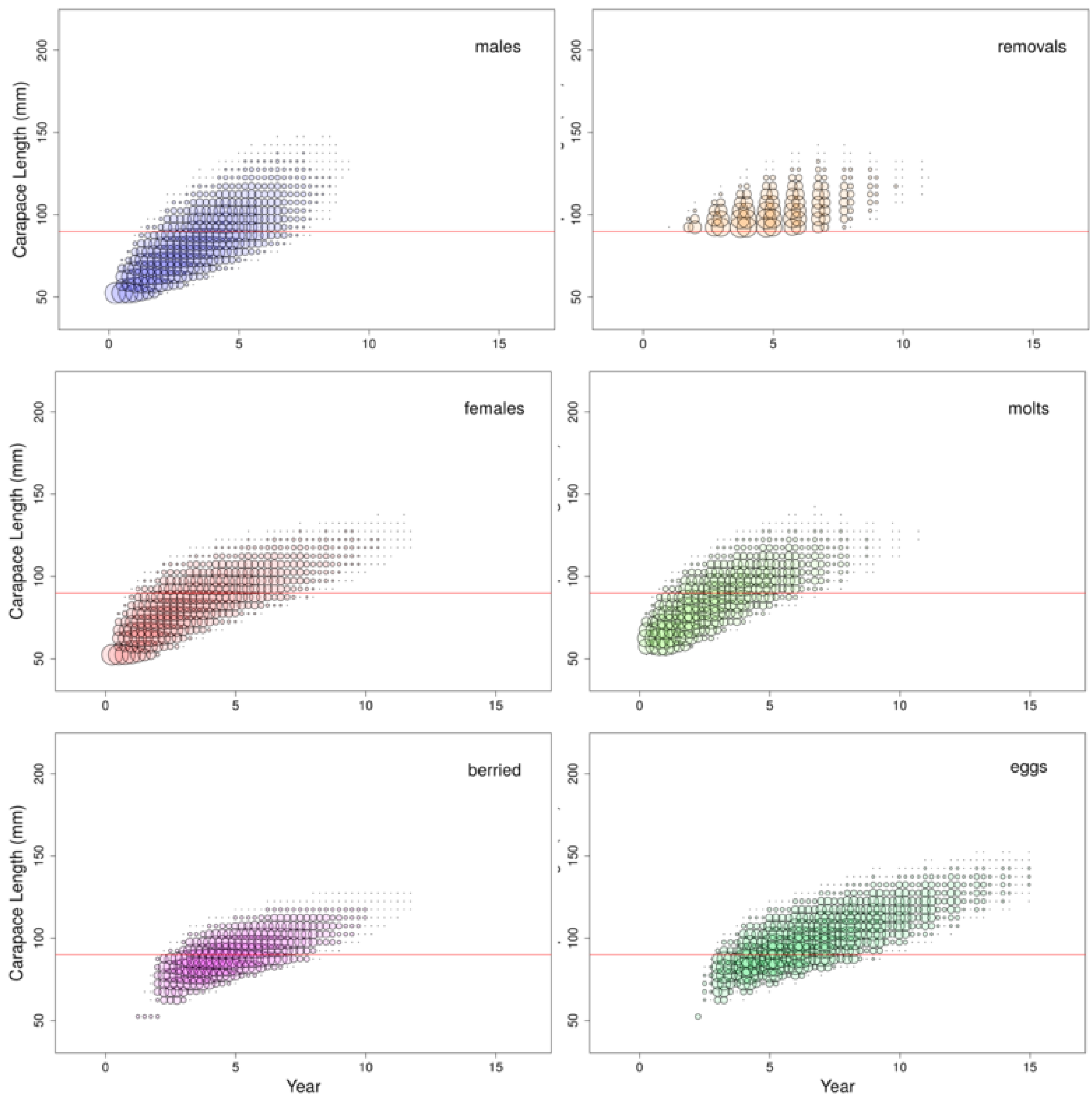


Figure 160: Bubble plot showing the simulated population where MLS was increased to 90mm for LFA 31A. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

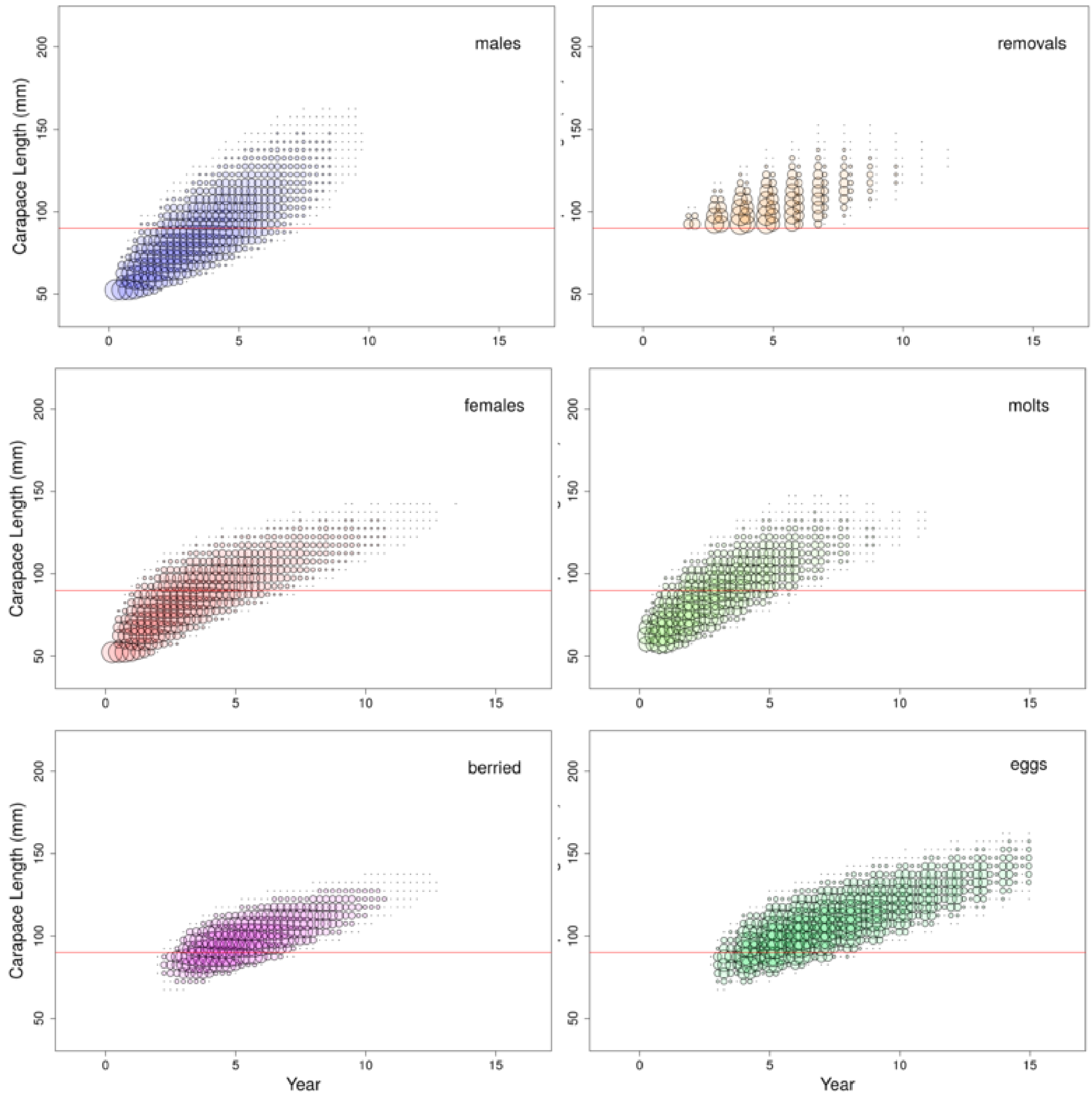


Figure 161: Bubble plot showing the simulated population where MLS was increased to 90mm for LFA 31B. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

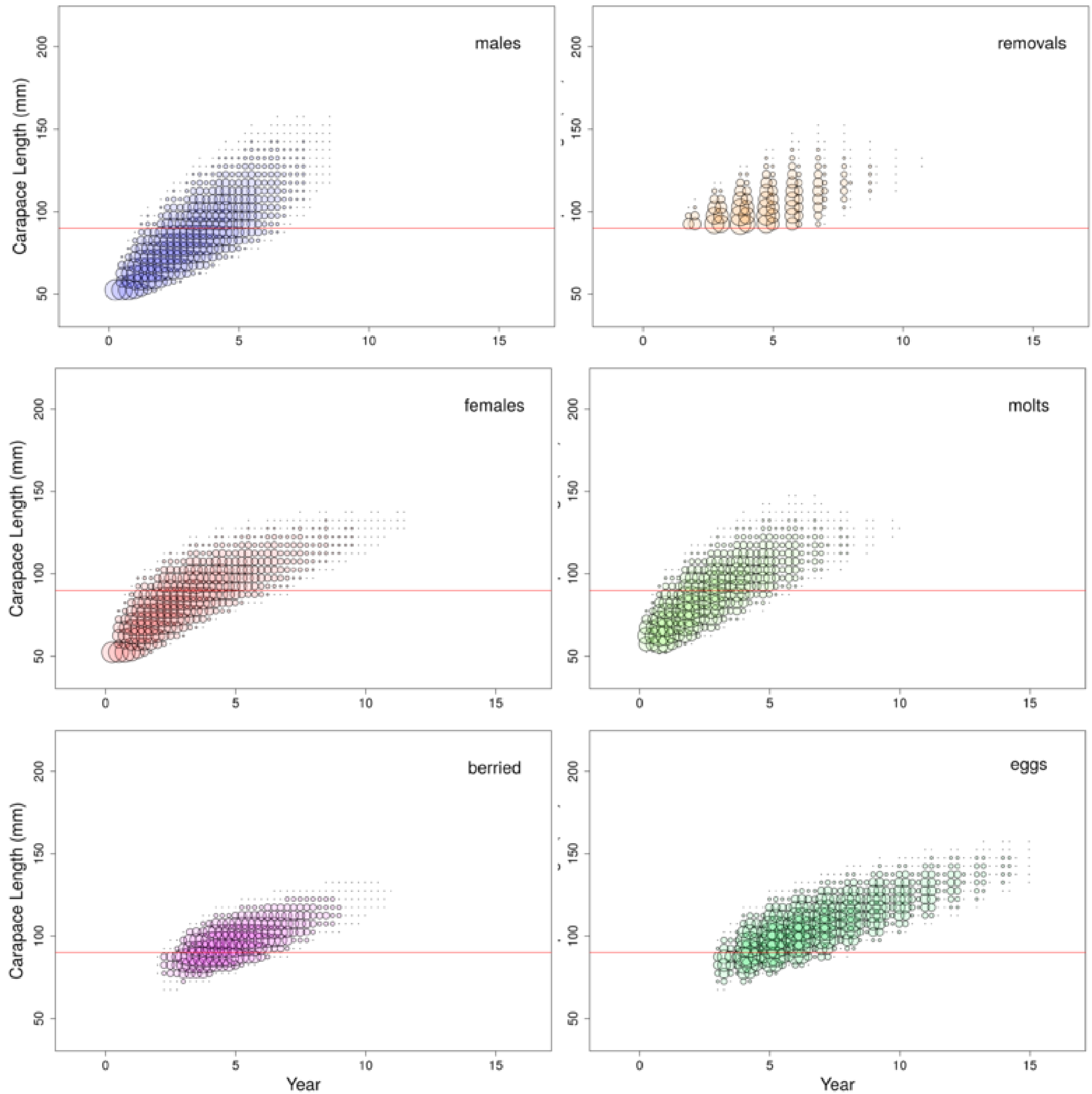


Figure 162: Bubble plot showing the simulated population where MLS was increased to 90mm for LFA 32. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

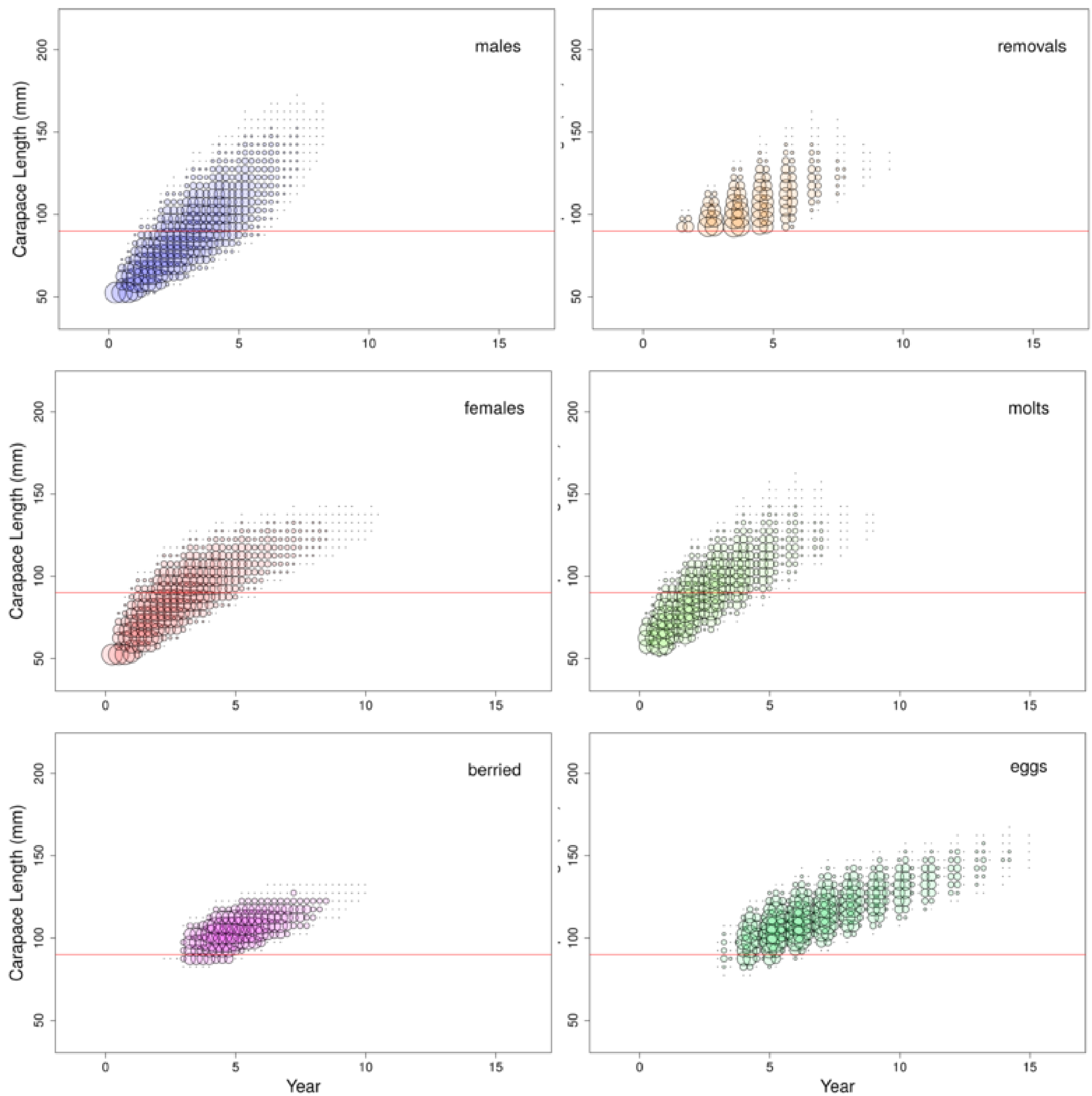


Figure 163: Bubble plot showing the simulated population where MLS was increased to 90mm for LFA 33E. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

