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Assessment of the American Lobster (*Homarus americanus*) Stock Status in Newfoundland (LFAs 3–14C) in 2021/2022

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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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TABLE OF CONTENTS

ABSTRACT

The American Lobster (*Homarus americanus*) is distributed nearshore around the island of Newfoundland and along the Strait of Belle Isle portion of the Labrador coast. Major life history events (i.e., molting, mating, egg extrusion, and hatching) generally occur from mid-July to mid-September, following the fishing season.

This stock was last assessed in 2019 and is currently assessed every three years. The present assessment of this stock was requested by Fisheries and Oceans Canada (DFO) Resource Management to provide current information on the status of the resource to be used in an updated Integrated Fisheries Management Plan. The Lobster Fishing Areas (LFAs) were assessed based on four assessment regions: Northeast Coast (LFAs 3–6), Avalon (LFAs 7–10), South Coast (LFAs 11–12), and West Coast (LFAs 13–14). The key indicators for the assessment are reported landings, catch per unit effort (CPUE), exploitation rate and total mortality in legal sized lobster, and biomass indices. Preliminary total reported landings in 2022 were at their highest level in a century (5,780 t); this reflects increasing trends in the South Coast, West Coast, and Northeast Coast regions, while reported landings in the Avalon region have remained low.

Despite showing signs of persistent high exploitation rates in most areas, all key indicators are consistent in showing sustained signs of growth throughout most areas of the Newfoundland and Labrador Region and immediate recruitment prospects, as well as those for the foreseeable future, appear favourable.

BACKGROUND

SPECIES BIOLOGY

The American Lobster (*Homarus americanus*) is a decapod crustacean characterized by a life cycle which is predominately benthic. Adult lobsters prefer rocky substrates where they can find shelter, but can also live on sand and muddy bottoms (Jarvis 1989, Dinning and Rochette 2019). In Newfoundland waters, at the northern range of the species distribution, it takes approximately 8–10 years for a newly hatched lobster to reach the minimum legal size (MLS) of 82.5 mm in carapace length (CL) (Ennis 1978, 1980). Lobsters have a total lifespan of more than 30 years (Lawton and Lavalli 1995) and growth is achieved through molting. Frequency of molting decreases with increasing age, with large lobsters molting once every few years. Growth is also affected by temperature since molting frequency tends to increase with water temperature (Fogarty 1989).

Molting and mating occur from July to September, and females typically extrude (spawn) eggs roughly one year subsequent to mating. Ovigerous (i.e., egg-bearing) female lobsters carry the eggs in clutches on the underside of their tail, protecting and maintaining the eggs for 9–12 months. Thus, female lobsters are typically characterized by a biennial molt-reproductive cycle (Aiken and Waddy 1982) although smaller mature females sometimes molt and spawn within the same year (Comeau and Savoie 2002). Laboratory studies have shown that large female lobsters (>120 mm CL) can also deviate from the typical biennial molt-reproductive cycle (i.e., successive-year spawning without an intervening molt; Waddy and Aiken 1986, Waddy and Aiken 1990); however, the size at which large female lobsters in nature can spawn in successive years without an intervening molt may vary from what is observed in the lab (Comeau and Savoie 2002).

The fecundity and egg quality of female lobsters increases with size (Aiken and Waddy 1980). Eggs from larger lobsters tend to contain more energy per unit weight, and larger females tend to release larvae earlier in the season, potentially enhancing growth and survival (Attard and Hudon 1987). Hatching occurs during a four-month period extending from late May through most of September, and newly hatched prelarvae undergo an initial molt to Stage 1 before being released by the ovigerous female (Ennis 1995). Once released, the larvae swim upward and undergo a series of three molts during a 4–6 week planktonic phase. Mortality is thought to be greatest during this phase. With the third molt, a metamorphosis occurs and the newly developed postlarvae, which resemble miniature adults, are prepared to settle to the benthic environment. Newly-settled lobsters progress through several stages before reaching sexual maturity (Lawton and Lavalli 1995). The adult lobster is thought to have few natural predators and commercial harvesting accounts for most adult mortality. Lobster diet typically consists of rock crab, polychaetes, gastropods, molluscs, echinoderms, and various finfish (Ennis 1973; Scarratt 1980).

THE FISHERY

The fishery is localized and prosecuted from small open boats during an 8–10 week spring season. Traps are set close to shore, at depths generally less than 20 m. Fishing effort is controlled through restricted number of licenses in each Lobster Fishing Area (LFA, Figure 1), number of fishing days, and daily trap limits. Regulations prohibit the harvest of undersized (<82.5 mm CL) lobster of both sexes and all ovigerous (egg-bearing) females. In addition, there is a voluntary practice of v-notching, which involves cutting a shallow mark in the tail fan of an ovigerous female. The mark remains in the tail for multiple molts and notched females cannot be retained in the fishery. The practice serves to protect mature females from harvest even when they are not brooding eggs externally.

The history of the American Lobster fishery in Newfoundland dates back to the early 1870s. Reported landings initially peaked at almost 8,000 t in 1889 (Figure 2). Early documentation indicates that all lobsters captured were landed and processed by small canning operations that existed around the coast. A stock collapse occurred in the mid-1920s, after which the fishery was closed for three years (1925–27). The fishery reopened in 1928, and reported landings reached over 2,000 t, but dropped sharply the following year. In the early 1930s, shipment of live animals to United States (US) markets commenced, and regulations protecting undersized and ovigerous animals were strictly enforced. By the early 1950s, essentially all landed lobsters were shipped to the US, and the fishery remained a live-market industry since. Effort was largely uncontrolled up to 1976, at which point a limited entry licensing policy was implemented, and daily trap limits were regulated (Ennis et al. 1997).

Following a 17-year period of general decline to 1,200 t in 1972, reported landings increased to about 2,600 t in 1979 (Figure 2). This trend was consistent with those of other Atlantic regions and was attributed to a period of strong recruitment associated with persistent favorable environmental/ecological factors which are still not fully understood. This general increasing trend in Newfoundland landings continued through the 1980s. In January 1986, LFAs were introduced as a new geographical management system to replace Lobster fishing districts (implemented in 1910). A conversion to uniform trap limits, which differ between LFAs, was implemented for all LFAs between the late 1980s and early 1990s.

In 1995, the Fisheries Resource Conservation Council (FRCC) published “A conservation framework for Atlantic lobster”. In this report, the FRCC expressed concerns about the future viability of Atlantic Canada’s lobster stocks, suggesting that high exploitation rates, combined with the considerable harvesting of immature animals could result in decreased egg production and recruitment failure in periods characterized by adverse environmental conditions (FRCC 1995). The report suggested several methods for increasing egg production and reducing exploitation rates, some of which were incorporated into subsequent management plans for the lobster fishery in Newfoundland. There was a 25% reduction in licenses in the Newfoundland lobster fishery from 1998 to 2002 (Figure 3), and the MLS for retention was increased from 81 mm CL to 82.5 mm CL in 1998. Between 1997 and 1998, reductions in trap limits, season lengths, and licenses issued were put in place and deemed necessary by fishery managers. In addition, for West Coast LFAs, a maximum legal size restriction of 127 mm CL was implemented (this conservation measure was lifted in 2015). The Atlantic Lobster Sustainability Measures Program (ALSM) and a Lobster Enterprise Retirement Program (LERP) were implemented in 2010 and 2011, respectively. Together these programs have led to license and trap limit reductions in the Newfoundland lobster fishery, particularly in the South and West Coast regions (Figure 3).

There are currently about 2,300 licenses with trap limits varying from 100 to 300 per licensed fisher, depending on LFA (Table 1). Traps must possess vents (1.75” or 89 mm in height and 152 mm in width) which allow undersized lobsters to escape. The lobster fishery is managed by input controls including number of days fished (i.e., fishing seasons), daily trap limits, minimum CL for retention, and prohibition on landing ovigerous/egg-bearing or v-notched female lobsters.

DATA SOURCES

This assessment was conducted in four assessment regions (Figure 1) which are geographical groupings of LFAs and are based on trends in landings:

1. Northeast Coast region (LFAs 3–6),
2. Avalon region (LFAs 7–10),
3. South Coast region (LFAs 11–12), and
4. West Coast region (LFAs 13–14).

The majority of available data are fishery-dependent, and varied by year, and LFA/region. The reported landings are the only data source that is reported up to 2022 for this stock assessment (2022 landings are preliminary, and include data available up to October).

REPORTED LANDINGS

Data sources included reported landings (provided by the Statistics Division, Policy and Economics Branch, DFO) which were available for each LFA and hence each region. However, due to the Government of Canada's 'Rule of 5' policy, the landings and CPUE for each LFA were combined with adjacent LFAs, as some of the LFAs have less than five fishers, buyers, or vessels. These type of aggregations can limit the robustness of analysis for a localized area. Reported landings are based on purchase and sale slips and are underestimated by an unknown amount because they do not account for local sales, poaching, and handling mortalities that can occur prior to the sale of the catch. The extent of local sales can be considerable and varies by location and year. Despite a level of underestimation, reported landings are thought to reflect abundance/biomass to some extent, since most of the exploitable biomass is caught in the year of recruitment to the fishery.

ADJUSTED LANDINGS

In order to develop indices for exploitable biomass and fisheries mortality, landings estimates need to be determined to better reflect true commercial removal levels. Accordingly, landings were re-scaled based on an adjustment factor (*Af*) defined as the ratio of the number of harvesters reporting a minimum of one sale to a processing facility to the number of harvesters registering for a fishing license in any given LFA each year (Figure 3). The *Af* was used alongside reported landings (landings / *Af*) to re-scale the landings for each LFA and assessment region.

FISHERY MONITORING

Fishery Logbook Data

Two sources of logbook data are available from the fishery: one from an index harvester program ("Food Fishery and Allied Workers Union (FFAW) logbooks") and one from a mandatory DFO program ("DFO logbooks"). Both programs capture self-reported information on date of fishing activities as well as numbers of lobster caught, and traps fished.

For the FFAW logbook series, data were available from 2004 to 2021 for each region and were utilized in the 2022 assessment, with representation from most LFAs for most years (Tables 2a, 2b, and 2c). Throughout the commercial lobster fishing season, beyond information on catch from commercial traps, fishers participating in this program collect information on the catch from modified (closed escapement) traps designed to prevent escapement of pre-recruit lobsters. The data are captured (in numbers) for groupings of lobster defined as eligible for harvest, ovigerous females, and both undersized males and females.

For the DFO logbook series, fishers are mandated to maintain a logbook detailing date of fishing, numbers of lobsters kept, and traps fished. This logbook program was implemented in

2010. Despite being mandatory, return rates are relatively low, averaging approximately 50% since 2010 and being as low as 30% in 2013/2014.

Logbook data have also been collected from the Eastport Marine Protected Area in LFA 5 (Northeast Coast region) since 1997. To be consistent with the time series of other data sources used in the assessment , these were only included since 2004.

At-Sea Sampling Data

At-sea sampling data from 2004 to 2021 were utilized in the 2022 assessment (Figures 4 and 5). These data have consistently been collected in the Northeast Coast region (LFA 5 since 1998 and LFA 4B since 2004) and in the South Coast (LFA 11) and West Coast regions (LFAs 14A and 14B) since 2004 and Avalon region (LFA 10) since 2005, with data from additional LFAs available in 2004–05 and since 2009 (Figures 4 and 5, Table 3).

At-sea sampling programs have employed observers who record daily catches onboard fishers' boats in specific locations around the province. Where possible, every trap is sampled and CLs of all lobsters, both commercial and non-commercial size, are recorded to the nearest mm. Lobsters which measure the MLS of 82.5 mm CL are recorded as 83 mm CL. Individuals are placed into one of seven categories to account for sex and, if female, reproductive status and presence or absence of a v-notch. These data are used to produce an index of population structure. The categories are as follows:

1. male,
2. female, non-ovigerous, no v-notch,
3. female, non-ovigerous, new v-notch,
4. female, non-ovigerous, old v-notch,
5. female, ovigerous, no v-notch,
6. female, ovigerous, new v-notch, and
7. female, ovigerous, old v-notch.

Modified (closed escapement) Trap and Temperature Data

Since 2007, modified (closed escapement: targeting pre-recruit/sublegal size lobster) traps have been distributed to index fishers and deployed throughout various LFAs (Figures 6 and 7). Logbook data and at-sea data were collected and reported on all lobsters caught from these traps. The catch rates (number lobster/trap) and size distributions (by sex) for each region are displayed using the at-sea sampling data from the modified traps.

Temperature probes were also attached to several of these modified traps during the fishing season. Mean temperatures from this data source were calculated on a monthly basis within each LFA, and also calculated over the time series (2007–21) for each region.

TRAP SURVEYS

Fisheries-independent trap surveys took place in April and May, and July from 2018 to 2022 in Conception Bay, in June 2021 and 2022 in Port Saunders, in September from 2020 to 2022 in Comfort Cove and in April 2022 in Harbour Breton (Figures 8 and 9). At each location approximately 50 traps were deployed including commercial and modified (closed escapement) lobster traps at depths between <5 m to 25 m. All lobster caught were measured and data were collected on reproductive status, v-notch status, and shell condition, along with pot soak times, locations, bycatch, and bottom temperature obtained through temperature probes.

Data from the lobster trap surveys were used to develop a selectivity adjustment curve to apply to length frequency data from modified and commercial traps in both survey and at-sea sampling data.

METHODS

TRAP SELECTIVITY

Due to the short time-series of fisheries independent trap surveys, only the at-sea sampling commercial trap data are sufficient to attempt any time-series examination of demographic-specific differences in resource status. However, due to the escape vents used in commercial traps (1.75”), commercial traps do not capture a consistent signal of under-sized lobster, and thus cannot be used to assess relative abundance or mortality.

A selectivity conversion to the commercial trap data measurements from the at-sea sampling data was developed to re-shape length frequency distributions from commercial trap data to realistically determine abundance of pre-recruit lobster in the population and provide an accurate analyses of mortality and recruitment.

The modified trap data from the lobster survey were used to develop selectivity curves instead of the data from the modified traps from the at-sea sampling data series because of the low ratio of modified traps in that dataset. The high ratio of modified to commercial traps (i.e., ~50:50) in the lobster trap survey data were more appropriate for this type of analysis.

To develop a selectivity curve, survey catch data were matched by trap type (commercial versus modified) and day for any given survey (i.e., location or year). Subsequently, lobster were binned to 4 mm CL increments and the mean of daily catch rates (number per trap) of the ratio of commercial to modified trap catch rates for each length bin was calculated and used as the response variable in a logistic regression model. Since the lobster survey data from Conception Bay had the longest time series, the model was initially fit to Conception Bay alone (i.e., a control site with five years coverage) versus all other survey sites (shorter time series). The idea behind combining survey sites and years was that the capture efficiency index should be invariant to different densities of lobster (i.e., the relative capture efficiency should be constant at different densities) and the matching of data by day was assumed to largely control for soak time differences among traps, with commercial and modified traps being both set and hauled in uniform fashion (i.e., ~equal numbers deployed and hauled each day) during each survey.

Before fitting the selectivity model, data were restricted to a CL range of 57–85 mm, as this was a range in which the logistic function was expected to rapidly increase, as shown in previous studies (i.e., Estrella and Glenn 2006). It should be noted that size-specific observations above the size at which a capture efficiency ratio of 1 was first achieved in the observation data (78 mm CL) were set as 1 prior to fitting the model to allow a model of binomial form to be fit.

A generalized additive model (GAM) was used in the MGCV package (Wood 2017) in R (R Core Team 2023) to fit the selectivity model (Figure 10a). The simplistic model used the response variable of the mean ratio of number per trap against a single (thin-plate smoothed) predictor variable of size (CL). A quasi-binomial family was used, which reflected both the proportional nature of the response variable and the presence of 0 and 1 values in the data (i.e., beta regression would not allow for 0 or 1 values). A logit link was used, reflecting the logistic nature of the process, and seven basis knots (k = 7) were used for fitting along the CL continuum.

The selectivity model is defined as:

$$rComm \sim s(CL) \quad [1]$$

where rComm is ratio of catches in commercial traps and s(CL) is smoothed CL.

Model fits were assessed based on visual assessment of residuals (Figure 10b) and high adj. r^2 values for the two initial model runs (Conception Bay [adj. r^2 = 0.96] and other areas [adj. r^2 = 0.99]). Upon determining strong consistency in shape of the capture efficiency process between the control versus other survey sites, a model with all areas pooled was run for final determination of size selectivity adjustment factors to apply to the commercial at-sea time series measurements data. A qualitative comparison to conformity of the constructed selectivity curve to those presented in Estrella and Glenn (2006) for 2” to 2 & 11/16” escape vents was made prior to applying selectivity adjustments to the commercial trap data for the assessment.

FISHERY PERFORMANCE

CPUE (Unstandardized)

Using both the FFAW index fisher (2004–21) and DFO logbook (2010–21) data collected within each assessment region, CPUE (number of lobster/trap hauls) was calculated by day, month, and year, for individual fishing trips. Mean annual unstandardized CPUEs were subsequently calculated within each region, and CPUE plots were generated to compare trends from both logbook data sources. Using the DFO logbook data, annual CPUE was also calculated (2010–21) for each LFA, and on a weekly basis (5-day bins) to examine fishery performance throughout the season in each LFA and respective region from 2016 to 2021.

CPUE (Standardized)

The two sources of fishery logbook data created potential for both redundancy and divergence in estimating and interpreting fisheries catch rates. Unstandardized CPUE as presented in previous assessments (Coughlan et al. 2023) was recognized to be prone to biases stemming from individual fishing practices, spatiotemporal differences arising from adaptive fishing practices, or natural variation within and across fishing areas and seasons. Accordingly, a standardized CPUE index was developed for this assessment.

Relatively few variables were available to include in a CPUE standardization model as logbook information were limited to time (day of year) and space (LFA) of gear retrieval and the associated catch (number of legal lobster) and effort (number of trap hauls). Nonetheless, the spatial LFA term and the temporal day and year terms were considered useful explanatory variables to include in a CPUE standardization model.

CPUE was standardized within a generalized additive mixed model (GAMM) in the MGCV package. Day was treated as a continuous variable and refers to calendar day (on a 365 increment scale) and interacted with the continuous year variable with a tensor product (‘te’) interaction (i.e., “full interaction”) applied to a thin-plate smoothing spline (‘tp’). The interaction was fit with 12 basis knots (k = 12) to enable sufficient variability in trend to occur in model fits within the 18-year time series (2004–21). This temporal interaction term was fit by assessment region. LFA and Source (either DFO or FFAW logbook series) were treated as factor variables and implemented as random effects within the model, with the number of basis knots set to k = 6 and k = 2 respectively to conform to a limited number of LFAs in each assessment region along with two data source types. The LFA term was fit by assessment region while the data type source term was treated as a global effect term. A tweedie family distribution and associated log link were used to linearize the relationship between the response and predictor variables due to a priori observations that the distribution of CPUE was right-skewed (long right tail) in both data sources and all assessment regions, and that there were observations of zero catches in the data.

The bam option ("big gam") was used in lieu of GAM in fitting the model due to the large data size and to reduce computational time. The CPUE standardization model is described as:

[2] CPUE ~ te(day, year : Region) + s([r]LFA : Region) + s([r]Source)

Where, CPUE is fishery catch per unit of effort, day is calendar day, year is a continuous variable, LFA is lobster fishing area, and Source is FFAW or DFO logbooks. te denotes a tensor smoothing spline and s denotes a thin-plate smoothing spline. Region indicates an effect was fit by region, while [r] indicates a random effect.

Model fit was assessed as sufficient based on visual assessment of calculated residuals (observed – predicted values) from the input versus predicted data as well as the adjusted r^2 statistic for overall model fit.

Effort

Estimation of fishing effort was made through a series of conversion calculations. First, standardized fishery catch rates were transformed from #/trap to kg/trap through applying weights to mean sizes of animals in the catch, by sex. The mean sizes were based on a weighted mean from commercial traps in the at-sea sampling data, with length-specific sample sizes used as the weighting factor. These size means were subsequently converted to weights using length-weight relationships reported in Ennis et al. (1986). Note that for females, x and y parameters in the regressions were averaged for those reported for ovigerous versus non-ovigerous animals in the Ennis et al. (1986). The sex-specific index of kg/trap was subsequently calculated as the product of average weights by sex * pSex, which represented the proportion of the annual catch by sex calculated from at-sea sampling data. Finally, annual effort was estimated based on a given landings index (reported or adjusted) divided by the kg/trap index.

POPULATION DYNAMICS

The at-sea sampling data were used to generate metrics of population dynamics, including stage-specific (including pre-recruits, recruits, ovigerous, and larger lobster) relative abundances, the average size of individuals in the catch, the average size of ovigerous females in the catch, sex ratios, and size-at-ovigerous for females. Selectivity-adjusted length-frequency distributions from commercial trap data were used to investigate modal size structure in the population and as the basis for estimating total mortality and exploitable biomass. Selectivity-adjusted length frequency data from the localized surveys were also used to investigate for presence of modal structure in the population.

Stage-Specific Abundances

Mean lengths of total catch and ovigerous females in the catch were calculated from at-sea sampling data by assessment region and year to investigate changes in size structure of the population.

CPUEs of specific stages including pre-recruits (<83 mm CL), recruits (≥83 mm CL), large lobster (>110 mm CL), and ovigerous female lobsters were examined using at-sea sampling data to infer relative abundances for each group. The ovigerous females were further partitioned into pre-recruit (<83 mm CL) versus legal size (≥83 mm CL) groups. Mean CPUE for each group was generated annually by calculating the sum of total catch from traps sampled divided by the average number of traps sampled for each fisher, day, month, and year within each assessment region.

Sex ratios were estimated for each year as the proportion of females over males for each of the four assessment regions from 2013 to 2021 and sex ratios for all years combined over the size range for each region for 2004–21 were demonstrated as well. In addition, the proportion of ovigerous females for all years combined over the size range were also demonstrated in line plots for each region.

The at-sea sampling data were used to estimate proportions of females for each maturity category (including ovigerous, non-ovigerous, ovigerous v-notched, non-ovigerous v-notched) over the entire size ranges, for all years combined (i.e., 2005–21) for each of the four regions, prior to a model developing an annual estimate of size-at-ovigerous through a regression model.

Size-at-Ovigerous

A GAM using MGCV package was used to estimate proportions of female lobster ovigerous at length. The at-sea sampling data were binned into 8 mm CL units and the model regressed the response variable of the proportion of females that were classified within one of the ovigerous categories by size against explanatory variables of non-parameterized year and a full tensor product interaction of CL and year fit with a smoother. A quasi-binomial family was used due to the proportional nature of the response variable and presence of 0 and 1 values in the data. A logit link was used, reflecting the logistic nature of the process. A weighting term of length-bin specific sample sizes was used to help the model fit to the data. Four separate model runs were conducted, one for each region.

[3] $$pOvig \sim year + te(CL, year)$$

Where, pOvig proportion of female lobster that are ovigerous year is a continuous variable, CL is binned to 8 mm units, and te denotes a tensor smoothing spline.

Model fits were assessed based on visual assessment of residuals and high adj. r^2 values (range 0.76 in the South Coast region to 0.93 in the Northeast Coast region; Figure 51a).

Bi-annual fits of the model to the data were shown for each region and sizes at which 50% of the females in any given year and region was predicted to be ovigerous were estimated and plotted. Finally, the interaction of the partial effects of CL and year were shown as contour plots. This was done to help visualize potential shifts in the process over time.

Size Modes

Selectivity-adjusted commercial trap data from surveys and the fishery were examined for the presence of size modes. This was done for several reasons, first, it allowed for a qualitative examination of potential instar (a mode/phase between two period of molting) and age structure in the population (i.e., via comparisons with existing size and age estimates) and by extension how the current legal size benchmark of 82.5 mm CL may relate to age or instar structure in the population. The examination of size modes allowed for an investigation on whether or not the current pre-recruit size range used to report on recruitment potential in the assessment (i.e., <82.5 mm CL (83mmCL)) should be refined to more precisely identify pre-recruits, and finally, the analysis enabled an exploration on temporal differences in size structure between the fishing season versus the surveys within any given assessment region.

The investigation for the presence of size modes in the selectivity-adjusted survey commercial trap data was done using the mixtools Package (Benaglia et al. 2009) in R. For this exercise, all years of data were pooled by survey sites and a mixture analysis was applied by sex to size-specific catch rates. The exercise was undertaken with no specified model training on location (or spread) or number of modes, with the analysis limited to 61-85 mm CL lobster due to low sample sizes both before and after these sizes in the data. Effectively, the package was free to define the locations of modes (using the normalmixEM function), which specified identification of modes following a normal distribution, if they were present. The modal mean size and spread of each mode was displayed for each survey site. The investigation for the presence of size modes in the selectivity-adjusted at-sea sampling commercial trap data was done with the same procedure, but the analysis was limited to April-May (early season) samples to allow detection of modes before the fishery had sufficient time to substantially deteriorate the length frequency distribution.

Total Mortality and Exploitable Biomass

Length converted catch curves (LCCC) were used to estimate total mortality in legal sized lobster. Age conversions were done in consideration of the slowing molt and associated growth rates as lobster age. Accordingly, a length conversion to relative ages was deemed more appropriate than length in fitting linear mortality rate regressions to demographic data because large lobster in the population would decrease regression slopes more substantially in a strictly length-based fit than an approximated age-based fit that followed an asymptotic-shaped age-length conversion.

Length to relative age conversions were based on data presented in Ennis et al. (1986) who presented sex-specific von Bertalanffy growth curves for both sexes. However, due to particular uncertainty in the growth function of females in that study, and no need for precision in our estimations (i.e., relative ages), we approximated averages for the two sexes combined in constructing our “modified-Ennis” length-age curve (Figure 11). These approximated ages at length were applied to both sexes in the selectivity-adjusted at-sea commercial trap data (note S (Selectivity) = 1 in these sizes). Catch rates (#/trap) of individual CL groups for 82-116 mm CL lobster were natural-log transformed and a temporal rate representing change in time (dt) was applied based on the difference in relative age from the present to preceding length bin [4].

[4] $$\mathrm{dt} = \mathrm{r.age}(\mathrm{CL}[\mathrm{i}]) - \mathrm{r.age}(\mathrm{CL}[\mathrm{i}-1])$$

Where, dt is change in time, r.age is relative age, CL is carapace length, and i is CL stage.

Slopes from simple linear regressions of the form [ln(#/trap / dt) ~ r.age] fit by year and sex for each region were used to estimate total mortality (Z) in legal sized lobster, with standard errors (1.96 x s.e.) used to calculate upper and lower confidence intervals for mortality rates. Note the omission of lobster >115 mm CL removed sporadic incidence of outliers in the data which attributed to unrealistic regression slopes in the uncommon occasions when they were present in the sampling data. Simple loess regression curves were fit to the sex-specific mortality indices for presentation of trends.

Indices of exploitable biomass for legal sized lobster (by sex) were derived from the total mortality estimates (converted to annual [A] scale as $A = 1 - (e^{-Z})$) in conjunction with landings information and an additional estimated parameter of annual natural mortality rate, which was estimated at 5%. To estimate landings by sex, proportions of males and females in the legal sized catch from the at-sea sampling data [pSex] by region and year were calculated and applied to both the reported and adjusted catch. Thus, two biomass estimates were made, one reflecting each measure of landings.

[5] $$\text{Exploitable Biomass} = ((\text{landings} * \text{pSex} * 1.05) / \mathrm{A}))$$

Where, landings are either reported or adjusted landings, pSex is the proportion of legal sized lobster in the catch by sex, 1.05 represents a 5% natural mortality adjustment, and A is annual mortality rate.

Sex-specific estimates of biomass along with an additive (both sexes) index of total biomass were plotted for both metrics of landings (reported versus adjusted) for consideration in the assessment. In extension, fishery exploitation rates, defined as ((landings * pSex) / biomass) were presented by sex as well as in total. Note that both the reported and adjusted landings produced the same results for exploitation rates because landings ultimately scale biomass estimates using this method.

MANAGEMENT CONSIDERATIONS

V-notching

The proportion of v-notched females was calculated for all years combined over the size range for each region. The number of lobster/trap separated by categories (i.e., males, ovigerous females, old v-notched ovigerous females, non-ovigerous females, and old v-notched non-ovigerous females) was presented as size frequency distributions for each of the four assessment regions from 2012 to 2021.

Index fisher logbook data were used to generate plots displaying the percentage of v-notching of ovigerous females (number of ovigerous females v-notched that day/total commercial ovigerous females) annually within each region.

Per-Recruit Models

Estimations of exploitation rate indices which were likely near true levels in legal- size lobster in this assessment enabled an exploration of useful management strategy models, in particular per-recruit metrics such as yield (long-term catch weight), spawner (animals reaching mature stages) and egg (population-level egg production) per-recruit metrics. These metrics were estimated to provide guidance on how the fishery and population may be performing relative to potential management benchmarks.

For the yield-per-recruit (YPR) model, an arbitrary sequence of CL ranging from 40 to 140 mm was first constructed for each sex. These sizes were then assigned weights based on the aforementioned length-weight relationships presented in Ennis et al. (1986). Next, arbitrary stages meant to conform to approximate modal centers were defined for each sex based on growth increments presented in Ennis et al. (1986). These stages were 50, 60, 70, 80, 92, 106, and 122 mm CL for males and 50, 60, 70, 80, 88, 96, 104, and 110 mm CL for females. Using the MQMF package in R (Haddon 2020), we simulated transition of a starting population of 10,000 animals for each stage group over time for fisheries harvest rates ranging from 5 to 95% per year and an assumed natural mortality rate of 5% per year. The model also incorporated trap selectivity as previously described (i.e., Figure 10), using the 'all survey sites' index of length-specific S to refine the pattern of mortality rates in the simulated populations. Lifetime yields were calculated for each stage class in the model as well as the for the compilation of stage classes examined.

To develop spawner per recruit (SPR) estimates, an additional parameter of proportion mature by year and size, as estimated from the logistic ovigerous model, was introduced to the abundance estimates generated in the simulated YPR model. Further, an index of fecundity at size, estimated from relationships presented in Seiden et al. (2012), was applied to estimate egg per recruit (EPR). Each SPR and EPR model was presented by year class and region.

RESULTS AND DISCUSSION

REPORTED LANDINGS

Total reported landings for Newfoundland increased from approximately 1,900 t in 2010 to 4,572 t in 2019, then to the highest level in a century in 2022, with landings of 5,780 t (Figure 2, Tables 4 and 5). This peak in landings is approximately 2,800 t higher than the 20 year mean. This reflects increasing trends in the Northeast, South, and West Coast regions, while the landings in the Avalon region declined throughout the 1990s to mid-2000s and have remained low for more than a decade (Figure 12 and Table 5). Reported landings for 2022 are preliminary and are based on catch and effort reports up to October 2022.

Northeast Coast Region (LFAs 3–6)

From the early 1950s to the late 1960s, the reported landings in the Northeast Coast region averaged approximately 700 t then declined to around 300 t by the mid-1970s (Figure 13). The landings increased again to an average of 700 t in the 1980s then declined from 750 t in the early 1990s to approximately 430 t in 2022 (Table 6). Since 2011, the combined landings in LFA 3 (White Bay) and 4A (Notre Dame Bay) have averaged approximately 29 t, with 58 t in 2022. In LFA 4B , the landings have increased from approximately 75 t in 2019 to approximately 220 t in 2022. The landings in LFA 5 (Bonavista Bay) remained stable with an average of 90 t between 2019 and 2022. The landings in LFA 6 averaged 25 t between 2019 and 2021 and increased to 41 t in 2022 (Figure 13).

Avalon Region (LFAs 7–10)

Reported landings in the Avalon region averaged 150 t from the early 1950s to the mid-1970s, then increased to an average of 460 t in the 1980s and up to the early 1990s (Figure 14). The landings have since declined from approximately 460 t in the early 1990s, averaging 40 t since 2009, with approximately 71 t in 2022 (Table 7). In LFA 10 (Placentia Bay), the landings declined from approximately 53 t in 2009 to 10 t in 2021 then increased to 43 t in 2022. In LFA 7 (Conception Bay), the landings have averaged 25 t between 2020 and 2022, which constitutes 50% of the landings for the Avalon region. The combined landings from LFA 8 and 9AB (St. Mary’s Bay) have averaged 1 t since 2009, with 4 t in 2019, 3 t in 2020, 0 t in 2021, and 3 t in 2022.

South Coast Region (LFAs 11–12)

In the last decade, commercial lobster fishing in the South Coast region accounted for approximately 30 to 40% of the reported landings for the whole province. From the mid-1970s to early 1990s, reported landings averaged 400 t and increased by 70% to peak at approximately 1,300 t in 2010 (Figure 15); reported landings averaged 1,100 t from 2011 to 2015, and then increased to 1,744 t in 2022 (Table 8). LFA 11 (Fortune Bay) accounts for 75 to 80% of the landings in the South Coast region.

West Coast Region (LFAs 13A–14C)

Since the early 2000s, the reported landings in the West Coast region have accounted for approximately 50% of the total reported landings in Newfoundland and Labrador (NL) (Figure 16). Reported landings in this area have varied since the early 1950s, and averaged 600 t up to the early 1970s, then increased from 950 t in 1976 to 1,600 t in 1989. They continued to vary before decreasing to approximately 750 t in 2000; they have since increased up to 2,400 t in 2019 and 3,530 t in 2022 (Table 9). In LFAs 13A and 13B, the reported landings have increased by 60% since 2015, to 680 t and 1,160 t, respectively, in 2022. In LFA 14A landings increased from 520 t in 2019 to 920 t in 2022, and in LFAs 14BC, combined landings increased from 430 t in 2019 to 760 t in 2022 (Figure 16).

REPORTED AND ADJUSTED LANDINGS

The trends in reported landings compared to adjusted landings (Figure 17) for each LFA, from 2010 to 2021, demonstrates a very similar trend (and magnitude) for the South and West Coast regions. However, the adjusted landings are higher than the reported landings over the time series in the Northeast Coast and Avalon regions, where in recent years they have been about double the reported landings. In the Avalon region there seems to be considerable variability in the results for LFA 8 and 9AB, but these LFAs account for a small portion of the regional level.

When comparing the reported landings and adjusted landings on a regional scale, the adjusted landings are higher (approximating or exceeding double in recent years) for the Avalon and Northeast Coast regions but show tight conformity in the South and West Coast regions (Figure 18).

The landings adjustment invokes an assumption that harvesters reporting sales sell all catch to processing facilities each year. Although this assumption is likely not always met, the close association between the reported versus adjusted landings in the South and West Coast regions (Figures 17 and 18), where the largest scale fisheries occur, suggests that in many cases the majority of sales from individual harvesters are indeed captured in the reported landings database and provides some assurance that the re-scaled landings estimates more accurately reflect true landings in the fishery in the data poor Northeast Coast and Avalon regions in particular.

TRAP SELECTIVITY

The trap selectivity model showed tight conformity between the models to the Conception Bay control site versus all other survey locations (Figure 10). In both cases, and more generally in the combined sites model curve, it was apparent that the most abrupt change in selectivity occurred from about 72 to 78 mm CL, increasing from a level of about 25% to 90% capture efficiency in commercial lobster traps over that size range. This knife-edge selectivity pattern closely reflected those shown in Estrella and Glenn (2006), for which sizes conforming to roughly 25% and 90% capture efficiency in 2” rectangular escape vent traps occurred at about 80 and 88 mm CL, respectively.

FISHERY PERFORMANCE

CPUE (Unstandardized) Trends

FFAW index logbook data, available since 2004, were used to compute annual mean unstandardized CPUE (i.e., number of lobster caught per trap haul) for each region. CPUE was also calculated from the DFO mandatory logbooks (2010–21), and comparisons with FFAW index logbook data showed similar trends within the four assessment regions (Figure 19).

Throughout the time series, the highest mean unstandardized CPUE values were from the South Coast and West Coast regions. This, along with landings data, suggests a higher density of lobsters along the South and West Coasts, compared to other regions. In the South Coast region, the CPUE increased from 0.75 in 2011 to approximately 1.5 in 2021; in the West Coast region CPUE increased from 0.45 in 2011 to 1.25 in 2021 (Tables 8 and 9). In the Northeast Coast region the CPUE increased from 0.36 in 2018 to 0.52 in 2021 and in the Avalon region

CPUE remained low throughout the time series, and was approximately 0.30 in 2021 (Figure 19, Tables 6 and 7).

DFO logbook data were also used to calculate unstandardized CPUE in each LFA from 2010 to 2021. For the Northeast Coast region the trends in CPUE by LFA (Figure 20) showed all unstandardized CPUE increased between 2018 to 2021 to approximately 0.4. In the Avalon region the unstandardized CPUE when compared between LFAs showed a higher CPUE of approximately 0.3-0.35 in LFAs 7, and 8, 9AB combined, and closer to 0.2 in LFA 10 (Figure 21). The unstandardized CPUE for the South Coast region (LFAs 11 and 12 combined) showed an increase in CPUE from 1.1 in 2018 to 1.6 in 2021 (Figure 22). In the West Coast region all LFAs have a similar trend with the lowest CPUE in LFAs 14A and 14BC, around 1.0 in 2021 and the highest CPUE In LFA 13B close to 2.0 since 2020 (Figure 23).

DFO logbook data were used to calculate unstandardized CPUE throughout the fishing season within 5-day bins for each LFA and respective regions from 2016 to 2021. The general trend is similar in the Northeast, South, and West Coast regions, where CPUE begins high early in the season and then declines and stabilizes at a low level (i.e., close to 0 or 1 lobster/trap) near the end of the season (Figure 24). However, for the Avalon region, the CPUE values tended to remain at a low level throughout the season and were often consistently low over the entire time series. When looking at the trends in unstandardized CPUE over the season in each LFA within the Northeast Coast region the CPUE specifically starts out higher early in the season in LFAs 4B and 5 from 2018 to 2020 and then drops off near the end of the season (Figure 25). In the Avalon region unstandardized CPUE remains low throughout the season besides in 2018 in LFA 7 where the CPUE started out slightly higher early in the season (Figure 26). In LFAs 11 and 12 combined the CPUE trend is similar as shown in South Coast trends in Figure 24 where in 2019 and 2021 the CPUE increased at the end of the season (Figure 27). For the LFAs in the West Coast region the unstandardized CPUE values showed similar trends for all LFAs over the season with the higher CPUE early the season and lower CPUE late in the season (Figure 28).

There are issues associated with using unstandardized CPUE as an index of abundance. Trap density and competition can affect how well catch rates measure local densities and fishing practices can affect catchability (McLeese and Wilder 1958; Miller 1990). Fishing practices may vary between fishers where soak times and redistribution of traps can vary greatly, and it is common for fishers to reduce effort substantially in the final weeks of the lobster season. Also, many lobster fishers hold licenses for other species (e.g., Snow Crab) and will adjust effort to permit harvest of these other species (Collins et al. 2009). Therefore, work has been conducted to develop standardized CPUE to ensure there is a better estimate of catch rates within the fishery.

CPUE (Standardized) Trends

The CPUE standardization model showed no systematic trends in residual fits to either the DFO or FFAW logbook series (Figure 29) and overall fit to middle-ground observations of the two data series over the time series and well reflected the progressive increase in CPUE captured by both data series respectively over the time series in both at the LFA and assessment region levels (Figure 30). The overall model adjusted r^2 was 0.43. Fisheries CPUE has progressively increased over the time series in all assessment regions. In Avalon it increased from 0.17 to 0.29 lobster/trap from 2005 to 2021, while during that same time it increased from 0.17 to 0.43 in the Northeast Coast, 0.60 to 1.52 in the South Coast, and 0.42 to 1.12 in the West Coast (Figure 31).

Modified (closed escapement) Trap and Temperature Data

The at-sea data from the modified traps were demonstrated in size frequency distributions and showed very low numbers overall (Figure 32). However, it should be noted this may be due to limited sampling in some LFAs where modified traps were deployed.