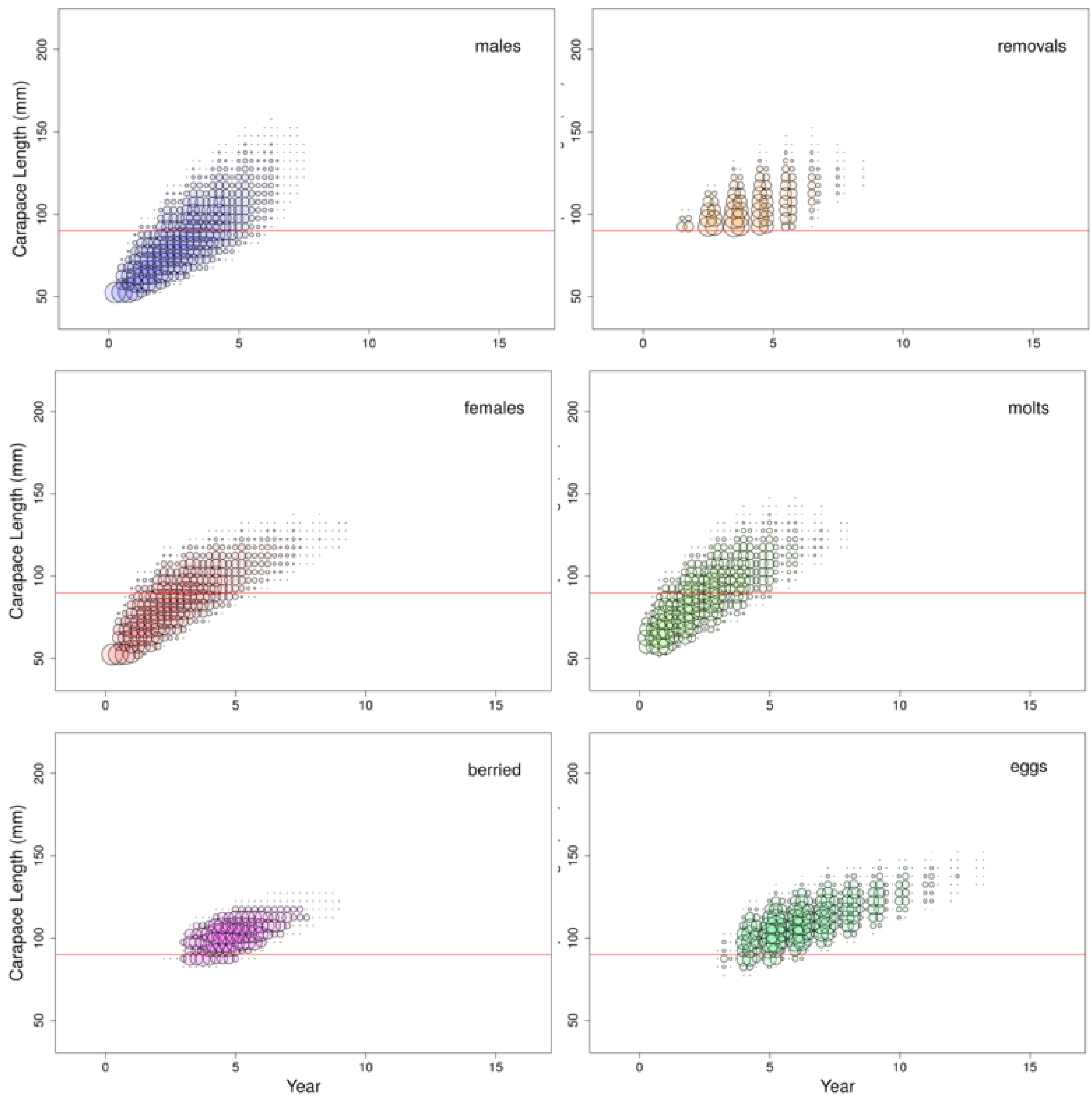


Figure 164: Bubble plot showing the simulated population where MLS was increased to 90mm for LFA 33W. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

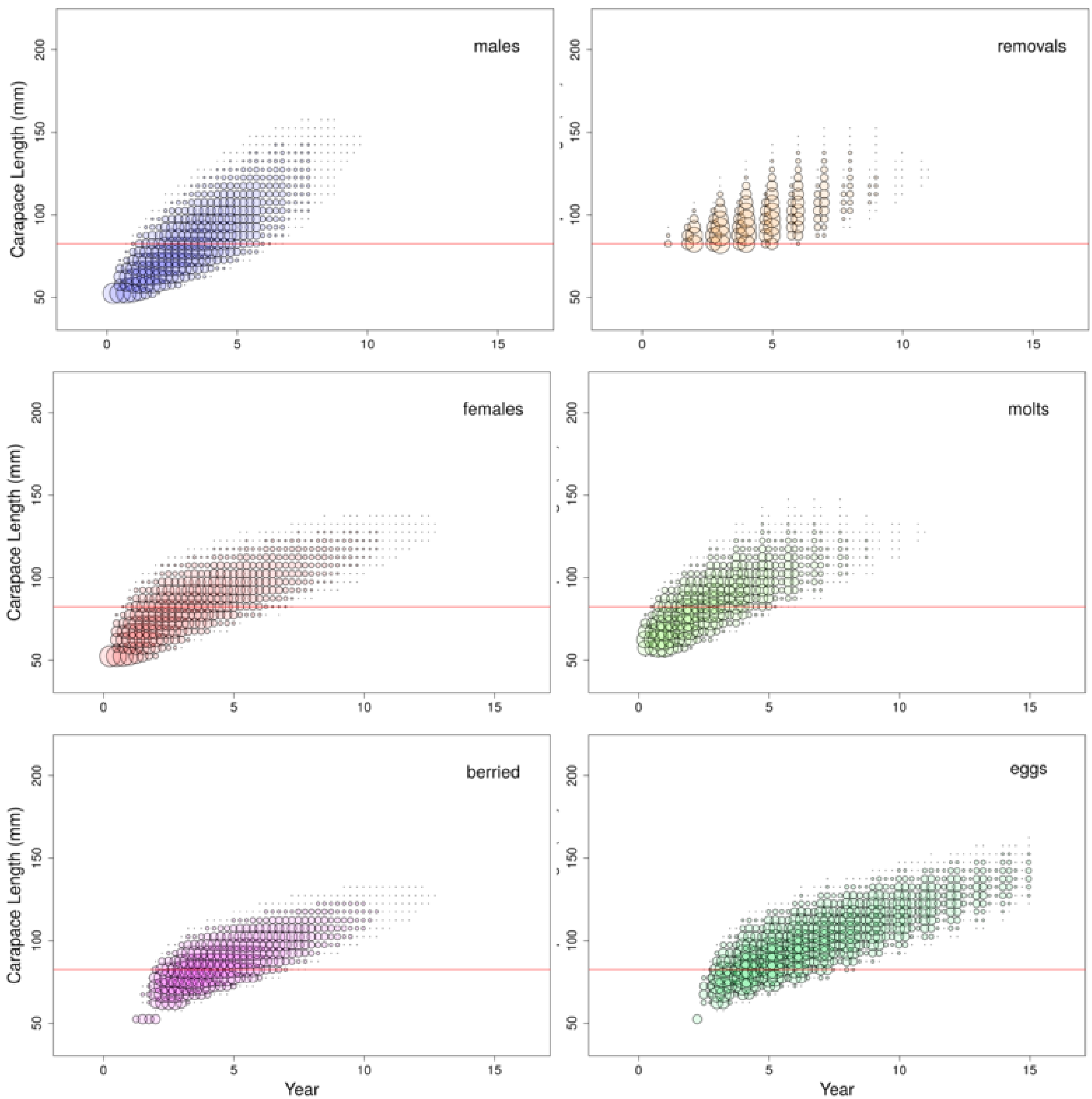


Figure 165: Bubble plots showing the simulated population where the season was shortened by 50 percent for LFA 27N. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

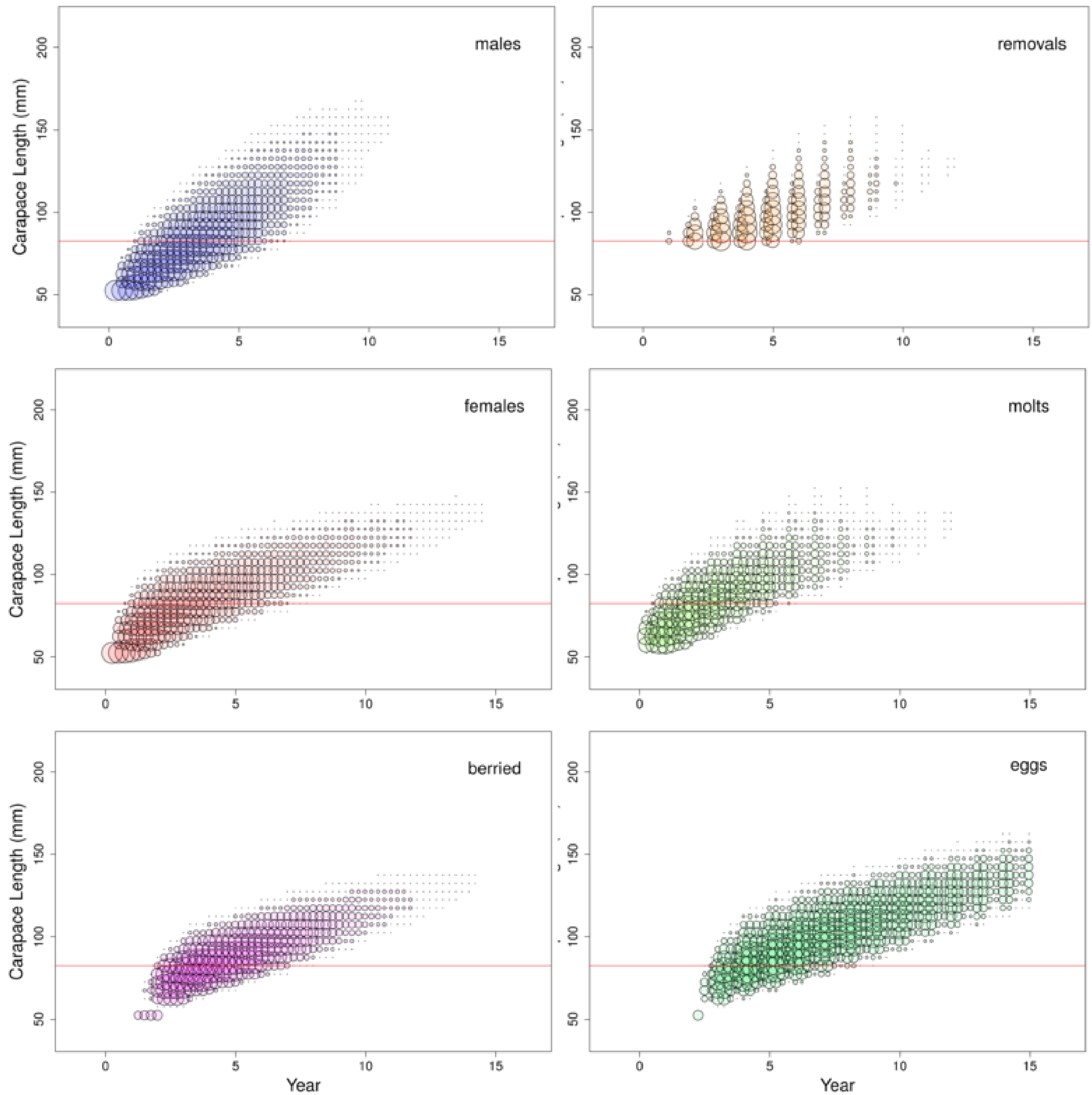


Figure 166: Bubble plot showing the simulated population where the season was shortened by 50 percent for LFA 27S. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

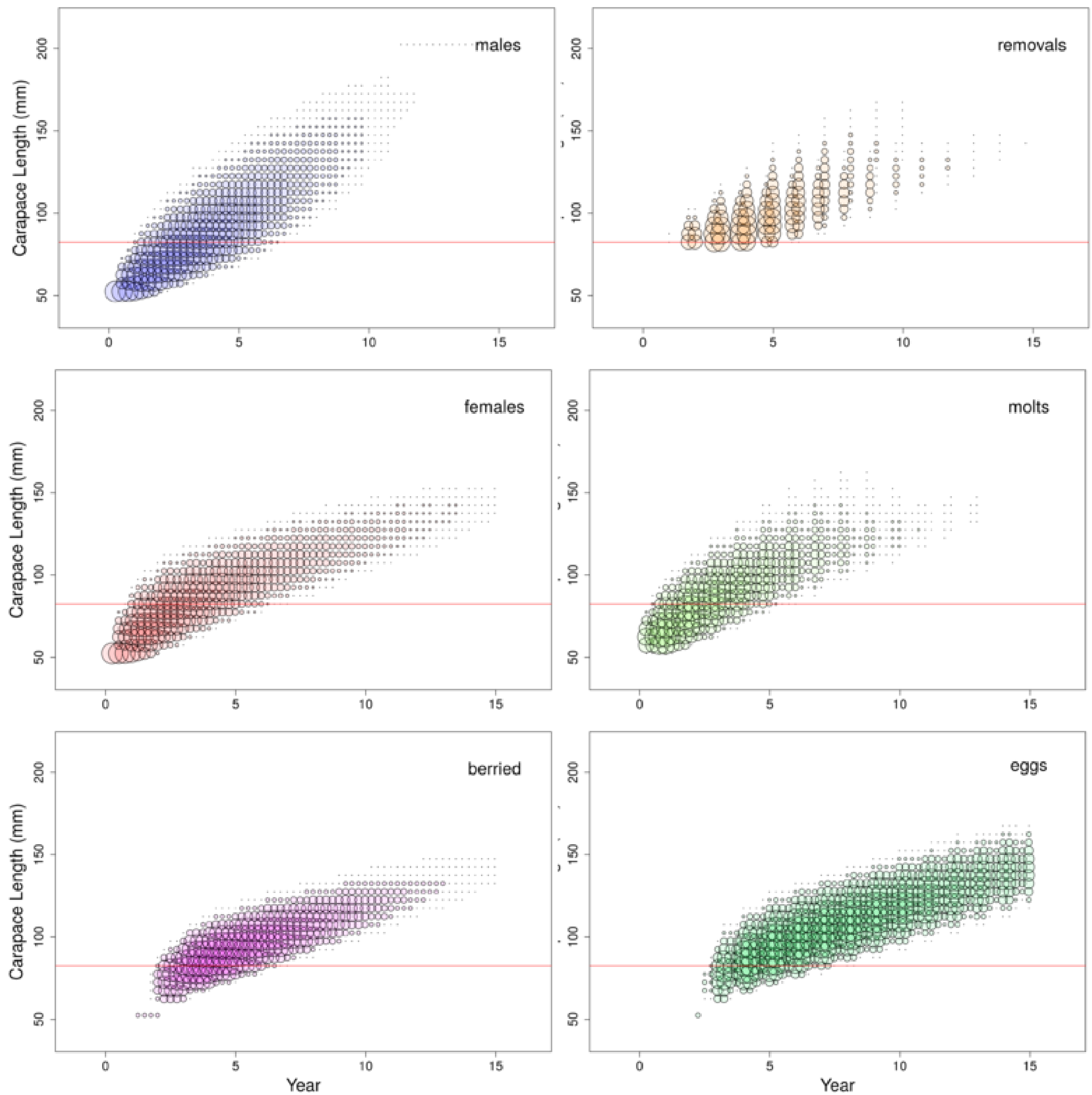


Figure 167: Bubble plot showing the simulated population where the season was shortened by 50 percent for LFA 29. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

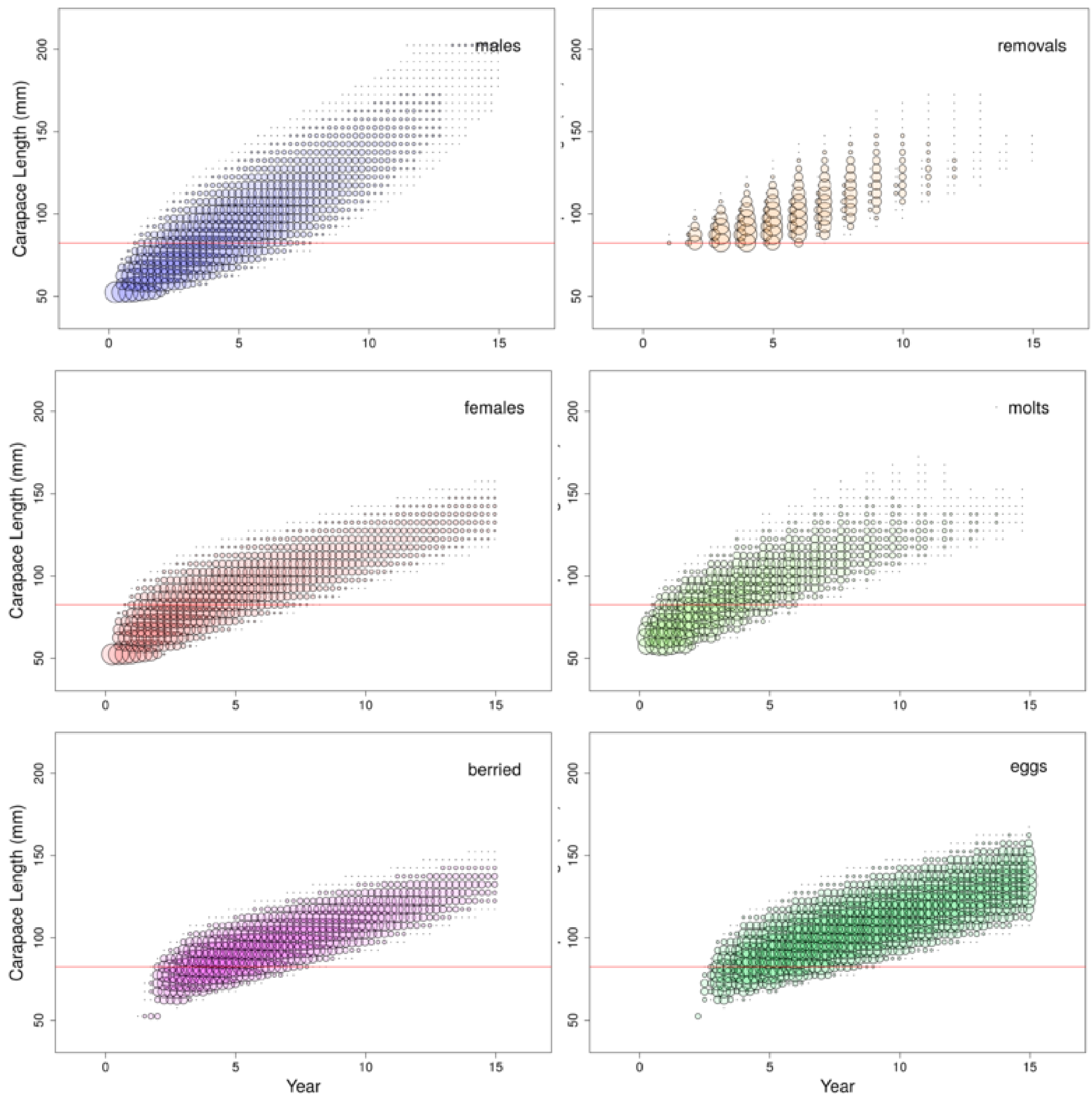


Figure 168: Bubble plot showing the simulated population where the season was shortened by 50 percent for LFA 30. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

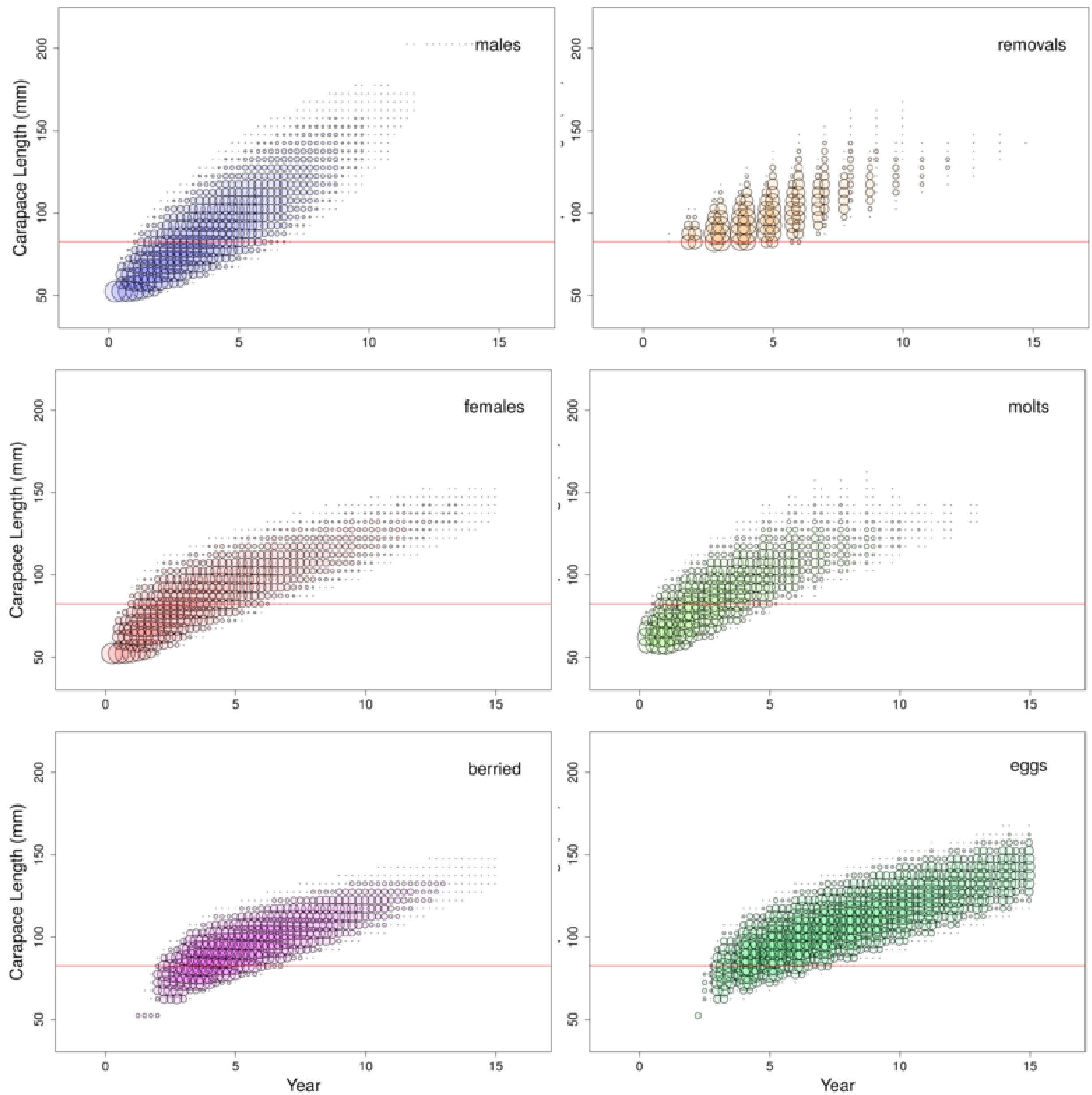


Figure 169: Bubble plot showing the simulated population where the season was shortened by 50 percent for LFA 31A. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

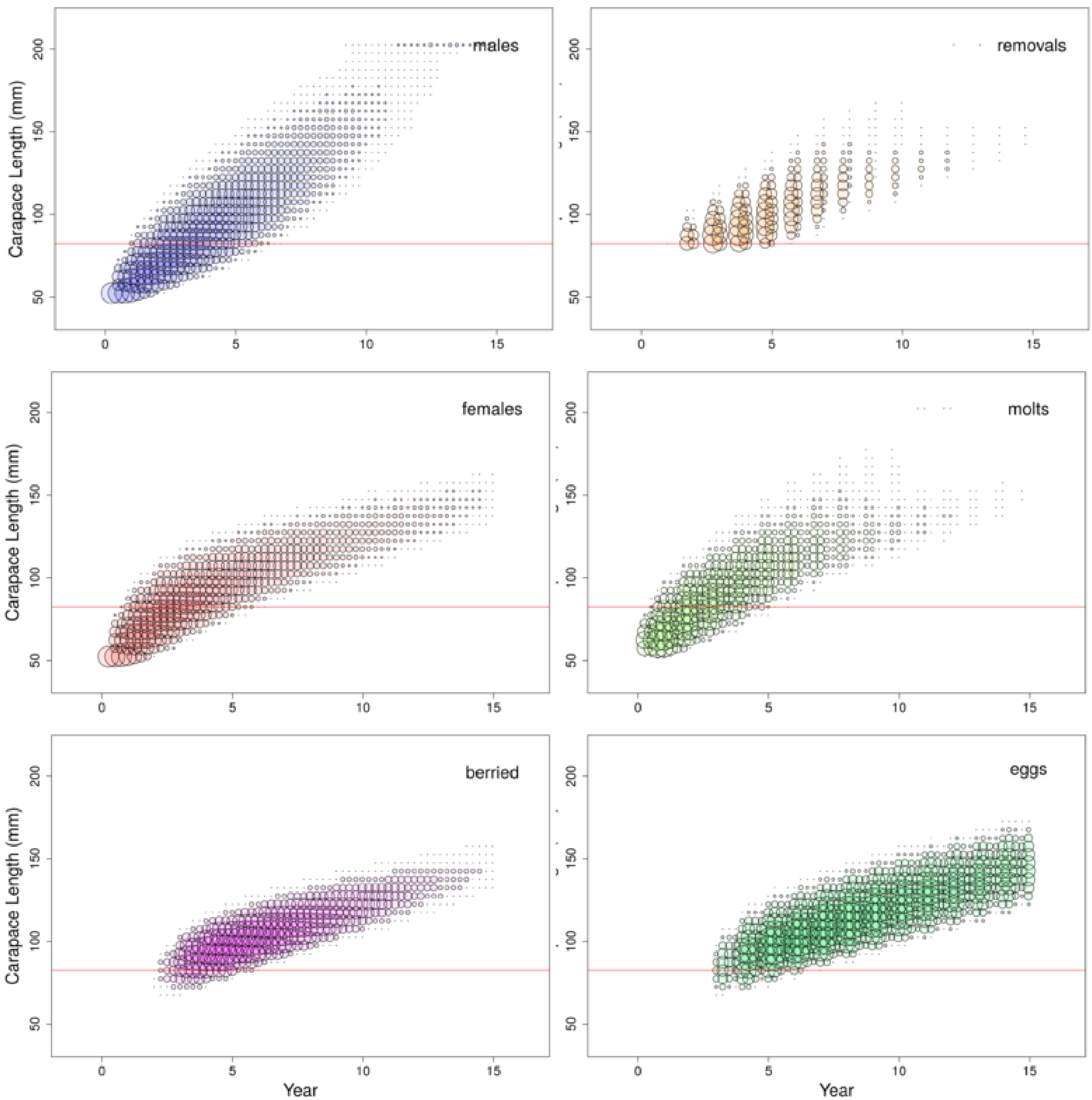


Figure 170: Bubble plot showing the simulated population where the season was shortened by 50 percent for LFA 31B. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

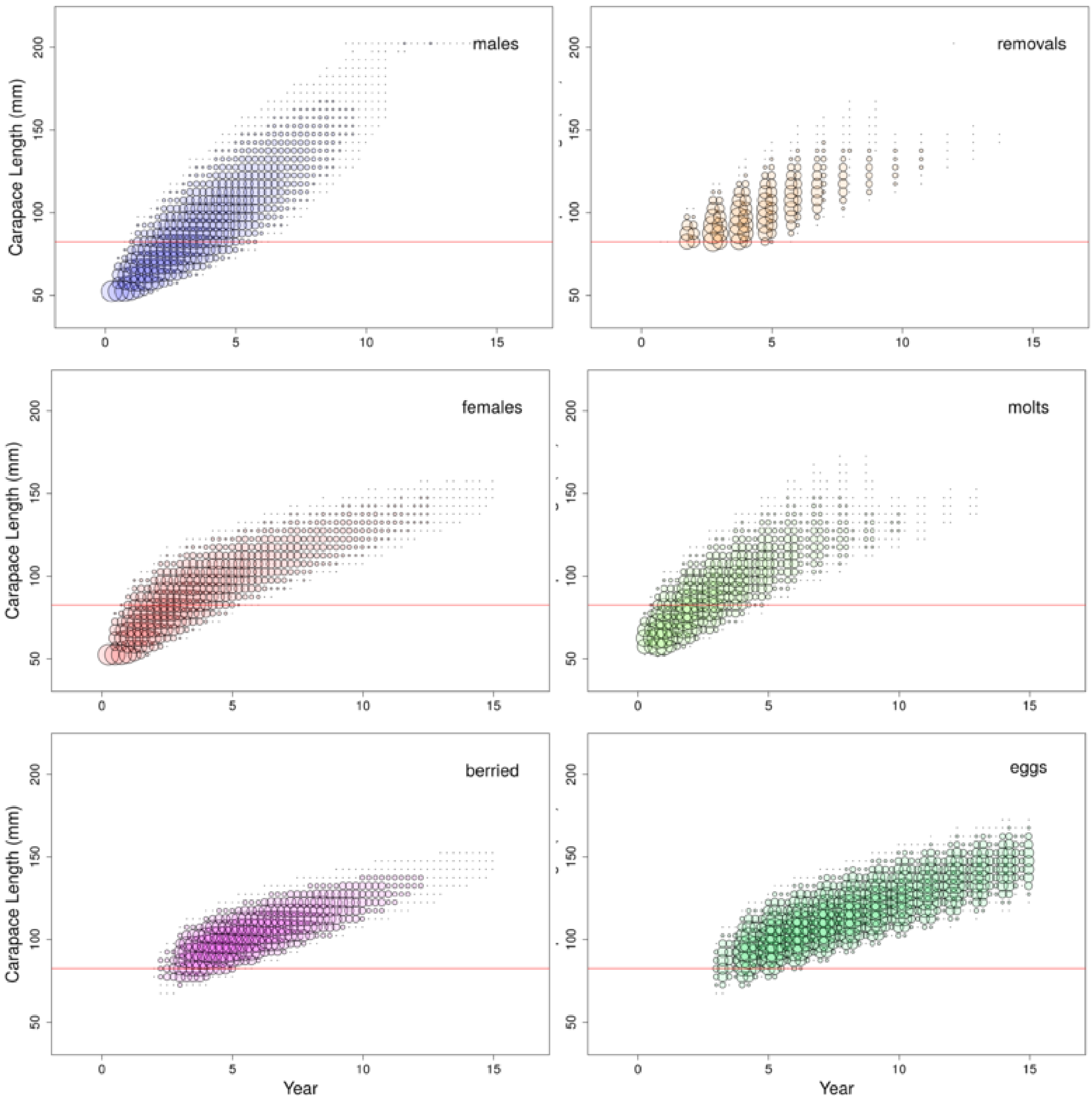


Figure 171: Bubble plot showing the simulated population where the season was shortened by 50 percent for LFA 32. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

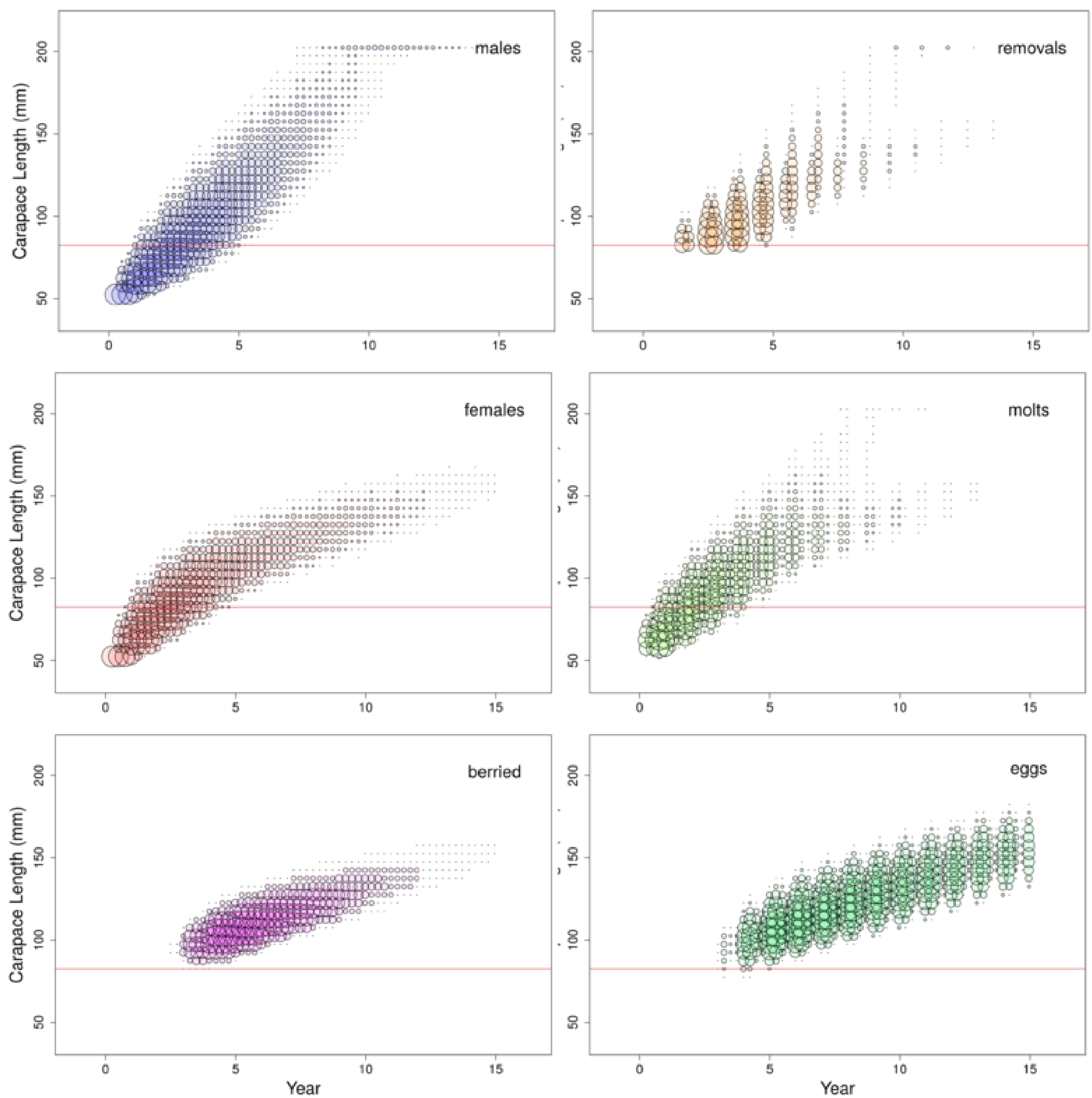


Figure 172: Bubble plot showing the simulated population where the season was shortened by 50 percent for LFA 33E. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