The trends in the average temperature from 2007 to 2021 based on the temperature probes attached to the modified traps were variable (Figure 33), as these probes were not always consistently placed in the same locations annually. In the Northeast Coast region, the average temperature increased until it peaked in 2017 at approximately 7°C. The Northeast Coast region had the highest temperature range with the highest average temperature above 7°C in 2020. For the other regions, the temperatures were variable, but followed similar trends through the time series, with average temperatures usually below 5°C and an increase in temperatures to between 6°C and 7°C in 2021. In Figure 34, the monthly temperature is displayed for each LFA in each respective region and, as expected, the mean temperature increases gradually from April to July.

Effort

Overall, there has been an estimated average of 22.23 million trap hauls per year in the fishery over the 2004–21 period, based on adjusted landings. This corresponds to an average of 2.7, 5.3, 5.5, and 9.2 million trap hauls on average each year in the Avalon, Northeast Coast, South Coast, and West Coast regions, respectively. Effort has been relatively steady in each region since 2016, averaging an estimated 2.6, 4.7, 5.0, and 8.8 million traps hauls for each region respectively (Figure 35).

POPULATION DYNAMICS

Stage-Specific Abundances

Average Carapace Length

The at-sea sampling data were used to calculate the average CL of lobster within each region. Average size is larger (above MLS) within the Northeast Coast and Avalon regions (where landings are low), and smaller (below or very close to MLS) within the South and West Coast regions, where landings are considerably higher (Figure 36). From 2004 to 2016, the average size of lobster has increased in the Avalon region then decreased in recent years from 91 mm CL in 2016 to an average of 87 mm CL between 2018 and 2021. In the Northeast Coast region between 2004 and 2014 average size increased to 89 mm CL then decreased to 84 mm CL in 2021. In the South and West Coast regions, the average size of lobster peaked in 2012 at close to MLS and has remained below MLS since 2014, at approximately 80 mm CL in the West Coast region and 81 mm CL in the South Coast region in 2021 (Figure 36).

The average size of ovigerous females within the South and West Coast regions is smaller than that of the Northeast Coast and Avalon regions (Figure 37). For the South Coast region, in particular, the average size of ovigerous lobsters was consistently below MLS up until 2020 when the average size was above MLS, while the average size of ovigerous lobster in the Avalon and Northeast Coast regions is consistently above MLS, averaging between 85 mm and 87 mm CL in recent years.

CPUE (Unstandardized) Trends of Size Ranges

On a regional scale, the trends in CPUE for pre-recruit size lobster was highest in recent years in the West Coast region, with the South Coast region as the second highest (Figure 38).

Overall, the CPUE for pre-recruit lobster, increased in the South and West Coast regions, but remained low and variable in the Northeast Coast and Avalon regions.

The CPUE of recruit size (>83mm CL) lobster (Figure 39) were highest in the South Coast region on average above 1.0 lobster/trap since 2019. For recruit size lobster, the CPUEs increased in the Northeast, South, and West Coast regions, but remained low in the Avalon region (below 0.5 lobster/trap).

The CPUE of large lobster (>110 mm CL) was consistently low in all assessment regions, with the lowest CPUE in the South and West Coast regions and highest CPUE in the Northeast Coast region (Figure 40). Since 2011, the CPUE of large lobster in the Northeast Coast region has ranged between 0.045–0.07 lobster/trap; since 2013, the CPUE of large lobster in the South and West Coast regions ranged from 0.02–0.03 lobster/trap.

The CPUE for the ovigerous females followed the same pattern as the pre-recruit and recruit size lobster, with the highest CPUE in the West and South Coast regions, and lower CPUEs in the Northeast Coast and Avalon regions from 2004–21 (Figure 41). In the Avalon region, the CPUE of ovigerous females has declined from 0.13 lobster/trap in 2009 to less than 0.1 lobster/trap over the last 10 years, while in the Northeast Coast region the CPUE of ovigerous females has remained close to 0.1 lobster/trap since 2010. (Figure 41). The CPUE of ovigerous females in the West Coast region varied between 0.15 and 0.3 lobster/trap throughout the time series. In the South Coast region, the CPUE of ovigerous females varied without trend up to 2019, between 0.25 and 0.4 lobster/trap and then increased between 2019 and 2021 to 0.7 lobster/trap.

Trends in CPUE of ovigerous lobster (pre-recruit size <83 mm CL) also showed higher for the South and West Coast regions, and lower CPUEs for the Northeast Coast and Avalon regions with a slight increase in CPUE of ovigerous lobster since 2019 at 0.1 lobster/trap (Figure 42). The trend in CPUE of ovigerous lobster (recruit size >83 mm) showed the highest CPUE in the South Coast region between 2020 and 2021 at 0.4 and 0.3 lobster/trap respectively, with CPUEs closer to 0.1 for the other regions (Figure 43).

Size Frequency Distributions

At-sea sampling data were used to generate size frequency distributions of number of lobster per trap (by sex) for males, ovigerous females, old v-notched/ovigerous females, non-ovigerous females, and old v-notched/non-ovigerous females for each region from 2012 to 2021 (Figures 44 and 45). Size compositions and catch rates are influenced by catchability. Environmental conditions, soak time, and changes in fishing gear can affect catchability (Miller 1990). Unlike the commercial component of the catch, which is removed after the first capture, sublegal lobsters could be captured multiple times during a fishing season, potentially biasing interpretation of size compositions.

With respect to the size structure, there was a larger range of sizes caught in the Northeast Coast and Avalon regions for both sexes, with more lobster surviving to attain larger sizes (i.e., more than 92 mm CL) throughout the time series; in the South Coast and West Coast regions, there was little sign of lobster surviving to larger sizes (Figure 44) and the size frequency distributions for both males and females show a sharp decline at MLS, consistent with knife-edge recruitment to the fishery (Figure 45). This suggests that fishing pressure is high in these regions.

When comparing the magnitude of the actual number of lobster per trap there was an increase in the number of lobster in the Northeast, South, and West Coast regions between 2019 and 2021 (Figure 44). There is also a difference in the scale of number of lobster per trap on the y-axis with higher numbers of lobster in the South and West Coast regions compared to the Northeast Coast and Avalon regions.

Sex Ratios

The sex ratios from at-sea sampling data demonstrated a higher proportion of female lobster in all regions. This was particularly evident in the larger lobster in the South and West Coast regions (Figure 46). This skew towards females could be largely driven by fishery regulations whereby female lobster cannot be retained when ovigerous and/or v-notched. Skewed ratios can be a result of sexual differences in fishing mortality due to catchability or behavior. Differences in habitat structure, temperatures and salinity preferences can affect the movement patterns of males and females which could potentially lead to skewed sex ratios (Jury and Watson 2013, Boudreau et al. 2015).

The sex ratios in the Northeast Coast and Avalon regions were between 0.5 and 0.6 from 2013 to 2021, up to about the MLS (i.e., 82.5 mm CL), while the proportion of large females to males seems to have decreased since 2020 (Figure 46). Since 2015 there have been larger lobster noted in the South Coast region and an increase in the proportion of larger sized females. When comparing the sex ratio based on the proportion of females for all years within each region (Figure 47) the figure clearly demonstrates that the proportion of females at larger sizes increased in 2021 in the South and West Coast regions and slightly decreased in the Avalon and Northeast Coast regions when compared to previous years.

Proportions of Females

The at-sea sampling data were used to examine the proportion of females that were in each maturity category for all years sampled (2004–21) over the size ranges within each region. The results showed that the highest proportion of larger females were non-ovigerous/old v-notched females or they were ovigerous/old v-notched.(Figure 48).

The proportion of ovigerous females over the size range within each year as shown in Figure 49, demonstrated an increase in the proportion of ovigerous females at larger size ranges in the Northeast, South, and West Coast regions in all years and the proportion of ovigerous females at 50% (0.5 proportion) in these regions was approximately 100 mm CL. However, the Avalon region showed a lower proportion of ovigerous females and variation in the size at which females were ovigerous at 50% (0.5) (Figure 49).

Size at Ovigerous

The ovigerous model was overall able to fit the dynamic data well in most assessment regions and years (Figures 50 and 51a,b). When sizes at ovigerous were directly compared by year for each region, it was evident that a shift in pattern has occurred in the Avalon region over time and that other oddities occurred in this region. For example, in the Avalon region near the start of the time series (2004), there was an unusually high proportion of females (i.e., >0.3) that were ovigerous at sizes below about 80 mm CL (Figure 52). This high rate has decreased over the time series, but the proportion of lobster that are ovigerous at sizes below about 80 mm CL remains higher than all other regions (i.e., 0.25). Moreover, there has a been an obvious shift toward larger sizes at maturity in the Avalon region over the time series (Figure 52). The size at 50% ovigerous has shifted from 82 mm CL in 2004 to 128 mm CL in 2021 in the Avalon region. In all other regions size at 50% ovigerous has remained consistent since 2007, within a range of about 97–112 mm CL (Figure 52).

Size Modes

The size selectivity adjusted length frequencies were compared to the length frequencies from the commercial traps by sex and maturity group for each lobster survey site and year (Figure 53). It was evident that there was no change in the relative abundance of legal sized lobster in commercial traps (where S=1) but that the abundances of under-sized lobster increased. There are two noteworthy observations in Figure 53; first, in many survey sites and years size modes appeared in the adjusted data (i.e., see Harbour Breton and Port Saunders 2022 data) and, second, in some instances the relative abundance of progressively larger modes were similar or lower in relative abundance than the preceding mode size mode (i.e., again see Harbour Breton and Port Saunders 2022 data), conforming to what would be expected in a natural population undergoing progressive mortality within a cohort. Accordingly, an investigation was undertaken to determine if defined size modes were present within the adjusted survey data.

Based on the lobster trap survey data, the presence of size modes (modal mean size) were at approximately 64 and 74-75 mm CL in both sexes at all survey sites (Figure 54). Based on the selectivity-adjusted commercial trap catches (at-sea sampling data) the presence of size modes (modal mean size) were at approximately 71-72 and 81 mm CL for males in all regions and approximately 73 and 81-82 mm CL for females in all regions (Figure 55).

Based on the mixture analysis for the modal mean size, the selectivity adjusted length frequency distributions for commercial traps by sex and maturity group for each region and year were displayed (Figure 56). Several characteristics, more obvious through an examination of grouped years (Figures 57 and 58), were notable. First, in recent years consistent spikes have arisen near 72–73 mm and 81–82 mm CL, indicative of the size modes (Figure 57). However, the mode centered near 81–82 mm CL is clearly intercepted by the fishery, thus only about half the expected mode is present in any given year. This observation was subsequently used to refine the pre-recruit index in the assessment to that mode centered at 72–73 mm CL given the potential for variably confounding fishing effects on a recruitment index including all sub-legal sized catch. An examination of log-transformed catch rates shows that in most regions and years, even the selectivity-adjusted catch curves, do not allow for estimation of total mortality (i.e., natural mortality) rates in sub-legal sized lobster due to increasing abundance over the sub-legal-lobster size range (Figure 58). However, this pattern has been countered in the South and West Coast regions in recent years, where the relative abundance of ~70 mm CL lobsters is higher than that of ~80 mm CL lobsters, for example. A time series of total mortality in sub-legal sized lobster was not estimated for this assessment, but the development of the potential to do so as recruitment increases within some populations is important moving forward.

Recruitment Index

The recruitment index of 68–78 mm CL lobster, based on the refined mode not subjected to fishing mortality in the selectivity adjusted commercial trap data (at-sea sampling data), was calculated for each year (2004–21) by sex and region (Figure 59). The recruitment index has increased slightly in the Northeast Coast region in recent years and has remained low over the time series in the Avalon region. In the South and West Coast regions, the recruitment index for males and females has increased with a pronounced increase in the females in recent years.

Total Mortality and Exploitable Biomass

The “modified Ennis” von Bertalanffy growth curve produced the desired result of introducing an asymptotic process into estimation of relative ages in the lobster (Figure 11). The smallest (82.5 mm MLS; recorded as 83mm) lobsters in the legal population were estimated at 8.26

years relative age while the largest 115 mm CL lobsters used in mortality estimation were estimated at 18.09 years relative age.

Overall, the linear regressions of relative abundance versus relative age fit the data well for both sexes in most regions and years (Figures 60 and 61). However, there was a systematic “hockey stick” shape to the data distributions created by low abundances of relatively old lobster in the population that occurred in many cases. Ultimately, this results from the process that the length conversion performs better over using length as the x-axis metric, and a more refined range of sizes (in turn relative ages) along the x-axis; research into a true length-age relationship may improve this method. Overall, the Z estimations were deemed a reasonable approximation of mortality occurring in legal sized lobster.

Males showed higher annual mortality rates than females and mortality rates were overall higher in the South and West Coast regions than in the Avalon or Northeast Coast regions (Figure 62). The higher mortality in males likely reflects both the skewed sex ratios in NL lobster populations, with more females present, as well as some protection afforded to females such as prohibitions on landing ovigerous females and v-notching. In 2021 females [f] and males [m] were estimated to have the following annual mortality rates (%): Avalon – f46, m44, Northeast Coast – f47, m51, South Coast – f52, m64, West Coast – f55, m71.

Legal size biomass by sex was estimated to be higher in females than males in all assessment regions and years (Figure 63), again likely reflecting the skewed sex ratios and additional protections afforded to females in the fishery. The biomass indices from reported catch in the Avalon and Northeast Coast regions were deemed unrealistic (too low) and less reflective of true biomass than estimates based on adjusted landings. The analysis shown that biomass has grown to different extents in all regions in recent years, with only the Avalon region not showing progressive increases since 2017. In the Avalon region, the total biomass has ranged about 450–900 t from 2018–21, in the Northeast Coast region it has increased from about 625–1,400 t during that time, while the South Coast and West Coast regions increased from 2,800–4,500 t and 3,500–5,000 t respectively during that period (Figure 63).

Exploitation rate indices based on LCCC-derived biomass estimates closely reflected trends in total mortality, being higher in the South and West Coast regions than in the Avalon and Northeast Coast regions and higher in males than females (Figure 64). In 2021, total (sex-combined) exploitation rate indices in the Avalon, Northeast Coast, South Coast, and West Coast regions were 42.9%, 46.5%, 54.1%, and 59.2%, respectively.

MANAGEMENT CONSIDERATIONS

V-Notching

V-notching of ovigerous female lobsters has been taking place annually since its introduction in the NL Region in the 1990s. There are no reliable accounts of the percentage of v-notching that occurs, but based on FFAW index logbooks it is estimated to be less than 15%, and variable among areas.

FFAW index logbooks were used to estimate the percentage of v-notching (number of ovigerous females v-notched/total ovigerous females) annually for all regions. On average, the extent of v-notching ranged from 4% to 15%, with the lowest rate of v-notching in the South and West Coast regions and the highest in the Avalon region (Figure 65). In general, based on the FFAW index logbooks there has been an overall decline in the percent of ovigerous females v-notched since the late 2000s.

Large female lobsters are thought to produce more viable eggs than smaller females (Attard and Hudon 1987) and protecting these large females in the population is a reasonable step towards increasing egg production. The practice of v-notching should be encouraged among harvesters.

Based on the proportions of v-notched lobster over the size range (based on at-sea sampling data), it was evident in all regions that the majority of large surviving lobster in the population were v-notched females (Figure 66). This indicates that v-notching has a high level of efficacy at protecting large egg-bearing females from fishing mortality.

Per-recruit Models

The YPR model showed overall maximum levels of long-term yield to correspond to annual harvest rates approximating about 30% per year in both males and females (Figure 67). These overall patterns reflected greatest contributions to overall yield stemming from allowing the largest stage classes to persist in the population through low-moderate harvest rates (i.e., <25%). This reflects the non-linear benefits of accrued weight gain with size. For reference, this optimal harvest rate, synonymous with F_{msy} is lower than that currently estimated to be occurring in any region, although the Avalon and Northeast Coast regions are relatively close.

In terms of SPR and EPR, the patterns expectantly showed progressive loss in both indices as exploitation rates increased (Figure 68). However, for both metrics exploitation levels beyond about 30–40% per year were associated with outcomes near or past the central inflection portions of the model curves. Finally, the shift in size at ovigerous (Figure 49) in the Avalon region over time has led to a progressive loss in SPR and EPR potential over time and may underscore the need to investigate this maturity shift.

ECOSYSTEM CONSIDERATIONS

Summer sea surface temperature (SST) has increased since 1981 over the four geographical regions, characterized by a low in the early-1990s and a high in the early-2010s (Figure 69). This has led to more favorable oceanographic habitat conditions for American Lobster (Le Bris et al., 2018, Steneck and Wahle, 2013) including recent improvements in recruitment prospects.

SOURCES OF UNCERTAINTY

The assessment is mainly based on fishery-dependent data. Reported landings are based on purchase slips that are supplied to Fisheries and Oceans Canada by buyers and do not account for local sales, poaching, and handling mortalities that can occur prior to the sale of the catch. The extent of local sales, in particular, can be considerable and varies by location and year. Therefore, is it difficult to obtain an estimate of total annual removals for any given year.

With respect to the use of mainly fishery-dependent data in this assessment, potential effects of year-to-year differences in spatial and temporal coverage are unknown. Differences in catchability among sizes and categories (i.e., immature versus sexually mature; v-notched versus not notched), as well as density-dependent effects, can complicate the interpretation of both at-sea sampling and logbook data. Environmental conditions, soak time, and changes in type of fishing gear (size, materials) can also affect catchability. There are vast changes in relative amounts of size categories over the fishing season; therefore, size data aggregated over the entire fishing season are difficult to interpret.

There is uncertainty in how the landings were adjusted for this assessment and the potential impacts this could have on the biomass estimates. However, this concern is largely offset by minimal difference between reported and adjusted landings in the dominant West and South Coast regions, thus overall stock-level biomass indices should be relatively robust against this issue. In addition, the length-weight relationship data sources are dated (from the 1980s), which may affect interpretation of the analysis for this assessment.

CONCLUSIONS

In 2022, preliminary landings were at the highest level recorded in a century (5,780 t); this reflects increasing trends in the Northeast, South, and West Coast regions, while reported landings in the Avalon region have remained low. However, reporting rates vary across regions and reported landings likely do not reflect total removals. Biomass indices have increased to time-series highs in all assessment regions in recent years.

Despite showing signs of high exploitation rates in most assessment regions (40–70% in 2021), all key indicators are consistent in showing sustained signs of growth throughout all assessment regions. Short-term recruitment prospects appear steady in the Northeast Coast and Avalon regions and at the highest levels in the time series in the South and West Coast regions. Recent improvements in recruitment appear to be associated with increasing SST in the assessment regions.

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APPENDIX I – TABLES

Table 1. Daily trap limits per licensed fisher, by LFA in 2019 to 2021.

LFA	Number of Traps
3	200
4A	200
4B	200
5	150
6	100
7	150
8	100
9A	200
9B	100
10	200
11	185
12	135
13A	180
13B	220
14A	250
14B	250
14C	300

Table 2a. The number of FFAW index fisher logbook and mandatory DFO logbook returns in the Northeast Coast region (LFAs 3–6) from 2004–21.

Year	LFA 3		LFA 4A		LFA 4B		LFA 5		LFA 6	
	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO
2004	-	-	-	-	7	-	3	-	2	-
2005	1	-	2	-	6	-	3	-	2	-
2006	1	-	2	-	14	-	7	-	6	-
2007	2	-	2	-	15	-	6	-	7	-
2008	1	-	10	-	5	-	6	-	7	-
2009	2	-	12	-	5	-	6	-	9	-
2010	2	14	18	158	33	204	13	177	18	151
2011	1	16	11	114	35	167	12	125	15	114
2012	1	7	11	34	35	88	13	74	14	63
2013	2	2	5	2	29	5	8	7	13	2
2014	1	10	3	47	29	100	7	95	9	86
2015	1	13	4	50	26	86	7	80	7	66
2016	-	10	7	48	22	123	9	86	10	69
2017	-	11	5	72	21	123	10	87	7	92
2018	-	10	4	74	17	116	7	103	8	93
2019	-	7	2	48	17	92	5	83	8	59
2020	-	19	1	85	14	130	8	122	5	81
2021	-	18	1	87	7	145	4	122	4	109

Table 2b. The number of FFAW index fisher logbook and mandatory DFO logbook returns in the Avalon region (LFAs 7–10) from 2004–21.

Year	LFA 7		LFA 8		LFA 9A		LFA 9B		LFA 10	
	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO
2004	-	-	-	-	-	-	-	-	-	-
2005	3	-	1	-	-	-	2	-	7	-
2006	6	-	3	-	1	-	4	-	22	-
2007	7	-	3	-	1	-	5	-	21	-
2008	6	-	3	-	1	-	4	-	19	-
2009	7	-	2	-	1	-	4	-	23	-
2010	13	70	5	29	1	2	4	14	32	164
2011	10	48	5	21	2	2	1	7	30	106
2012	12	26	5	15	2	2	2	7	27	55
2013	7	1	3	2	1	-	-	-	21	5
2014	7	39	3	13	1	4	1	5	19	53
2015	7	32	4	10	1	3	-	4	17	47
2016	6	40	4	18	2	4	-	4	21	49
2017	7	50	4	25	1	3	-	3	17	59
2018	5	51	3	37	1	2	-	5	15	58
2019	6	37	3	10	3	5	1	5	15	33
2020	3	50	2	31	1	6	4	4	11	53
2021	3	46	-	28	1	9	3	7	9	57

Table 2c. The number of FFAW index fisher logbook and mandatory DFO logbook returns in the South Coast (LFAs 11–12) and West Coast regions (LFAs 13A–14C) from 2004–21.

Year	LFA 11		LFA 12		LFA 13A		LFA 13B		LFA 14A		LFA 14BC	
	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO	Index Fisher	DFO
2004	-	-	-	-	-	-	-	-	-	-	6	-
2005	5	-	-	-	1	-	2	-	1	-	4	-
2006	13	-	7	-	3	-	8	-	8	-	11	-
2007	15	-	7	-	3	-	8	-	6	-	11	-
2008	17	-	5	-	3	-	5	-	4	-	5	-
2009	22	-	8	-	5	-	5	-	8	-	12	-
2010	34	303	8	43	7	132	7	147	19	172	21	158
2011	33	210	8	38	6	92	6	103	17	129	19	127
2012	32	135	7	31	8	27	5	56	17	71	19	64
2013	33	14	8	-	5	3	6	7	19	9	20	5
2014	31	152	7	26	4	49	5	57	14	77	18	77
2015	32	133	7	23	4	42	4	52	12	62	18	62
2016	30	143	7	35	3	53	5	58	12	85	16	82
2017	29	172	7	35	3	49	5	62	13	106	16	98
2018	28	157	7	24	2	49	3	67	11	93	16	95
2019	30	112	7	12	4	34	4	46	14	60	17	43
2020	18	184	7	31	2	58	5	81	13	124	14	94
2021	21	187	6	26	1	64	5	66	10	111	12	108

Table 3. LFAs where at-sea sampling took place for each of the four regions, from 2004–21.

Year	Northeast Coast	Avalon	South Coast	West Coast
2004	4A, 4B, 5, 6	NA	11	13B, 14A, 14B
2005	4A, 5	10	11	14A, 14B
2006	5	10	11	14A, 14B
2007	4B, 5	10	11	14A, 14B
2008	4B, 5	10	11	14A, 14B
2009	4A, 4B, 5	10	11	14A, 14B
2010	3, 4A, 4B, 5, 6	7, 8, 9A, 10	11, 12	13A, 13B, 14A, 14B
2011	4B, 5	8, 9A, 10	11	14A, 14B
2012	3, 4A, 4B, 5, 6	7, 8, 9A, 10	11, 12	13A, 13B, 14A, 14B
2013	4B, 5, 6	7, 8, 9A, 9B, 10	11, 12	13A, 13B, 14A, 14B
2014	4B, 5	8, 9A, 9B, 10	11, 12	14A, 14B
2015	4B, 5	8, 9A, 9B, 10	11, 12	14A, 14B
2016	4B, 5, 10,11,12	7,8, 9A, 9B	11, 12	NA
2017	4B, 5, 6	7, 10	11, 12	14A, 14B
2018	4B 5, 6	7, 10	11, 12	14A, 14B
2019	4B, 5, 6	7, 10	11,12	14A, 14B
2020	5	10	11	14A, 14B
2021	5, 6	10	11	14A, 14B

Table 4. Annual licenses issued, trap limits, and reported landings for Newfoundland, 2004–22. Reported landings for 2022 are preliminary(*) and are based on catch and effort reports up to October 4, 2022.

Year	Licenses Issued	Trap Limits	Landings (t)
2004	-	-	1,911
2005	-	-	2,612
2006	2,908	3,400	2,640
2007	2,888	3,400	2,560
2008	2,887	3,350	2,954
2009	2,841	3,350	2,490
2010	2,835	3,350	2,507
2011	2,793	3,150	1,891
2012	2,690	3,120	2,059
2013	2,563	3,120	2,176
2014	2,491	3,120	2,101
2015	2,450	3,120	2,571
2016	2,353	3,120	2,791
2017	2,322	3,120	2,869
2018	2,280	3,120	3,339
2019	2,329	3,120	4,572
2020	2,327	3,120	4,451
2021	2,289	3,120	4,992
2022	2,256	3,120	5,781*

Table 5. Reported lobster landings (tonnes) by region and total NL landings, 1990–2022. Reported landings for 2022 are preliminary(*) and are based on catch and effort reports up to October 4, 2022.

Year	Northeast Coast	Avalon	South Coast	West Coast	Total Landings
1990	733	360	368	1,461	2,922
1991	729	441	448	1,461	3,079
1992	720	464	544	1,478	3,206
1993	467	333	557	1,266	2,623
1994	544	321	541	1,232	2,638
1995	506	337	501	1,204	2,548
1996	488	248	490	1,152	2,378
1997	435	185	463	1,096	2,179
1998	428	181	543	895	2,047
1999	398	151	496	773	1,818
2000	348	114	547	753	1,762
2001	386	127	619	1,032	2,164
2002	321	125	662	948	2,056
2003	313	97	722	1,122	2,254
2004	223	70	730	887	1,911
2005	309	78	949	1,274	2,612
2006	254	82	1,031	1,273	2,640
2007	197	44	1,061	1,258	2,560
2008	236	51	1,264	1,403	2,954
2009	197	61	1,141	1,090	2,489
2010	197	67	1,259	991	2,514
2011	126	45	968	753	1,892
2012	137	44	1,058	823	2,062
2013	135	30	1,160	851	2,176
2014	122	22	1,068	889	2,101
2015	142	29	1,205	1,195	2,571
2016	149	37	1,321	1,284	2,791
2017	154	31	1,231	1,453	2,869
2018	160	228	1,446	1,705	3,339
2019	229	64	1,839	2,440	4,572
2020	224	39	1707	2,481	4,451
2021	291	37	2033	2,631	4,992
2022	430*	71*	1744*	3,536*	5,781*

Table 6. Annual licenses issued, trap limits per license, reported landings, and mean CPUE for the Northeast Coast region (LFAs 3, 4A, 4B, 5,and 6). Reported landings for 2022 are preliminary(*) and are based on catch and effort reports up to October 4, 2022.

Year	Licenses Issued	Trap Limits	Landings (t)	Index Fishers logbooks Mean CPUE (#/Trap)	DFO logbooks Mean CPUE (#/Trap)
2004	-	-	223	0.15	-
2005	-	900	309	0.20	-
2006	1,167	1,000	254	0.20	-
2007	1,157	1,000	197	0.19	-
2008	1,155	850	236	0.24	-
2009	1,130	850	197	0.21	-
2010	1,126	850	197	0.26	0.27
2011	1,095	850	126	0.22	0.24
2012	1,117	850	137	0.25	0.26
2013	1,091	850	135	0.26	0.32
2014	1,070	850	126	0.31	0.35
2015	1,036	850	205	0.28	0.32
2016	957	850	157	0.26	0.26
2017	941	850	154	0.37	0.36
2018	913	850	161	0.28	0.30
2019	937	850	229	0.38	0.36
2020	935	850	224	0.45	0.42
2021	924	850	291	0.52	0.42
2022	896	850	430*	-	-

Table 7. Annual licenses issued, trap limits per license, reported landings, and mean CPUE for the Avalon region (LFAs 7, 8, 9A, 9B, and 10). Reported landings for 2022 are preliminary(*) and are based on catch and effort reports up to October 4, 2022.

Year	Licenses Issued	Trap Limits	Landings (t)	Index Fishers logbooks Mean CPUE (#/Trap)	DFO logbooks Mean CPUE (#/Trap)
2004	-	-	70	-	-
2005	-	750	78	0.17	-
2006	612	650	82	0.20	-
2007	605	650	44	0.16	-
2008	605	750	51	0.24	-
2009	584	750	61	0.24	-
2010	585	750	70	0.30	0.28
2011	574	750	45	0.26	0.27
2012	589	750	48	0.26	0.28
2013	570	750	30	0.29	0.37
2014	560	750	23	0.29	0.34
2015	553	750	30	0.27	0.28
2016	537	750	37	0.28	0.30
2017	522	750	37	0.29	0.30
2018	508	750	28	0.26	0.29
2019	533	750	64	0.29	0.35
2020	533	750	39	0.31	0.33
2021	508	750	37	0.29	0.30
2022	503	750	71*	-	-

Table 8. Annual licenses issued, trap limits per license, reported landings, and mean CPUE for the South Coast region (LFAs 11–12). Reported landings for 2022 are preliminary(*) and are based on catch and effort reports up to October 4, 2022.

Year	Licenses Issued	Trap Limits	Landings (t)	Index Fishers logbooks Mean CPUE (#/Trap)	DFO logbooks Mean CPUE (#/Trap)
2004	-	-	730	-	-
2005	-	350	949	0.62	-
2006	367	350	1,031	0.61	-
2007	364	350	1,066	0.56	-
2008	364	350	1,280	0.70	-
2009	364	350	1,145	0.69	-
2010	364	350	1,307	0.72	0.80
2011	364	350	994	0.63	0.66
2012	329	320	1,089	0.74	0.78
2013	306	320	1,164	0.83	0.89
2014	300	320	1,084	0.82	0.92
2015	300	320	1,232	0.90	0.96
2016	300	320	1,329	0.95	0.94
2017	300	320	1,230	0.98	0.97
2018	300	320	1,450	1.20	1.16
2019	300	320	1839	1.36	1.31
2020	300	320	1707	1.68	1.50
2021	300	320	2033	1.81	1.58
2022	300	320	1744*	-	-

Table 9. Annual licenses issued, trap limits per license, reported landings, and mean CPUE for the West Coast region (LFAs 13A, 13B, 14A, 14B, and 14C). Reported landings for 2022 are preliminary(*) and are based on catch and effort reports up to October 4, 2022.

Year	Licenses Issued	Trap Limits	Landings (t)	Index Fishers logbooks Mean CPUE (#/Trap)	DFO logbooks Mean CPUE (#/Trap)
2004	-	-	888	0.20	-
2005	-	1,400	1,276	0.44	-
2006	762	1,400	1,275	0.52	-
2007	762	1,400	1,260	0.49	-
2008	763	1,400	1,404	0.51	-
2009	763	1,400	1,096	0.51	-
2010	760	1,400	1,022	0.42	0.47
2011	760	1,200	769	0.40	0.45
2012	655	1,200	875	0.49	0.50
2013	596	1,200	873	0.55	0.63
2014	561	1,200	906	0.48	0.59
2015	561	1,200	1,211	0.63	0.73
2016	559	1,200	1,329	0.63	0.68
2017	559	1,200	1,490	0.70	0.72
2018	559	1,200	1,756	0.71	0.82
2019	559	1,200	2,440	0.98	1.17
2020	559	1200	2,481	1.34	1.47
2021	557	1200	2,623	1.06	1.31
2022	557	1200	3,536*	-	-

APPENDIX II – FIGURES

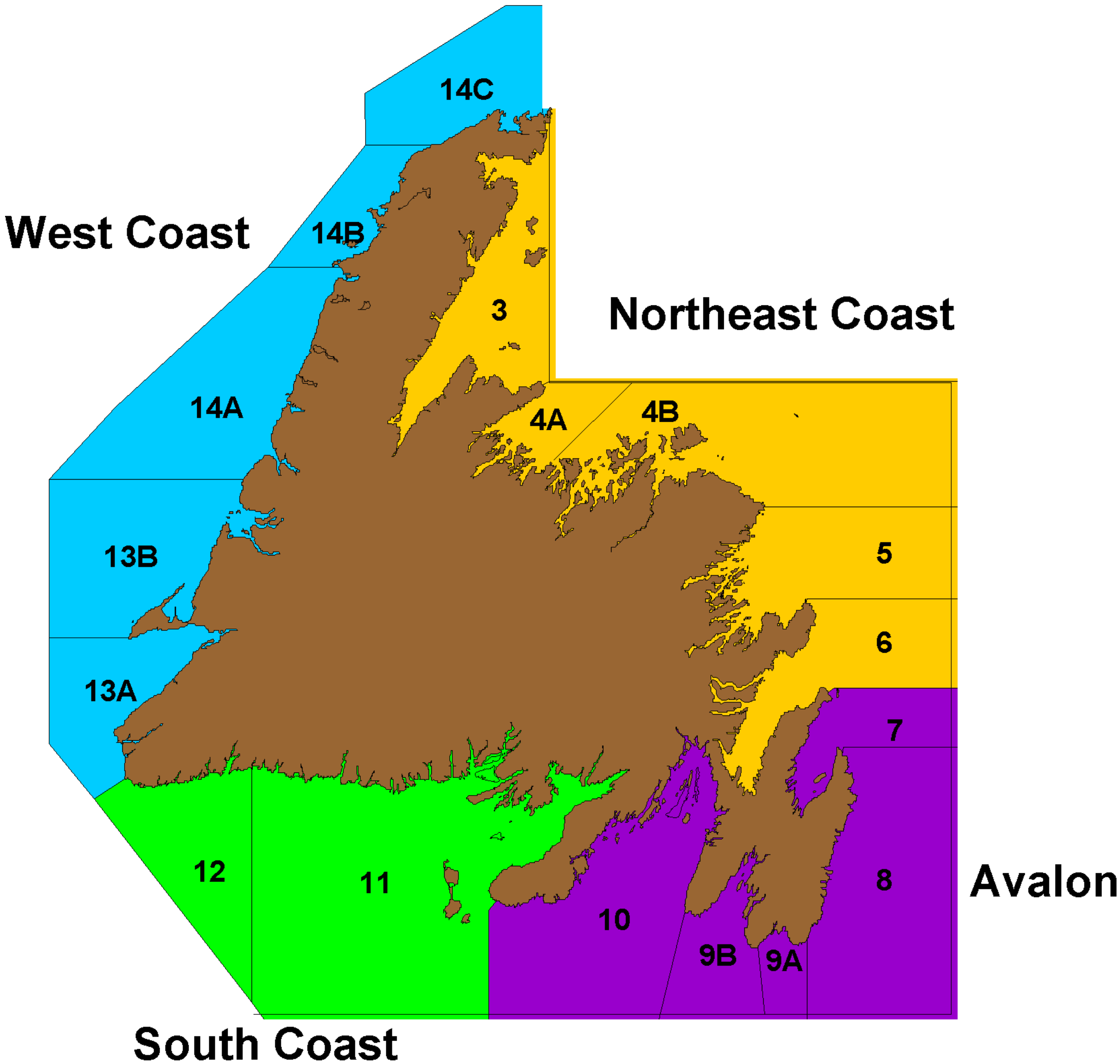

Figure 1. Map showing LFAs (3–14C) within the four assessment regions (Northeast Coast, Avalon, South Coast, and West Coast).

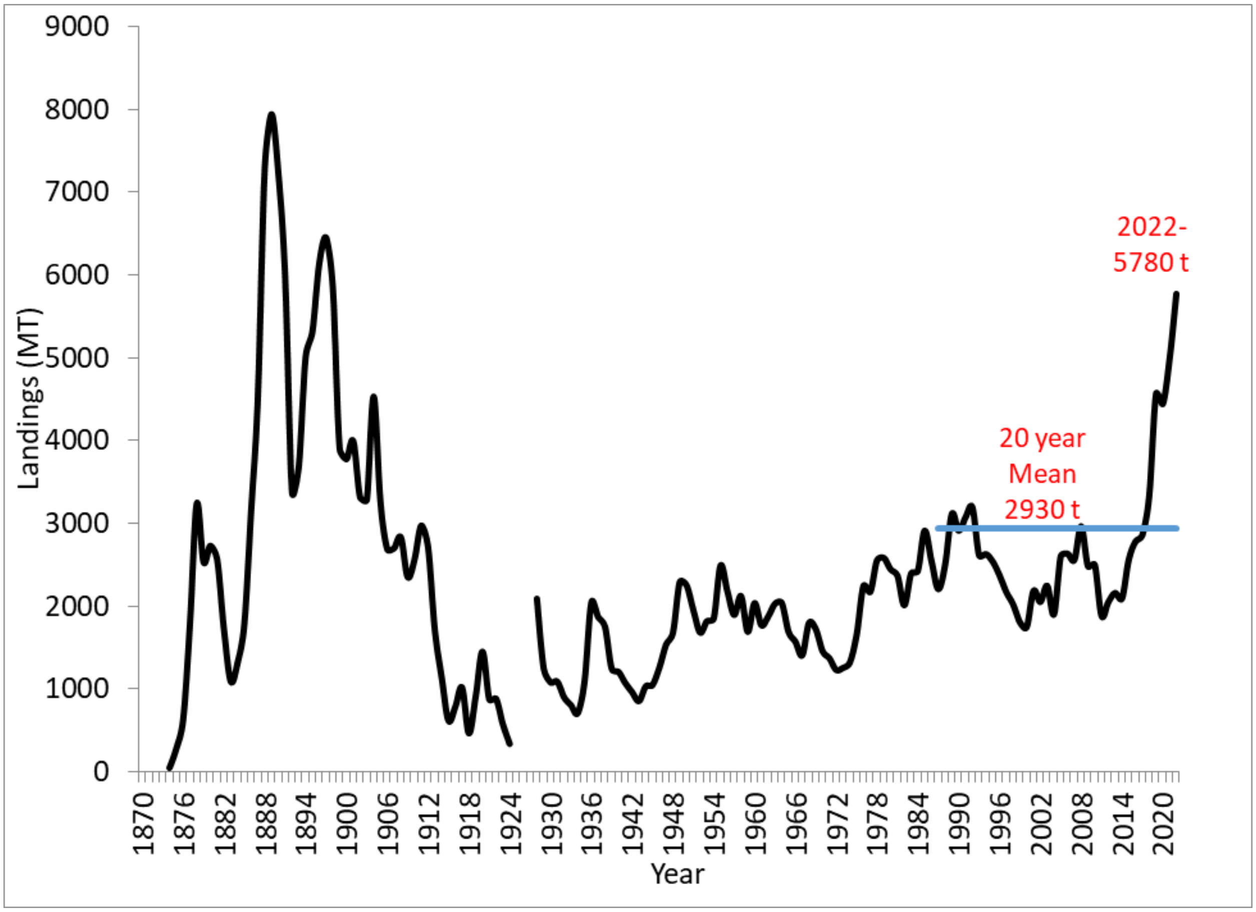

Figure 2. Reported landings (metric tonnes [MT]) for the Newfoundland lobster fishery from the mid-1870s to 2022 including the 20 year mean (solid blue line), and landings from 2022. Reported landings for 2022 are preliminary and are based on catch and effort reports up to October 4, 2022.