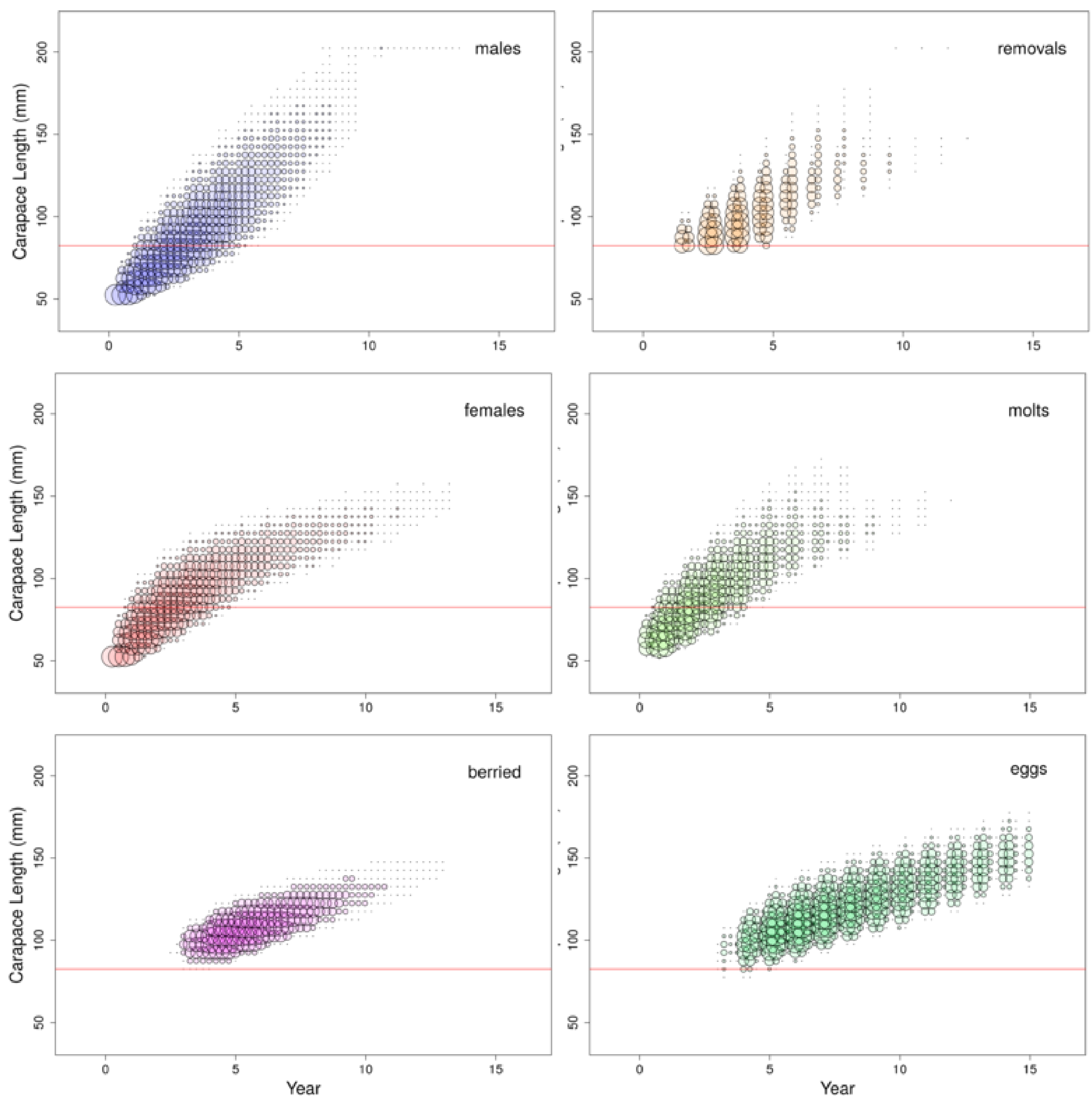


Figure 173: Bubble plot showing the simulated population where the season was shortened by 50 percent for LFA 33W. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

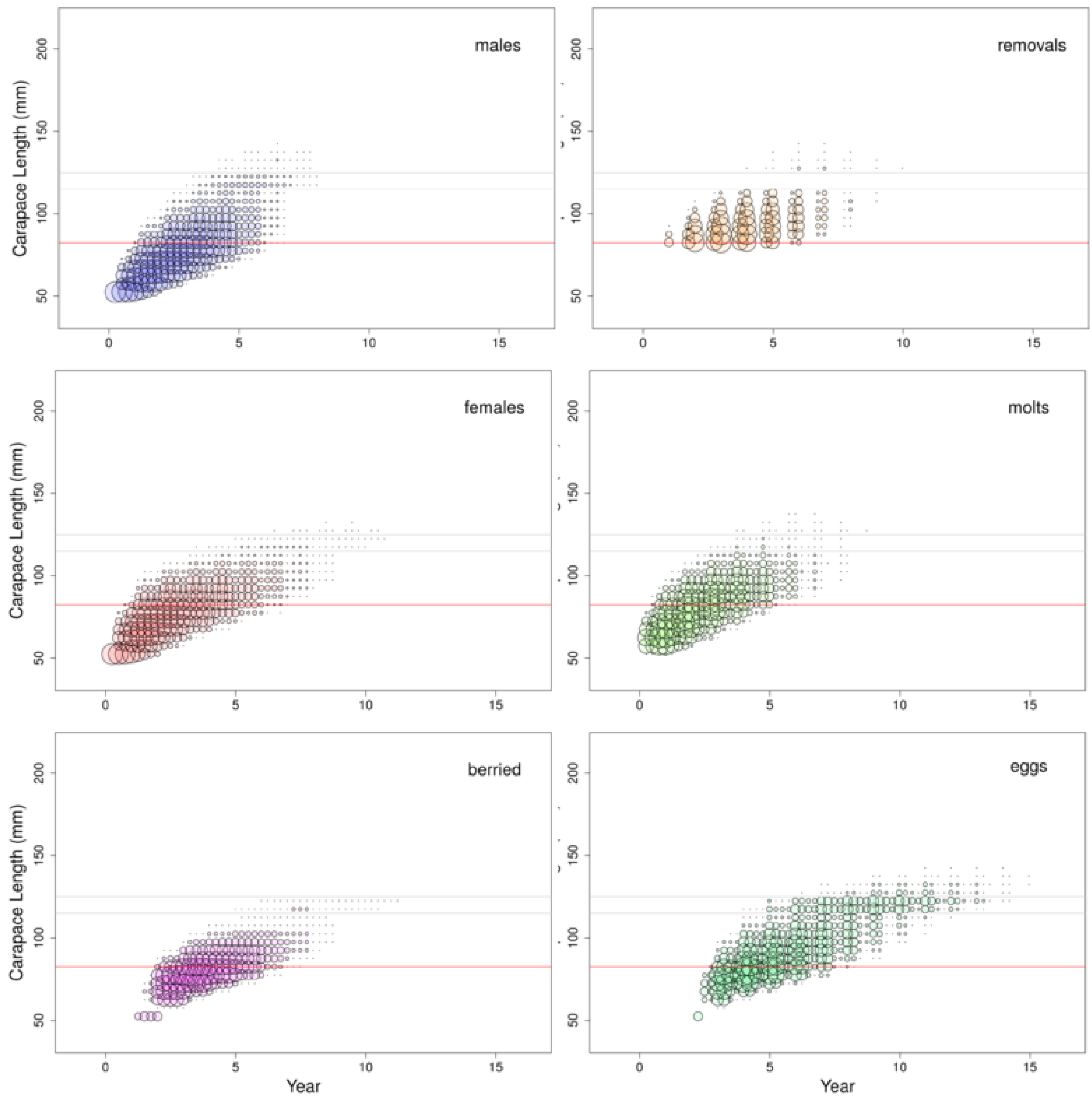


Figure 174: Bubble plots showing the simulated population where a small window (115–125 mm) was implemented for LFA 27N. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

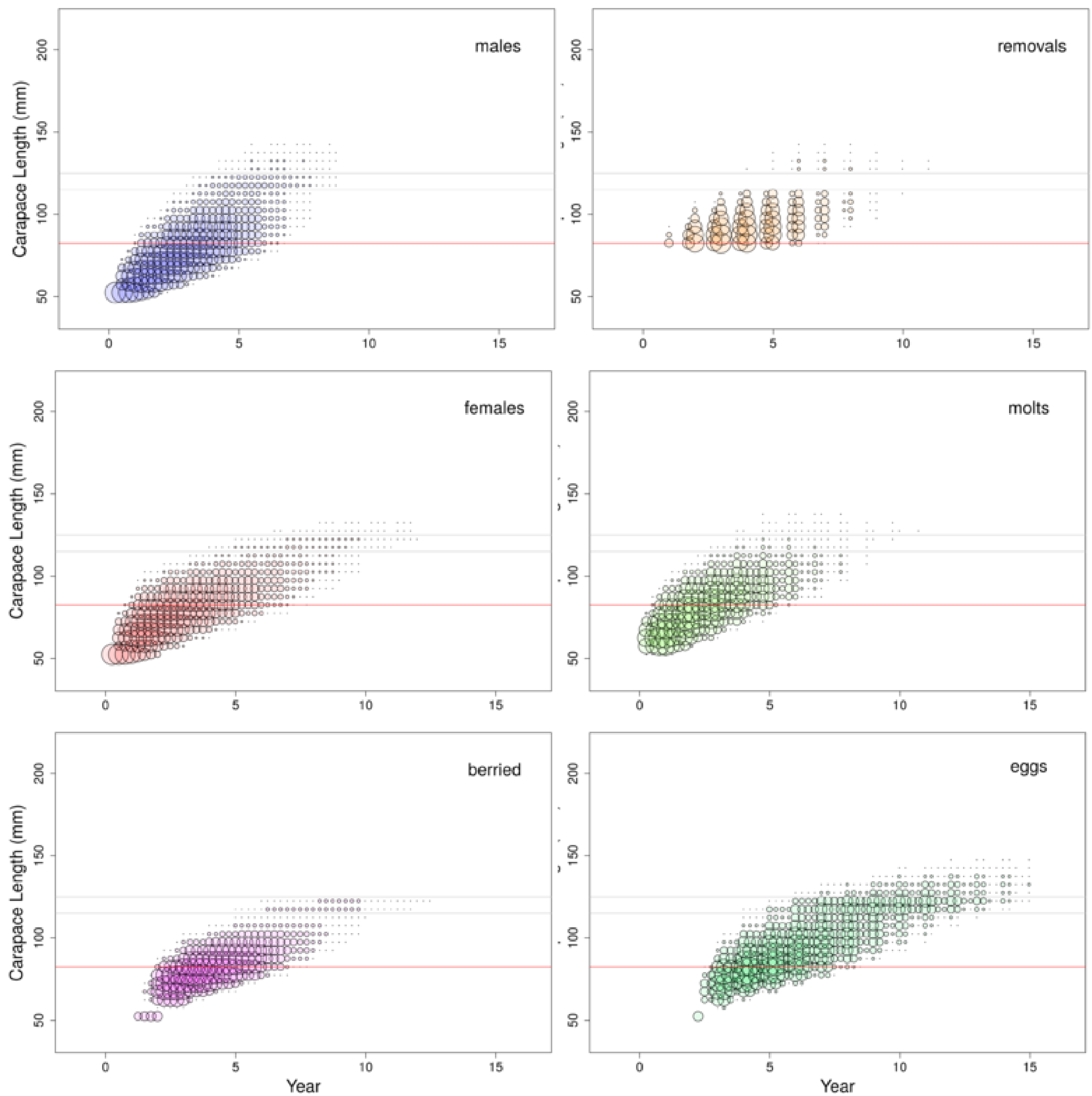


Figure 175: Bubble plot showing the simulated population where a small window (115–125 mm) was implemented for LFA 27S. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

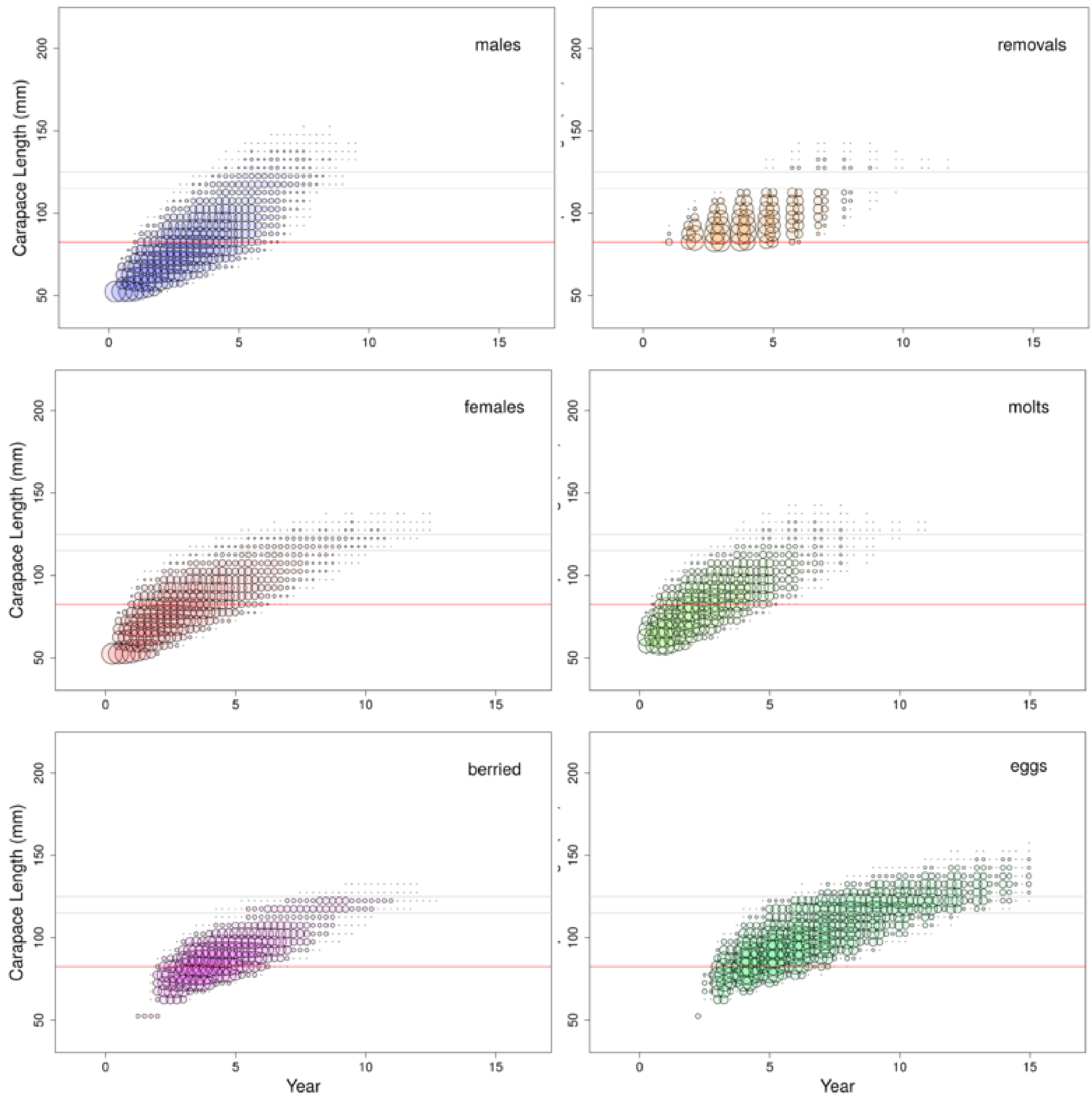


Figure 176: Bubble plot showing the simulated population where a small window (115–125 mm) was implemented for LFA 29. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

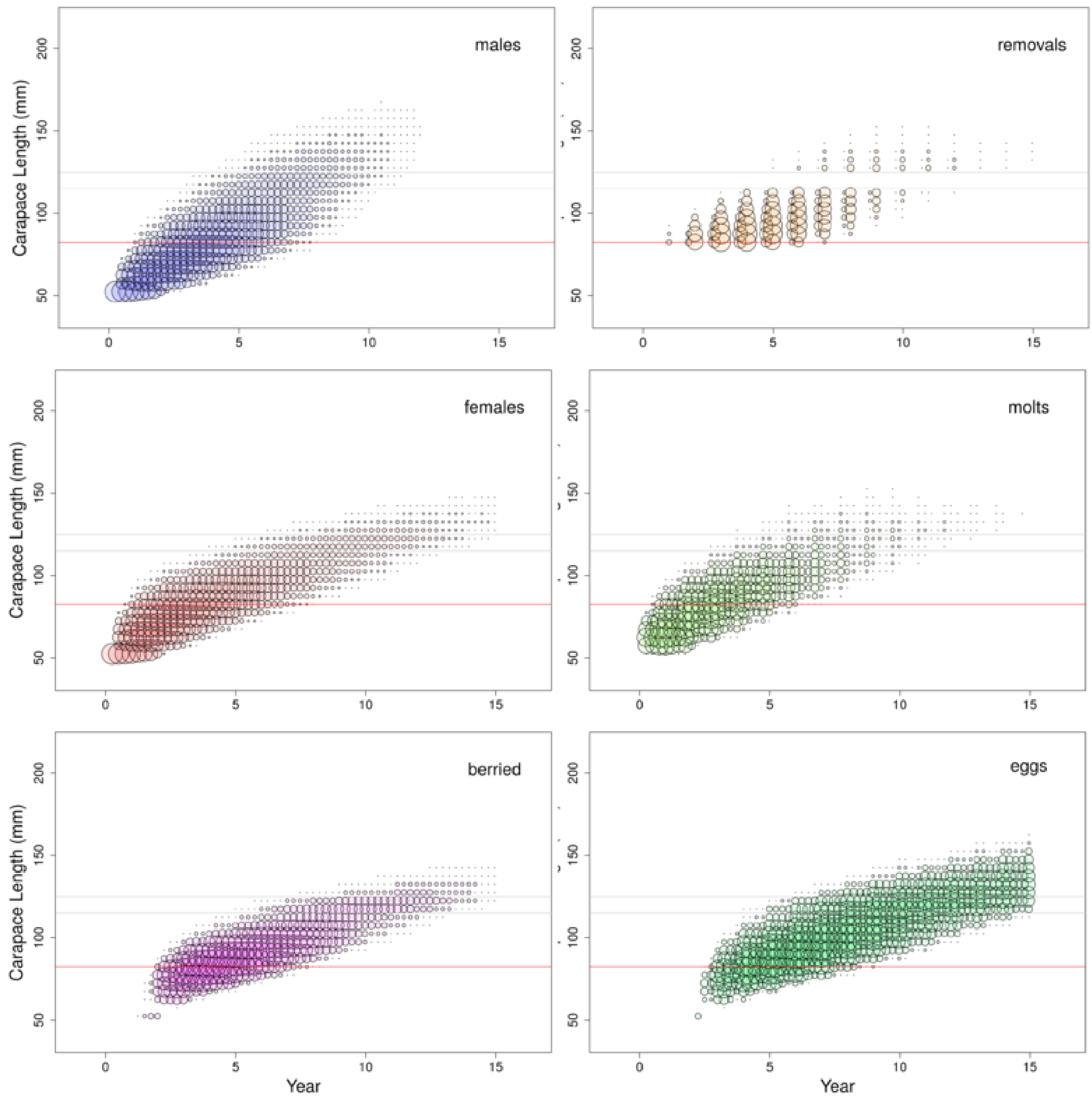


Figure 177: Bubble plot showing the simulated population where a small window (115–125 mm) was implemented for LFA 30. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

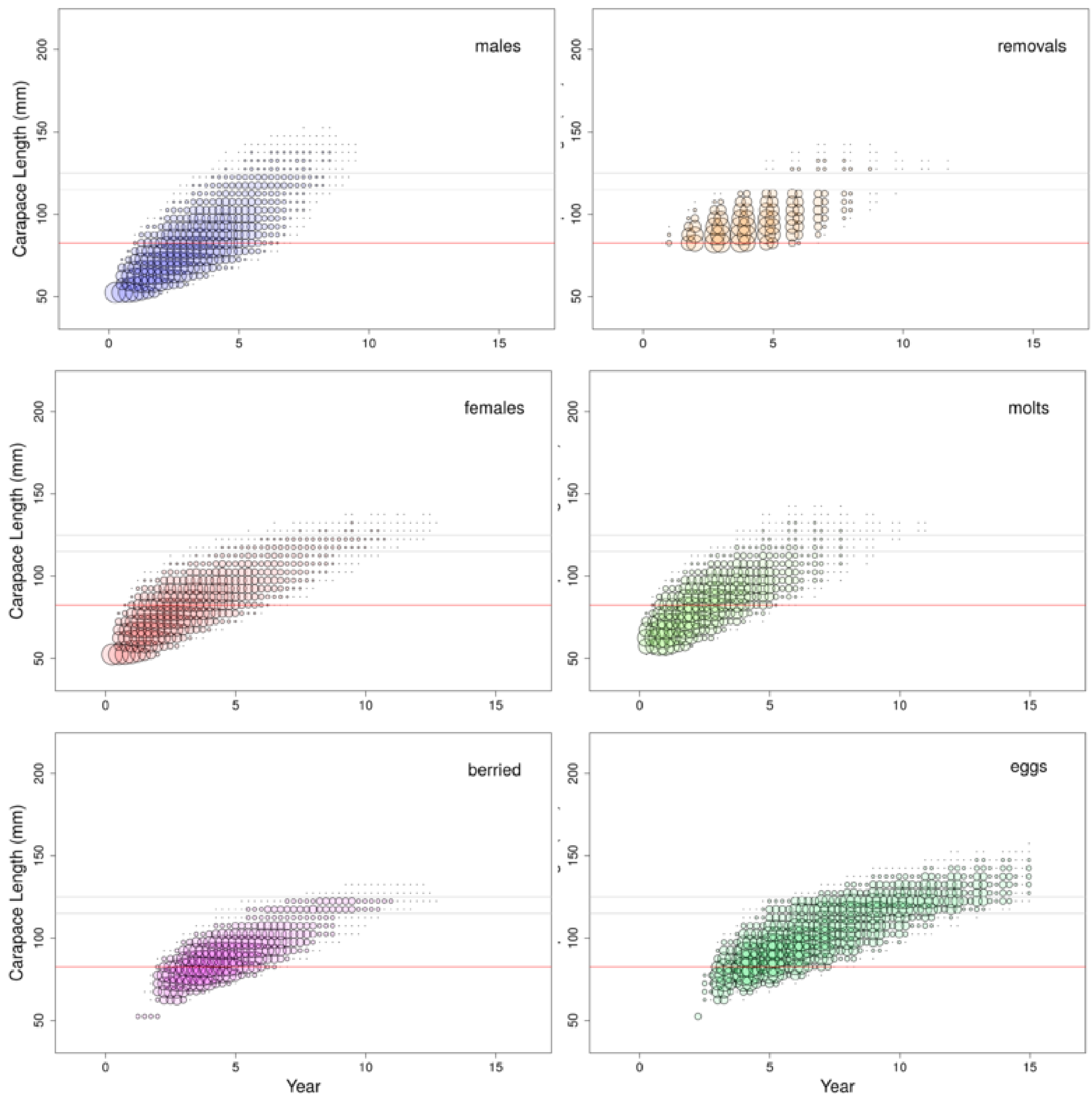


Figure 178: Bubble plot showing the simulated population where a small window (115–125 mm) was implemented for LFA 31A. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

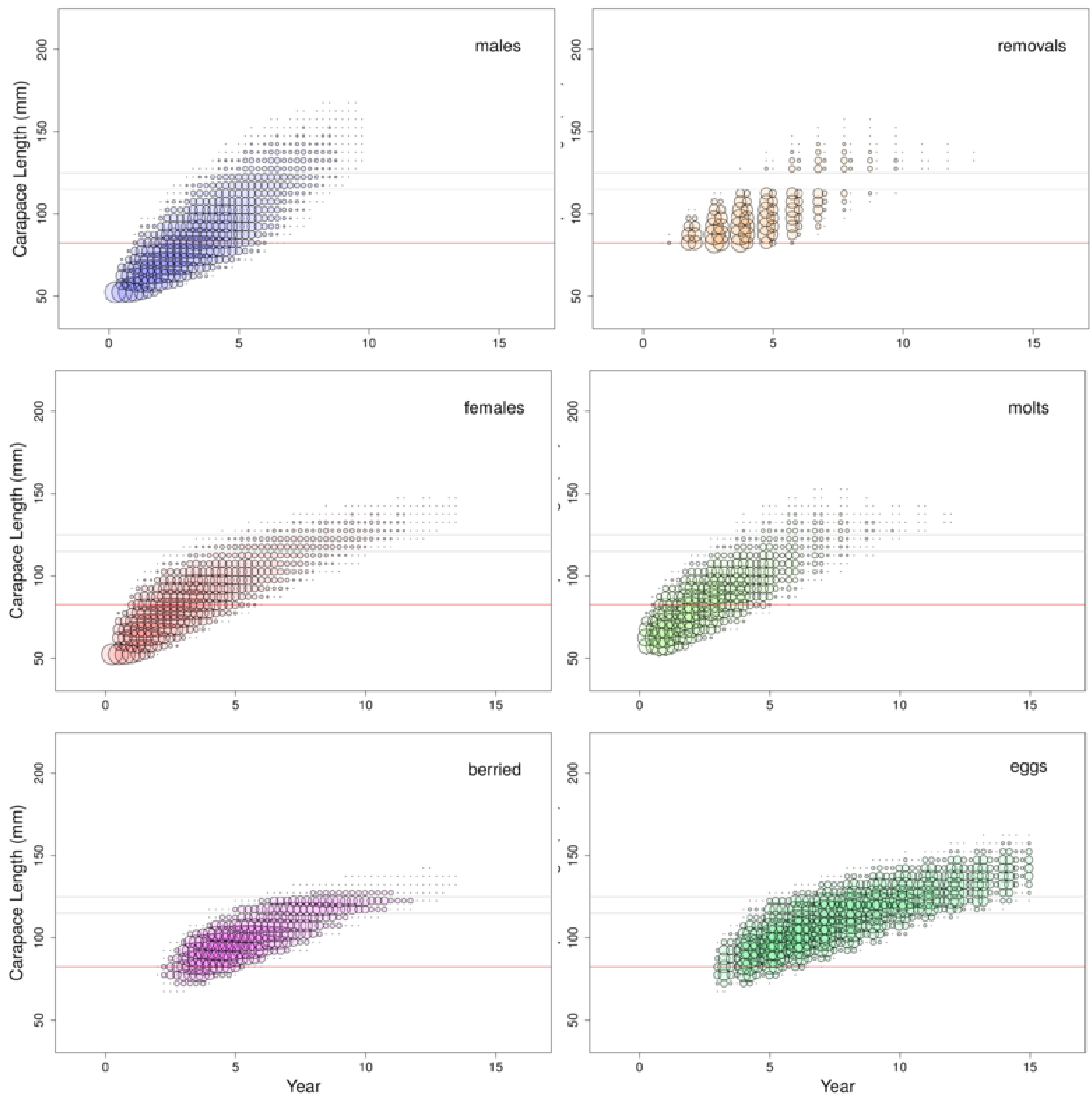


Figure 179: Bubble plot showing the simulated population where a small window (115–125 mm) was implemented for LFA 31B. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

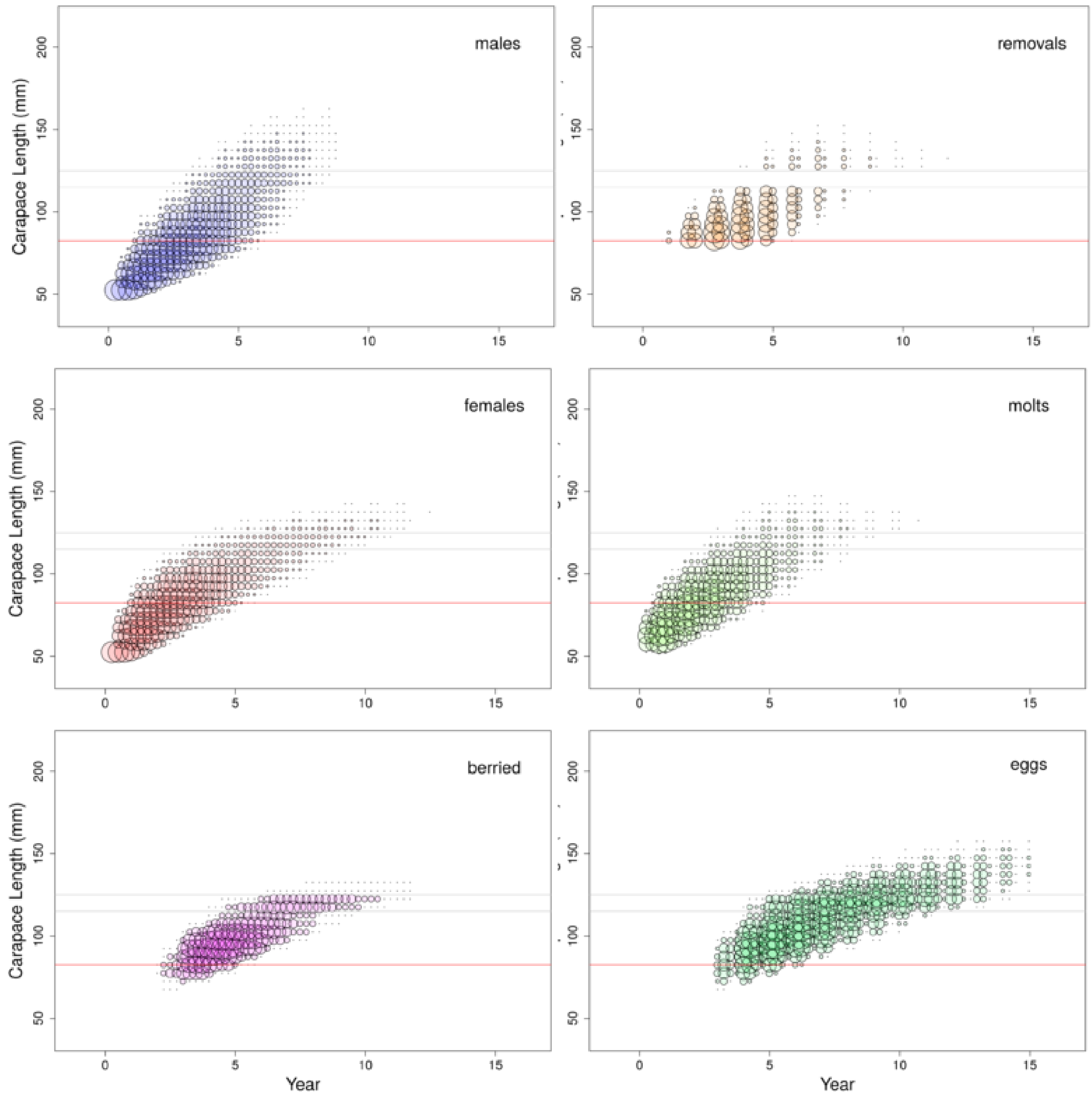


Figure 180: Bubble plot showing the simulated population where a small window (115–125 mm) was implemented for LFA 32. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