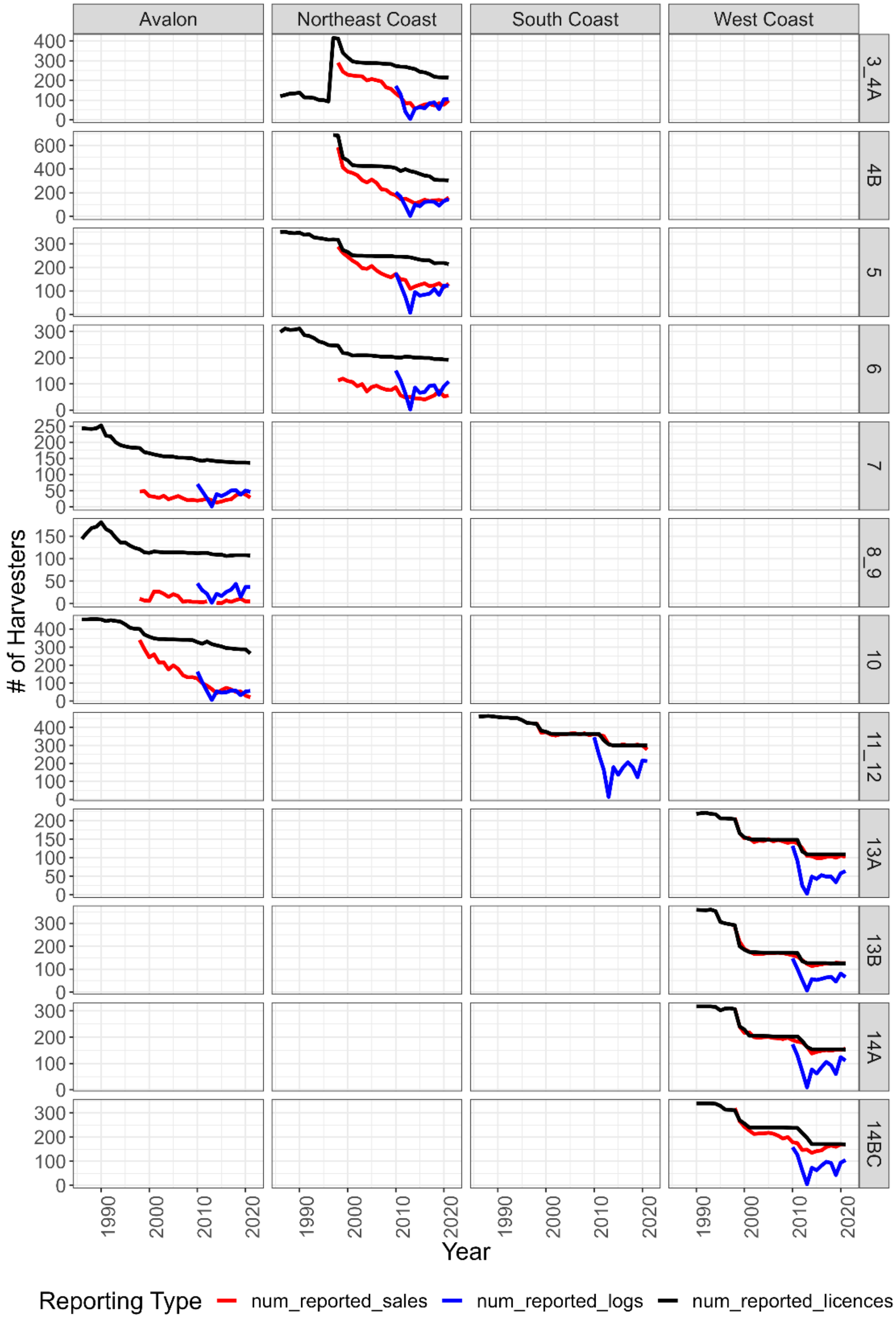

Figure 3. Number of harvesters registering licenses, having a report of one or more sales to a processor, and reporting one or more catch records in fishery logbooks by year, LFA, and region. Note 'num' in legend represents 'number.'

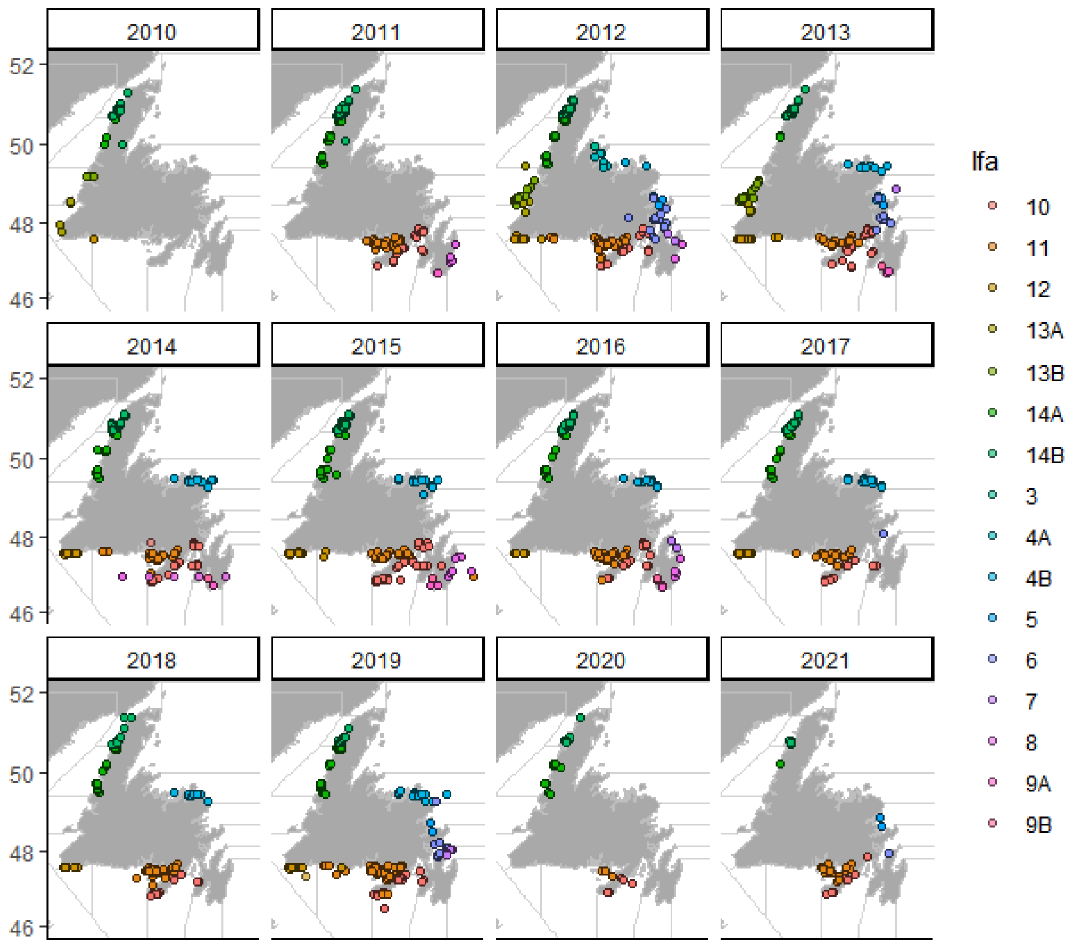

Figure 4. Map of at-sea sampling locations for commercial traps within each LFA from 2010 to 2021.

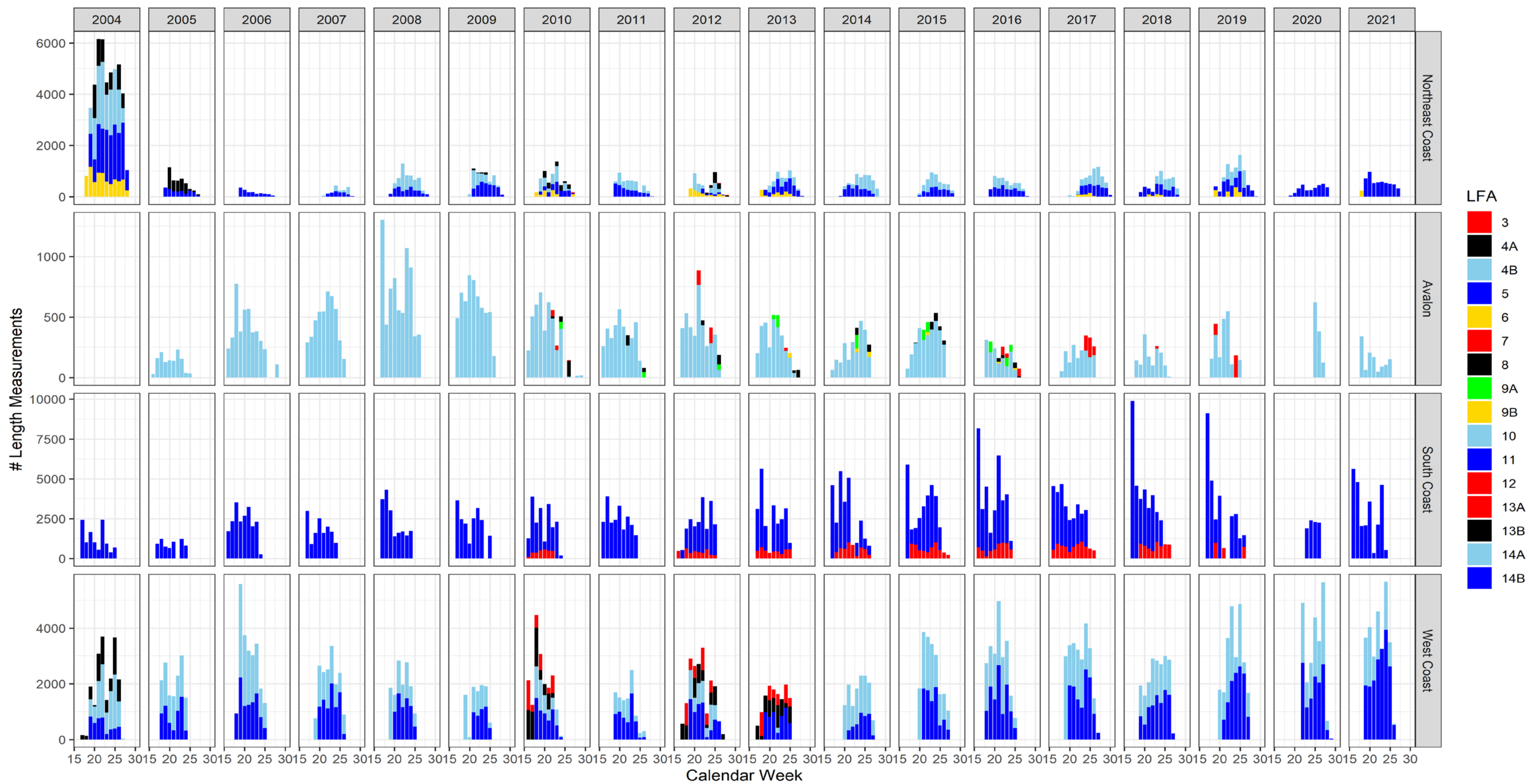

Figure 5. Distribution of at-sea sampling measurements collected from commercial traps in LFAs within each region between 2004 and 2021.

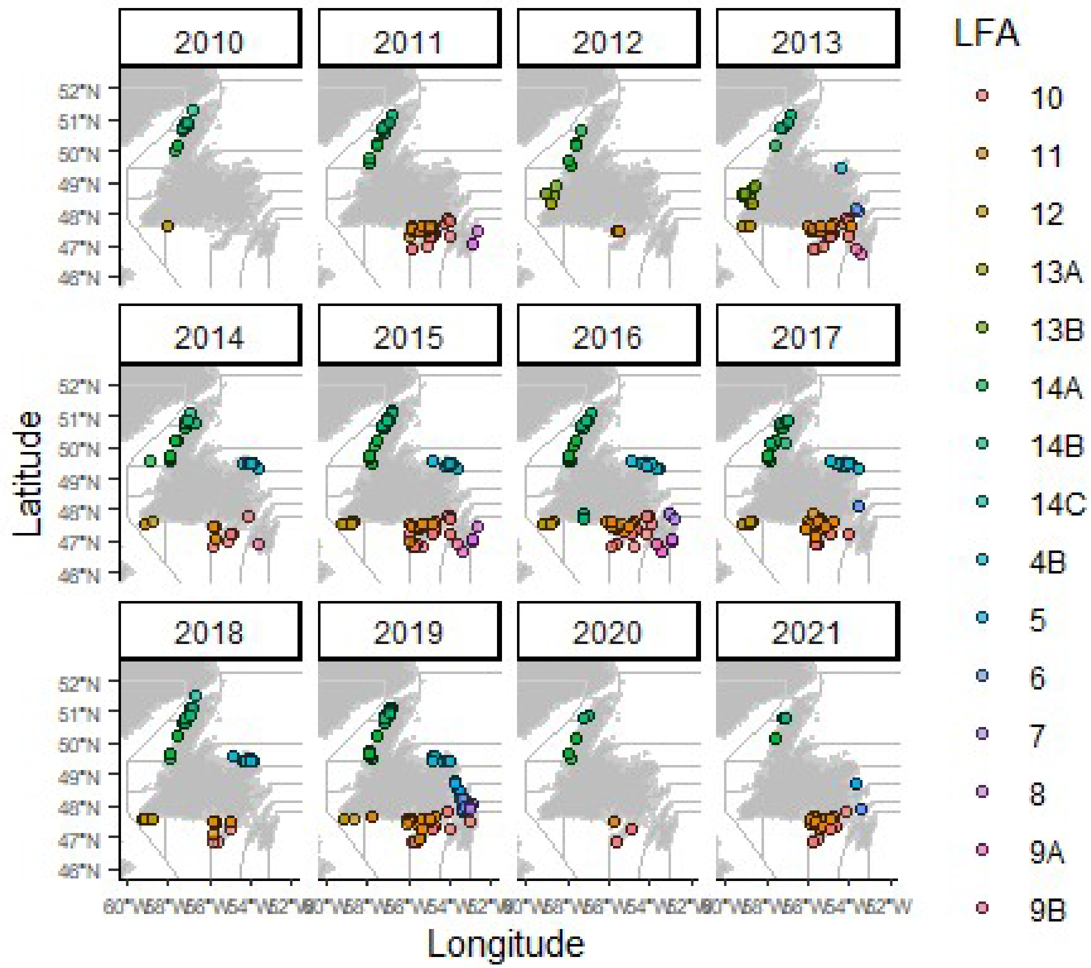

Figure 6. Map of at-sea sampling locations for modified traps (closed off escapement targeting sublegal size lobster) and temperature probes within each LFA from 2010 to 2021.

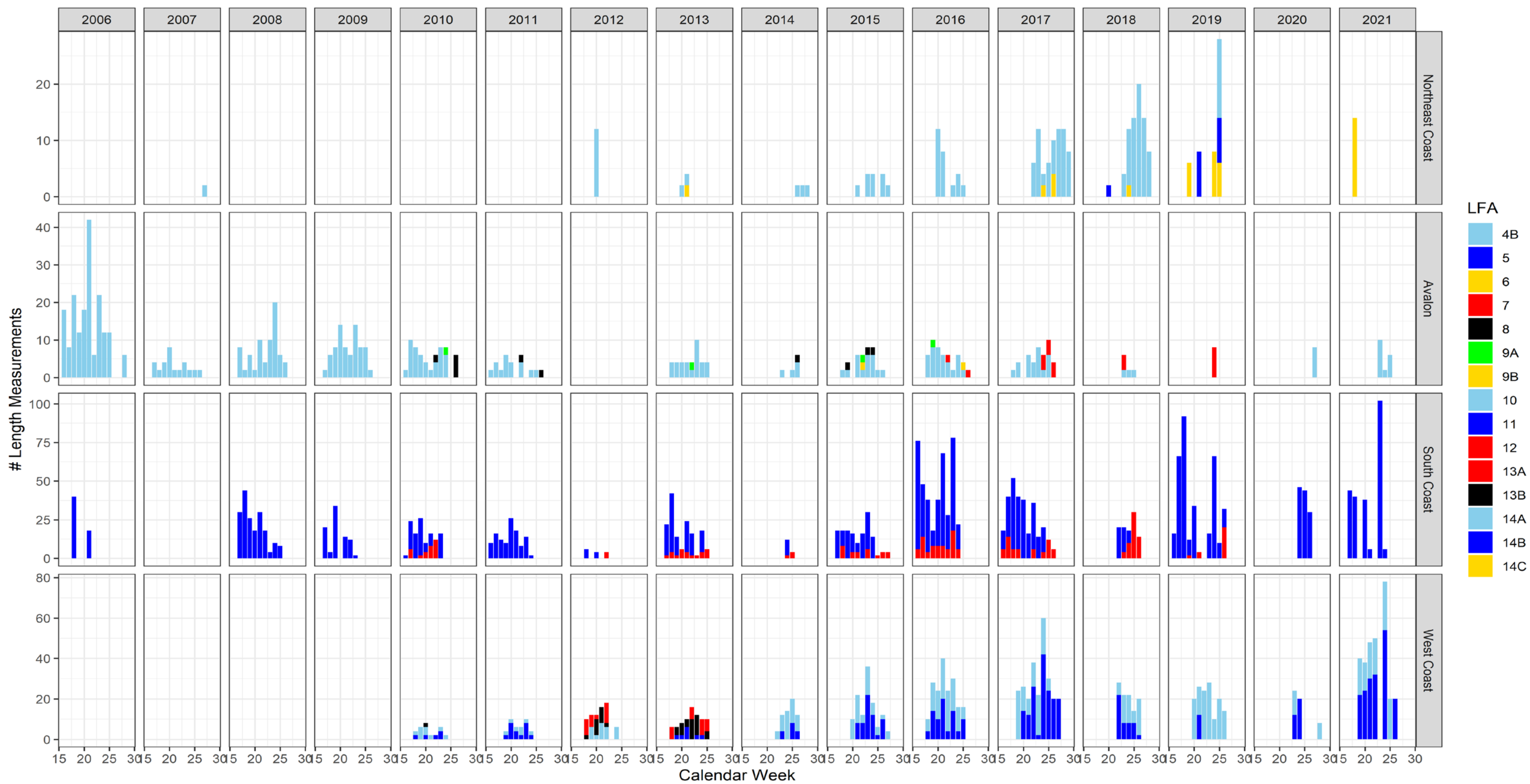

Figure 7. Distribution of at-sea sampling measurements collected from modified traps in LFAs within each region between 2004 and 2021.

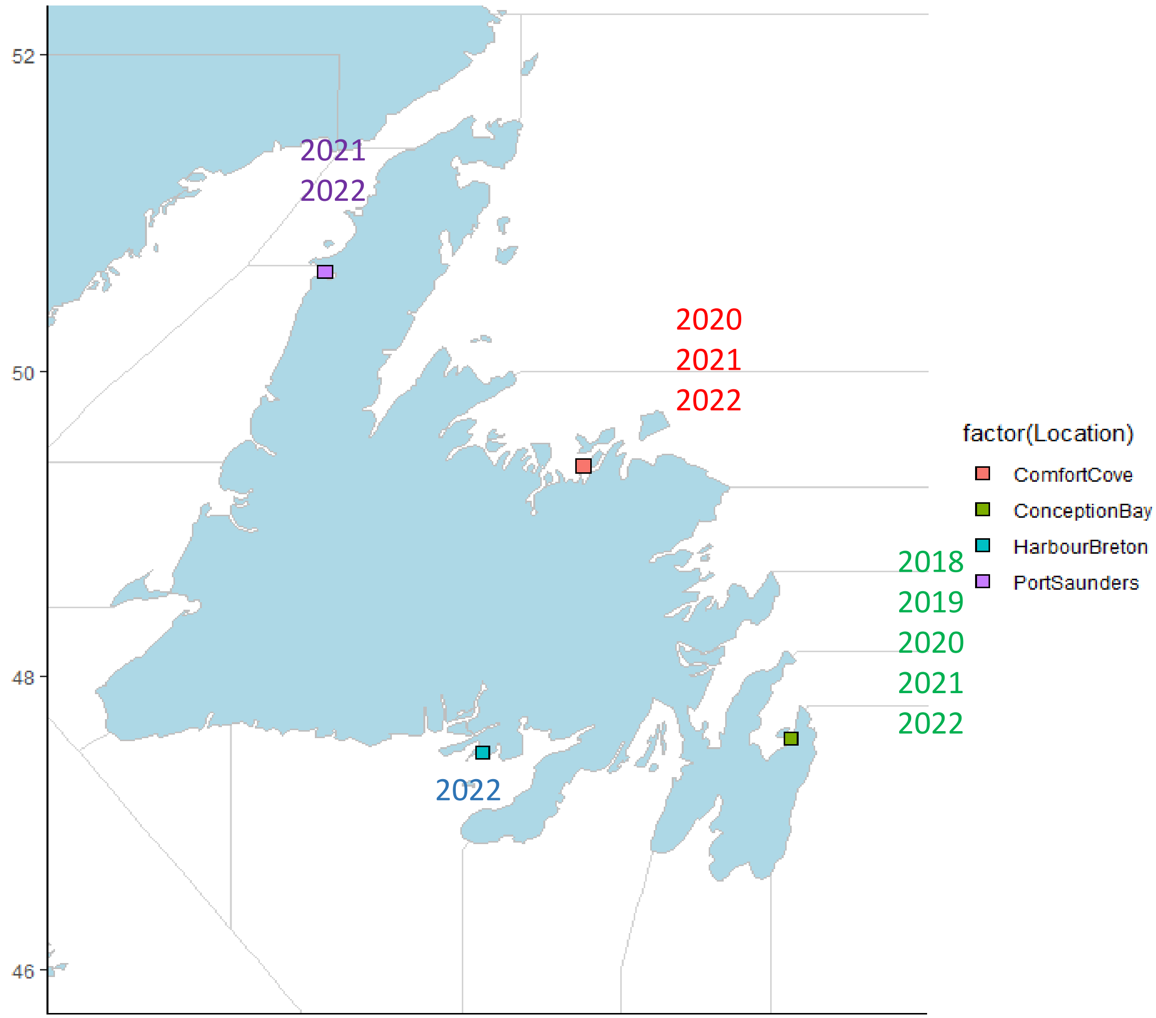

Figure 8. Map showing lobster trap survey locations and the respective years the surveys have taken place at each location.

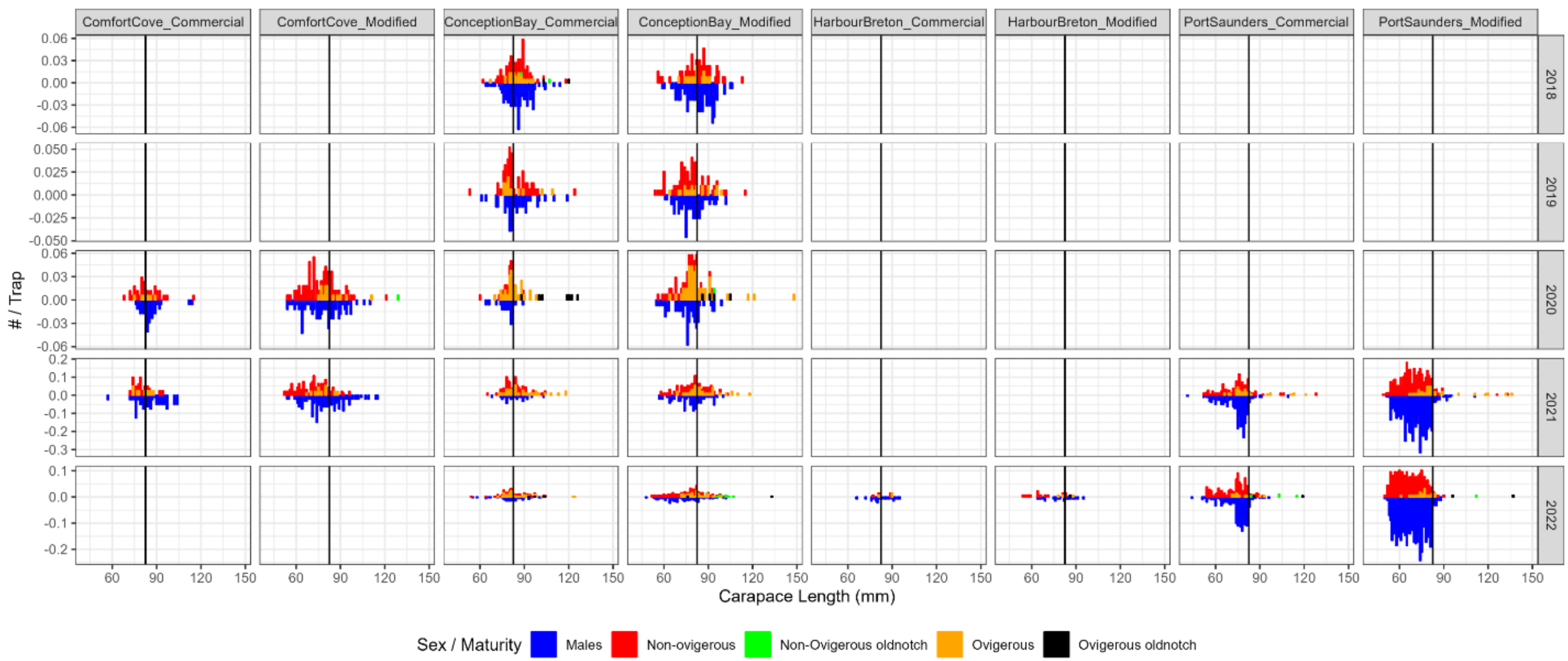

Figure 9. Distribution of lobster measurements collected in the lobster trap survey (commercial and modified traps) within each location (Conception Bay, Comfort Cove, Port Saunders, and Harbour Breton) between 2018 and 2022.

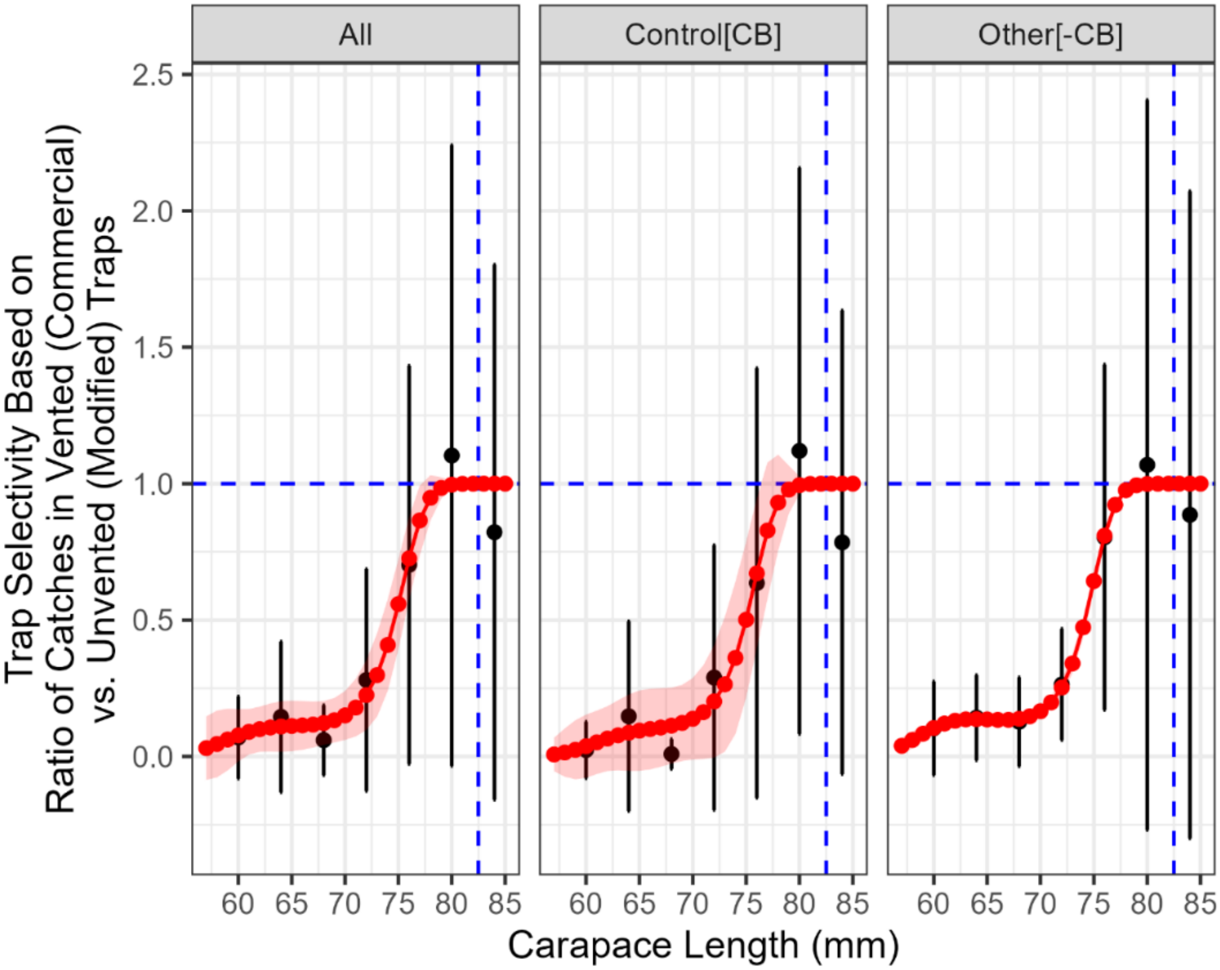

Figure 10a. Trap selectivity curves from lobster trap survey catch rates of commercial versus modified traps. Trap type catches matched by day in any given site and year. Carapace lengths binned to 4 mm increments. Black dots are mean estimates of catch ratios and black lines are 2 standard deviations. Red dots show model predicted values and red shaded areas show 2 standard errors. Note that catch ratios above those where 1 was first achieved were assumed to be 1 before fitting the model. Vertical blue dashed lines denote legal size and horizontal blue dashed lines represent a catch ratio of 1. Control[CB] refers to Conception Bay and Other[-CB] refers to Comfort Cove, Harbour Breton, and Port Saunders.

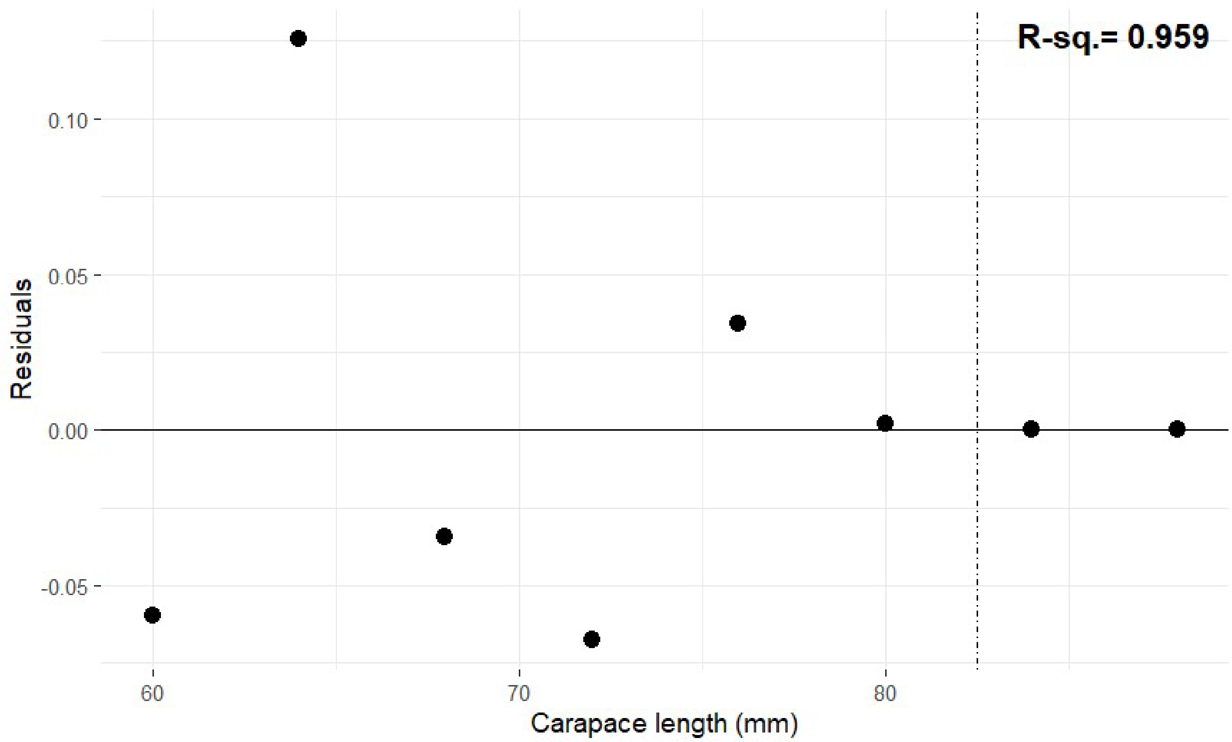

Figure 10b. Residual plots for trap selectivity curves from lobster trap survey catch rates of commercial versus modified traps, with R-Square value within plot.

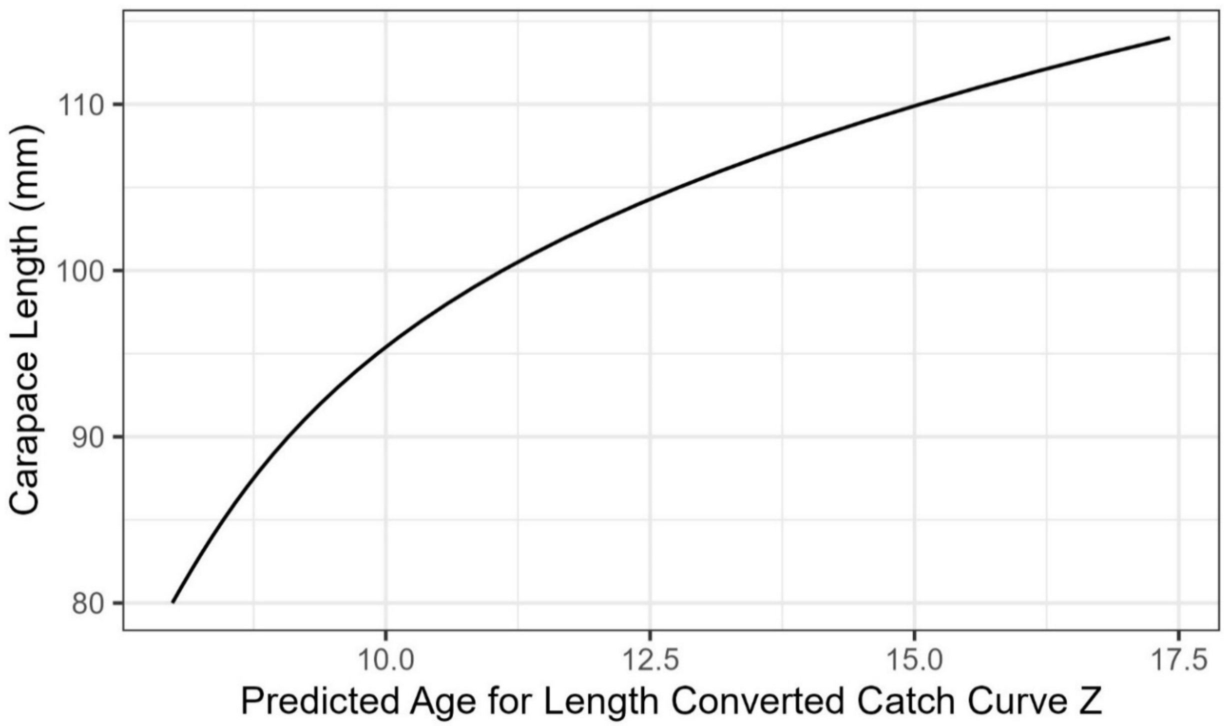

Figure 11. Length-age curve used for estimating relative ages for legal-sized lobster in length-converted catch curve. Data were estimated as average sizes for both sexes combined from von Bertalanffy growth curves presented in Ennis et al. (1986).

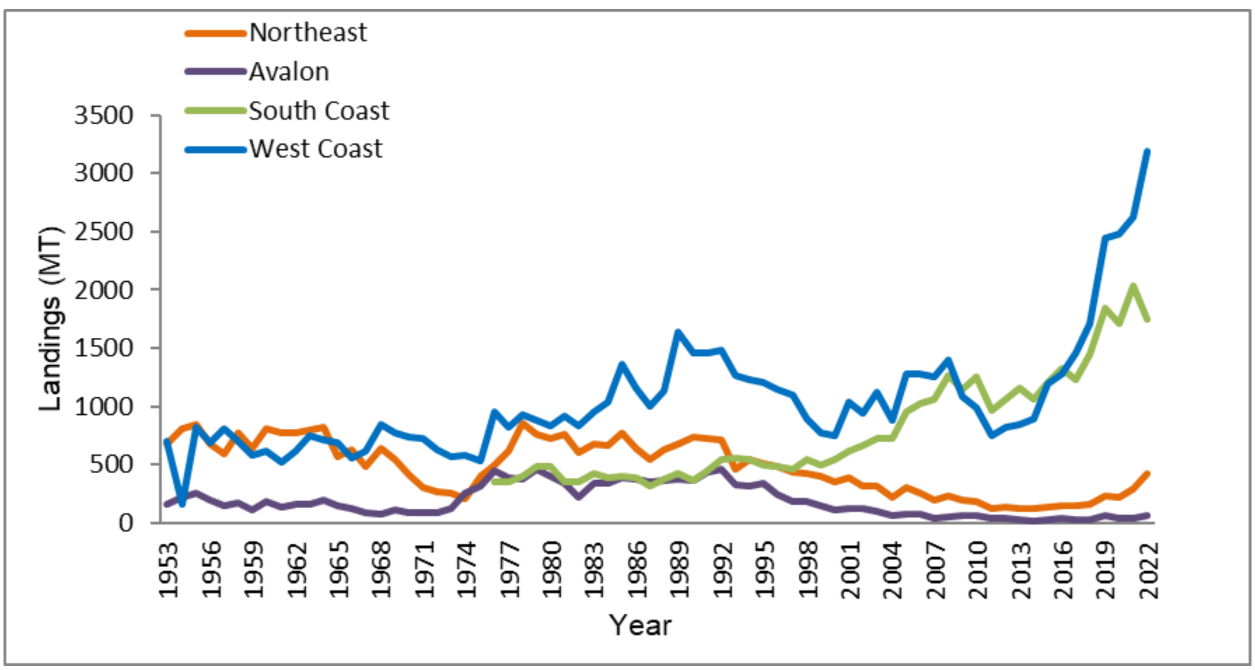

Figure 12. Reported landings (MT) in each assessment region from 1953 to 2022. Reported landings for 2022 are preliminary and are based on catch and effort reports up to October 4, 2022.

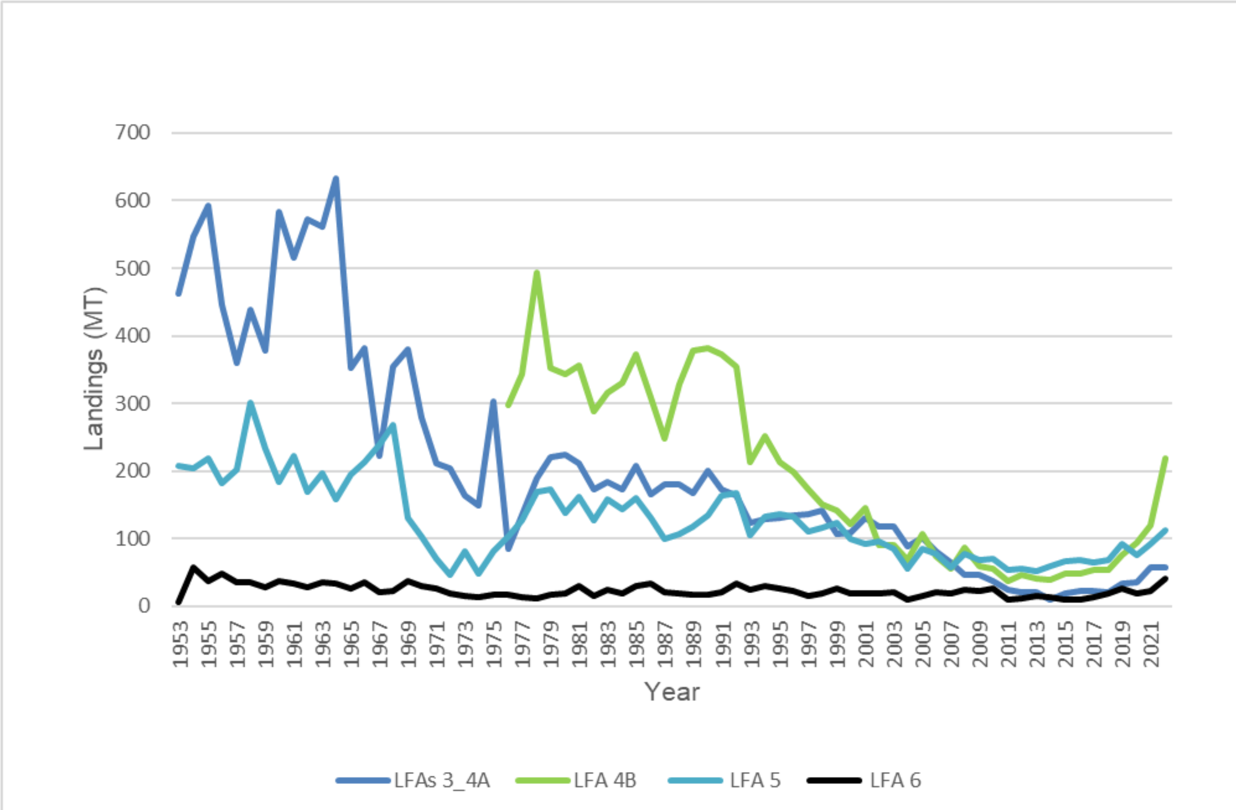

Figure 13. Reported Landings (MT) for LFAs 3–4A, 4B, 5, and 6 within the Northeast Coast region from 1953 to 2022. Reported landings for 2022 are preliminary and are based on catch and effort reports up to October 4, 2022. For some LFAs where there were less than 5 fishers, buyers, or vessels (Rule of 5), reported landings were combined.