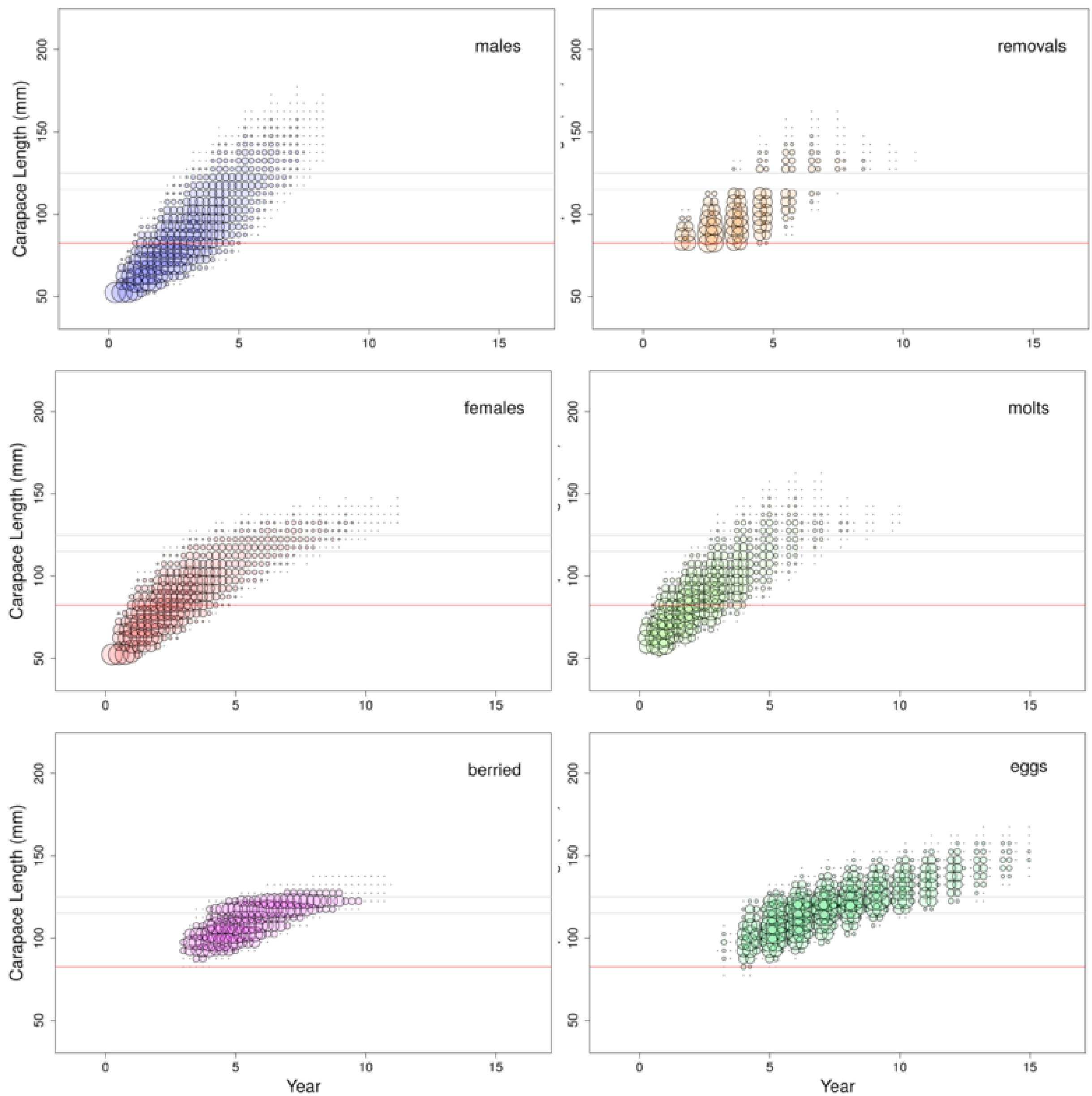


Figure 181: Bubble plot showing the simulated population where a small window (115–125 mm) was implemented for LFA 33E. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

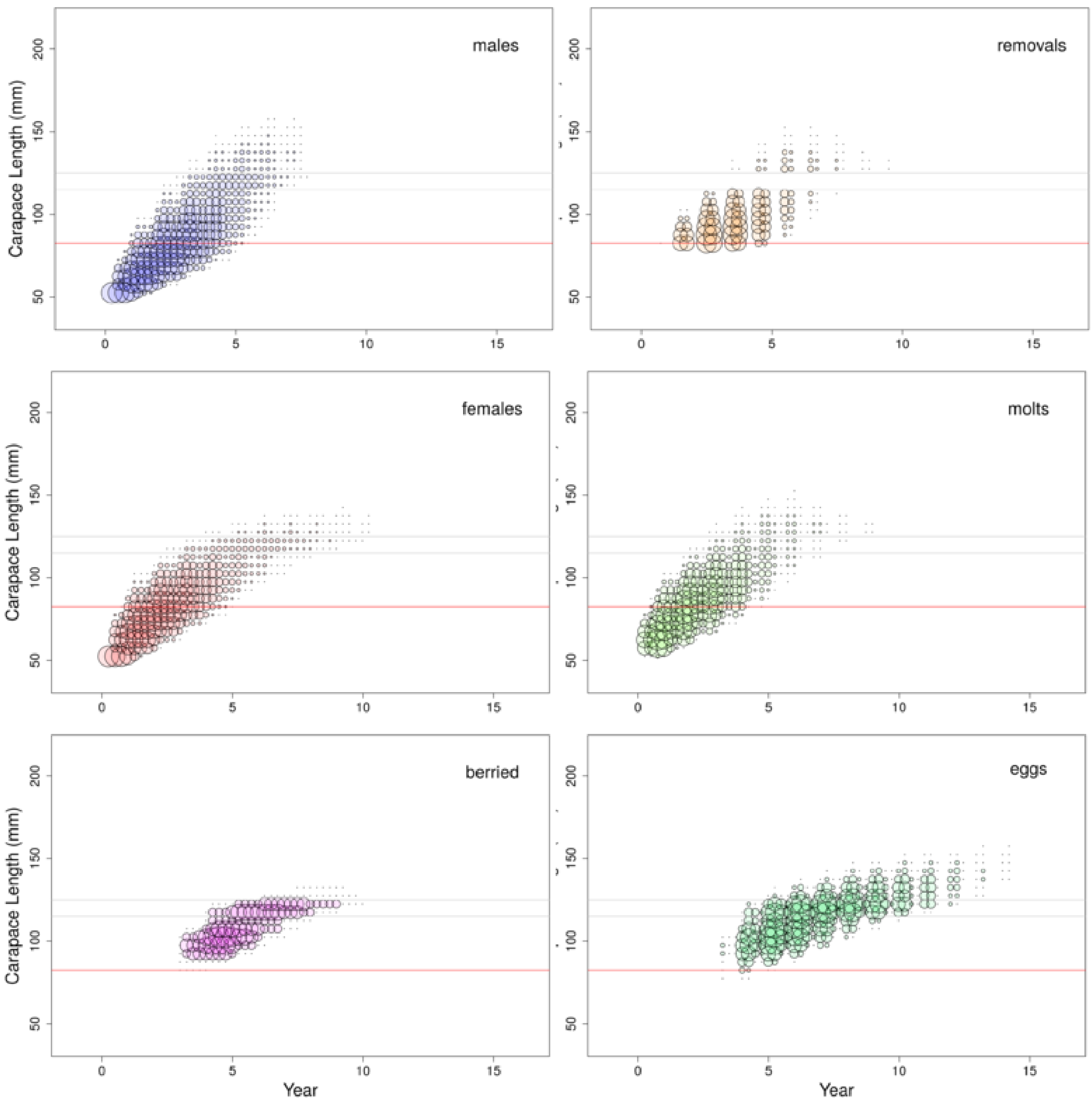


Figure 182: Bubble plot showing the simulated population where a small window (115–125 mm) was implemented for LFA 33W. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

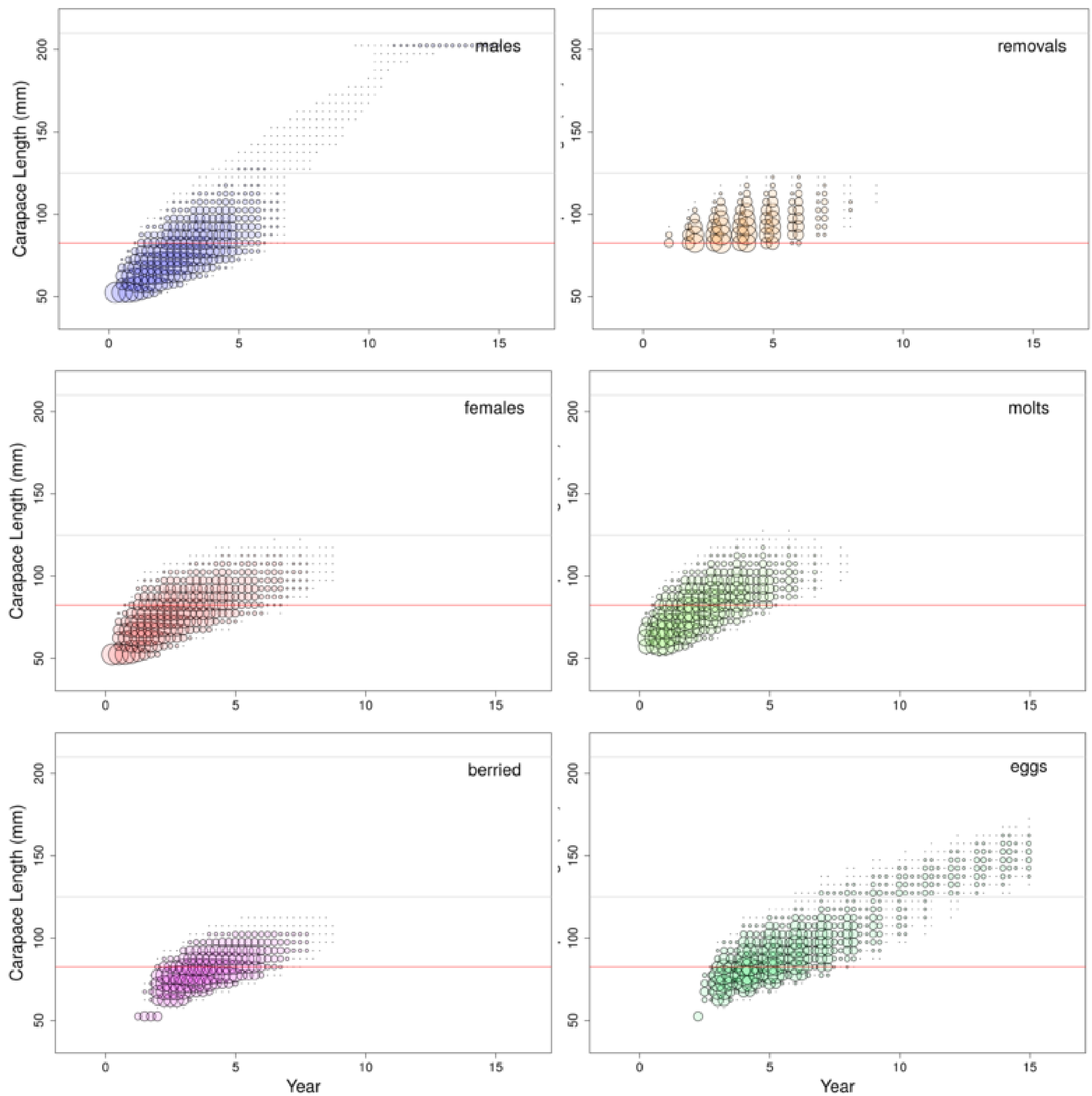


Figure 183: Bubble plots showing the simulated population where a maximum size of 125 mm was implemented for LFA 27N. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

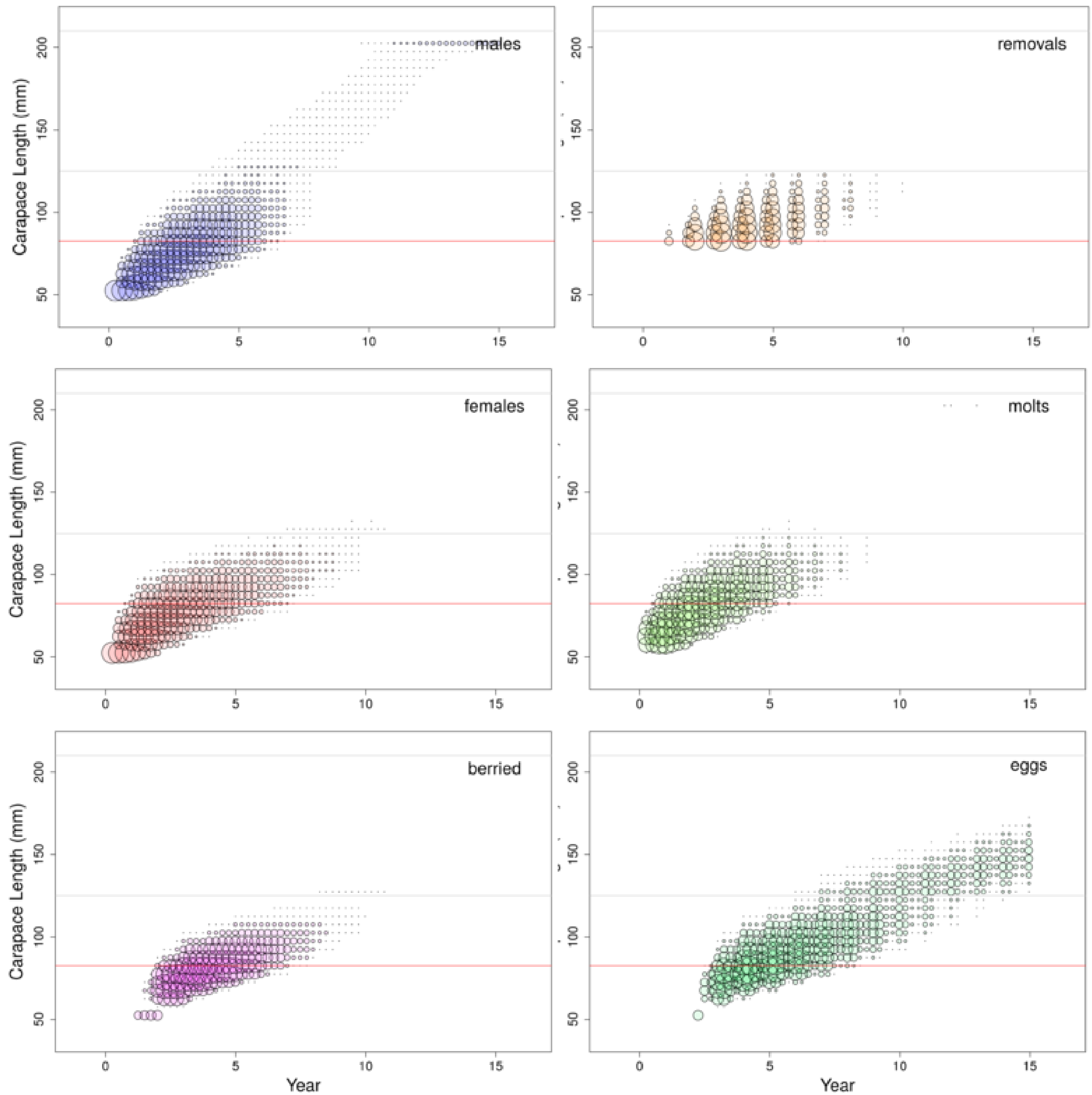


Figure 184: Bubble plot showing the simulated population where a maximum size of 125 mm was implemented for LFA 27S. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

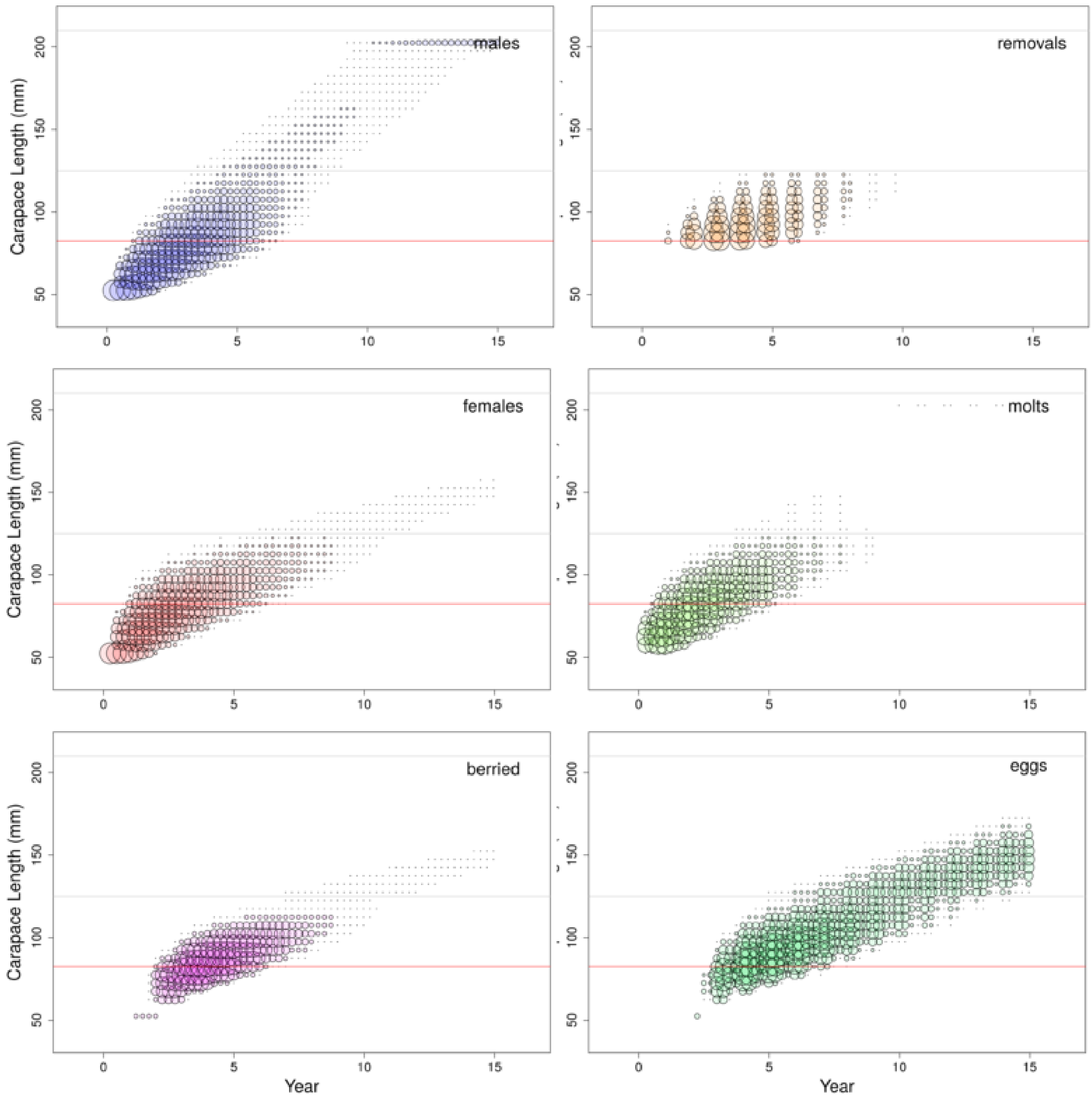


Figure 185: Bubble plot showing the simulated population where a maximum size of 125 mm was implemented for LFA 29. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

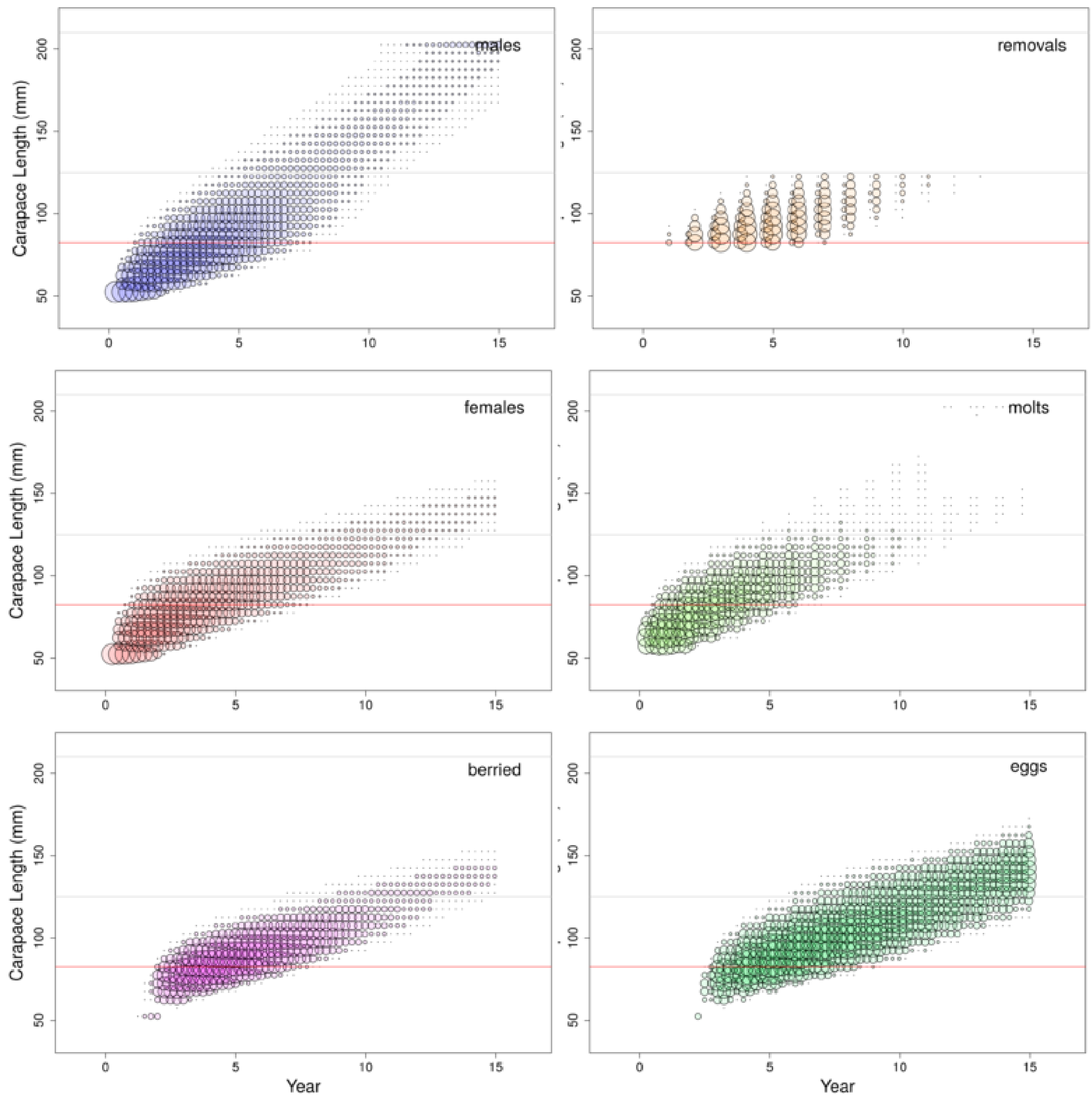


Figure 186: Bubble plot showing the simulated population where a maximum size of 125 mm was implemented for LFA 30. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

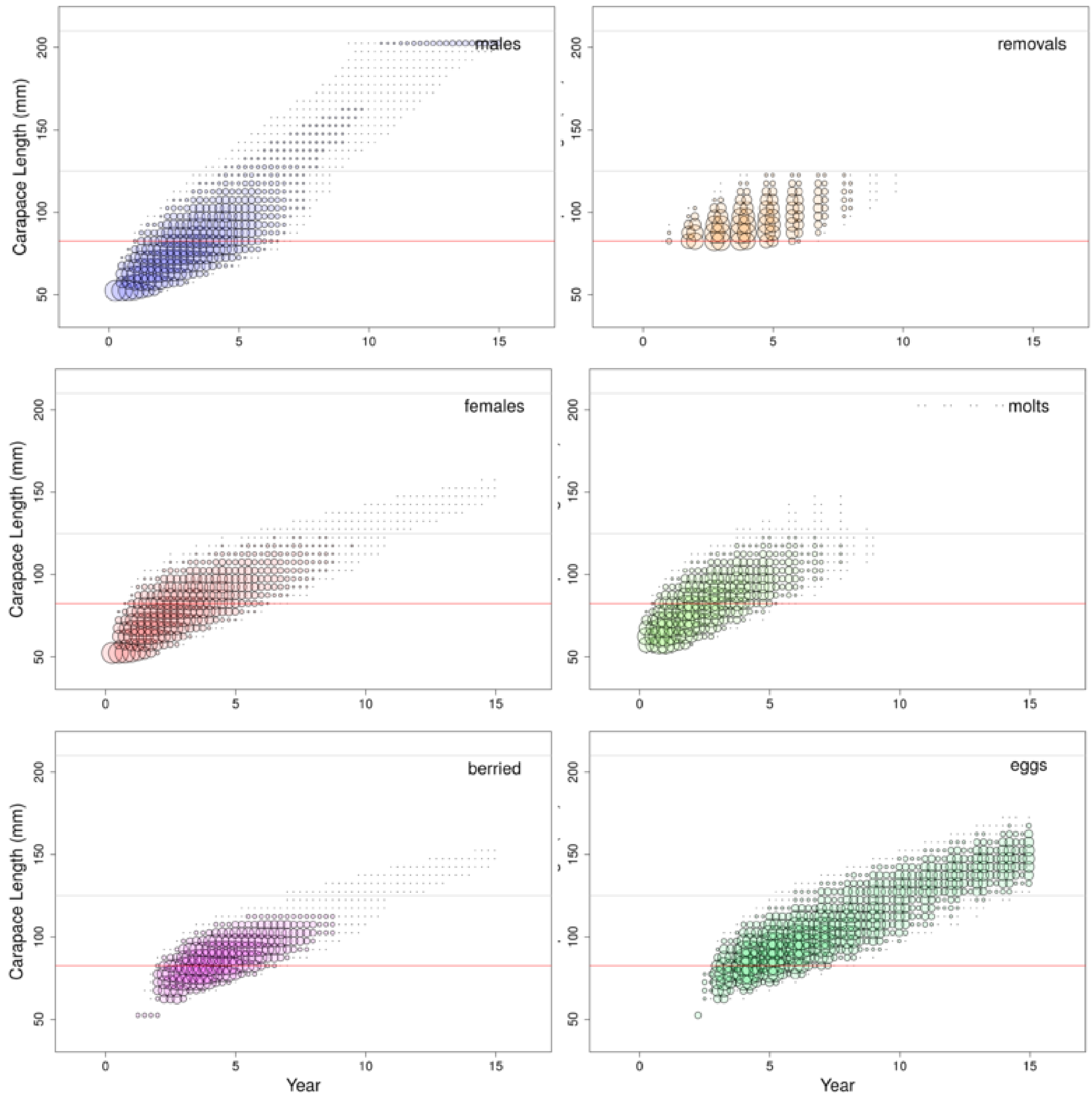


Figure 187: Bubble plot showing the simulated population where a maximum size of 125 mm was implemented for LFA 31A. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

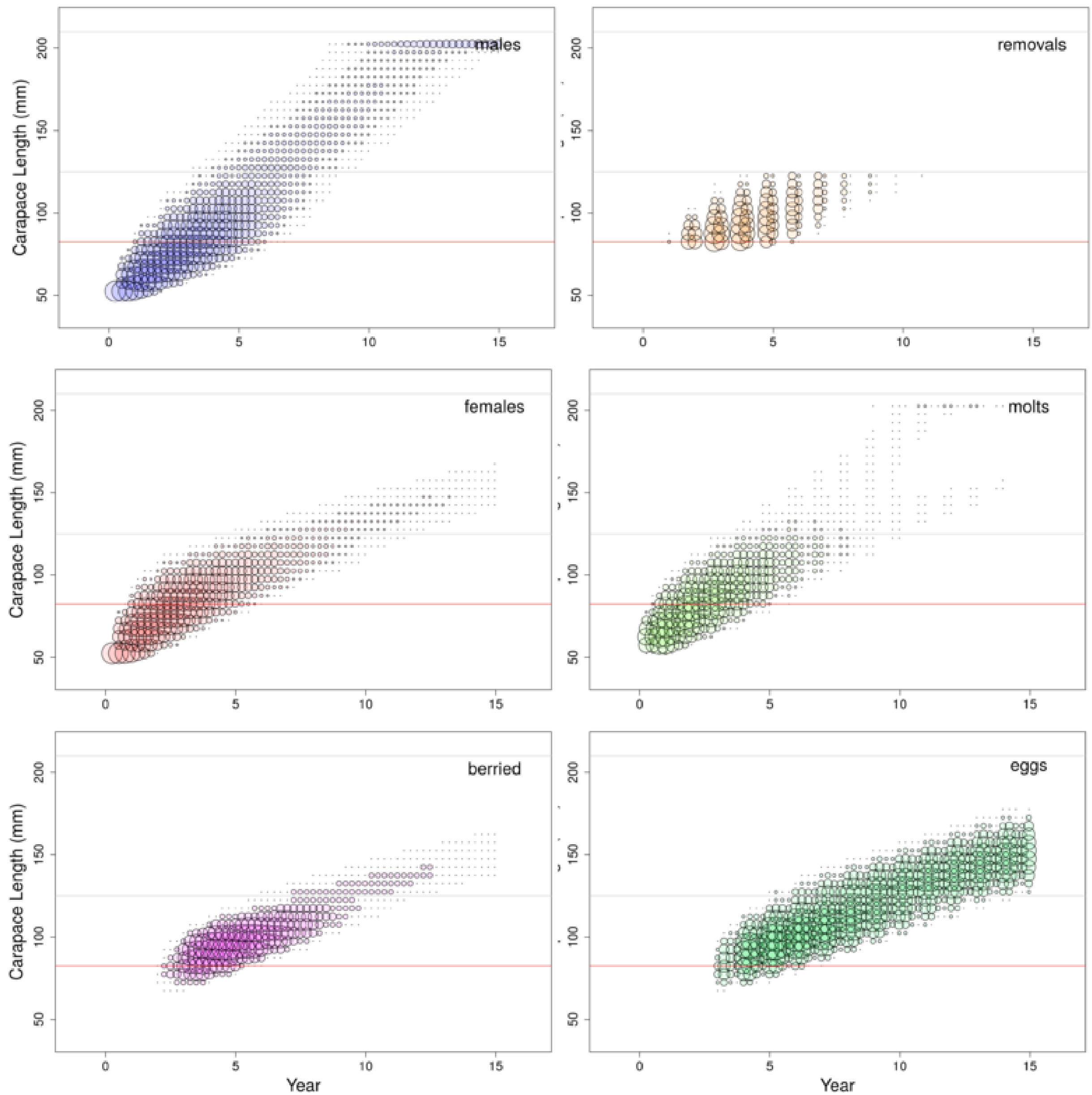


Figure 188: Bubble plot showing the simulated population where a maximum size of 125 mm was implemented for LFA 31B. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

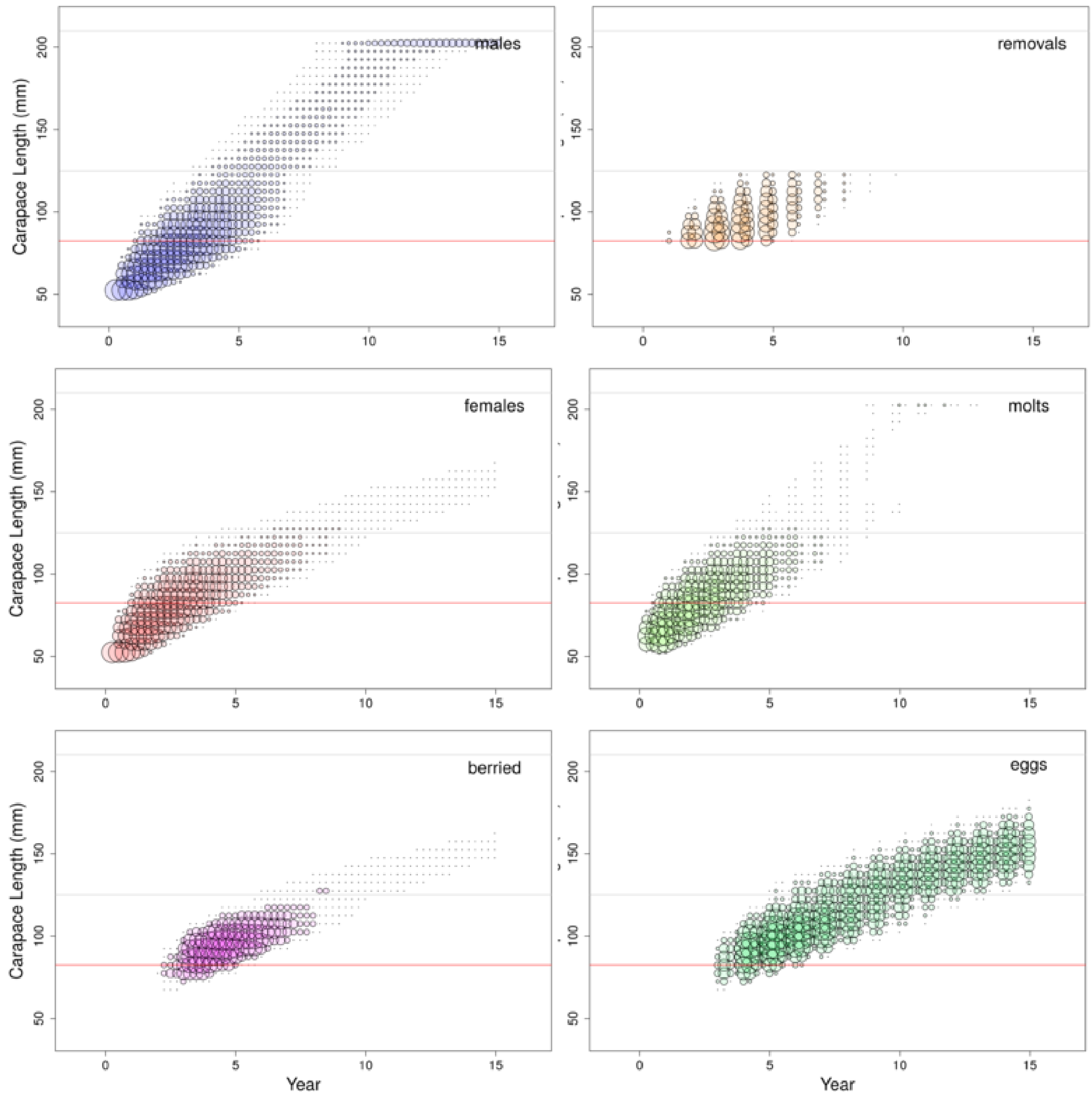


Figure 189: Bubble plot showing the simulated population where a maximum size of 125 mm was implemented for LFA 32. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