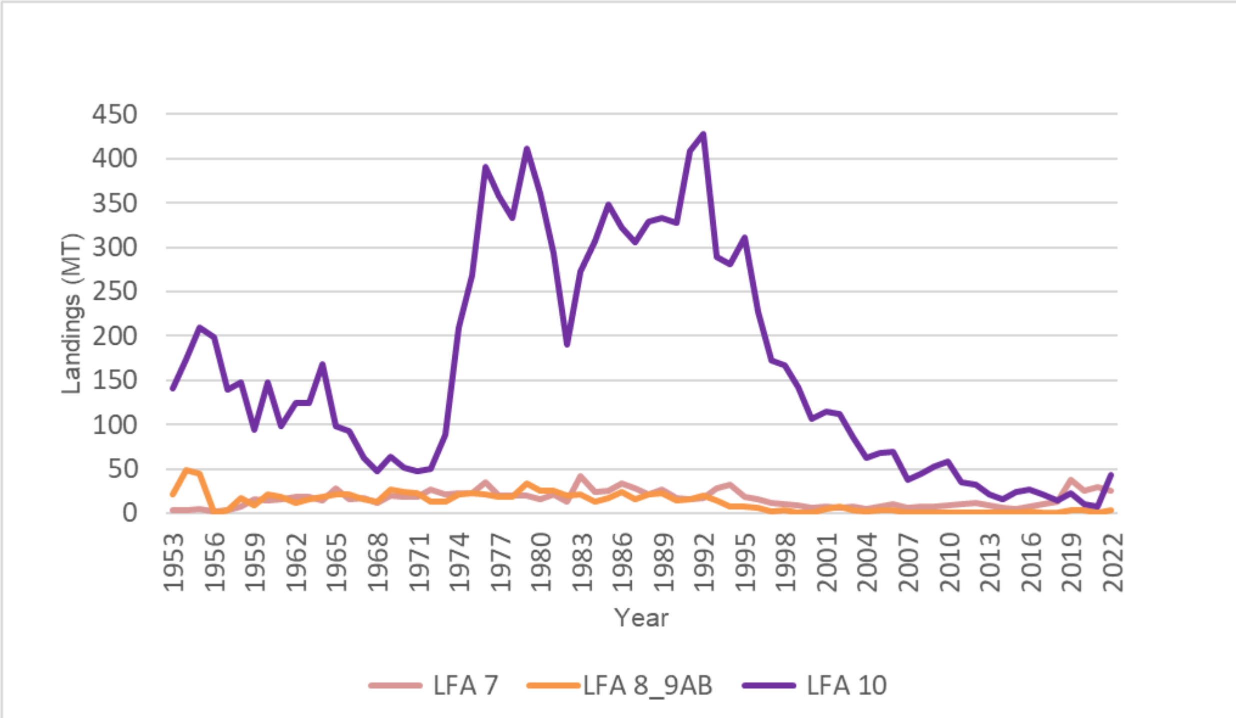

Figure 14. Reported Landings (MT) for the lobster fishery in LFAs 7, 8–9AB, and 10 within the Avalon region from 1953 to 2022. Reported landings for 2022 are preliminary and are based on catch and effort reports up to October 4, 2022. For some LFAs where there were less than 5 fishers, buyers, or vessels (Rule of 5), reported landings were combined.

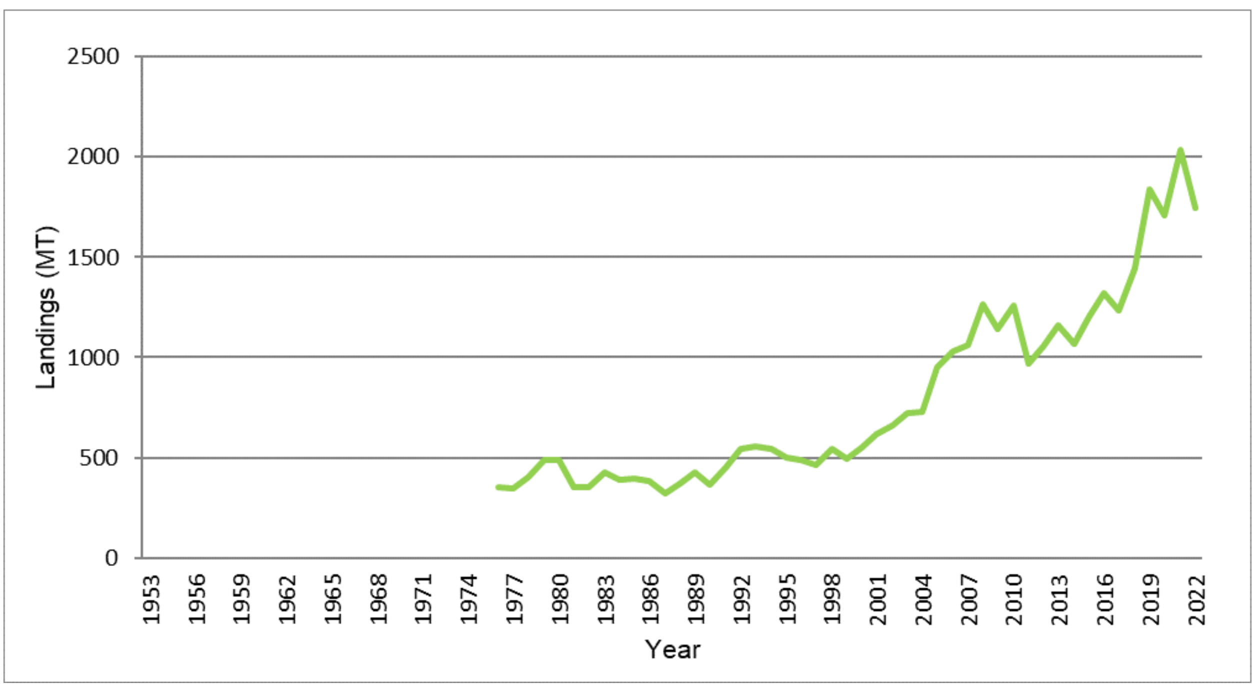

Figure 15. Reported Landings (MT) for the lobster fishery in LFAs 11 and 12 within the South Coast region from 1976 to 2022. Reported landings for 2022 are preliminary and are based on catch and effort reports up to October 4, 2022. For some LFAs where there were less than 5 fishers, buyers, or vessels (Rule of 5), reported landings were combined.

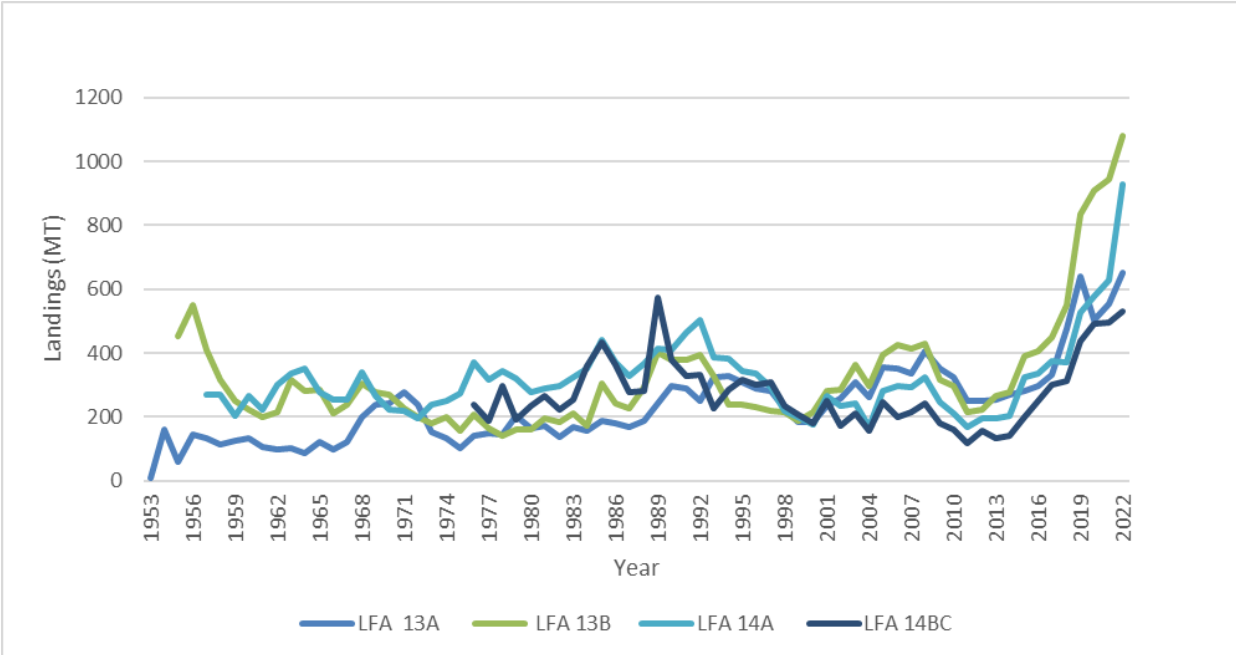

Figure 16. Reported Landings (MT) for the lobster fishery in LFAs 13A, 13B, 14A, and 14BC within the West Coast region from 1953 to 2022. Reported landings for 2022 are preliminary and are based on catch and effort reports up to October 4, 2022. For some LFAs where there were less than 5 fishers, buyers, or vessels (Rule of 5), reported landings were combined.

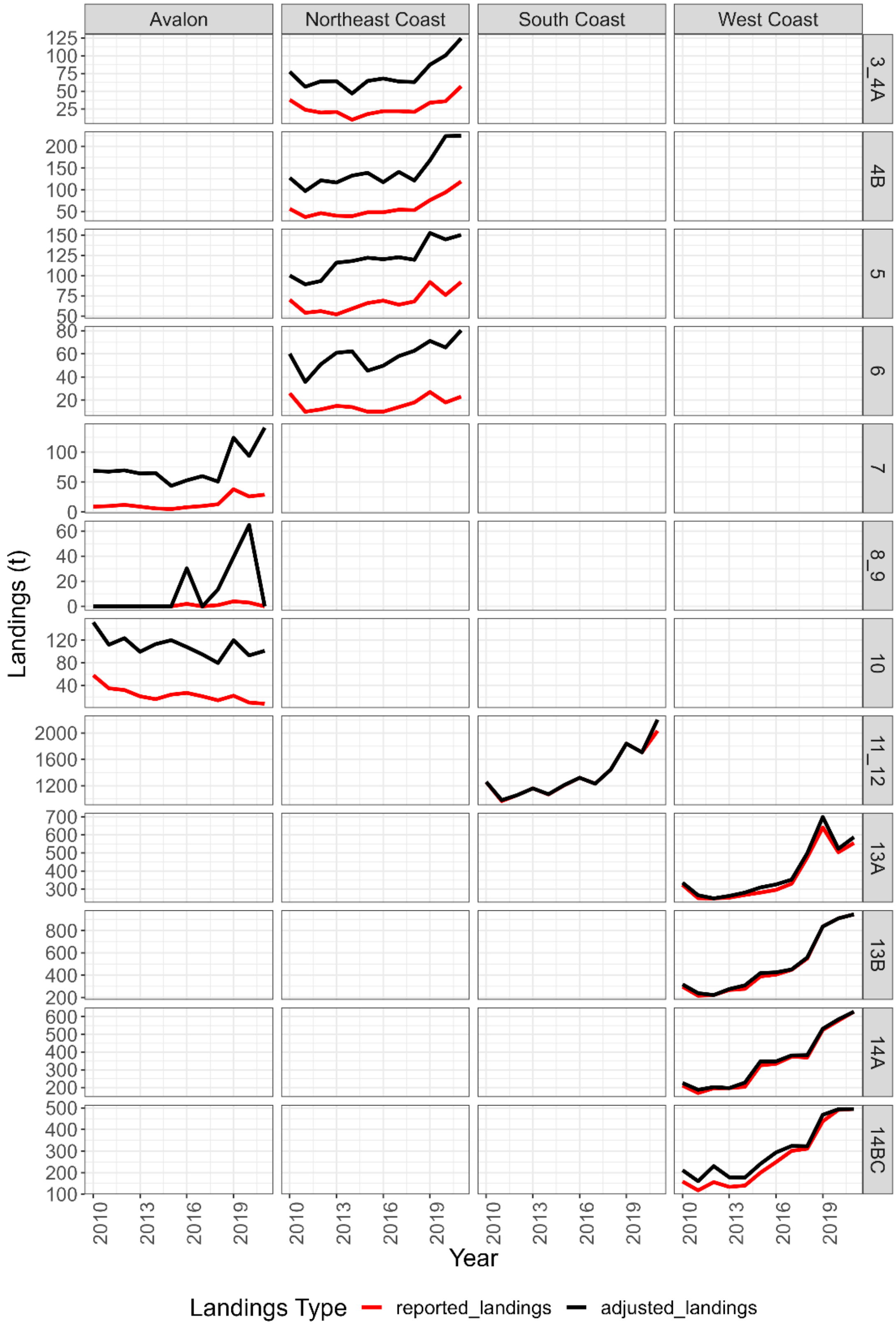

Figure 17. Reported landings from processor sales slips versus adjusted landings based on the ratio of number of registered licenses to number of harvesters reporting sales in processor sales slips.

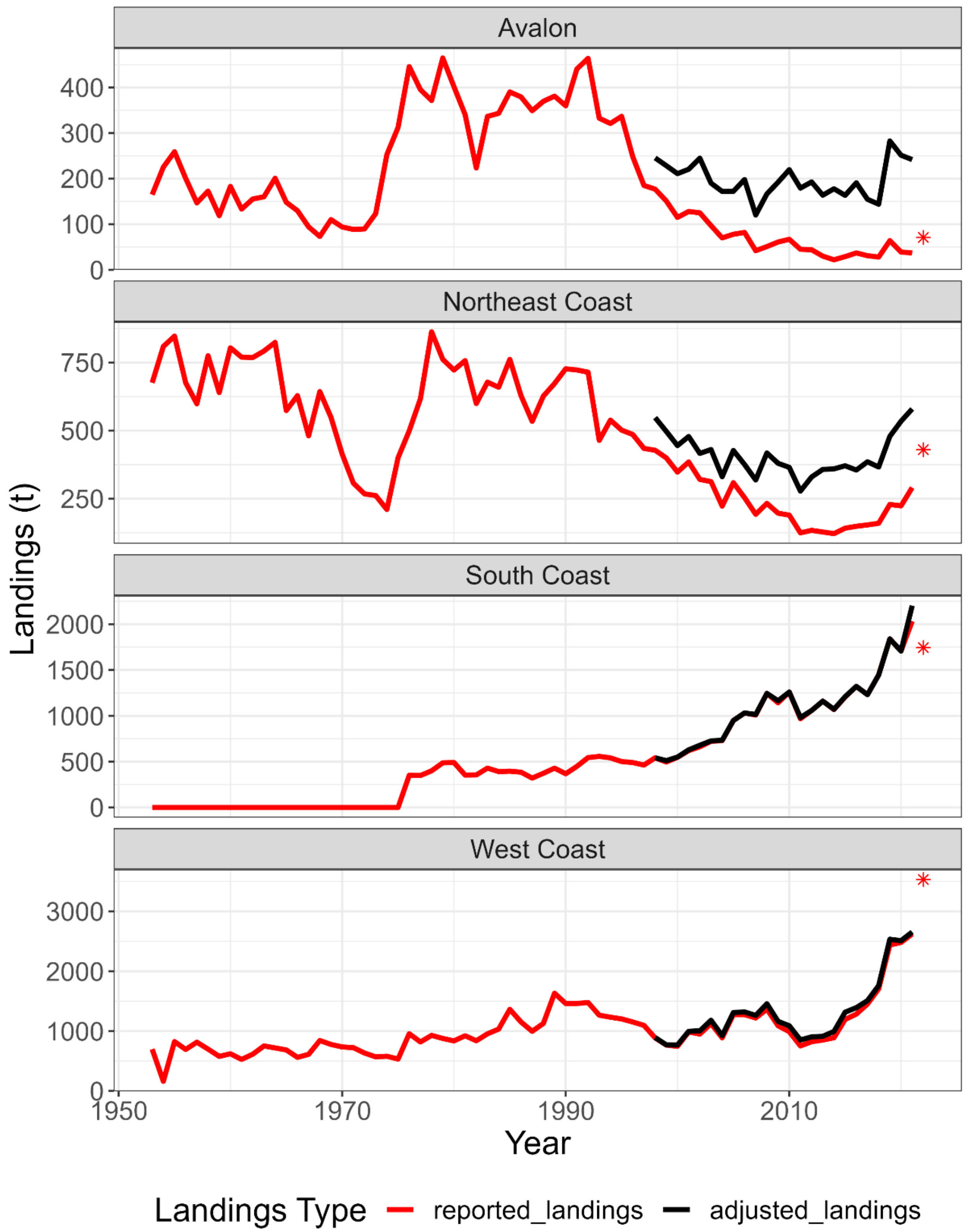

Figure 18. Reported (red line) versus adjusted (black line) landings, 1984 to 2022. Red Star denotes preliminary landings in 2022.

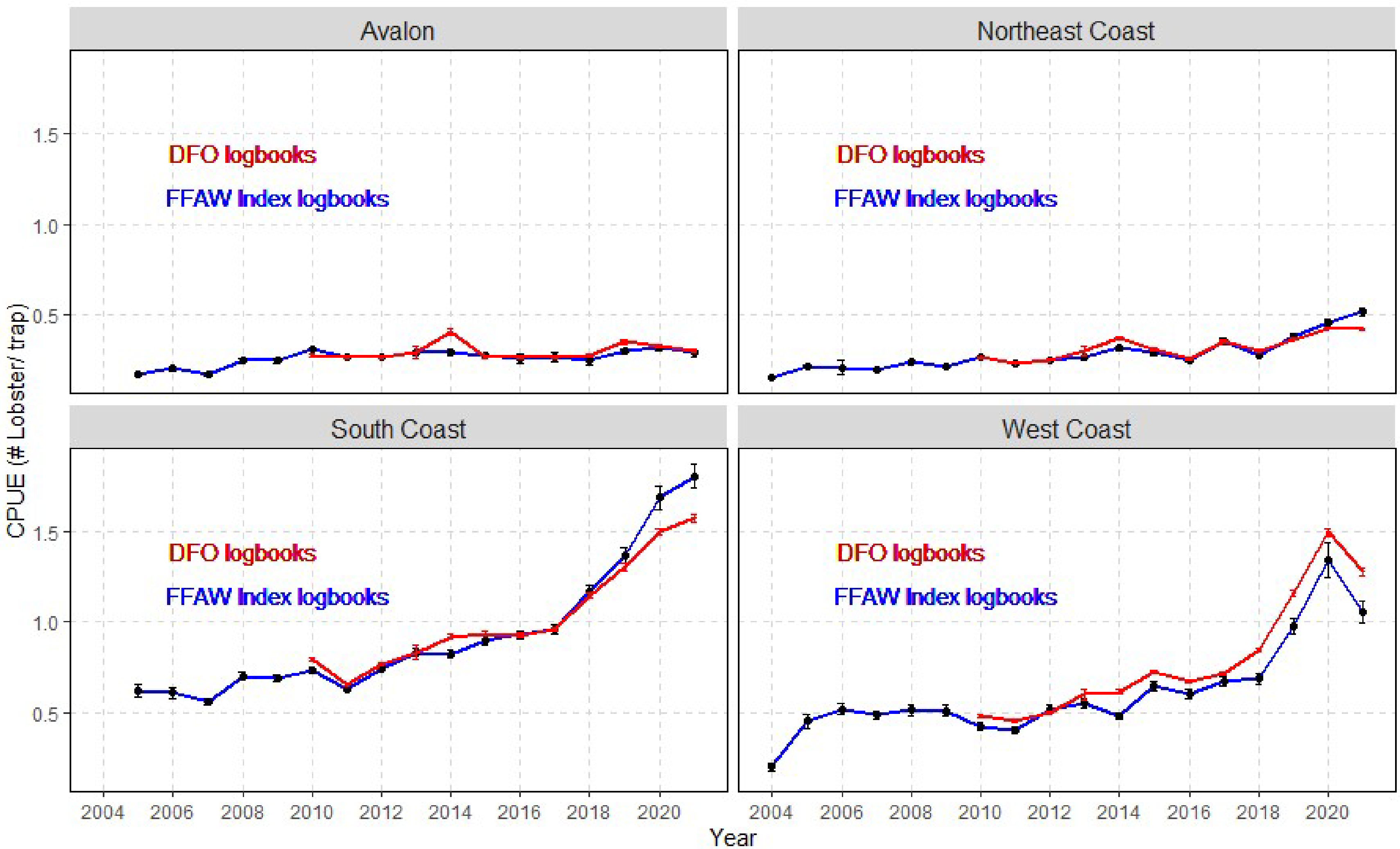

Figure 19. Unstandardized CPUE for each of the four assessment regions based on DFO logbooks (2010–21) and FFAW index harvester logbooks (2004–21). Both logbook data sources showed a similar trend.

Figure 20. Unstandardized CPUE based on DFO logbooks from 2010–21 for LFAs 3–4A, 4B, 5, and 6 within the Northeast Coast region. Note some LFAs were combined due to the Rule of 5.

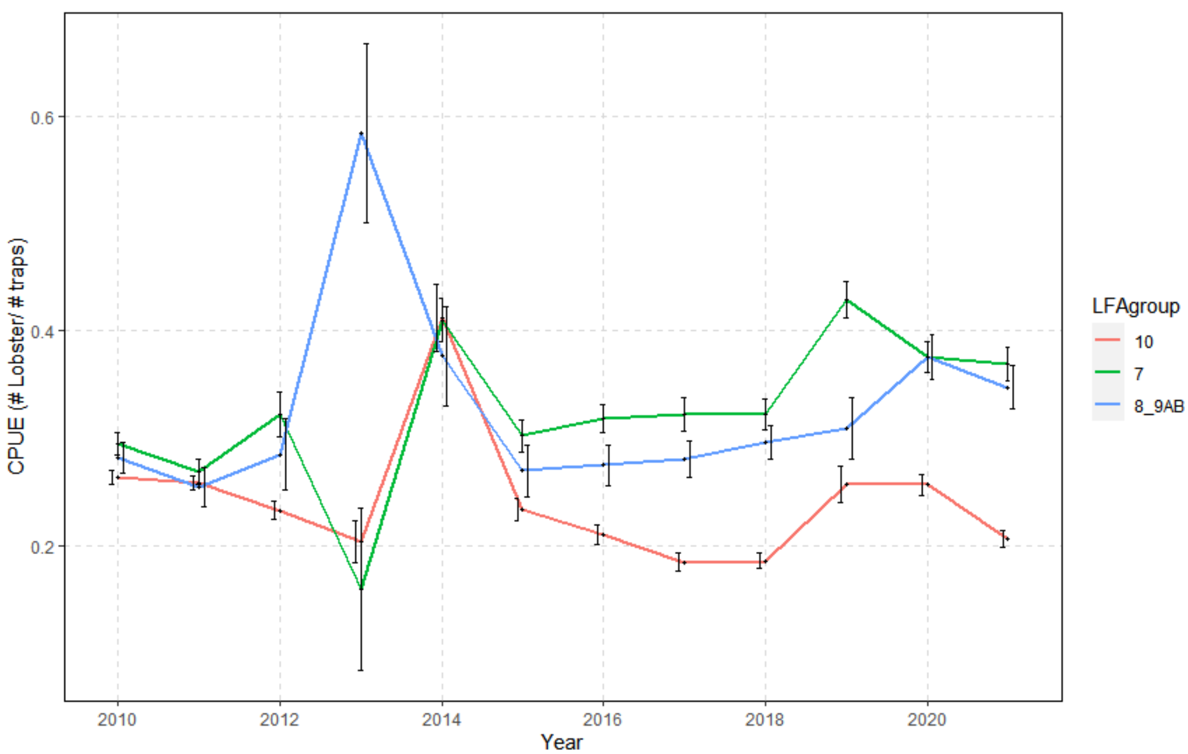

Figure 21. Unstandardized CPUE based on DFO logbooks from 2010–21 for LFAs 10, 7, and 8–9B within the Avalon region. Note some LFAs were combined due to the Rule of 5.

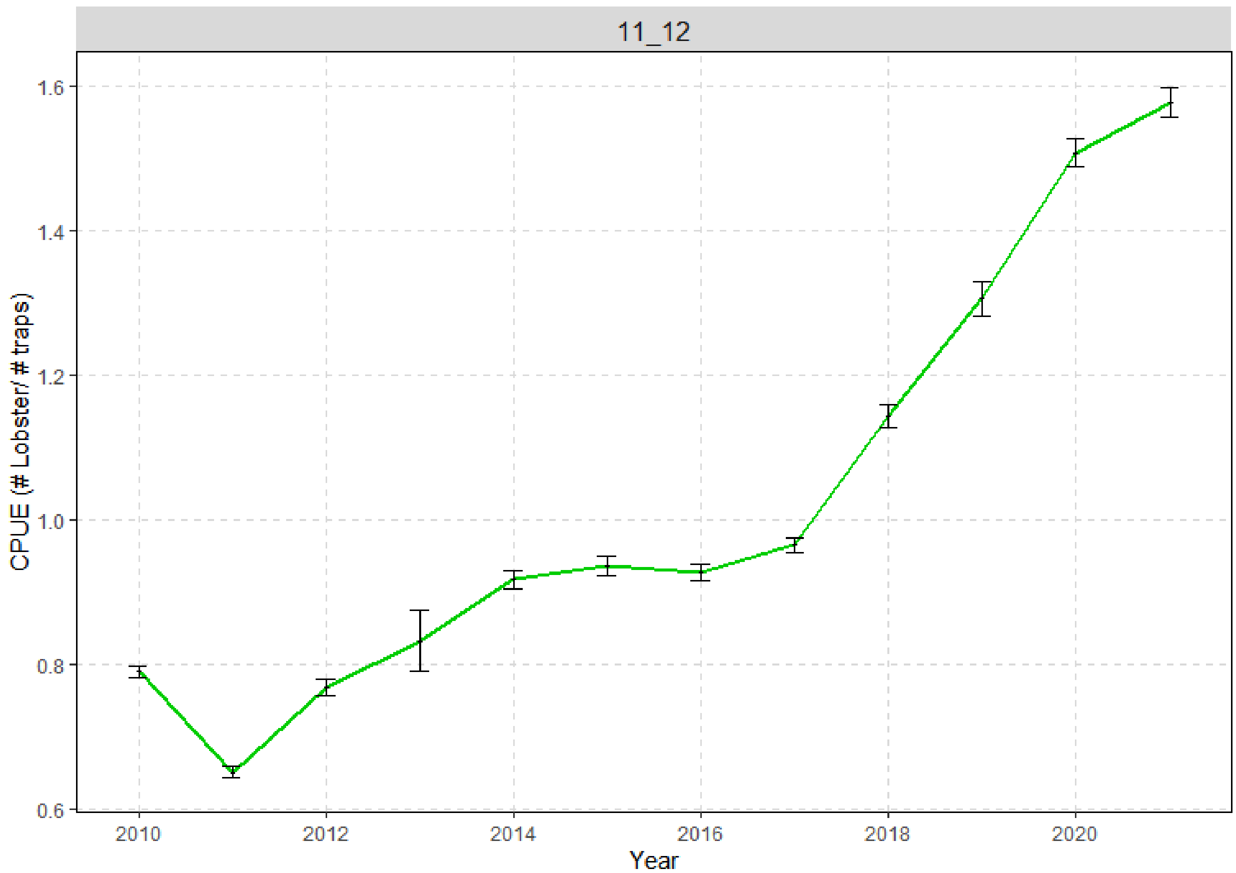

Figure 22. Unstandardized CPUE based on DFO logbooks from 2010–21 for LFAs 11 and 12 within the South Coast region. Note LFAs 11 and 12 were combined due to the Rule of 5.

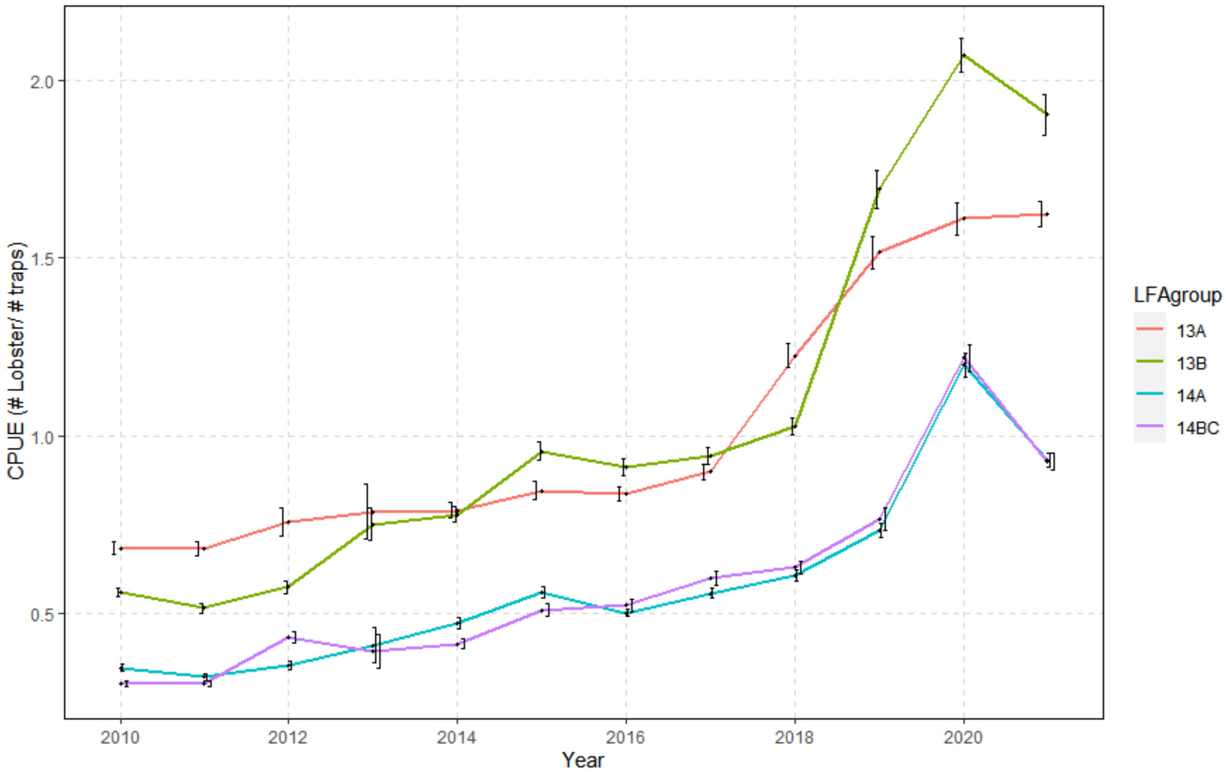

Figure 23. Unstandardized CPUE based on DFO logbooks from 2010–21 for LFAs 13A, 13B, 14A, and 14BC within the West Coast region. Note some LFAs were combined due to the Rule of 5.

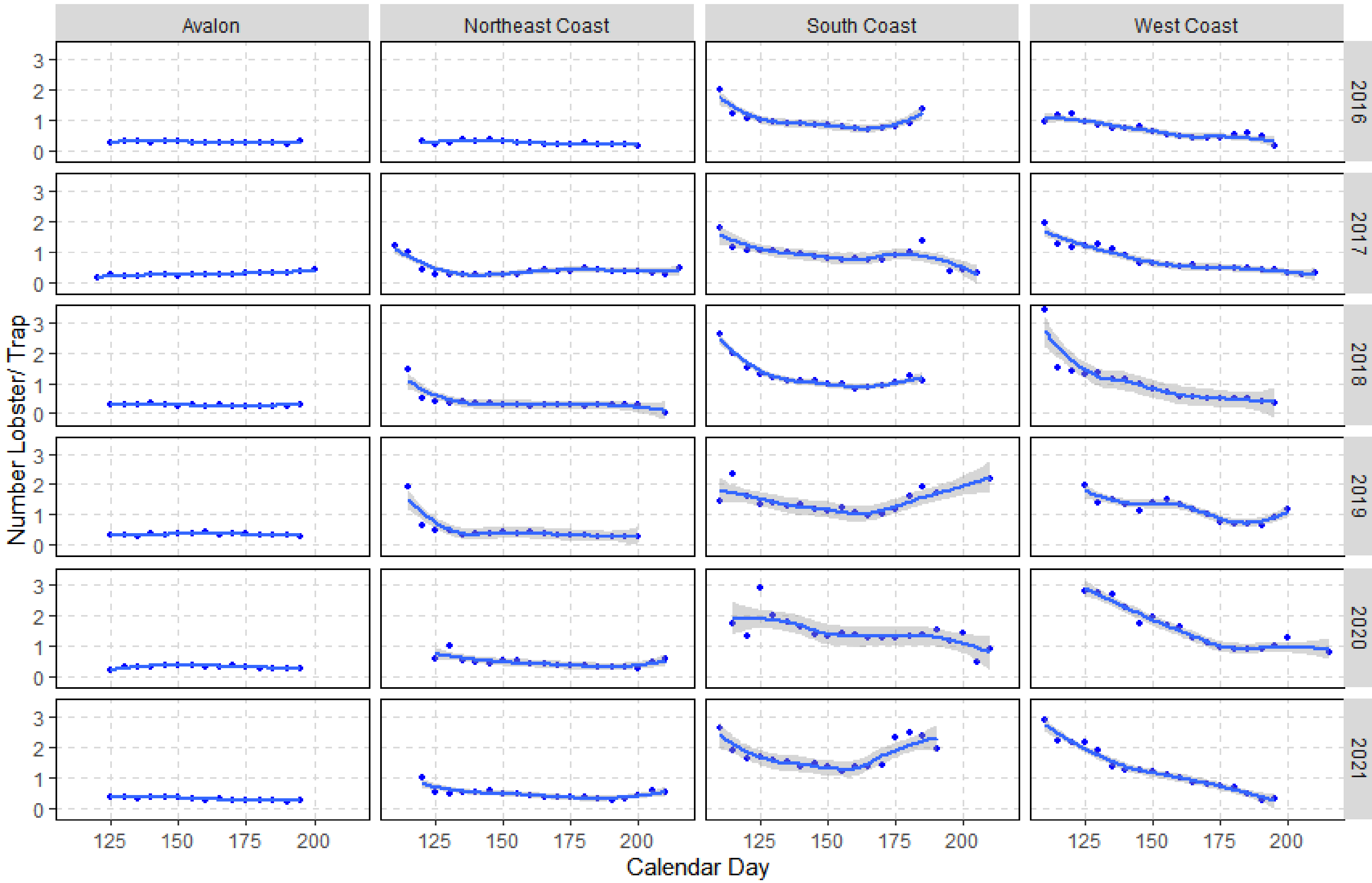

Figure 24. Unstandardized CPUE based on DFO logbooks from 2016–21 for each of the four assessment regions over the fishing season (5-day bins).

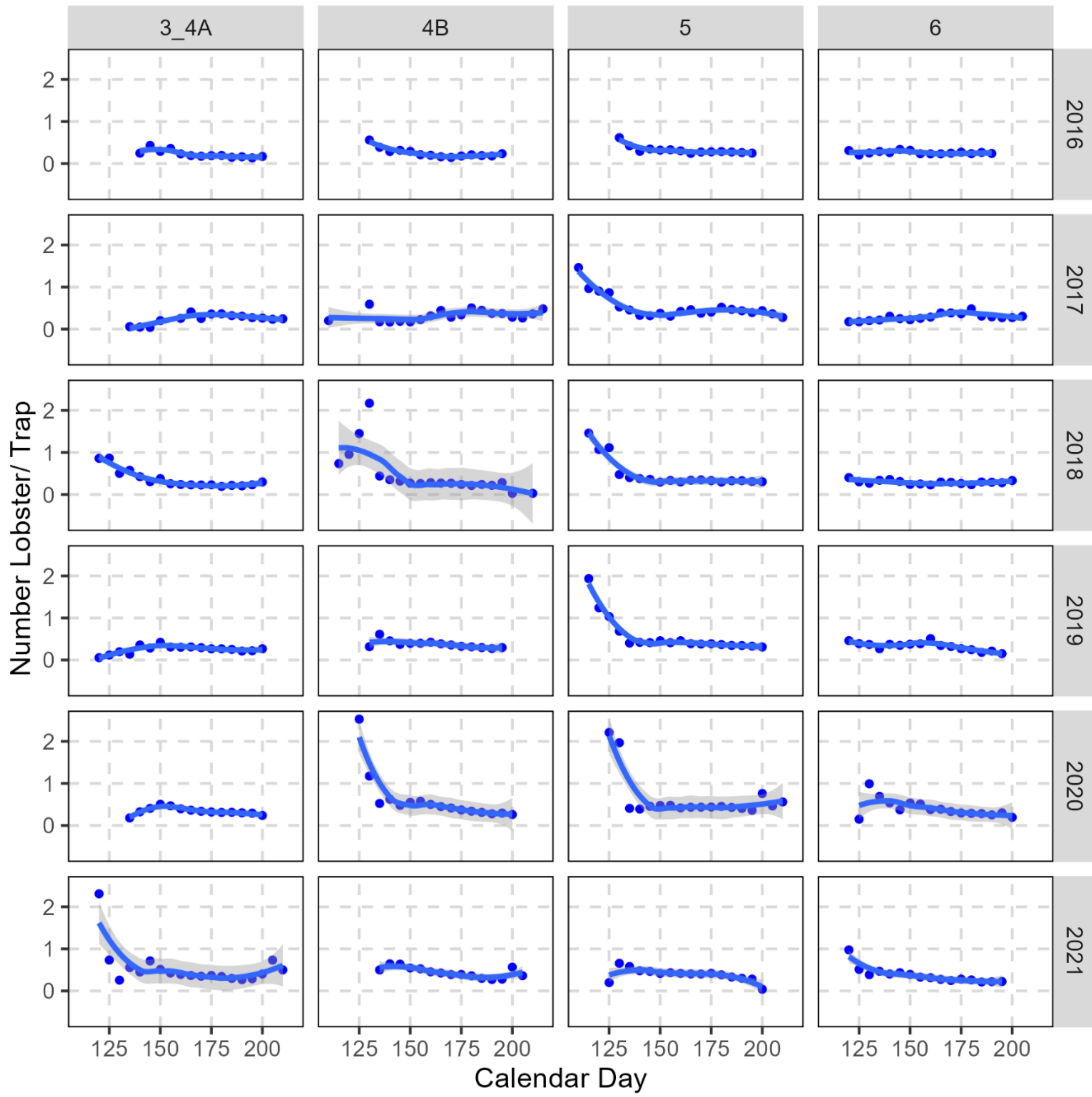

Figure 25. Unstandardized CPUE over the fishing season based on DFO logbooks from 2016–21 for LFAs 3–4A, 4B, 5, and 6 within the Northeast Coast region. Note some LFAs were combined due to the Rule of 5.

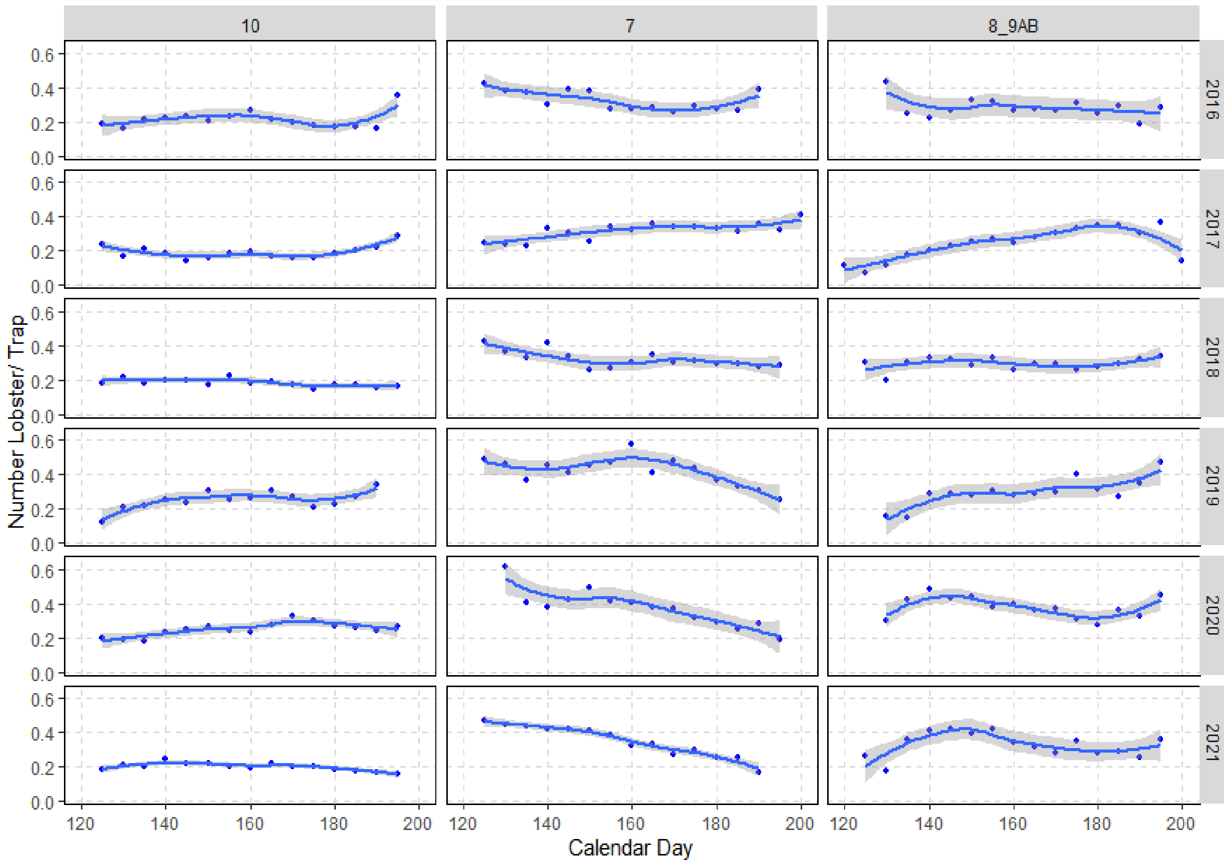

Figure 26. Unstandardized CPUE over the fishing season based on DFO logbooks from 2016–21 for LFAs 10, 7, and 8–9AB within the Avalon region. Note some LFAs were combined due to the Rule of 5.

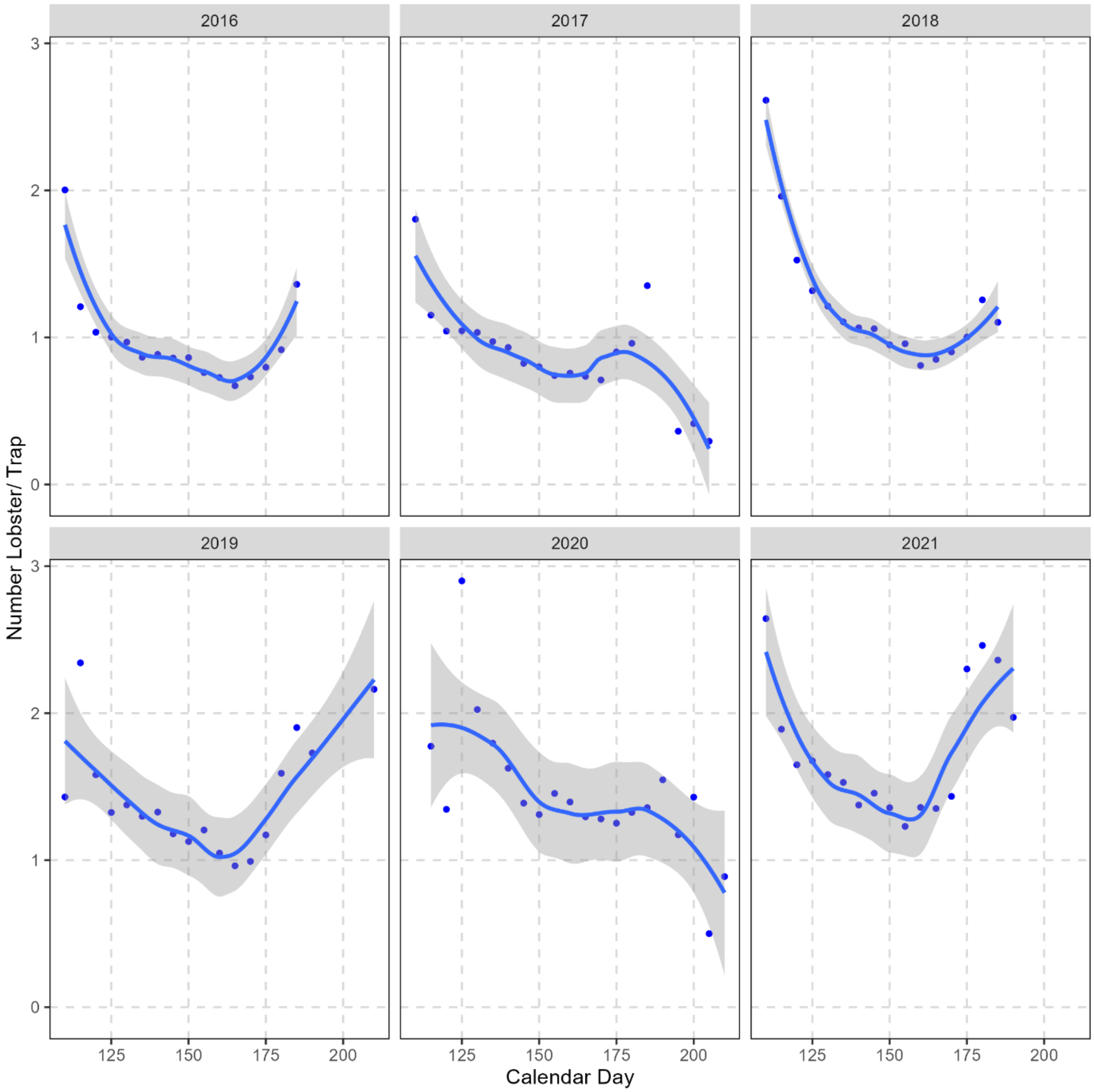

Figure 27. Unstandardized CPUE over the fishing season based on DFO logbooks from 2016–21 for LFAs 11 and 12 combined within the South Coast region. Note LFAs 11 and 12 were combined due to the Rule of 5.

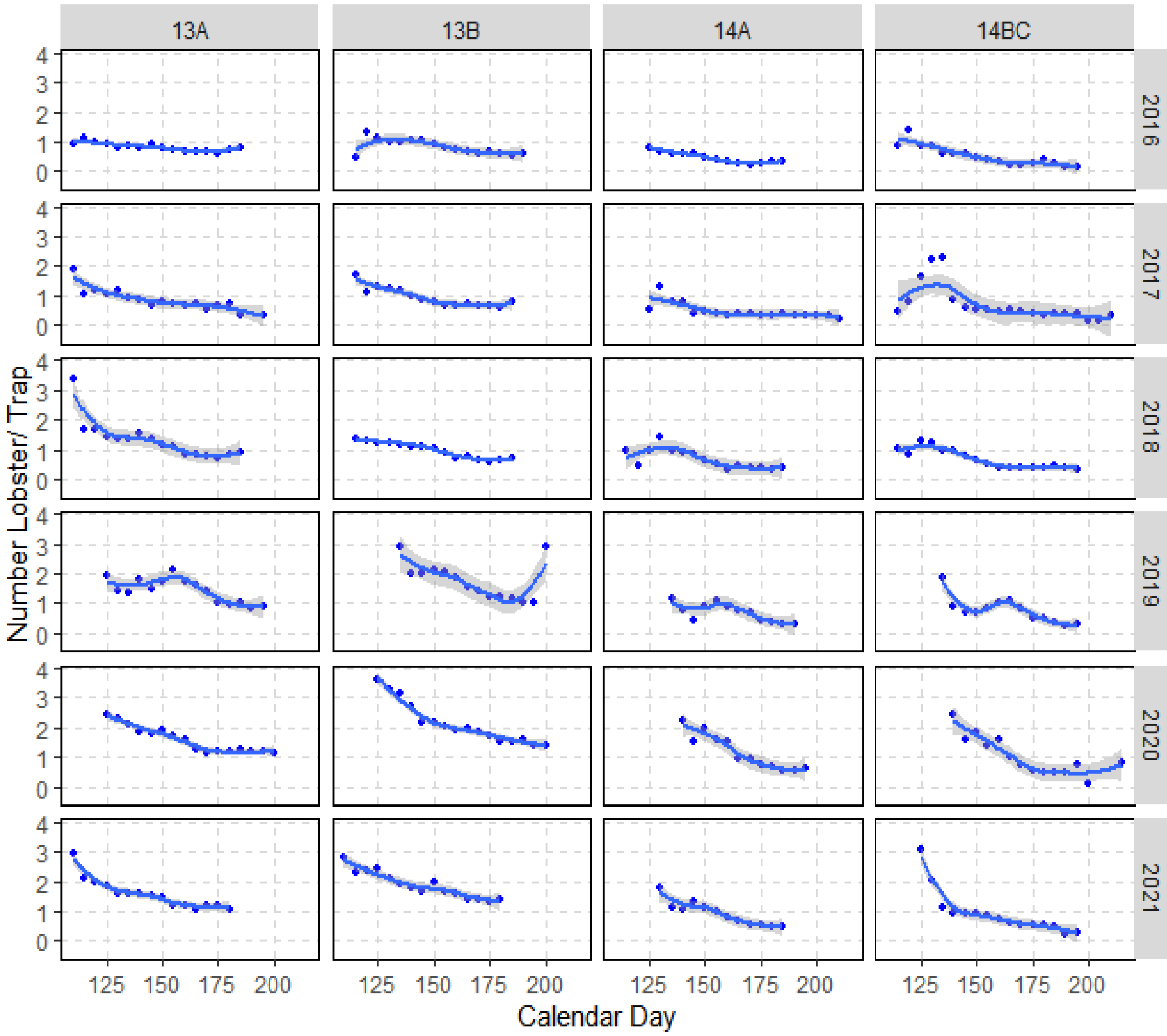

Figure 28. Unstandardized CPUE over the fishing season based on DFO logbooks from 2010–21 for LFAs 13A, 13B, 14A, and 14BC within the West Coast region. Note some LFAs were combined due to the Rule of 5.

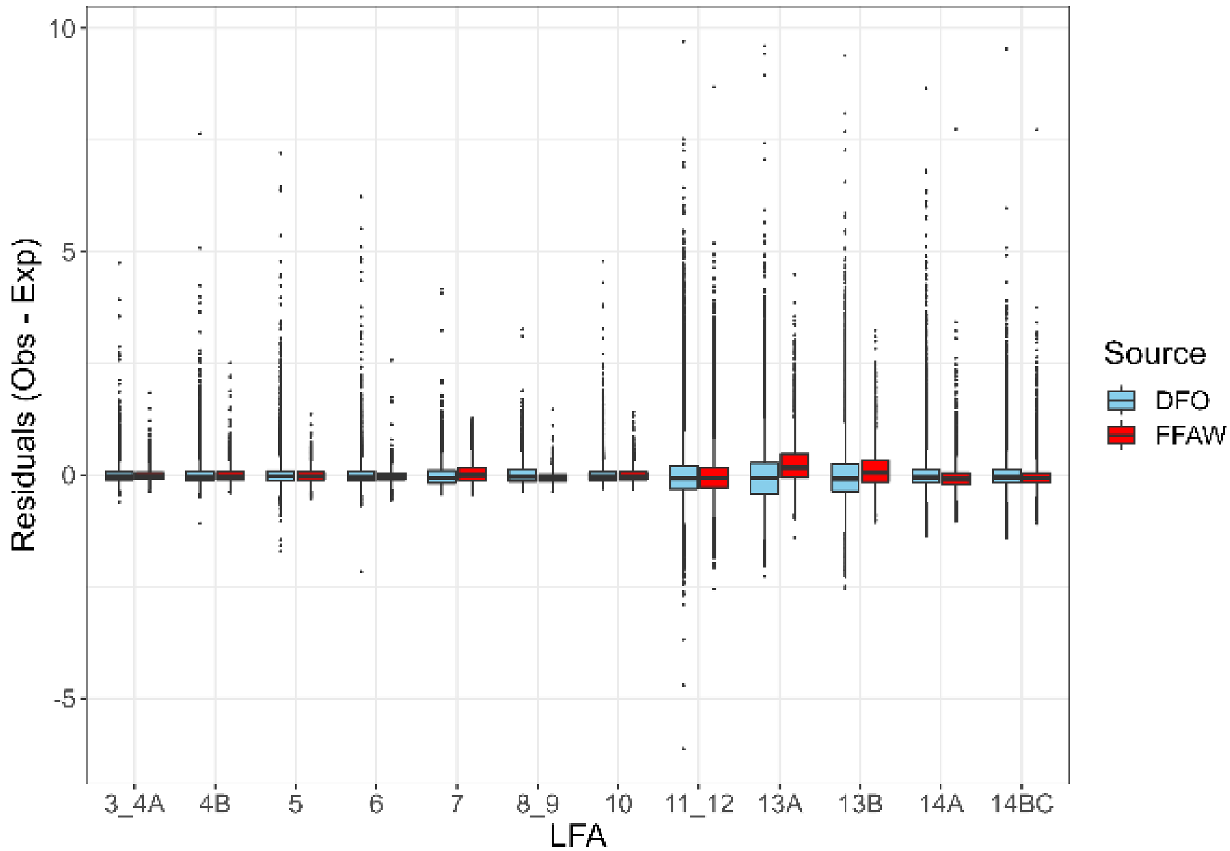

Figure 29. Residual fits for the CPUE standardization model for both logbook data sources (DFO and FFAW index fishers) for each LFA.

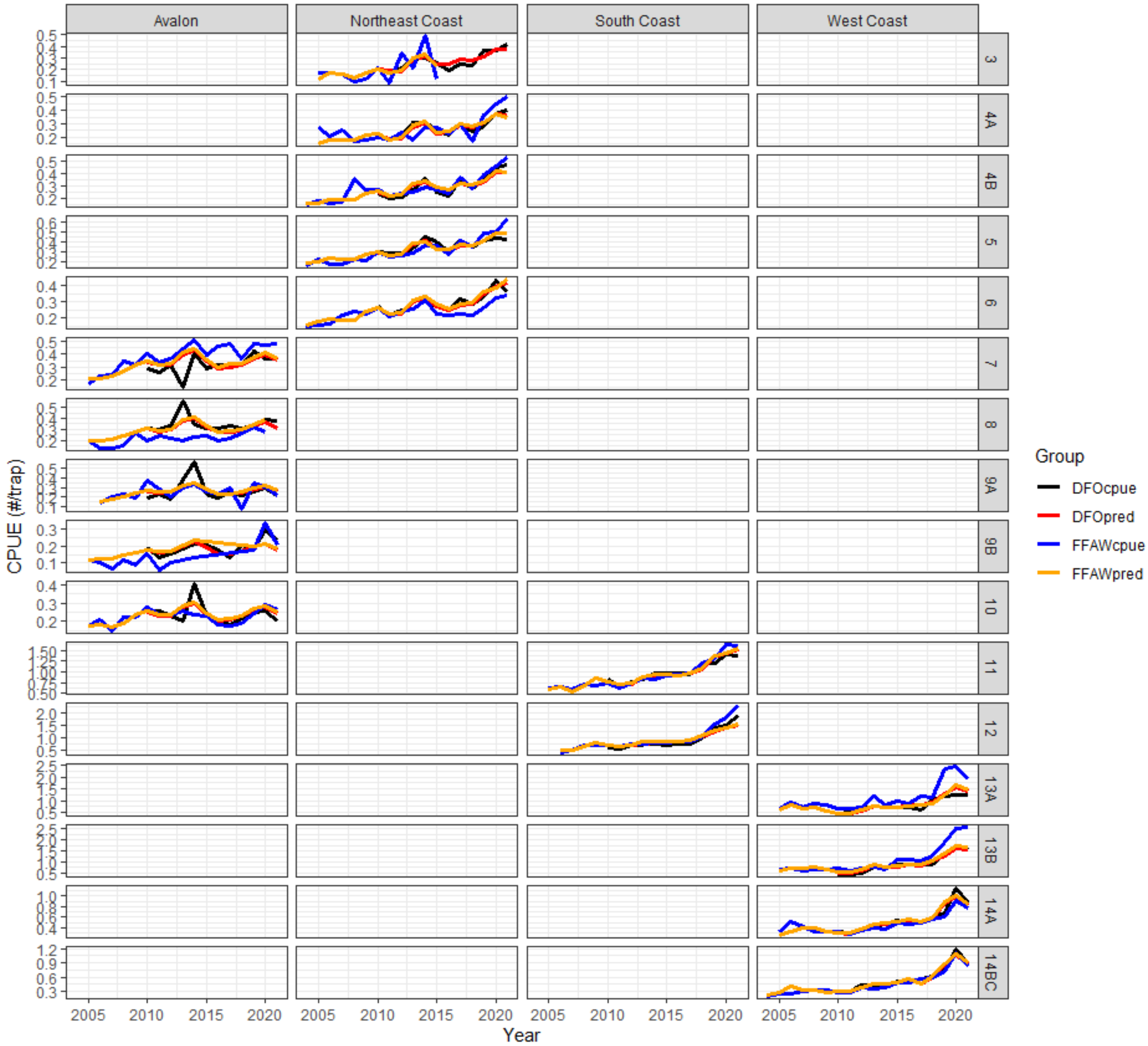

Figure 30. Unstandardized CPUE versus standardized (predicted) fishery CPUE by region, year, LFA, and source (DFO and FFAW index harvester logbooks).

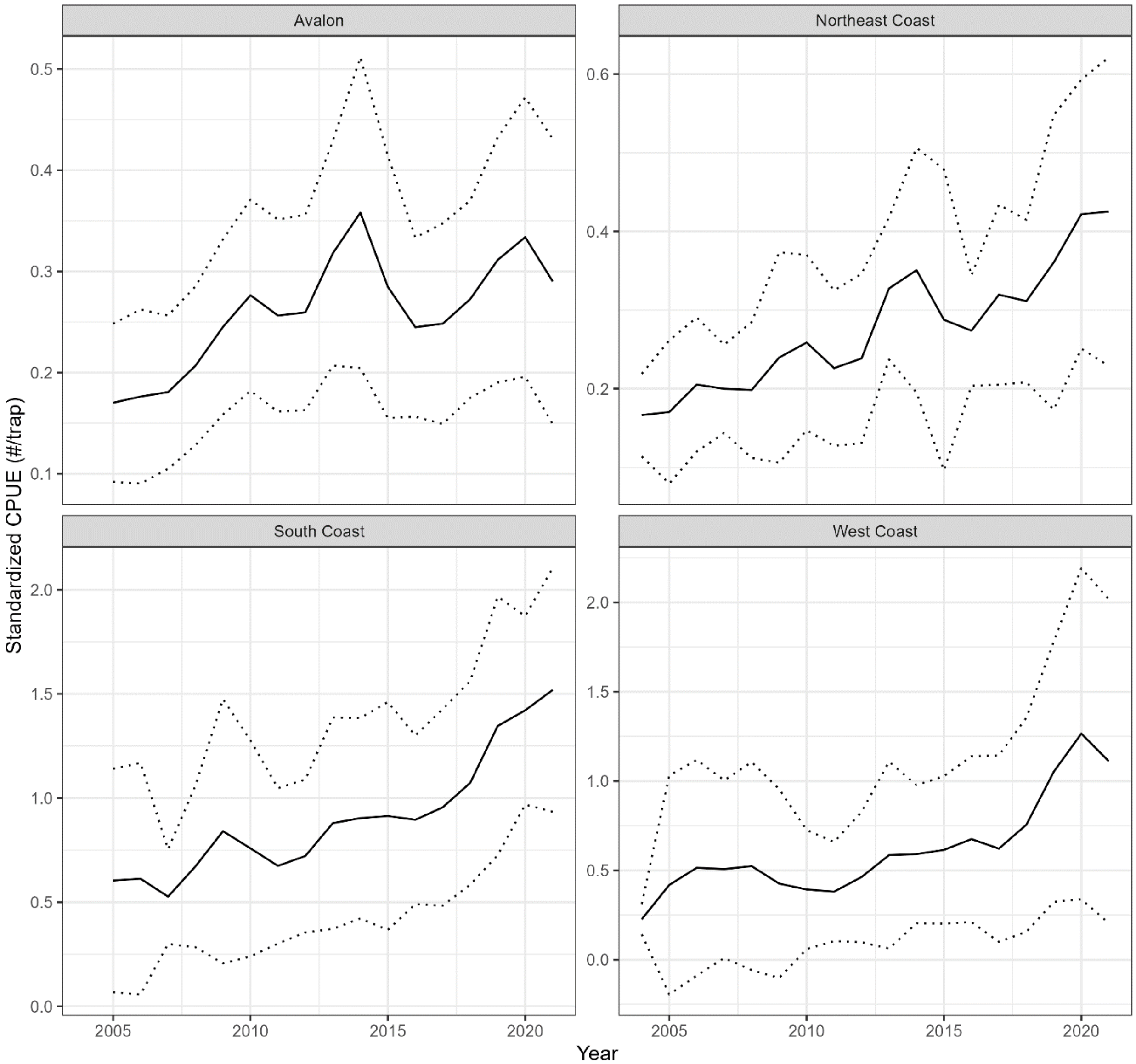

Figure 31. Standardized fishery CPUE from 2004 to 2021 in each region. Dotted lines represent 95% confidence intervals.

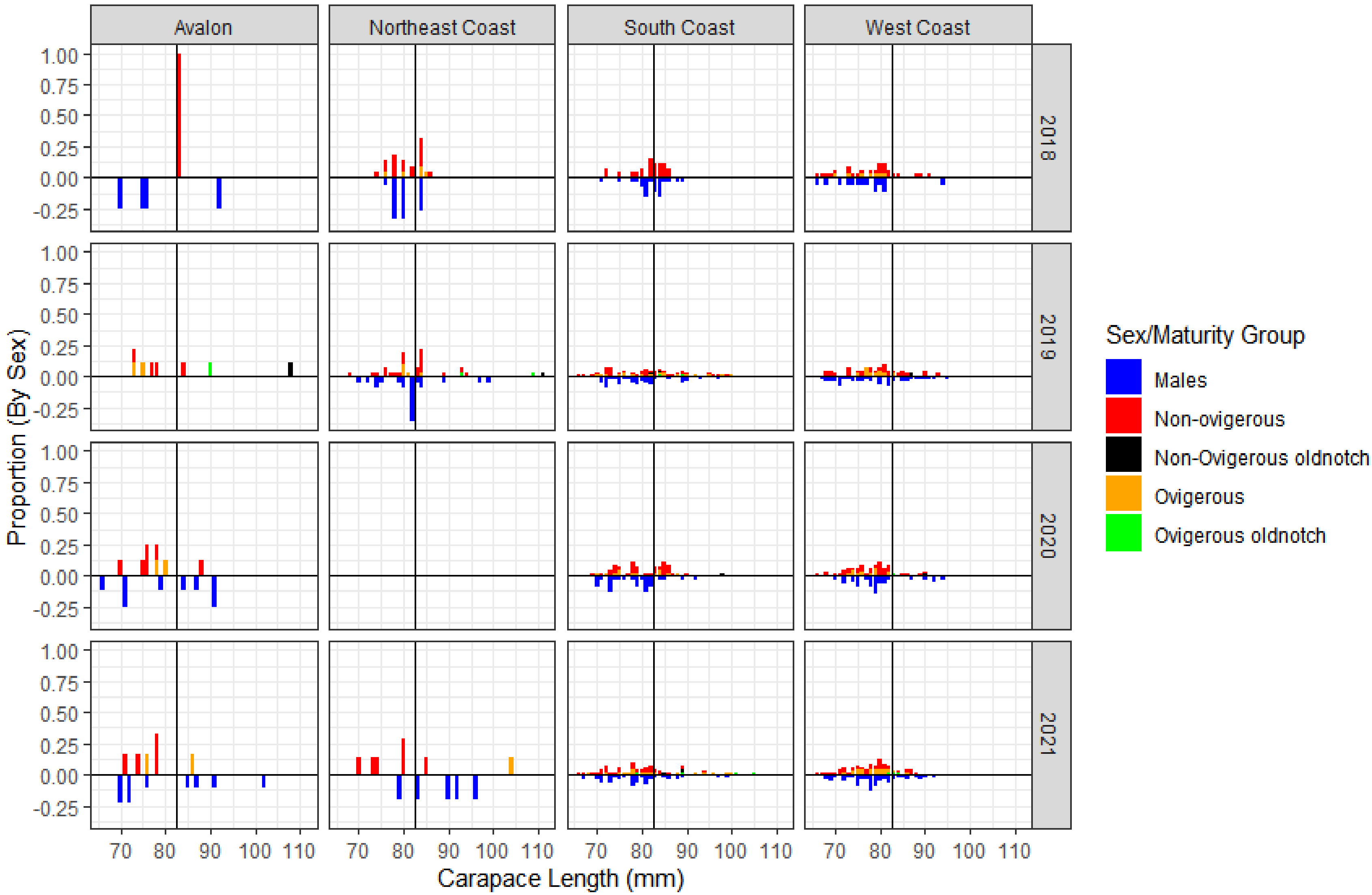

Figure 32. Length frequency distributions showing relative abundance (#/trap) of sex- and maturity-specific population components from at-sea sampling of modified (closed escapement) traps in each region from 2018–21. Note 'oldnotch' is defined as v-notched.

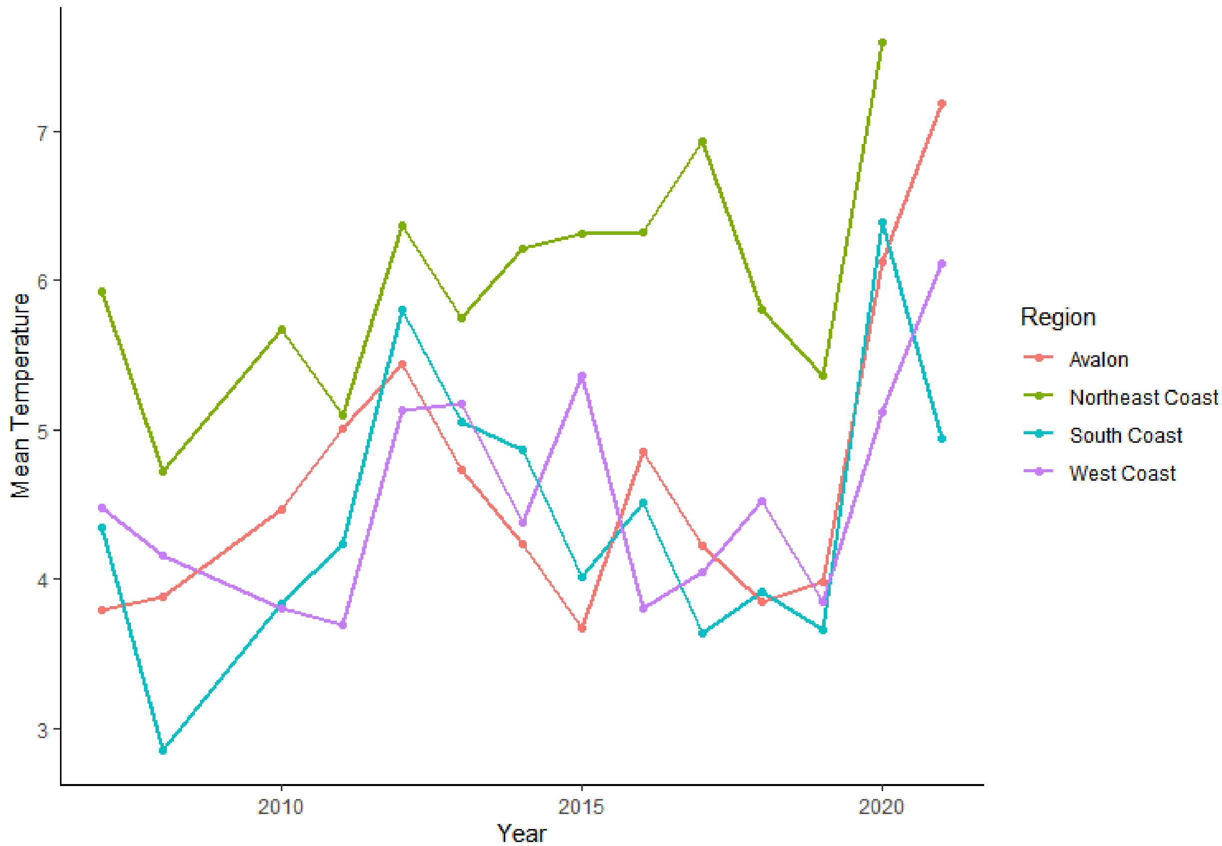

Figure 33. Annual mean temperature (°C) based on temperature probe data from 2007–21 for each of the four assessment regions. These data were collected by various FFAW index harvesters throughout the lobster fishing season. The temperature probes were placed on the modified traps or deployed at a set location within the respective LFA.

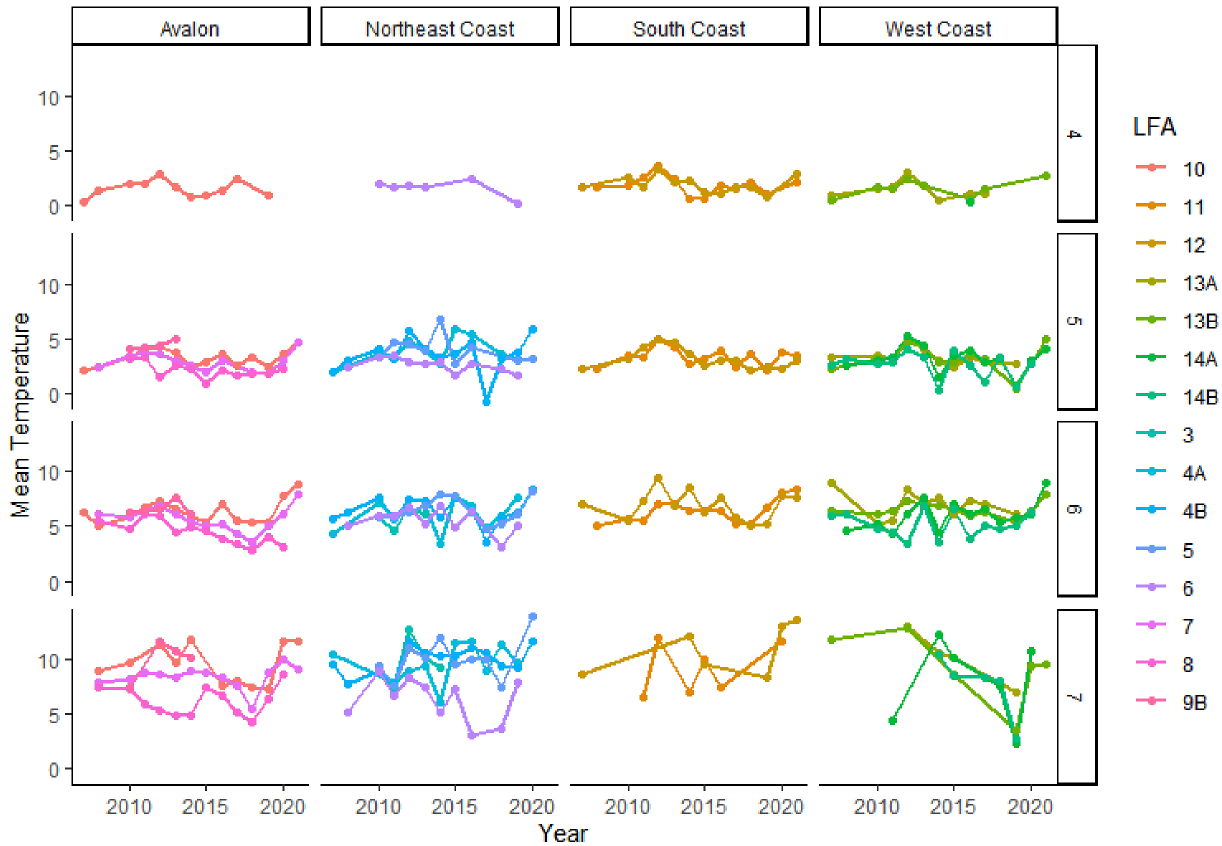

Figure 34. Mean temperatures results from 2007 to 2021 for each month (on the right axis- April-4, May-5, June-6, and July-7) for each LFA within respective assessment regions.

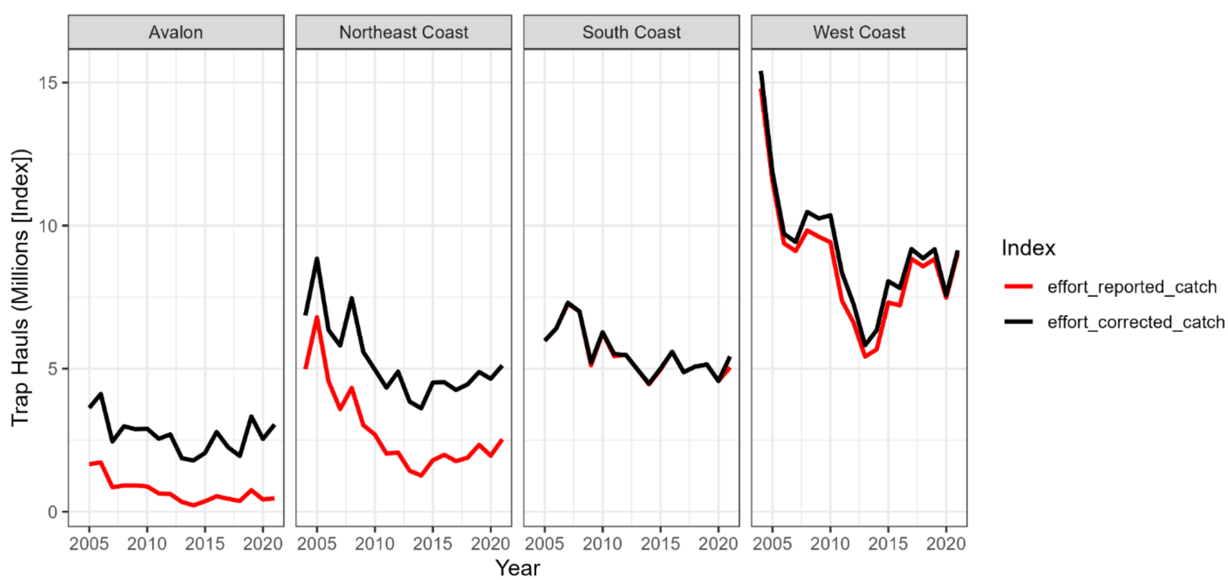

Figure 35. Estimated effort by region and year. Estimations based on reported [adjusted] landings and catch rate conversions based on mean sizes of lobster in the catch and published length-weight relationships.

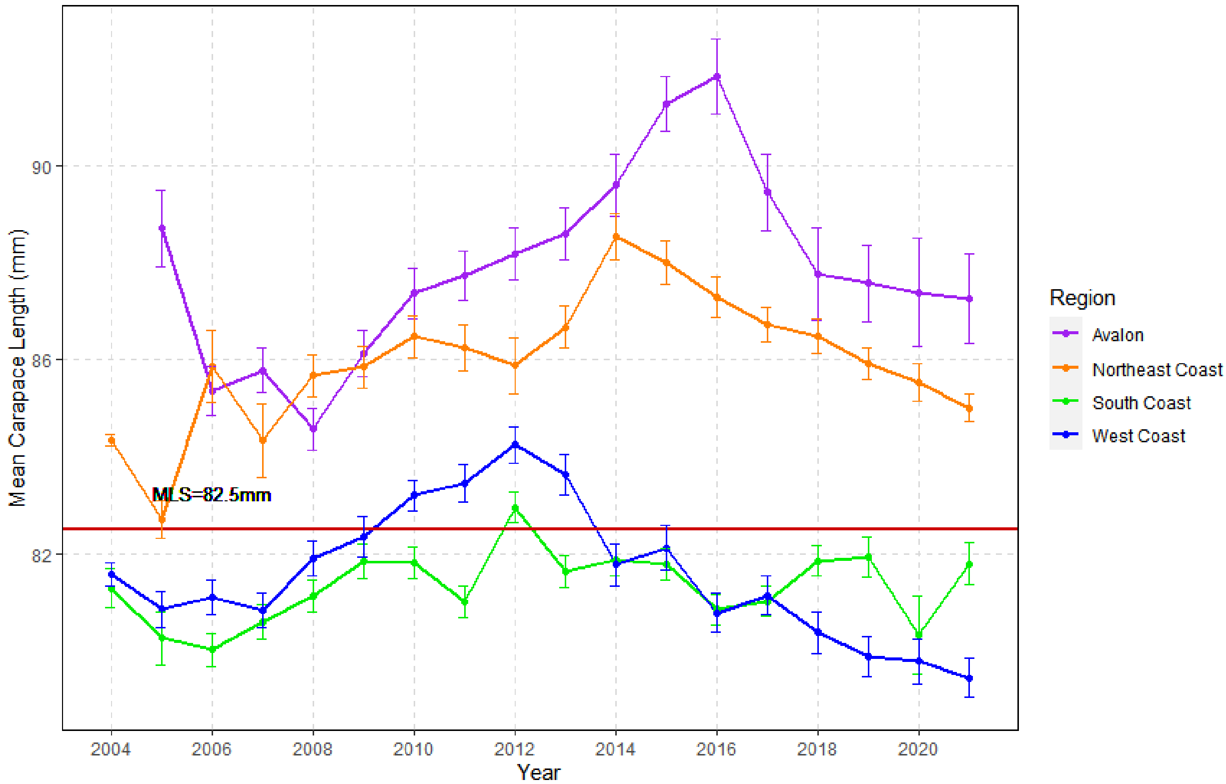

Figure 36. Mean carapace length (mm) of total catch from at-sea sampling data for each assessment region, 2004–21. The red horizontal line represents the MLS and error bars represent 95% confidence intervals.