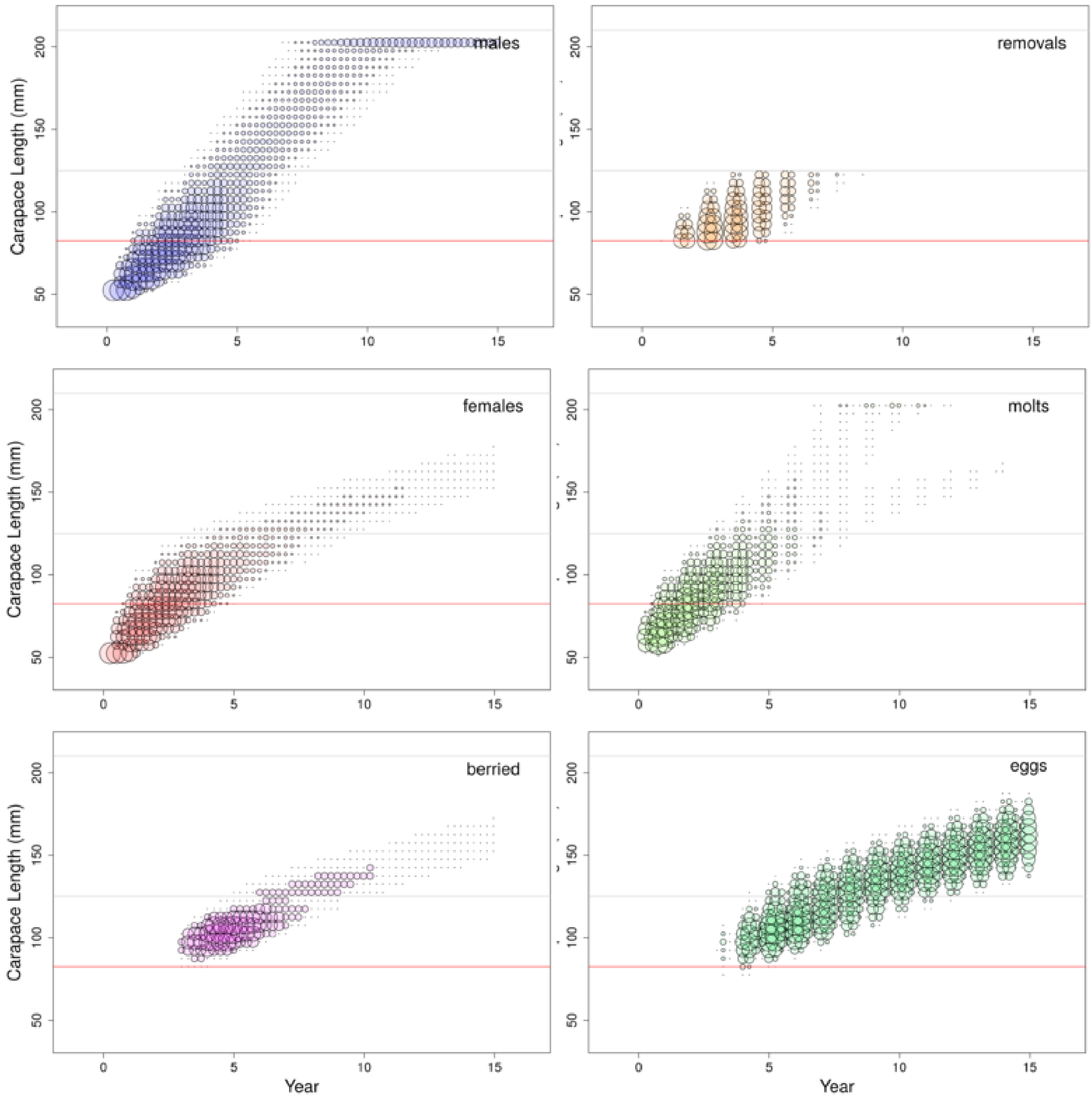


Figure 190: Bubble plot showing the simulated population where a maximum size of 125 mm was implemented for LFA 33E. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

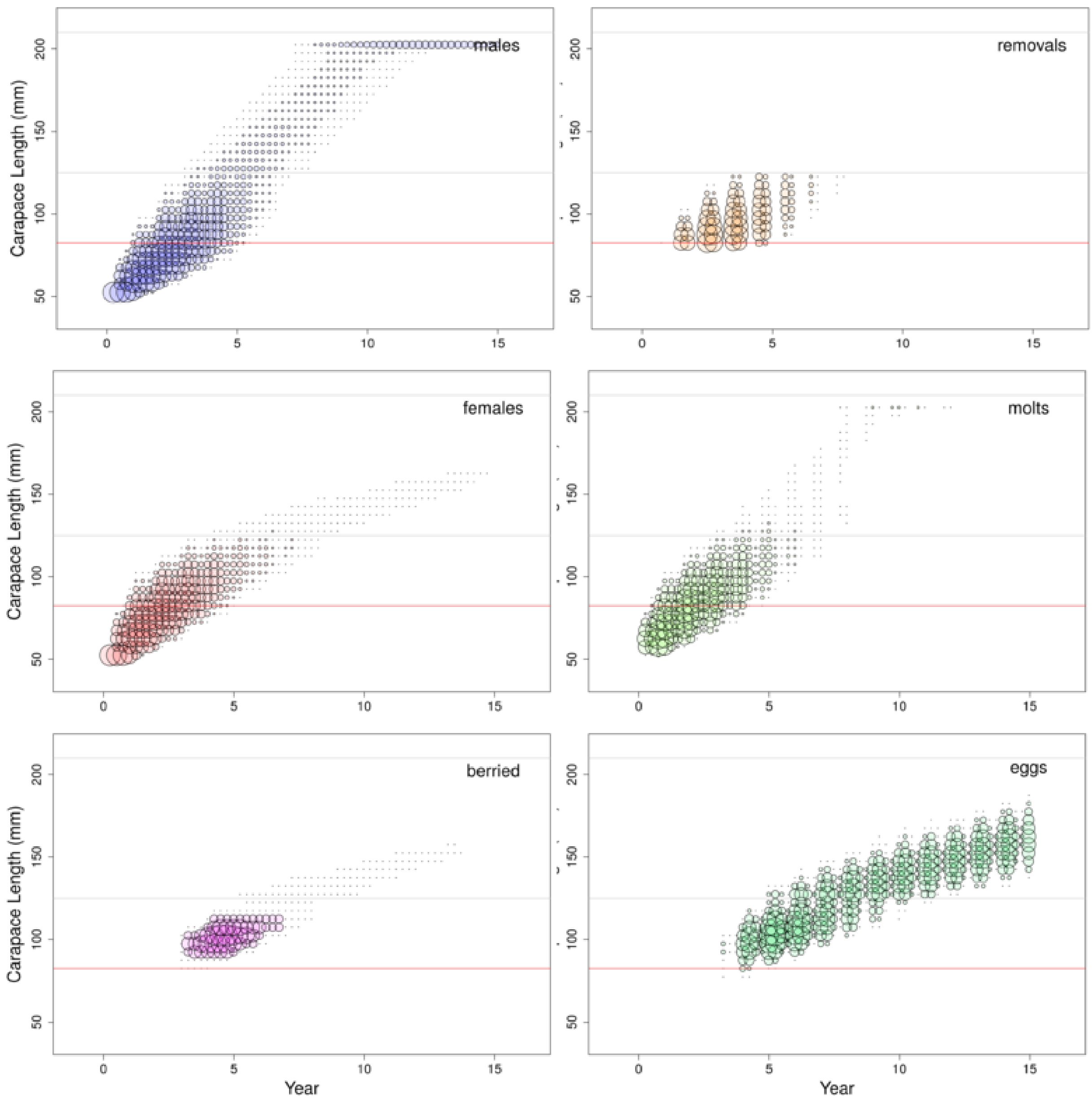


Figure 191: Bubble plot showing the simulated population where a maximum size of 125 mm was implemented for LFA 33W. The diameter of the bubbles are proportional to the log number of Lobster in a given size bin and time step.

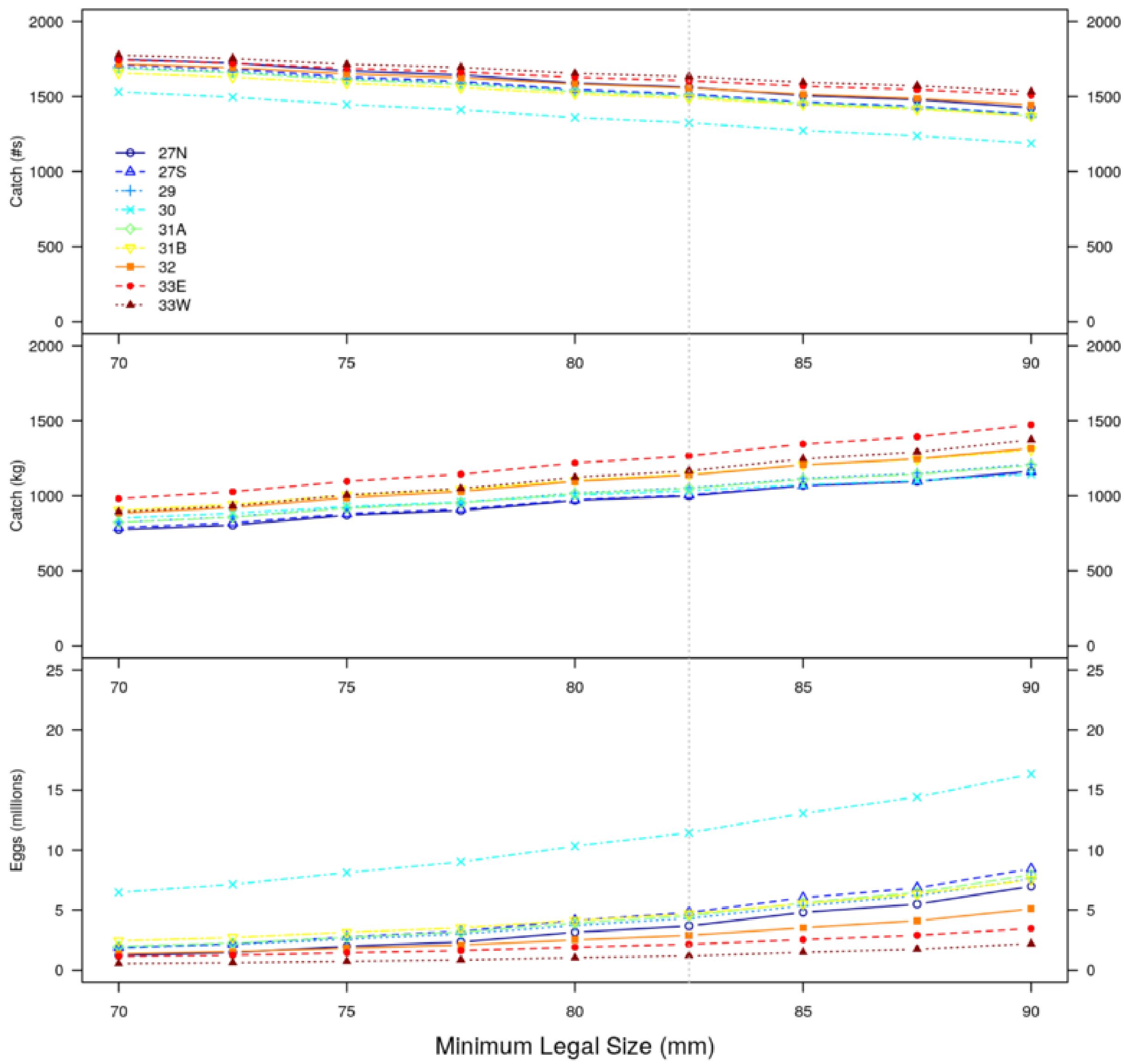


Figure 192: Summary of simulation model results for changes in Minimum Legal Size for each LFA.

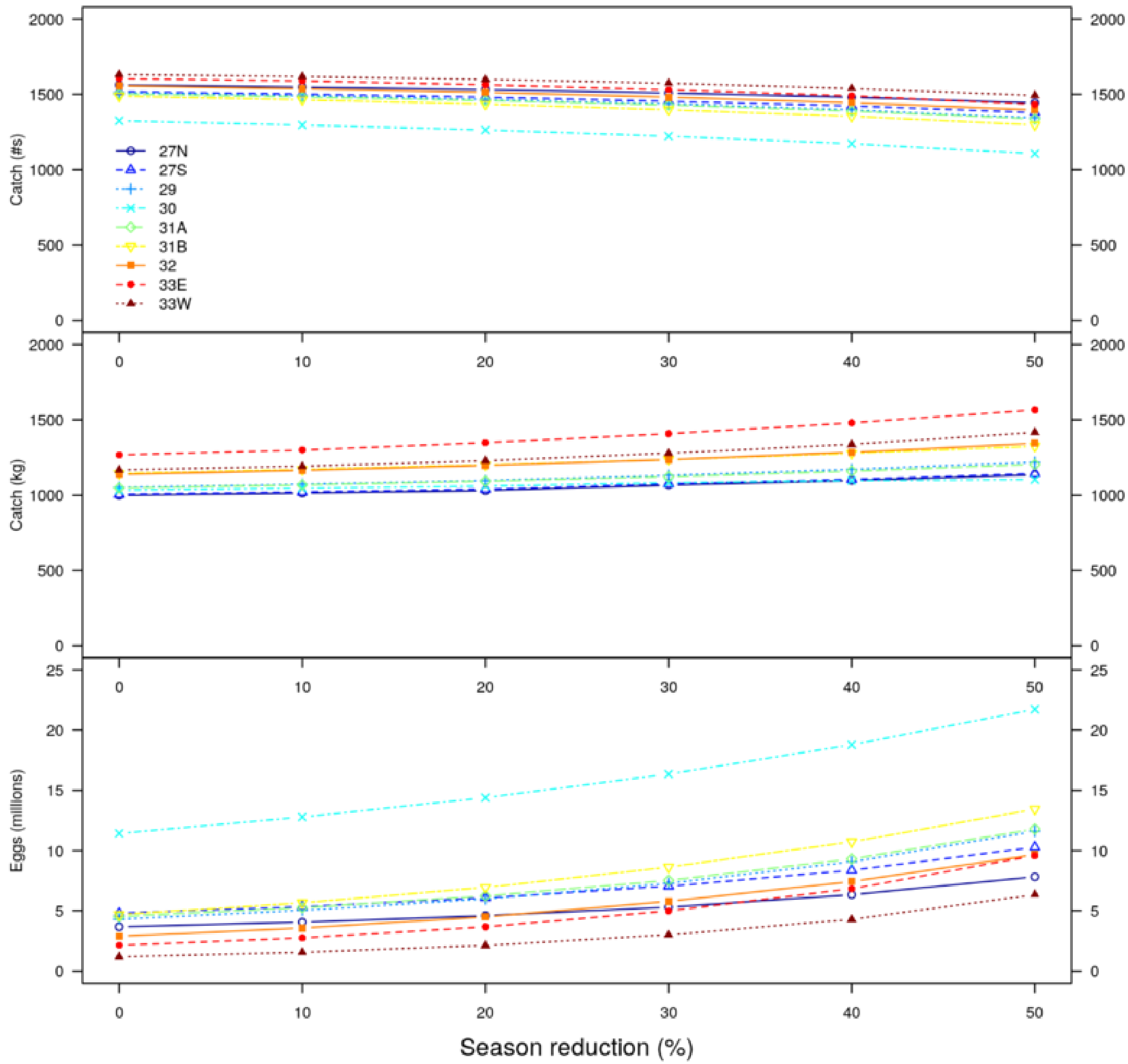


Figure 193: Summary of simulation model results for season reduction in each LFA.