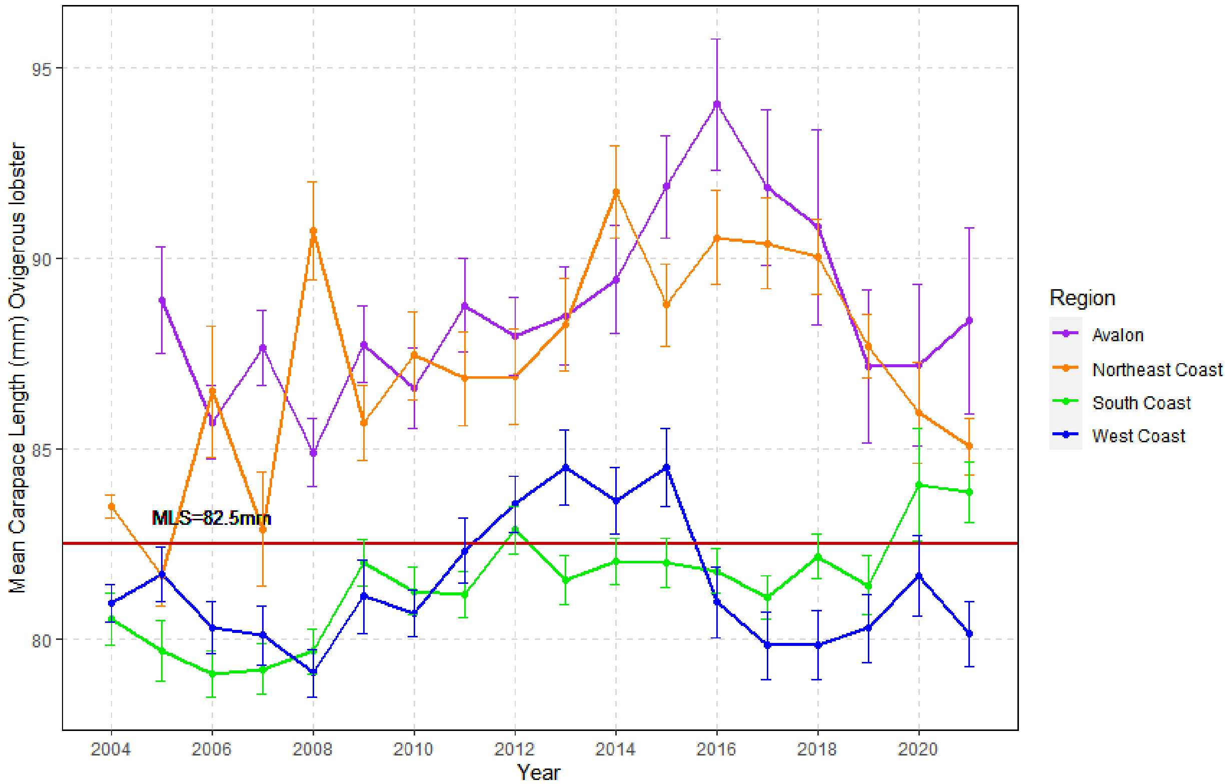

Figure 37. Mean carapace length (mm) of ovigerous female lobster from at-sea sampling for each assessment region, 2004–21. The red horizontal line represents the MLS and error bars represent 95% confidence intervals.

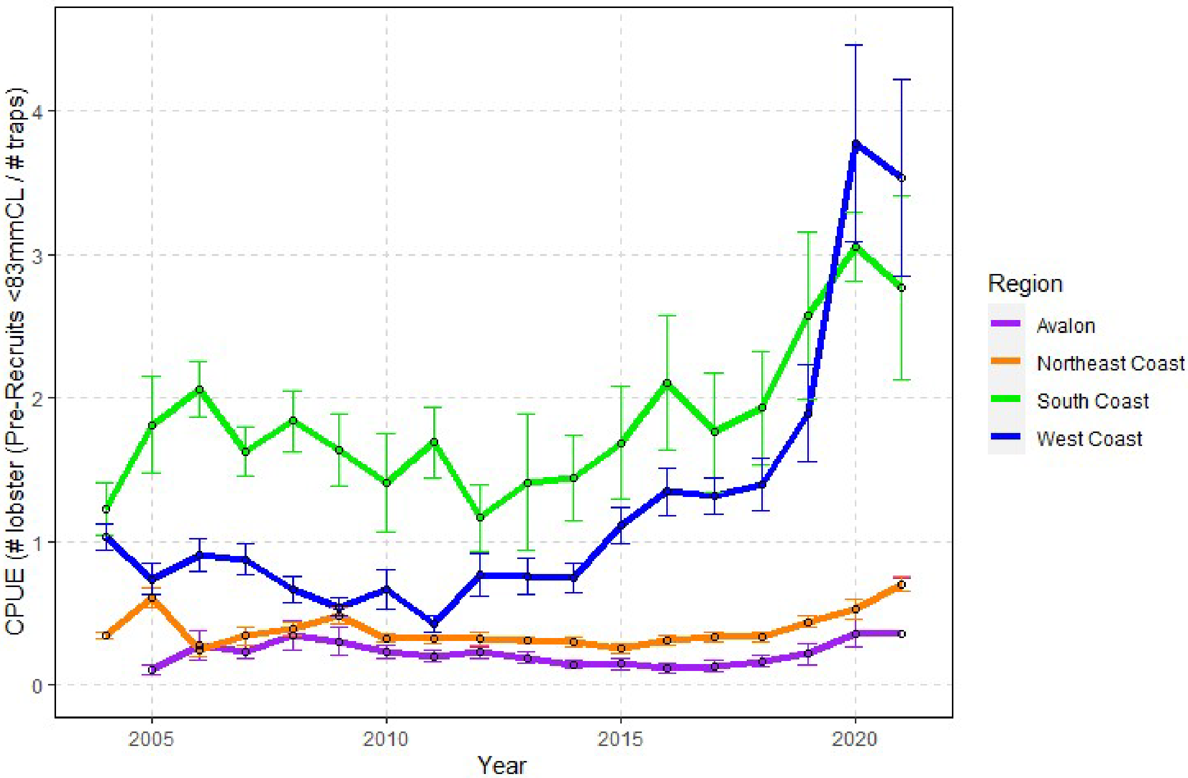

Figure 38. CPUE of pre-recruit (<83 mm CL) lobster from at-sea sampling data (commercial traps) collected in each assessment region, 2004–21. Error bars represent 95% confidence intervals.

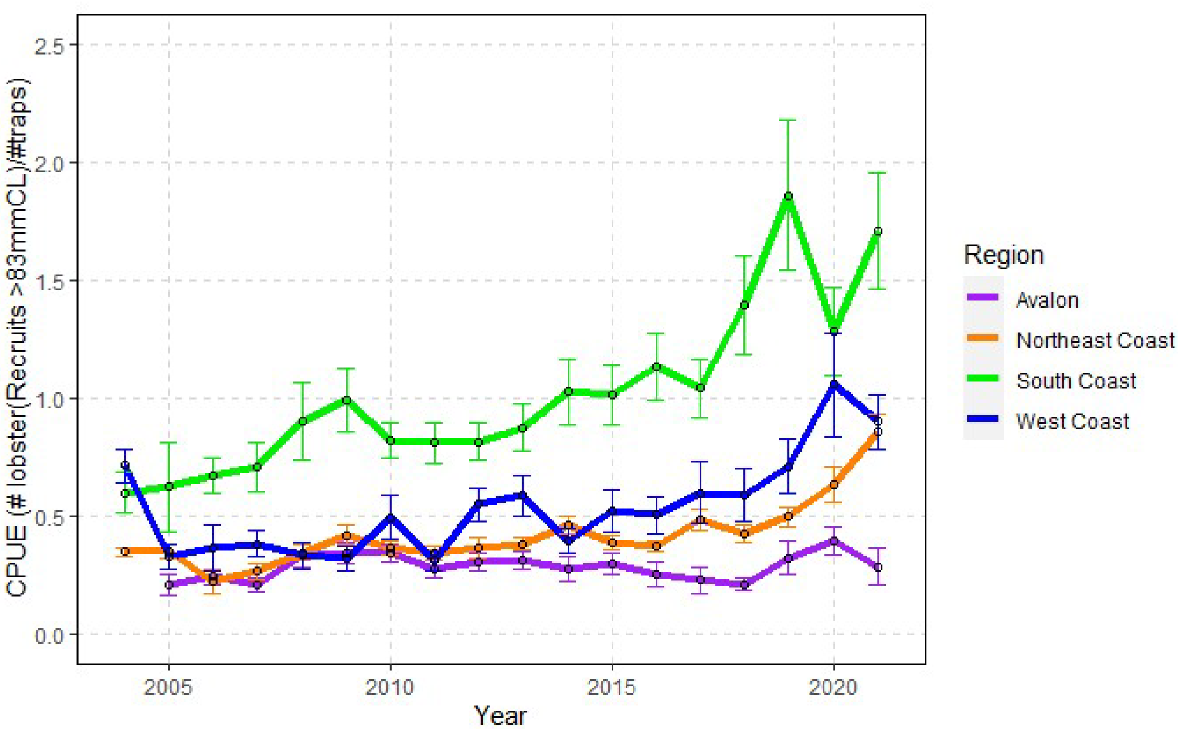

Figure 39. CPUE of recruit size (≥83 mm CL) lobster from at-sea sampling data (commercial traps) collected in each assessment region, 2004–21. Error bars represent 95% confidence intervals.

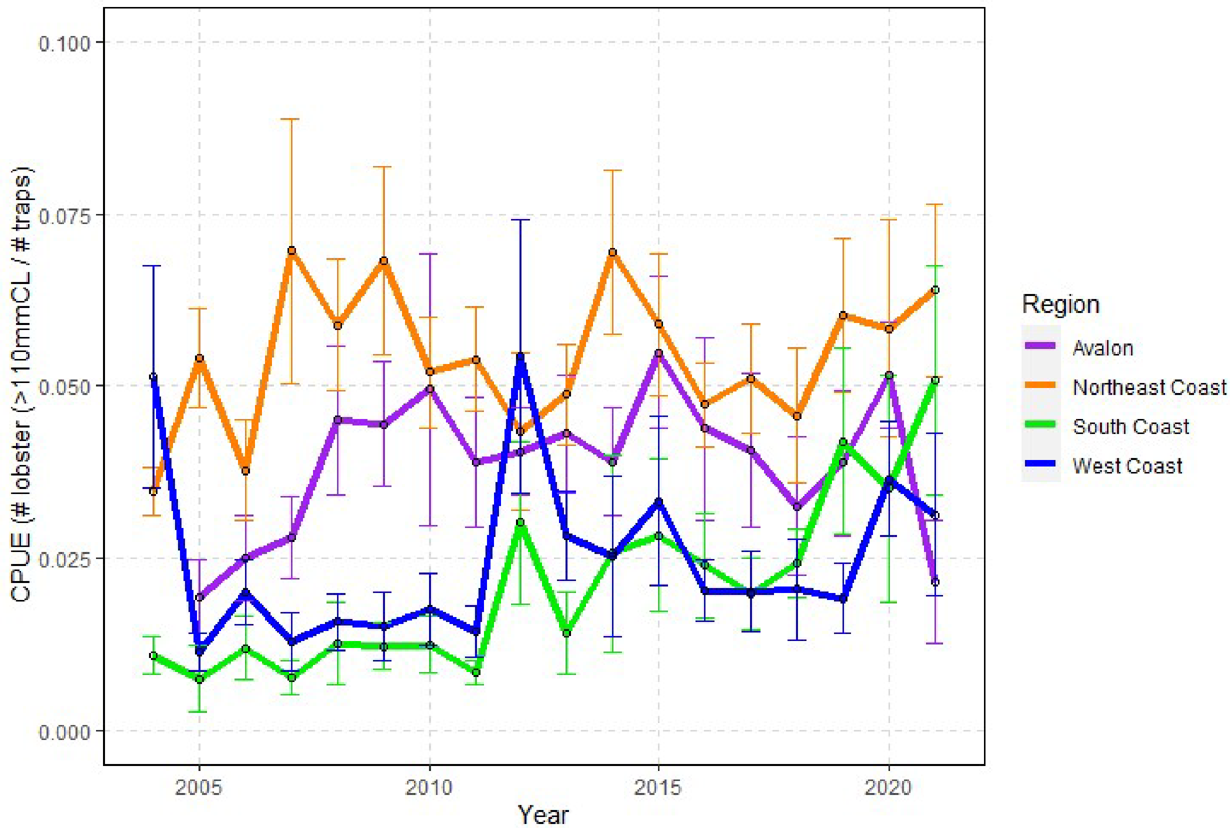

Figure 40. CPUE of large lobster (>110 mm CL) from at-sea sampling data (commercial traps) in each of the four assessment regions, 2004–21. Error bars represent 95% confidence intervals.

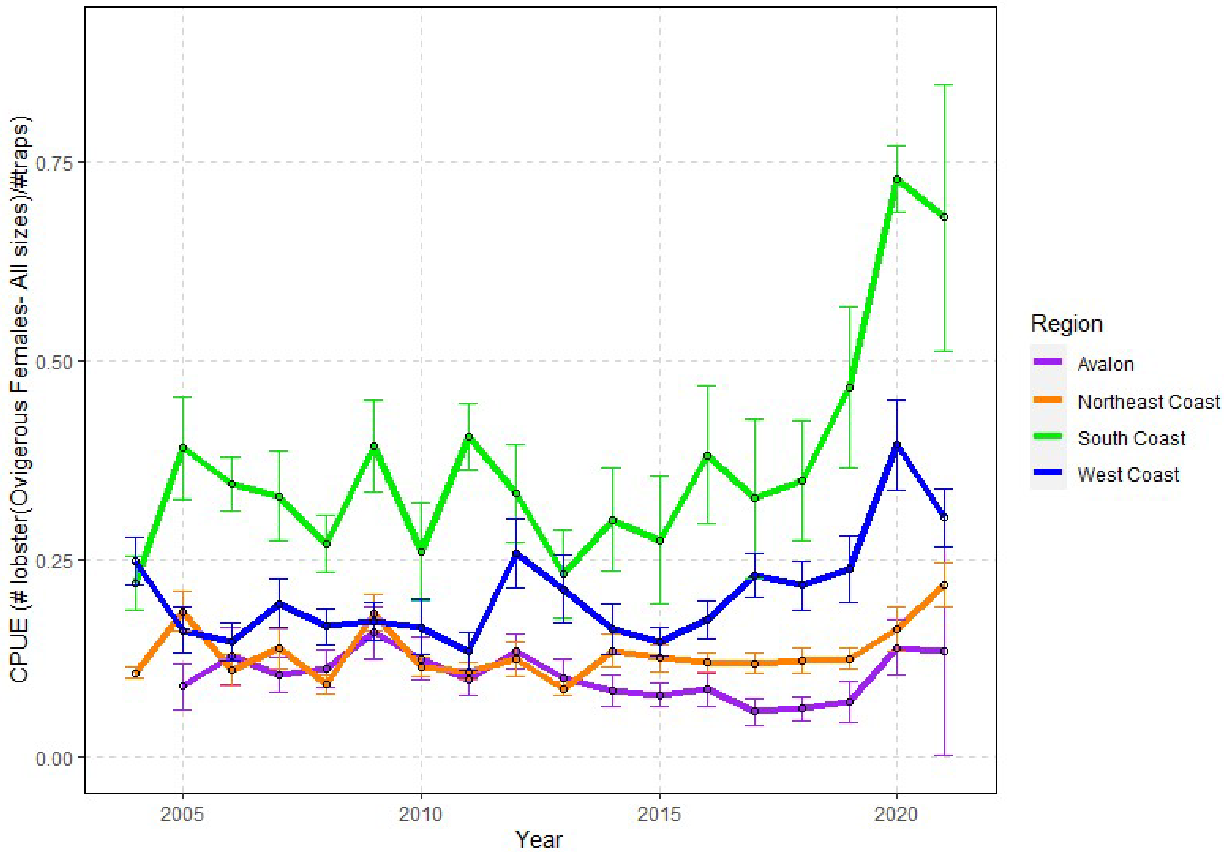

Figure 41. CPUE of ovigerous female lobster from at-sea sampling data in each of the four assessment regions, 2004–21. Error bars represent 95% confidence intervals.

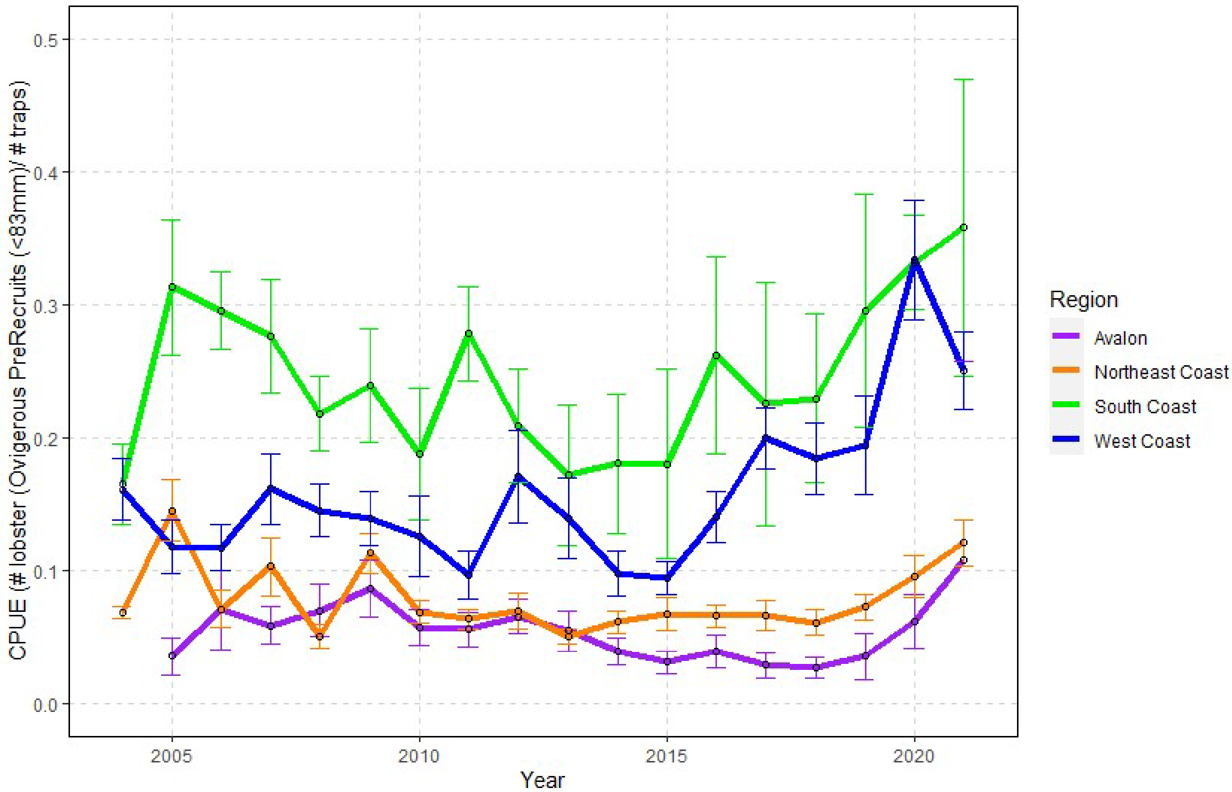

Figure 42. CPUE of ovigerous female lobster (pre-recruits <83 mm CL) from at-sea sampling data in each of the four assessment regions, 2004–21. Error bars represent 95% confidence intervals.

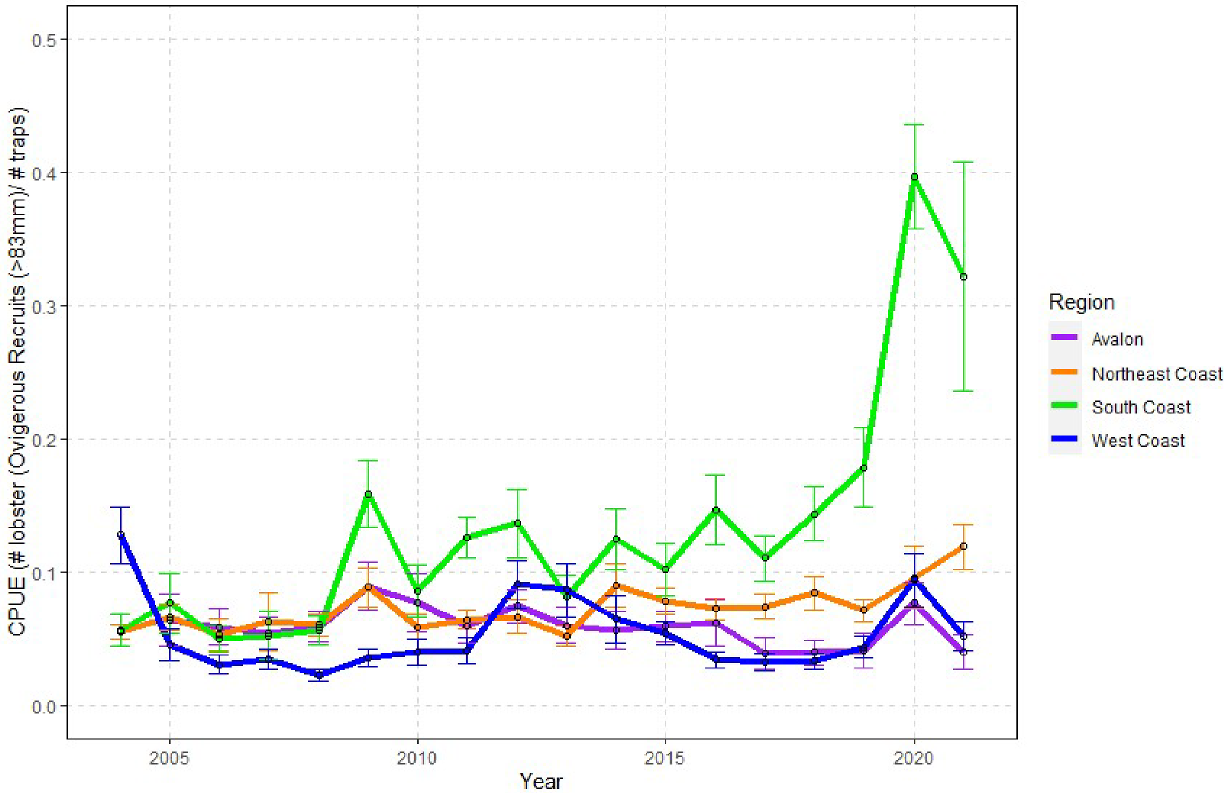

Figure 43. CPUE of ovigerous female lobster (recruits ≥83 mm) from at-sea sampling data in each of the four assessment regions, 2004–21. Error bars represent 95% confidence intervals.

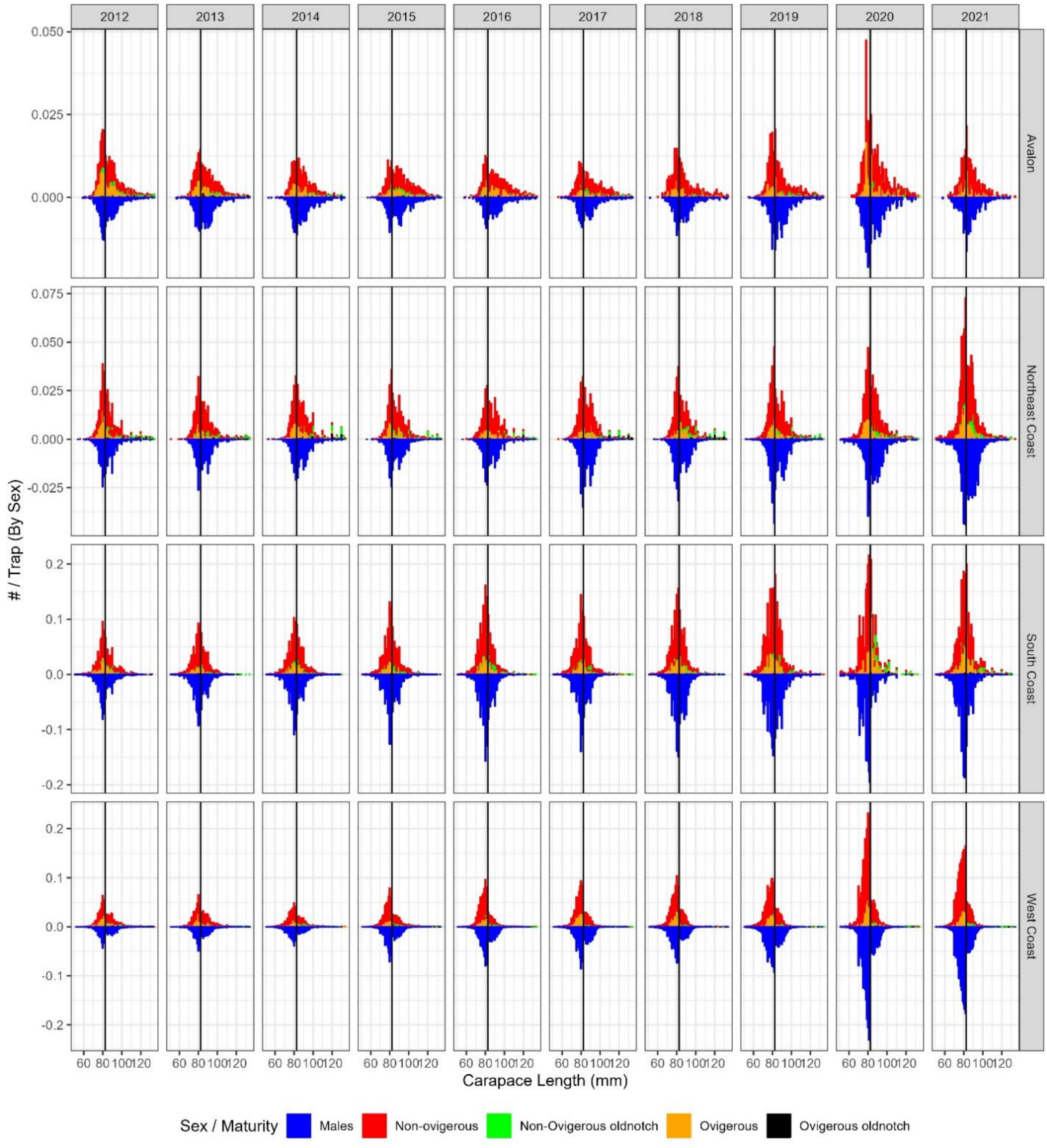

Figure 44. Annual distributions of number of lobster per trap for males (bottom half of each panel) and females (top half of each panel) from at-sea sampling data in each of the four assessment regions, 2012–21. The black vertical line represents the MLS (82.5 mm). Note 'oldnotch' is defined as v-notched.

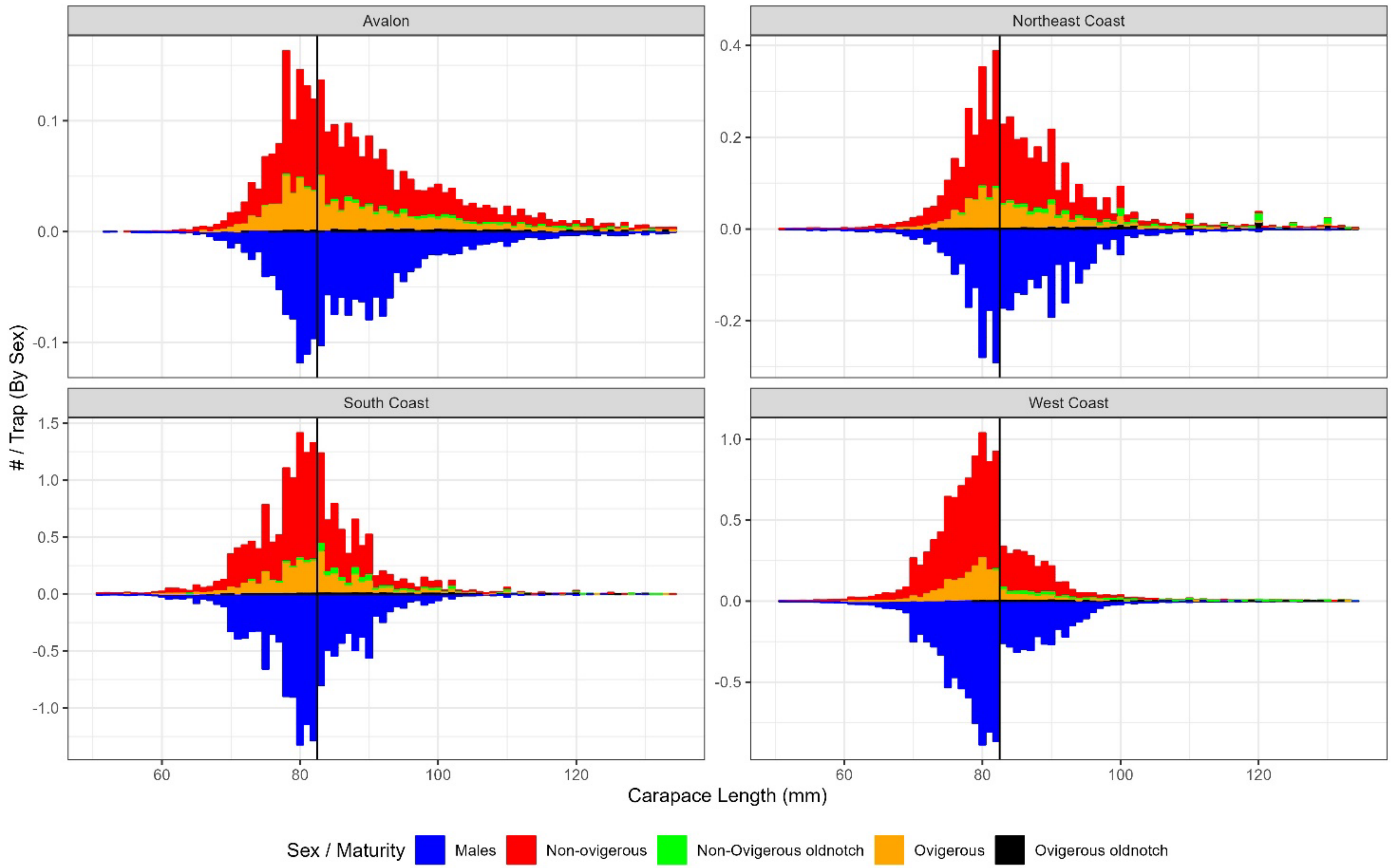

Figure 45. Annual distributions of number of lobster per trap for males (bottom half of each panel) and females (top half of each panel) from at-sea sampling data in each of the four assessment regions, including all years from 2012 to 2021. The black vertical line represents the MLS (82.5 mm).

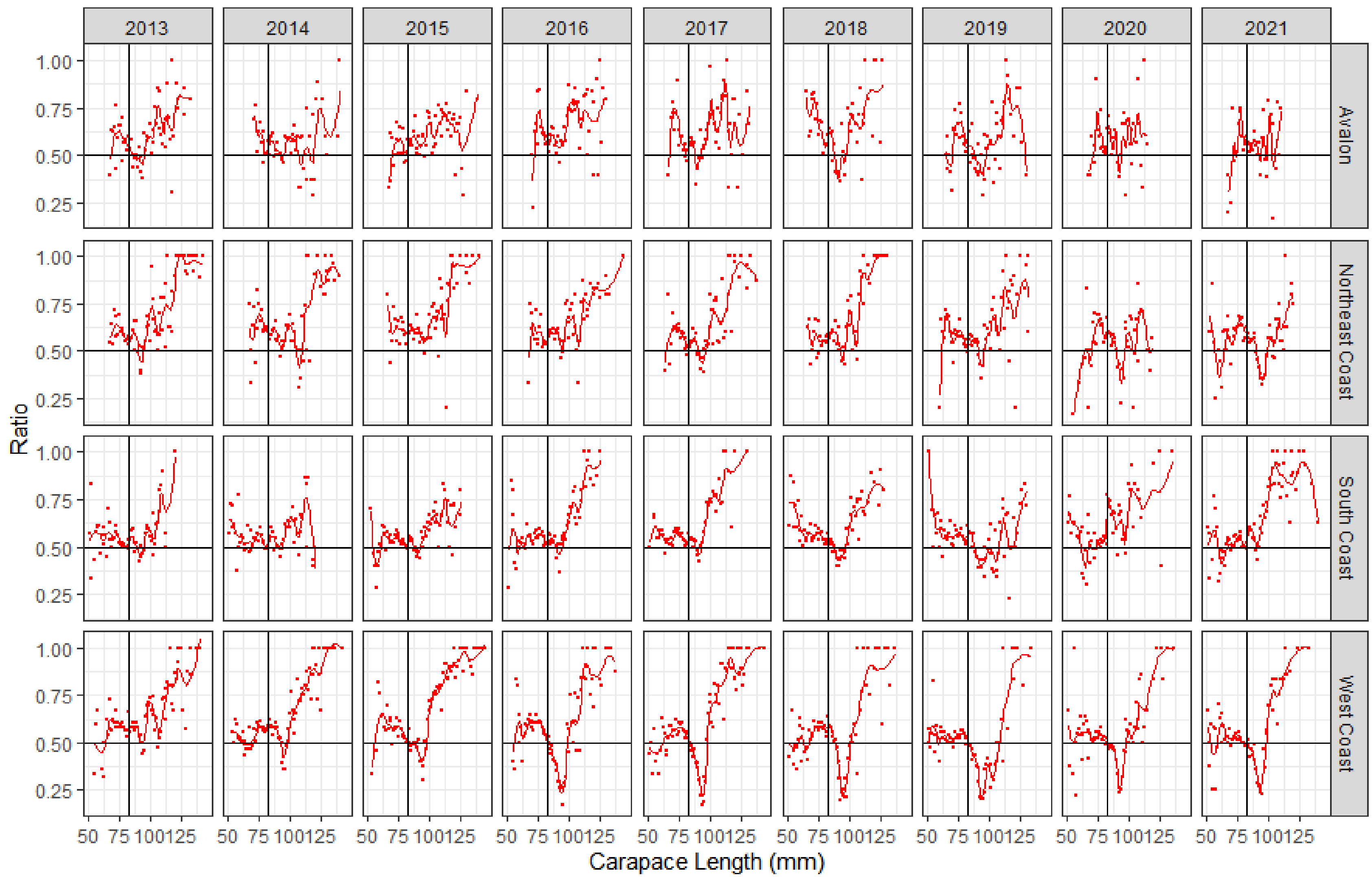

Figure 46. Annual sex ratios of females (proportion of females to males) from at-sea sampling data in each of the four assessment regions, from 2013 to 2021.

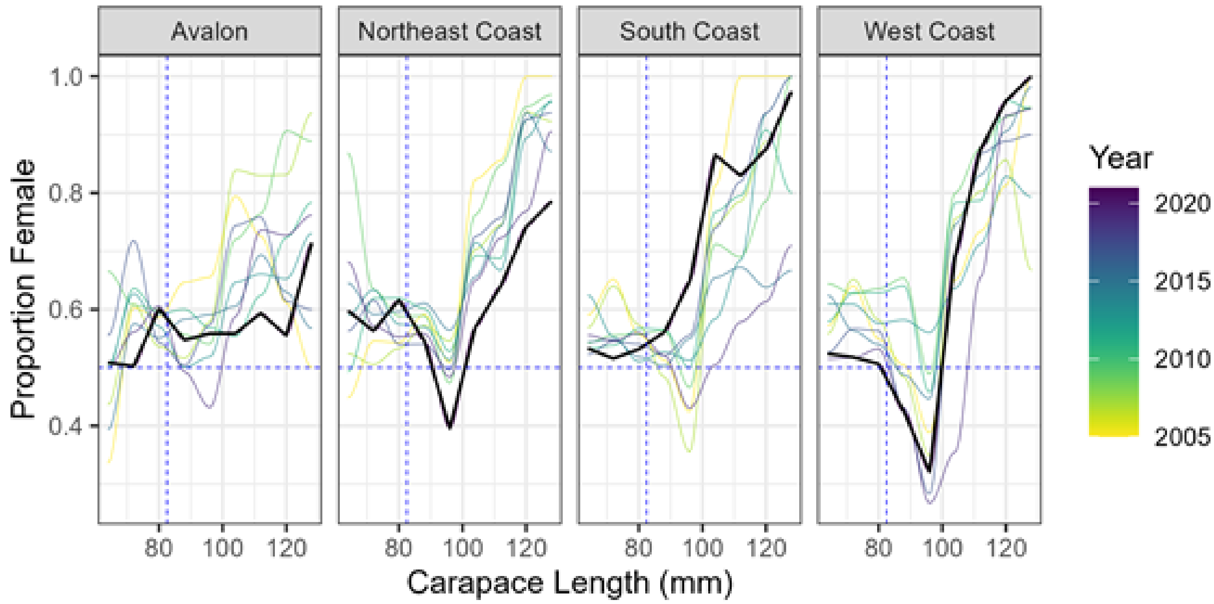

Figure 47. Annual sex ratios of females (proportion of females to males) from at-sea sampling data in each of the four assessment regions, per year (2005–21) by CL. The black line represents the sex ratio from 2021. The dotted vertical line represents the MLS (82.5 mm), the dotted horizontal line represents 50%.

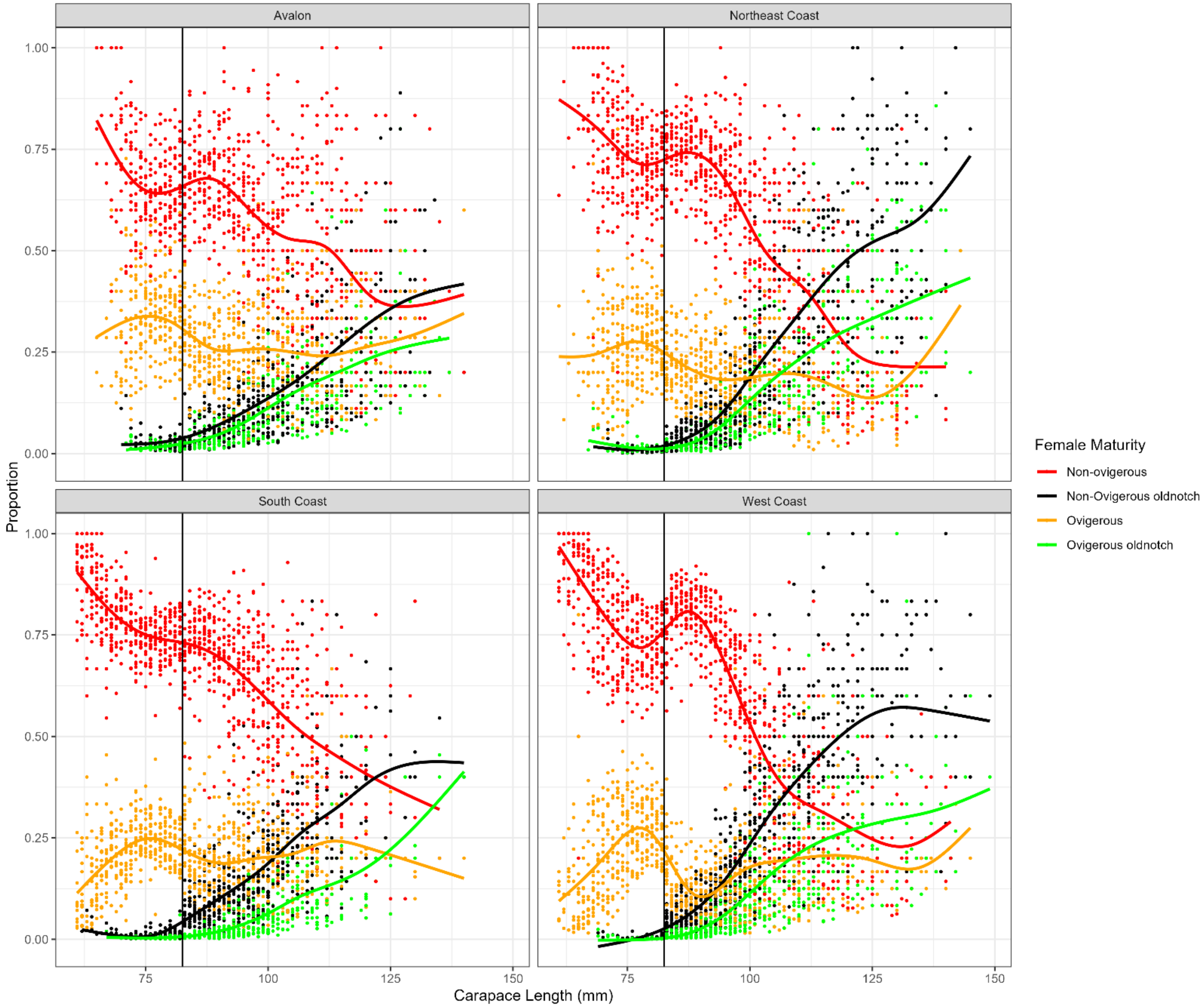

Figure 48. Proportion of females from at-sea sampling data in each of the four assessment regions, within each maturity category for all years combined by CL. The black vertical line represents the MLS (82.5 mm).

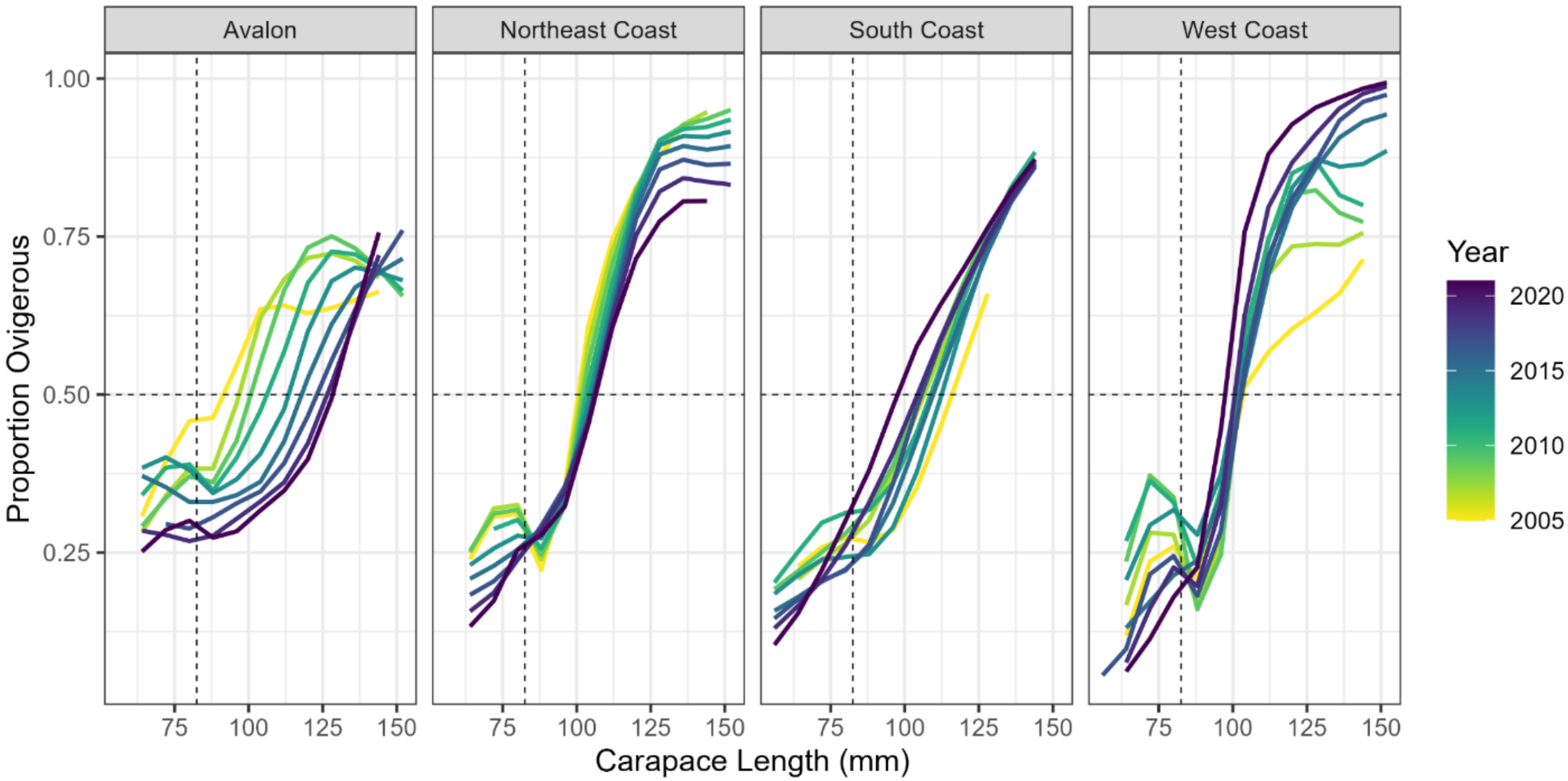

Figure 49. Proportion of ovigerous females from at-sea sampling data in each of the four assessment regions, per year (2005–21) by CL. The dotted vertical line represents the MLS (82.5 mm), the dotted horizontal line represents 50%.

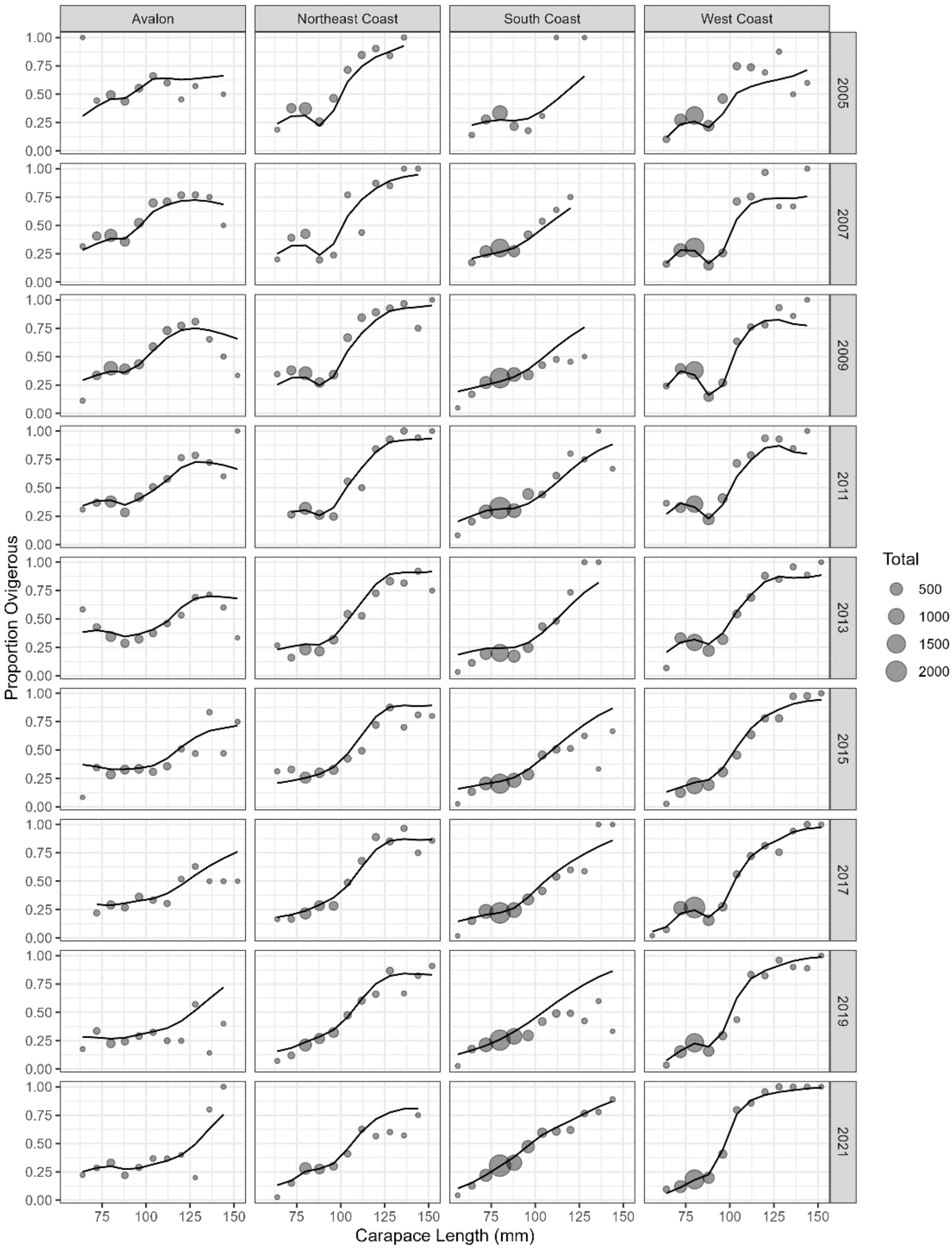

Figure 50. Logistic regression model fits of the proportion of ovigerous females by size from at-sea sampling data for each region and year. Data binned to 8 mm CL increments. Data point size represents sample sizes.

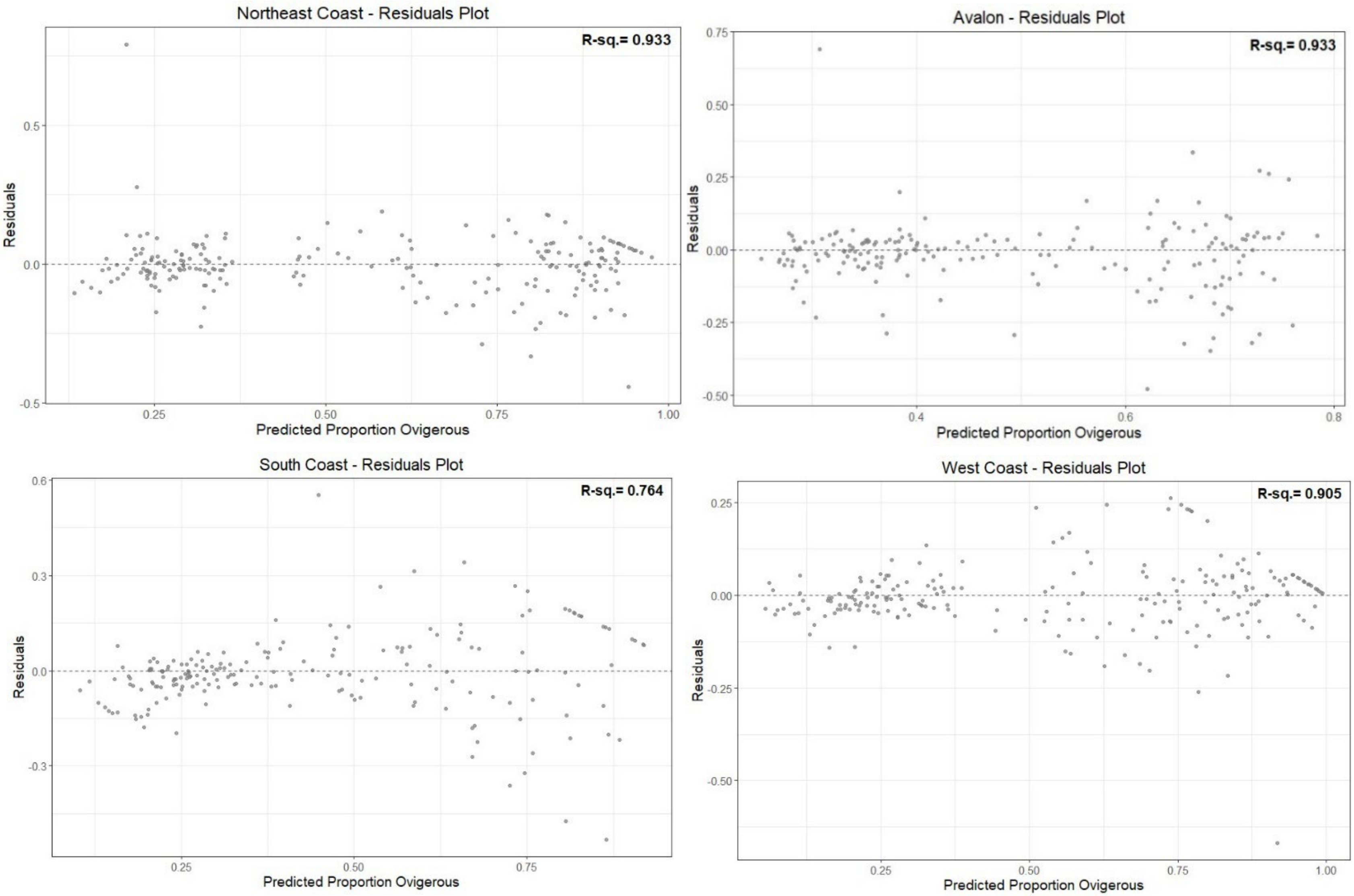

Figure 51a. Residual versus Predicted Proportion Ovigerous plots (including R-Squared value within each plot) for the logistic regression model fits of the proportion of ovigerous females by size from at-sea sampling data for each region and year (shown in Figure 51b).

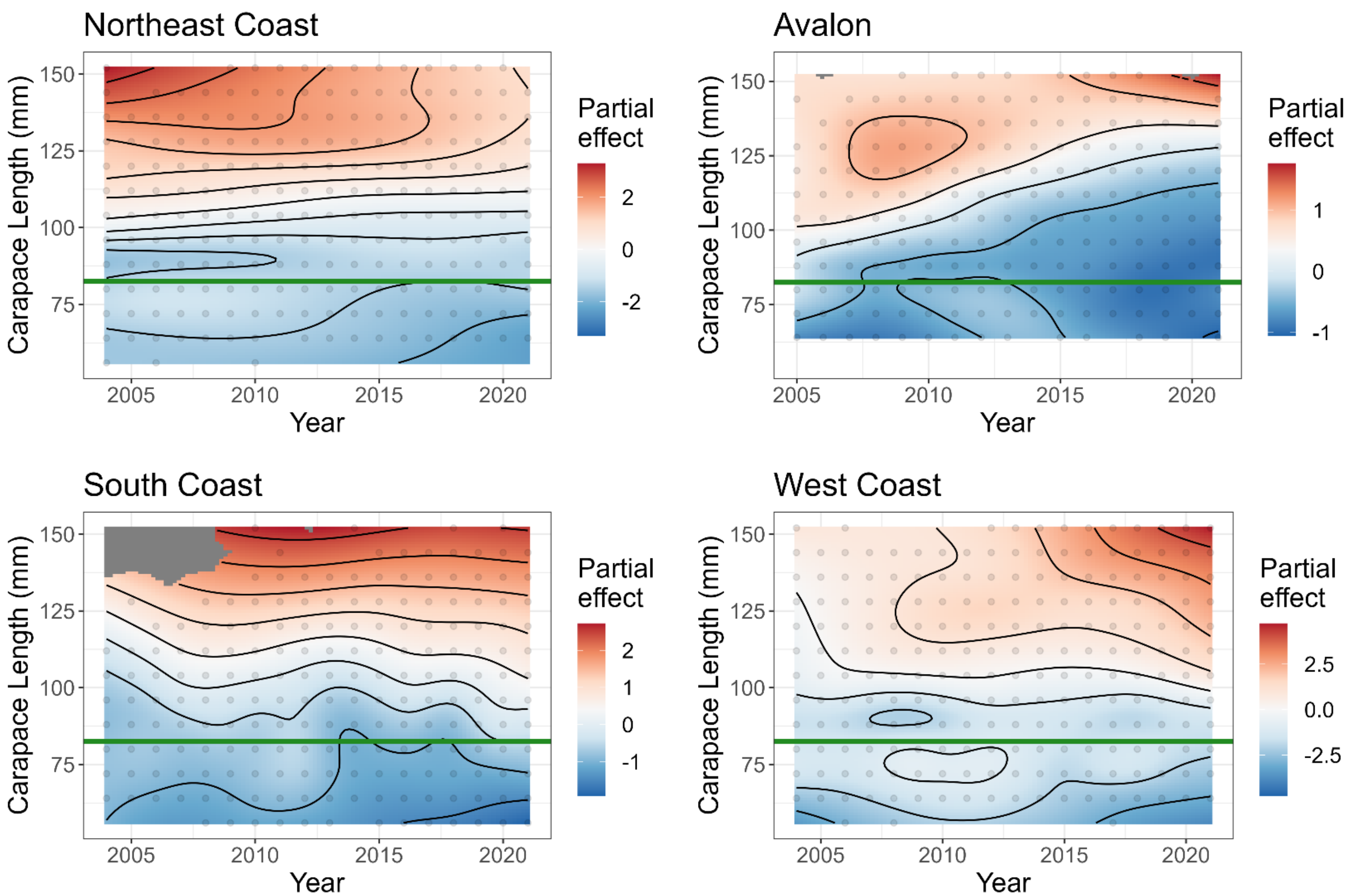

Figure 51b. Smoothed interactions of CL and year for female lobsters from at-sea sampling data for each region from 2004 to 2021. Size-at-ovigerous models. Horizontal green line denotes the MLS (82.5 mm).

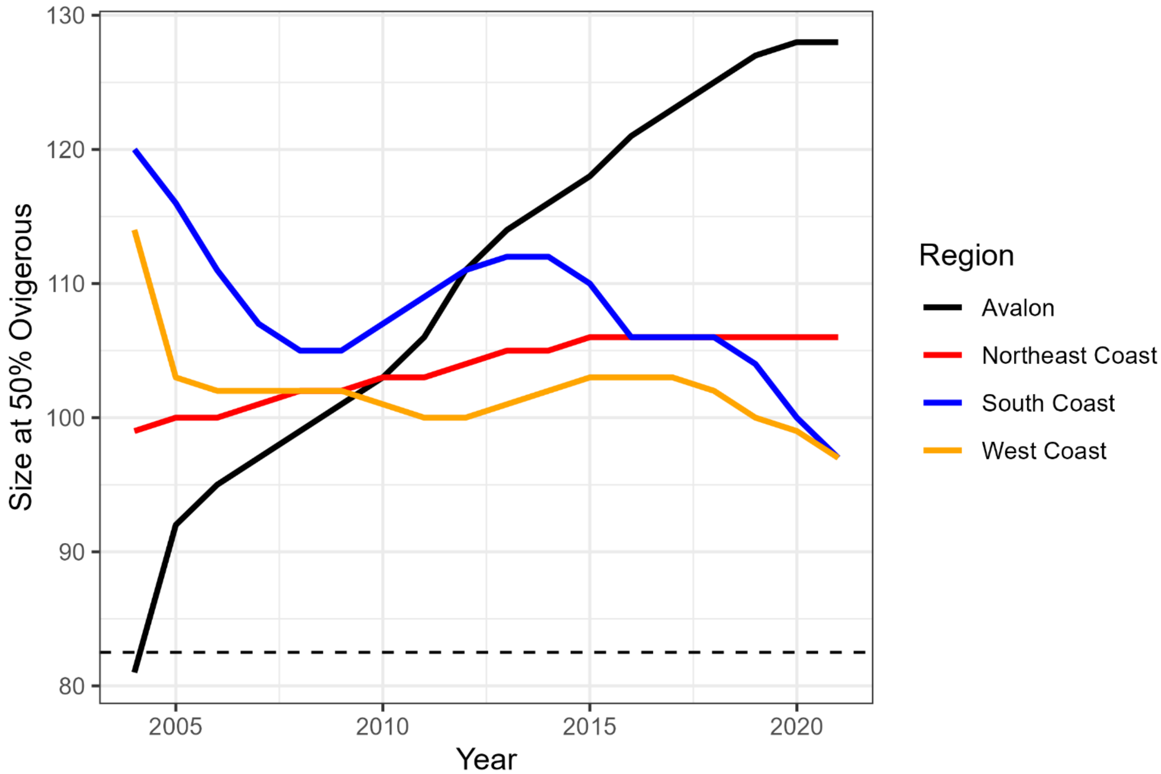

Figure 52. Estimated sizes at which 50% of female lobsters in the observed catch are ovigerous by region and year (2004–21).

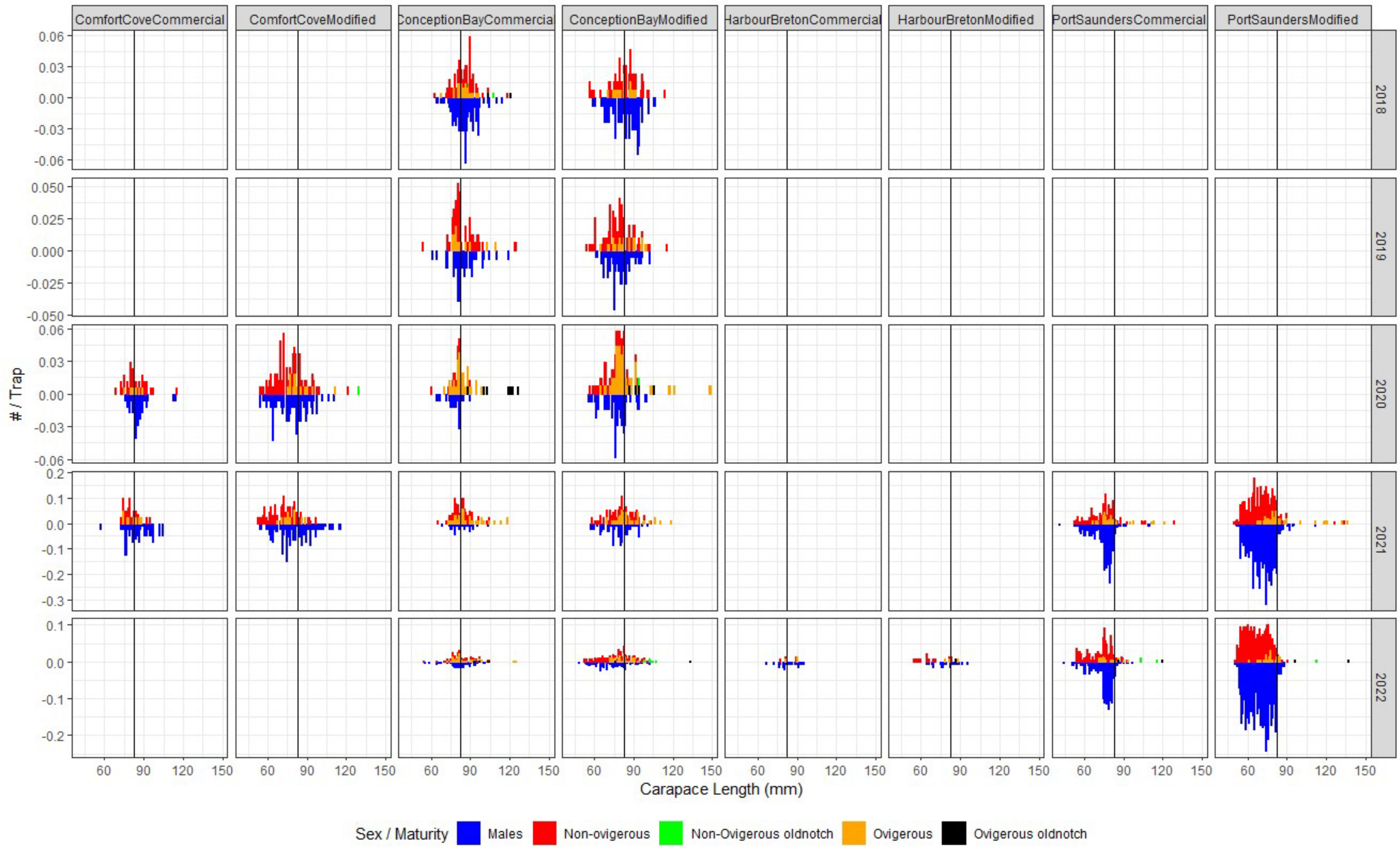

Figure 53. Selectivity-adjusted versus raw length frequency distributions for commercial and modified (closed escapement) traps by sex and maturity group for each lobster trap survey study site and year (2018–22).

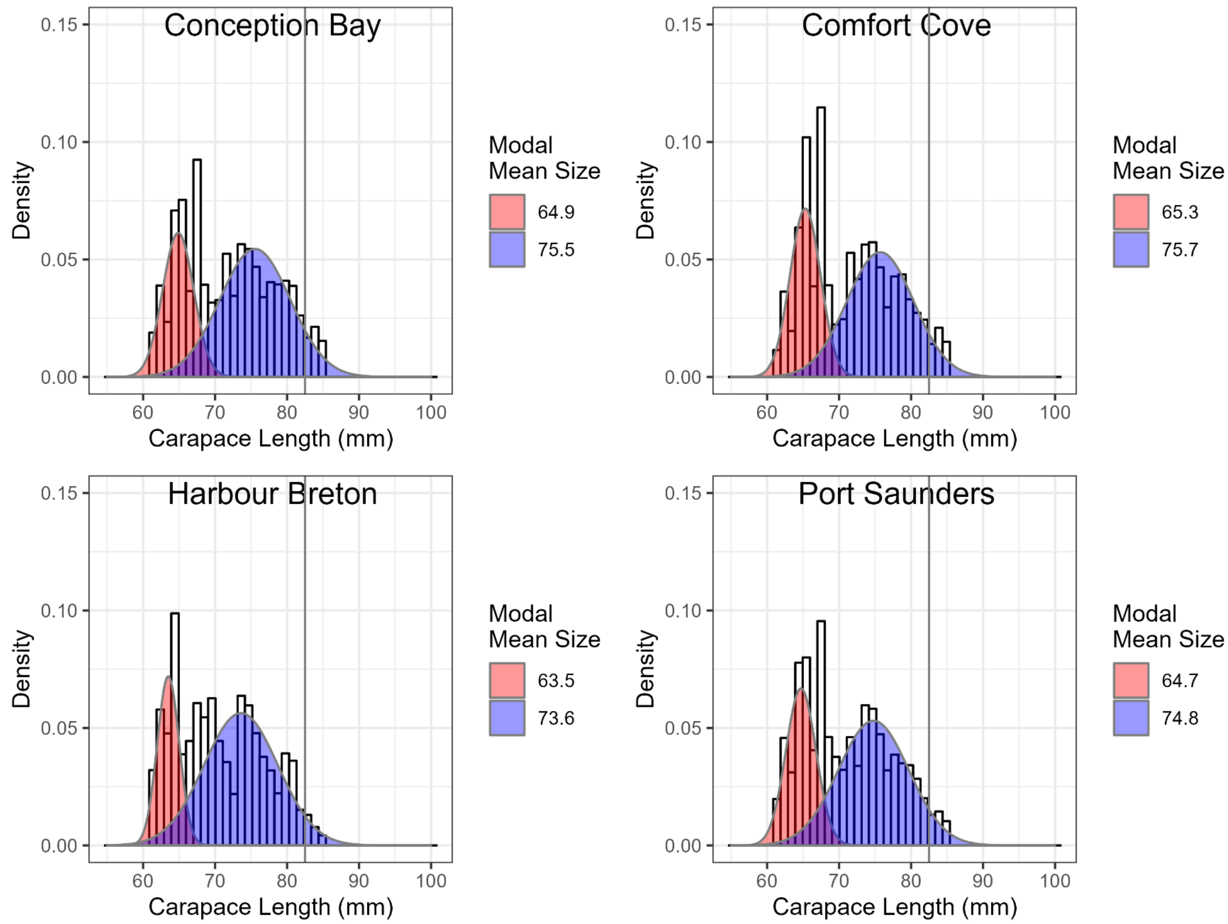

Figure 54. Mixture analysis on 61–85 mm CL lobster in selectivity-adjusted commercial trap catches from survey data (all years and both sexes pooled). Density refers to relative frequency of data observations by CL.

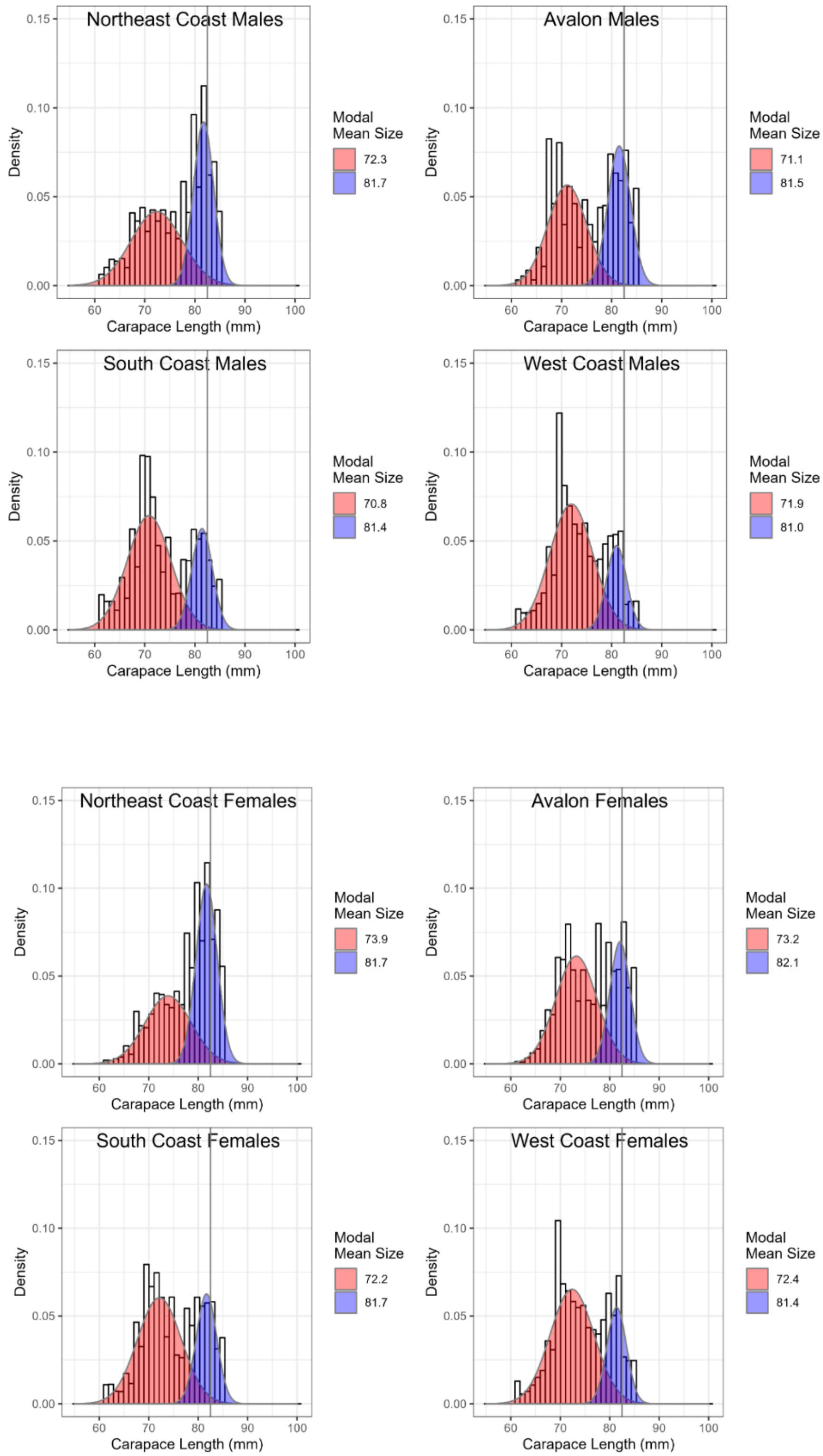

Figure 55. Mixture analysis on 61–85 mm CL lobster in selectivity-adjusted commercial trap catches from April-May fishery data (all years pooled 2004–21) for males (top four panels) and females (bottom four panels). Density refers to relative frequency of data observations by CL.

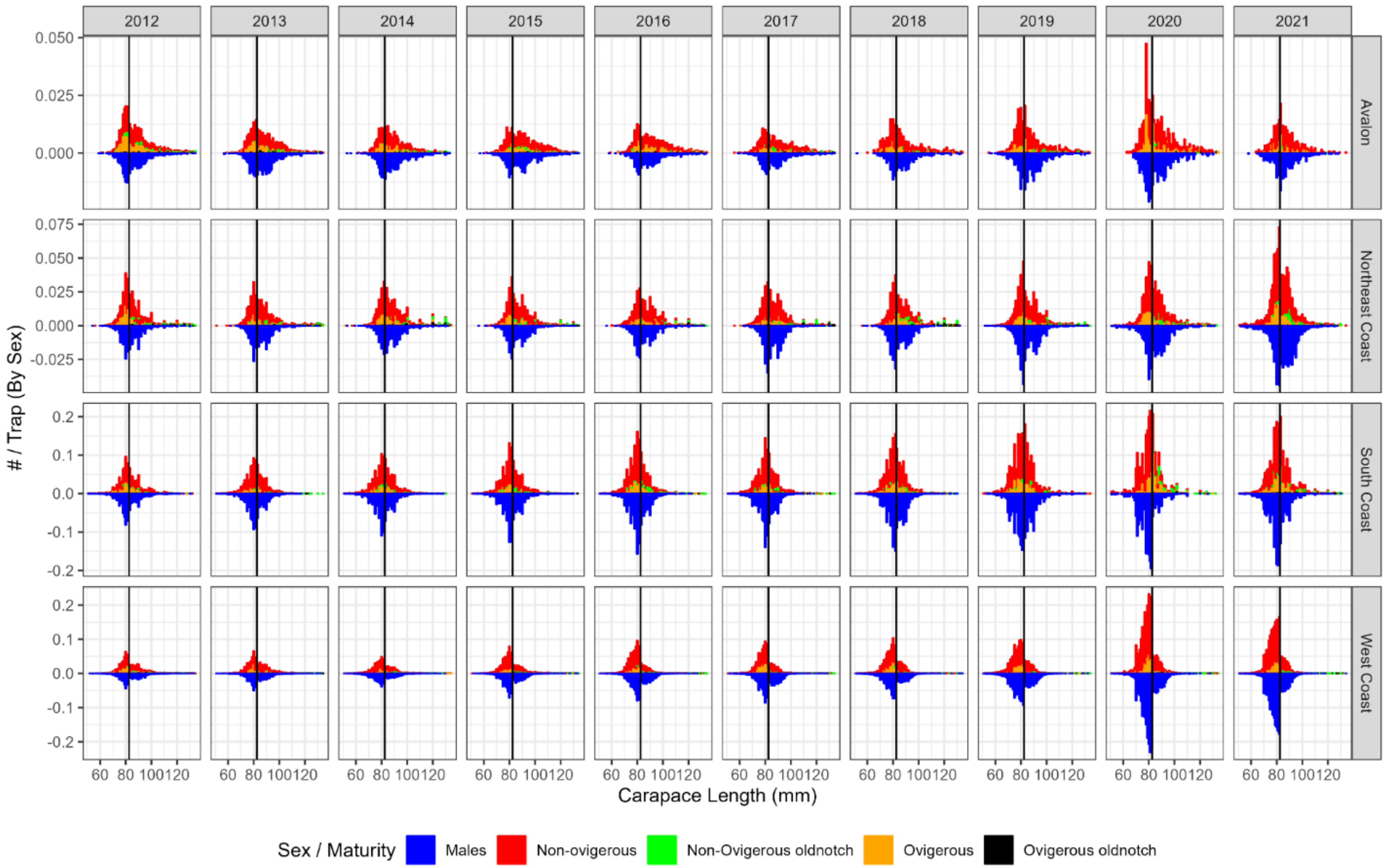

Figure 56. Selectivity-adjusted length frequency distributions for commercial traps (from at-sea sampling data) by sex and maturity group for each region and year.

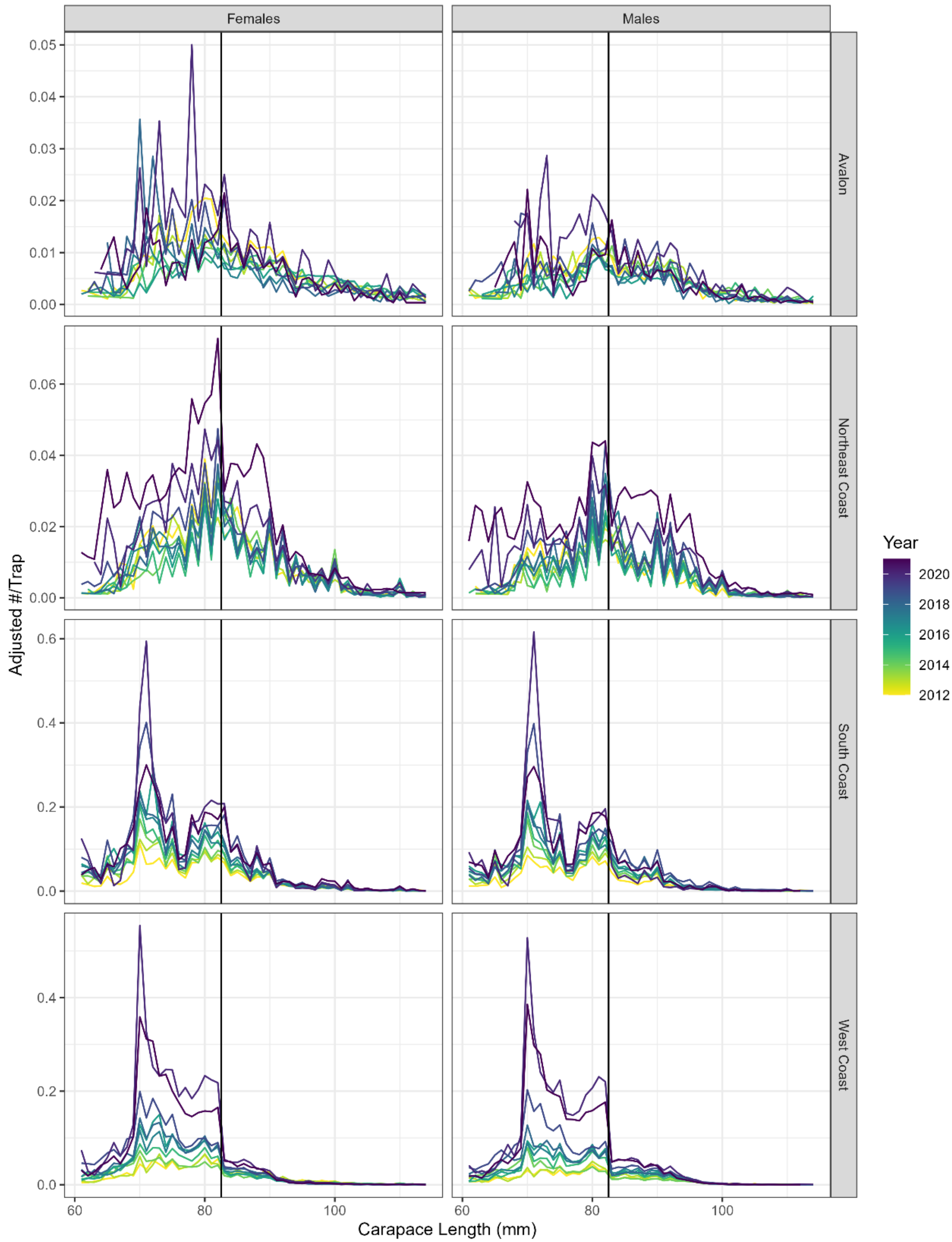

Figure 57. Selectivity-adjusted length frequency distributions for commercial traps (at-sea sampling data) by sex, region, and year (2012–21). The black vertical line is the MLS (82.5 mm CL).

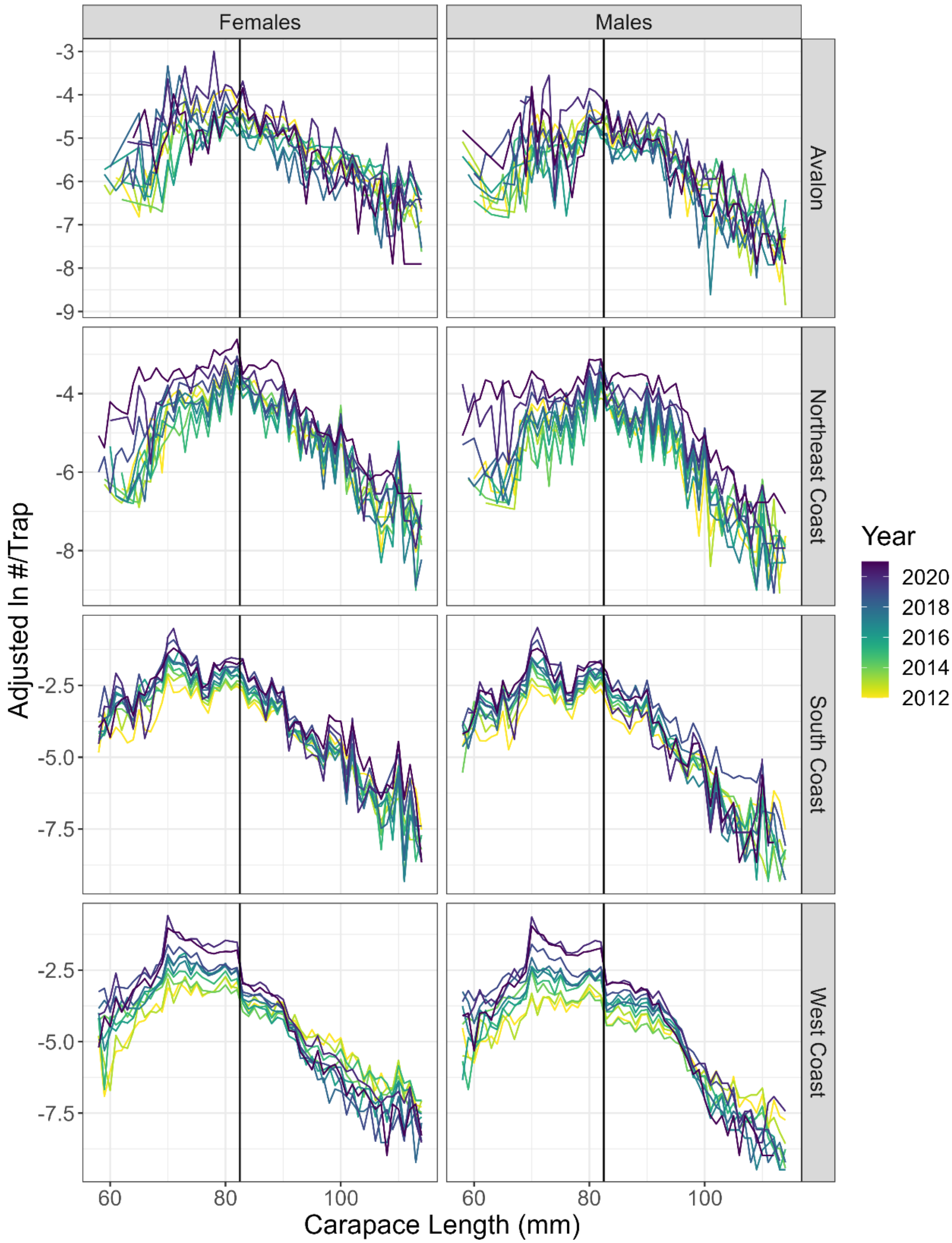

Figure 58. Selectivity-adjusted log-transformed length frequency distributions (ln #/trap) for commercial traps (at-sea sampling data) by sex, region, and year (2012–21). The black vertical line is the MLS (82.5 mm CL).

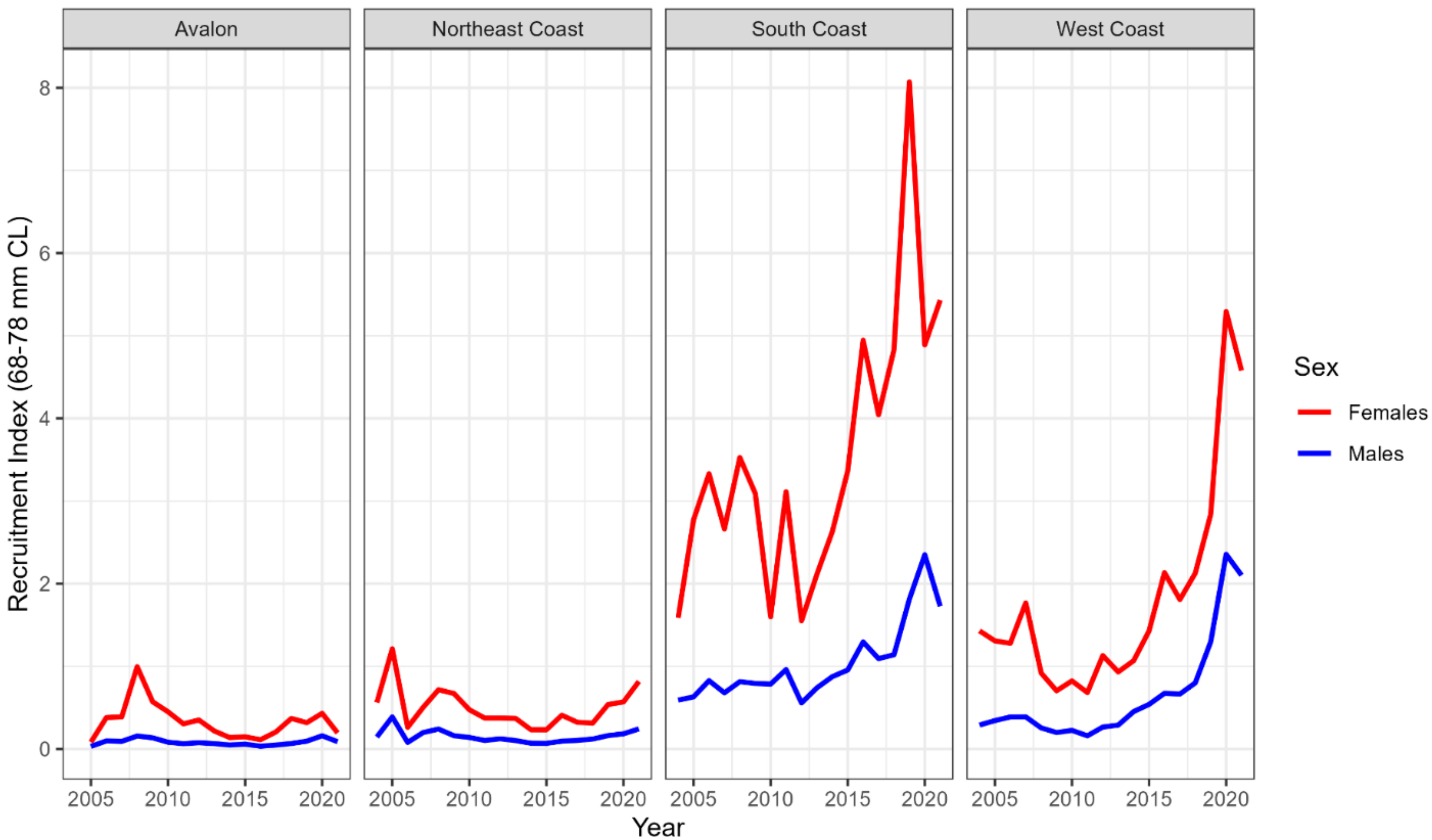

Figure 59. Recruitment Index of 68–78 mm CL lobster by year (2004–21), sex, and region. Index based on selectivity-adjusted commercial trap at-sea sampling data.

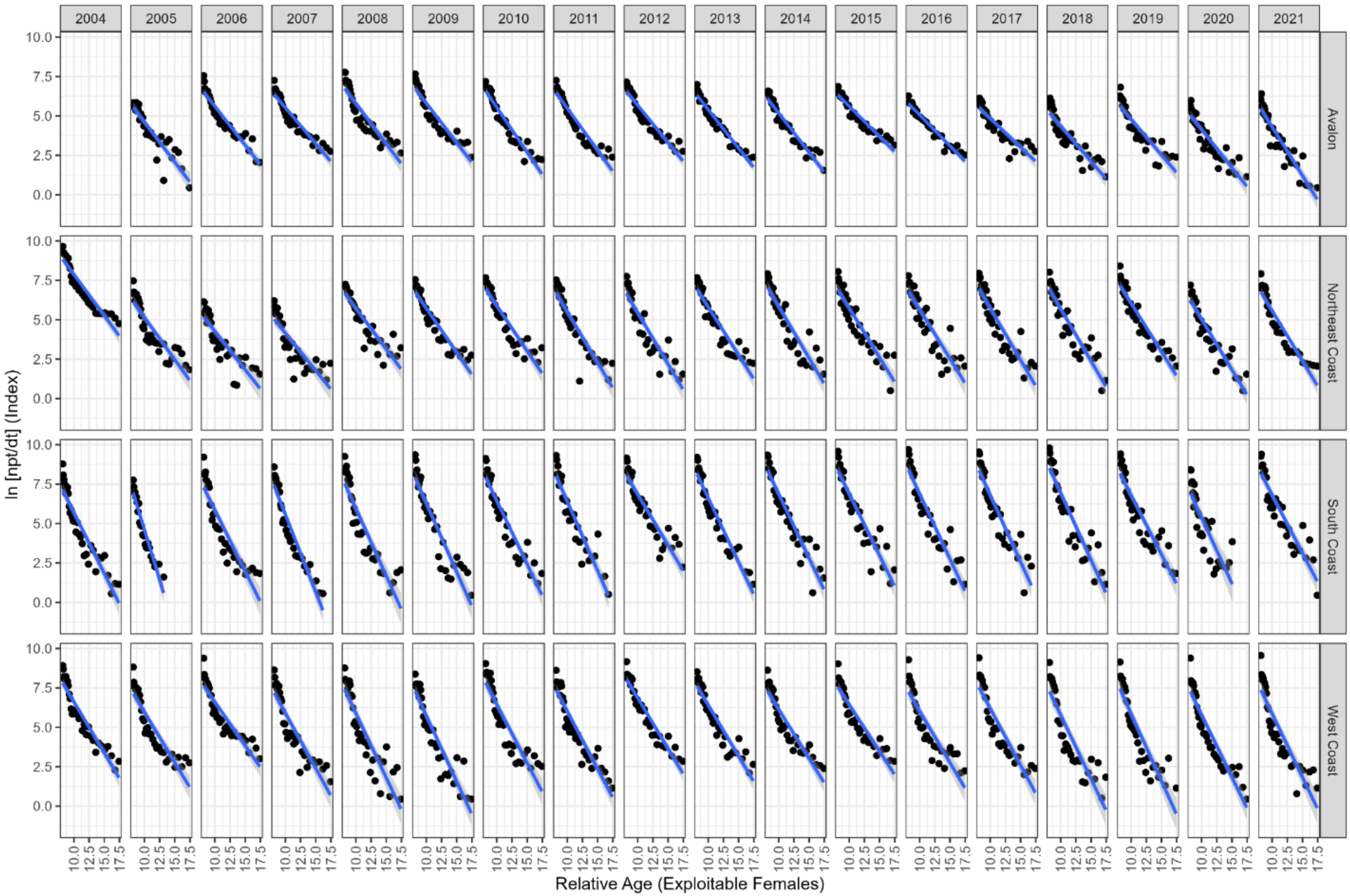

Figure 60. Length-converted catch curves. Linear regressions of ln (npt/dt) versus relative ages for legal sized females by year (2004–21) and region. npt refers to number per trap and dt is difference in estimated age from one size increment to the next.

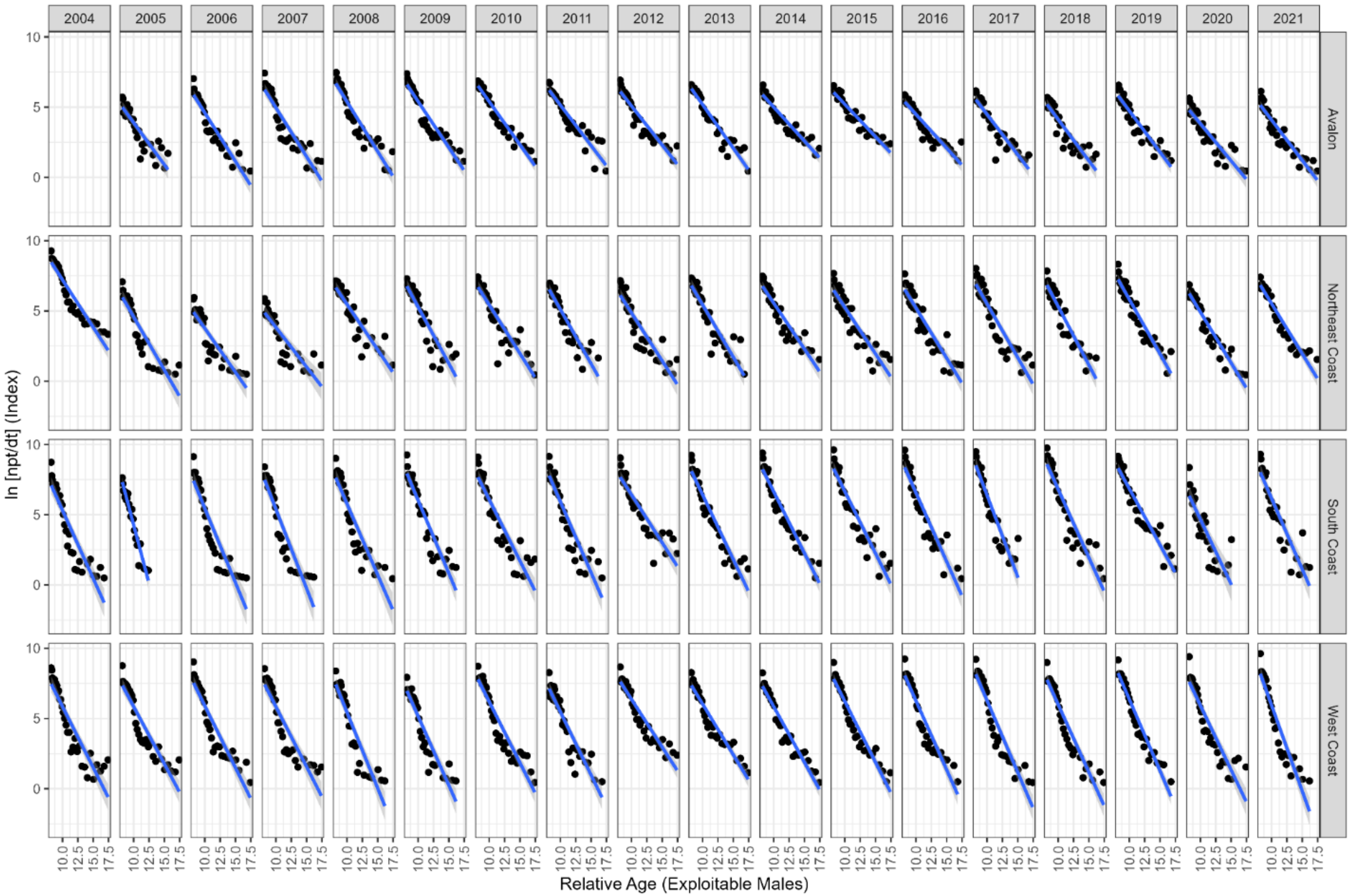

Figure 61. Length-converted catch curves. Linear regressions of ln (npt/dt) versus relative ages for legal sized males by year (2004–21) and region. npt refers to number per trap and dt is difference in estimated age from one size increment to the next.

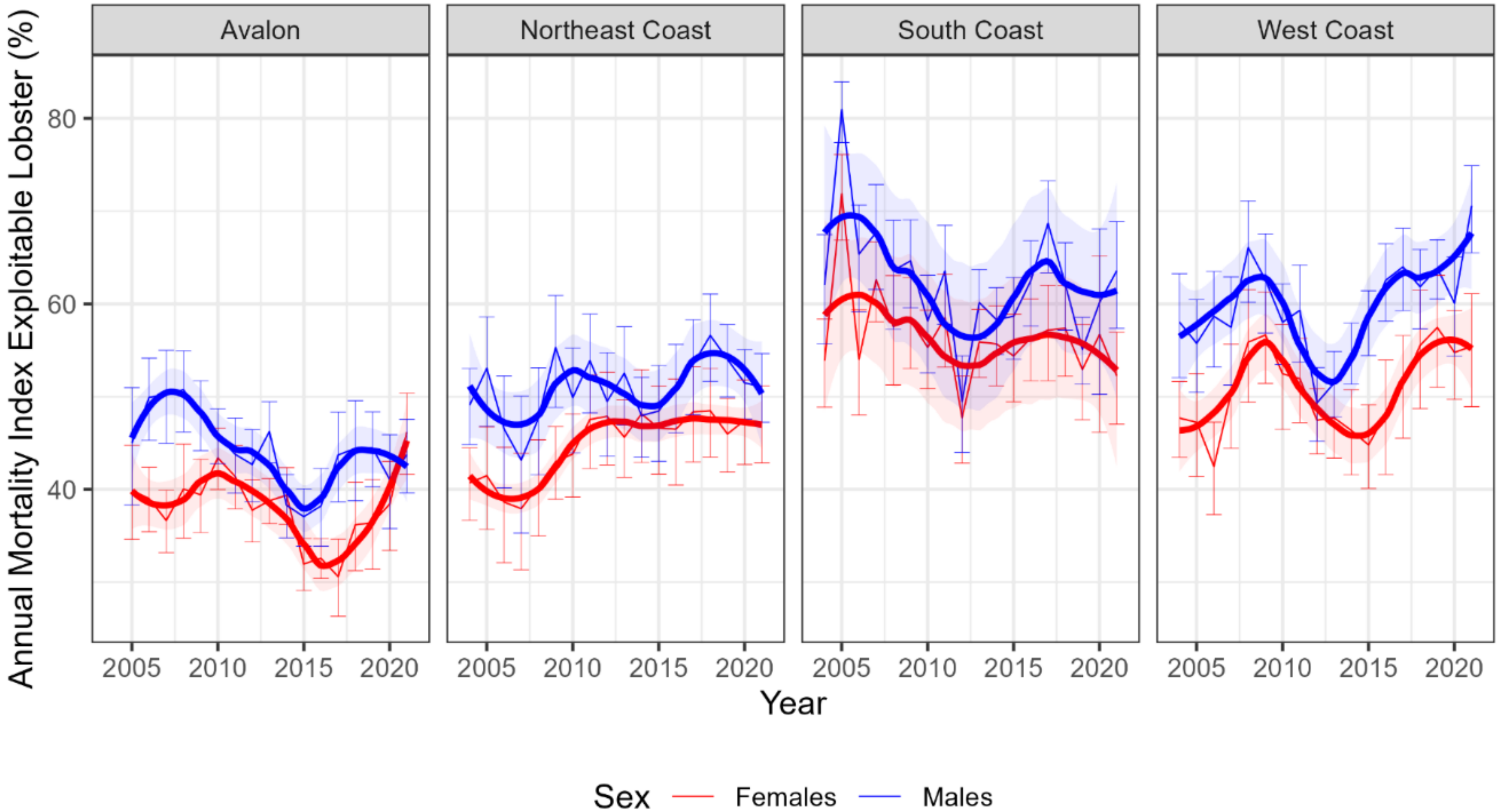

Figure 62. Total annual mortality index by sex, year (2004–21), and region, estimated from length converted catch curve linear regressions on legal-sized lobster.

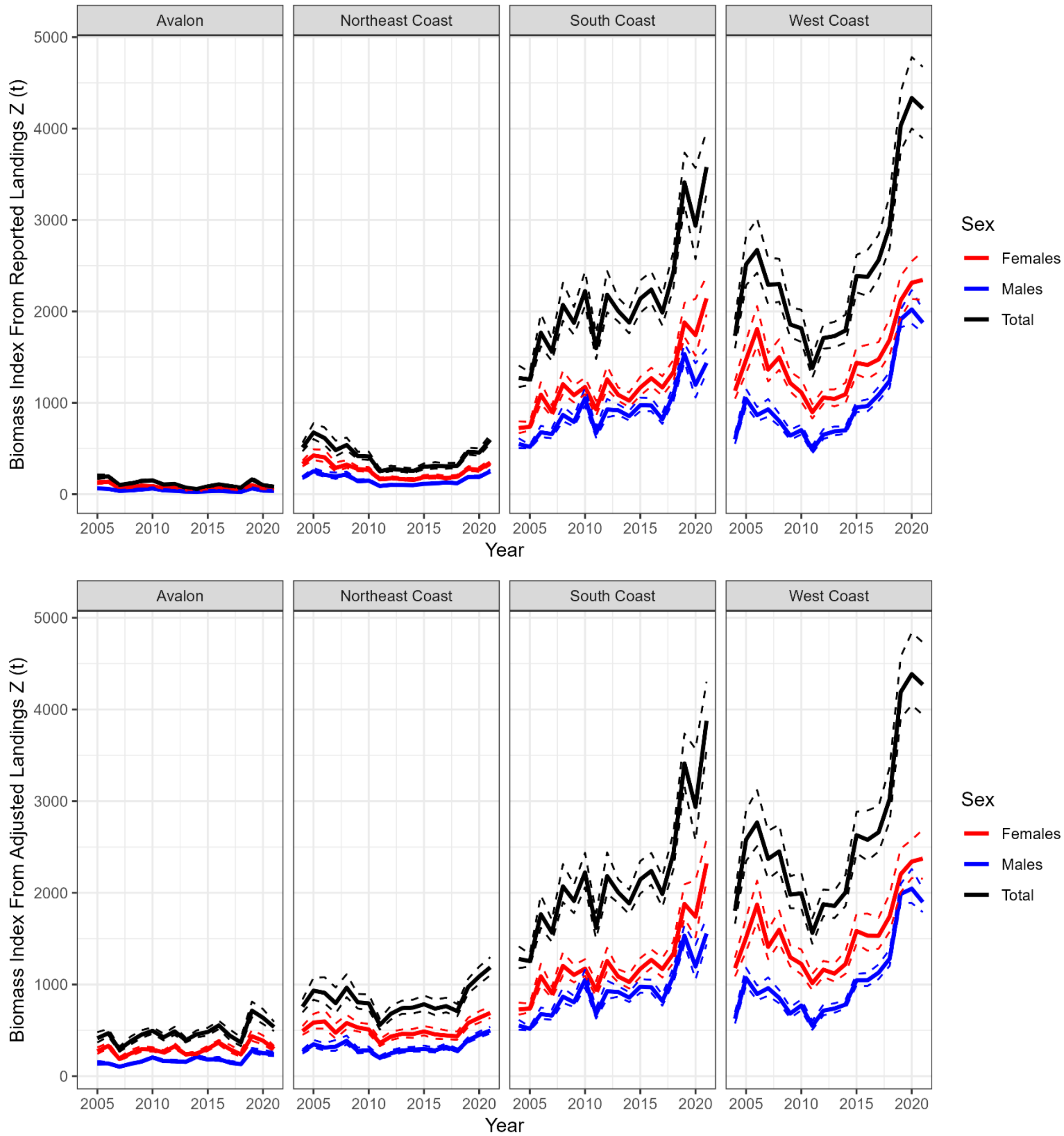

Figure 63. Length-converted catch curve biomass index based on reported unadjusted (top) and adjusted (bottom) landings estimates by sex, year (2004–21), and region. Dotted lines represent 95% confidence intervals.

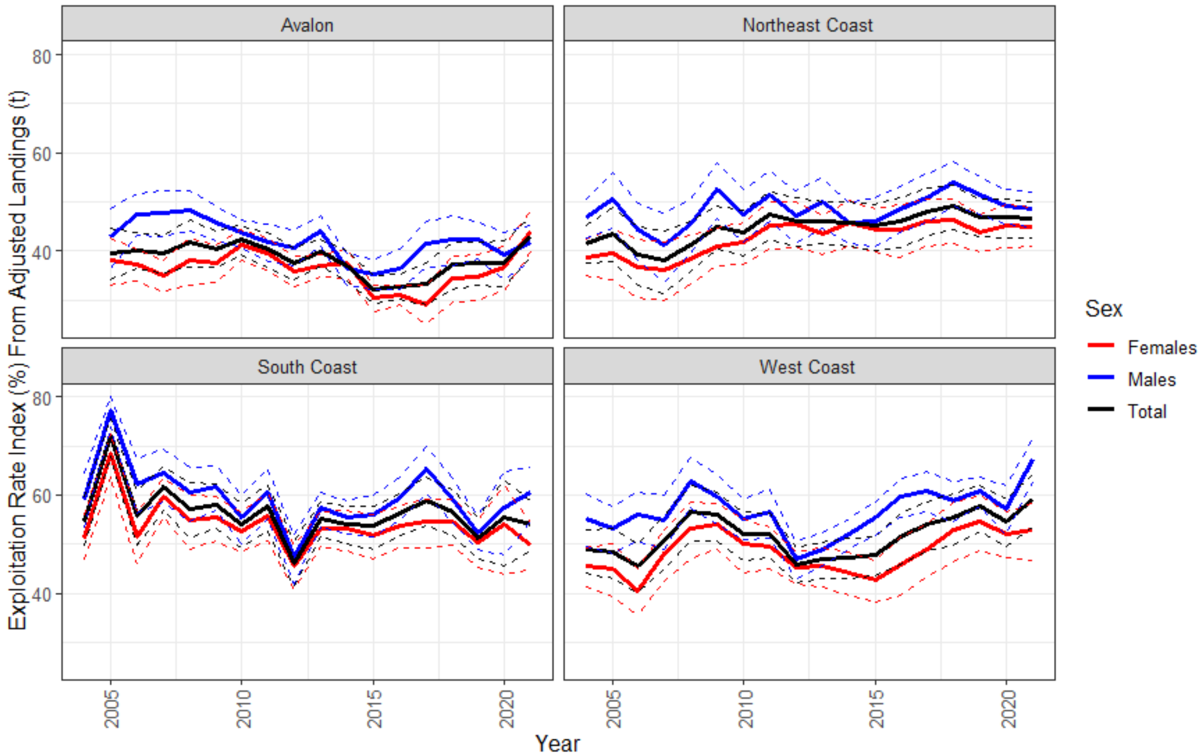

Figure 64. Length-converted catch curve exploitation rate index based on adjusted landings estimates by sex, year (2004–21), and region. Dotted lines represent 95% confidence intervals.

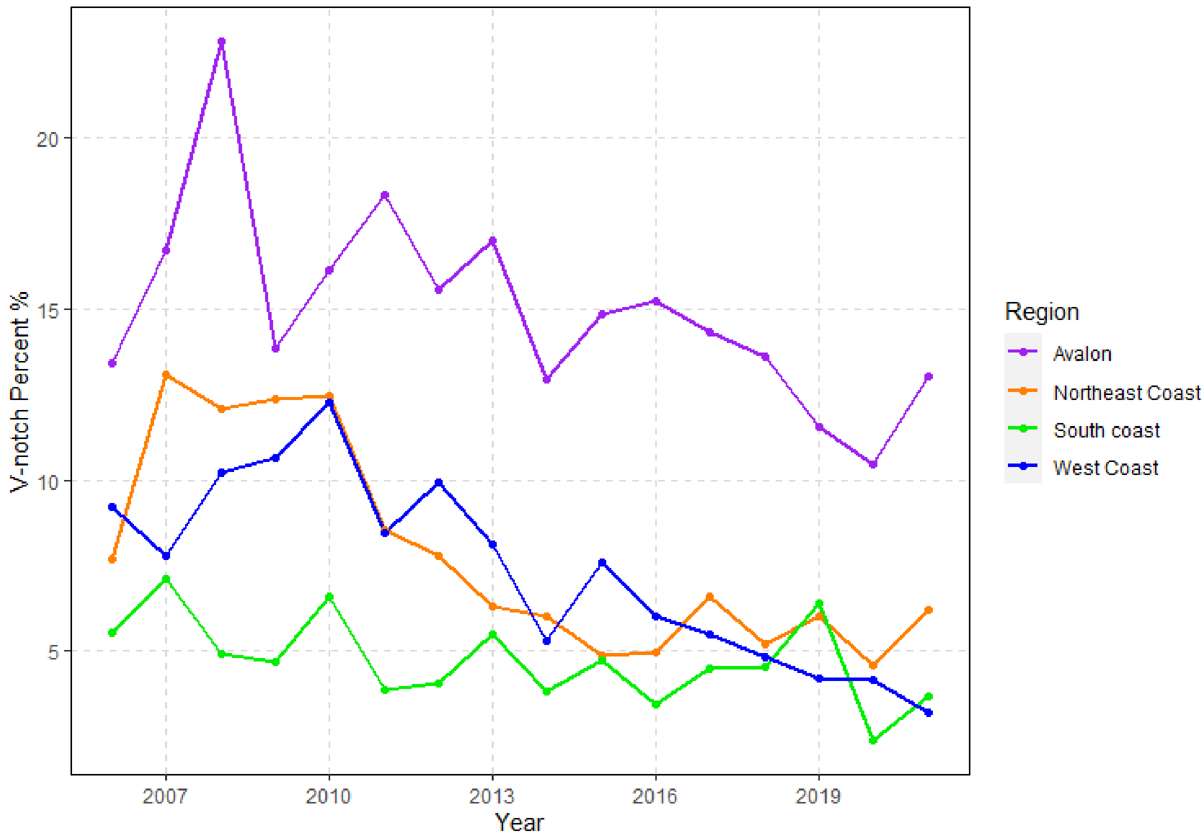

Figure 65. Percentage of female lobsters that get v-notched annually (2006–21) in each of the four assessment regions based on the FFAW index harvester logbooks.

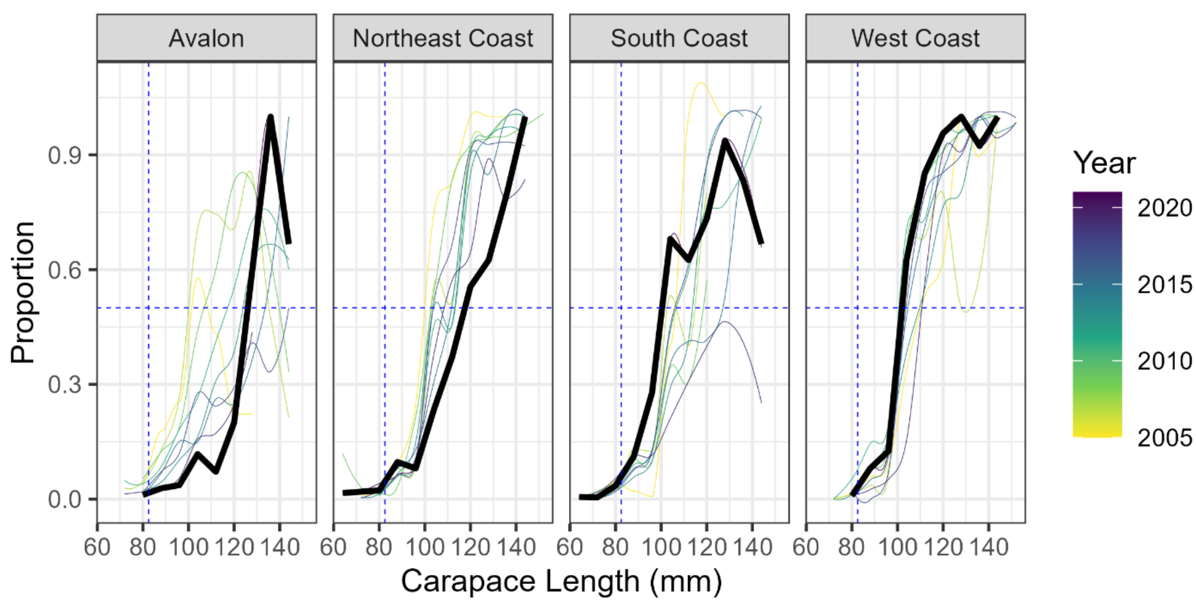

Figure 66. Proportion of lobster that were identified as v-notched from at-sea sampling data for all years (2004–21) combined over the size range (CL) within each assessment region. The black line represents the proportion of v-notched lobster in 2021. The dotted vertical line represents the MLS (82.5 mm), the dotted horizontal line represents 50%.

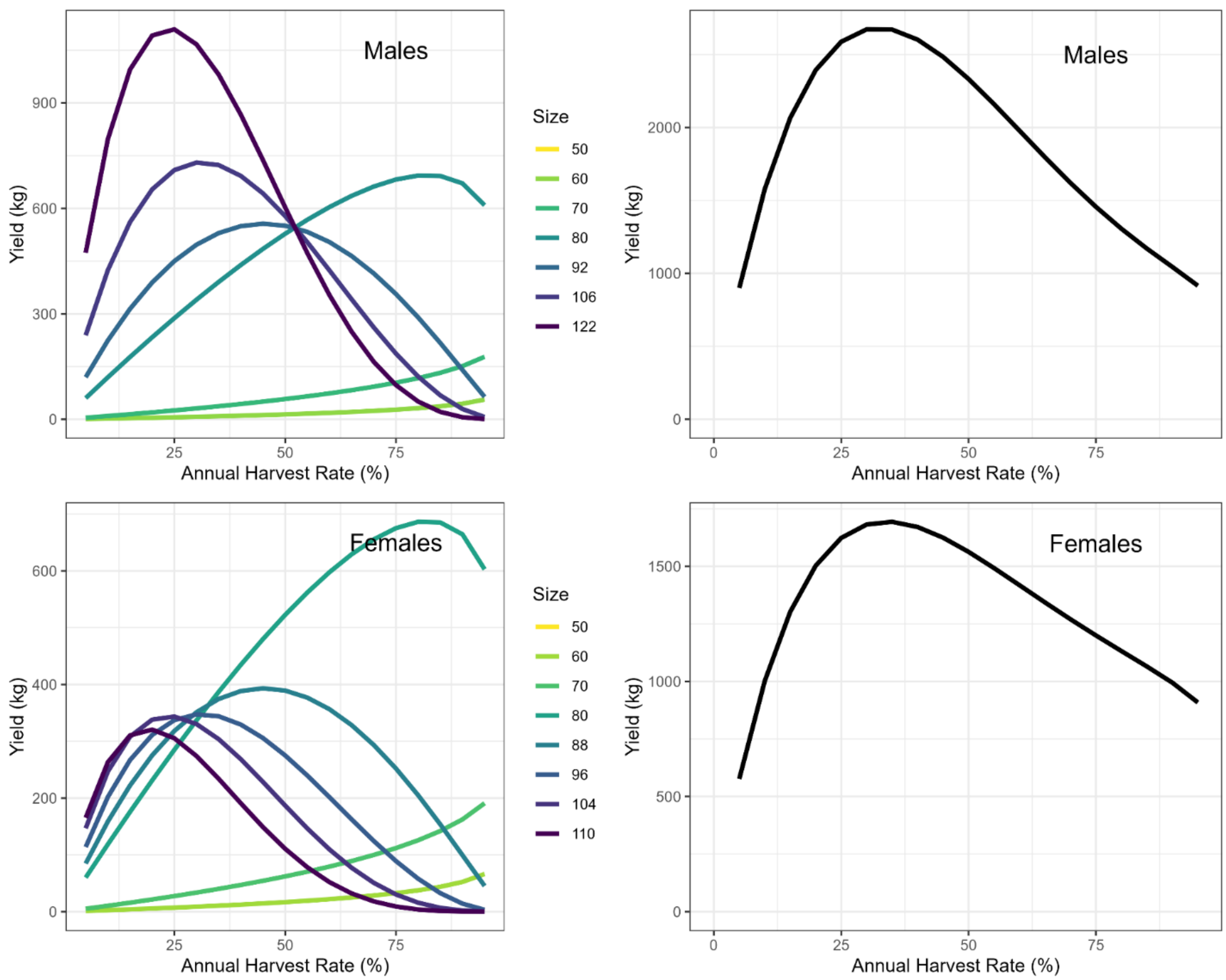

Figure 67. Yield-per-recruit models estimated by sex, based on growth estimations from Ennis et al. (1986). Yield estimated by size bin increments (left panels) and for the total population (right panels).

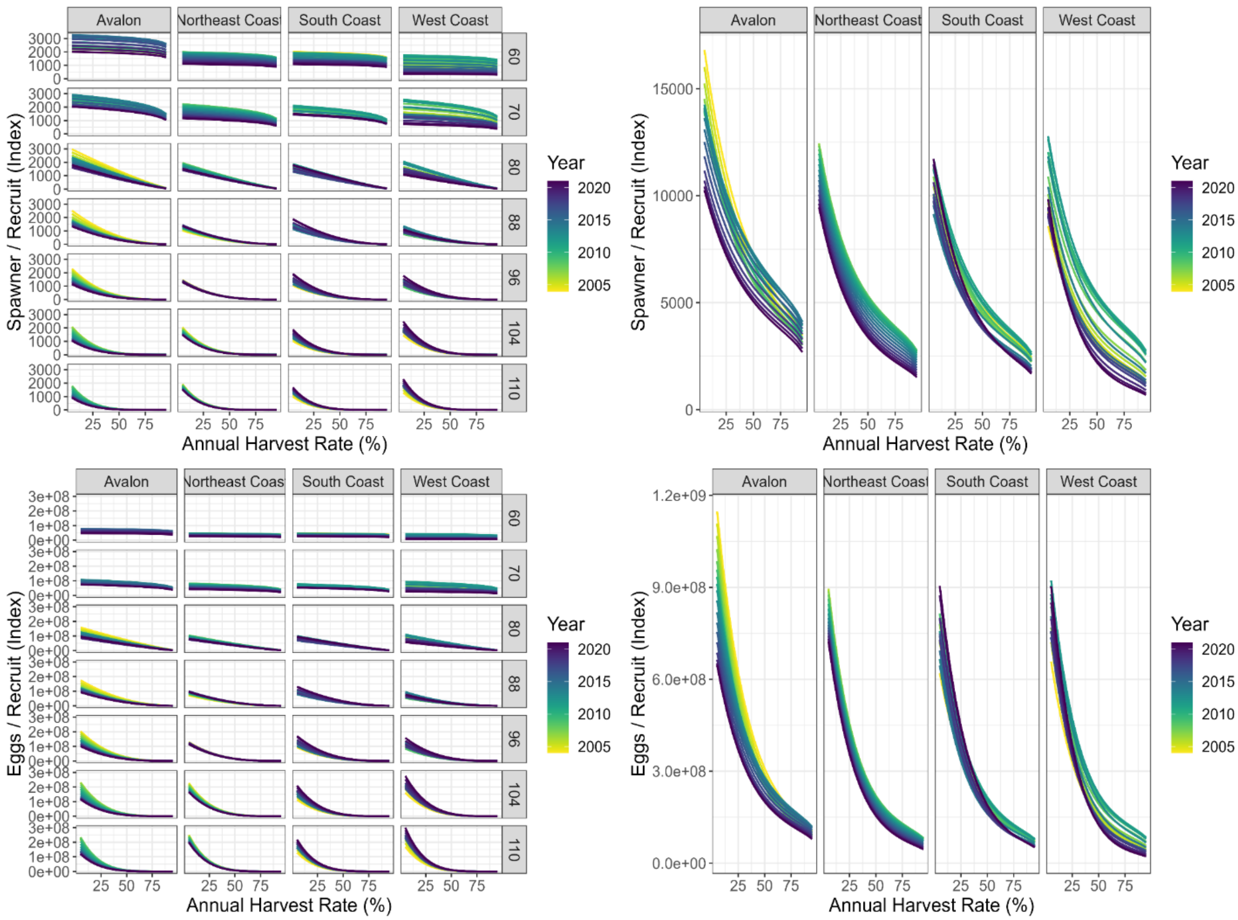

Figure 68. Spawner-per-recruit (top panels) and egg-per-recruit (bottom panels) models estimated for females by region, size stage, and year (left panels) and by region and year for all females pooled (right panels).

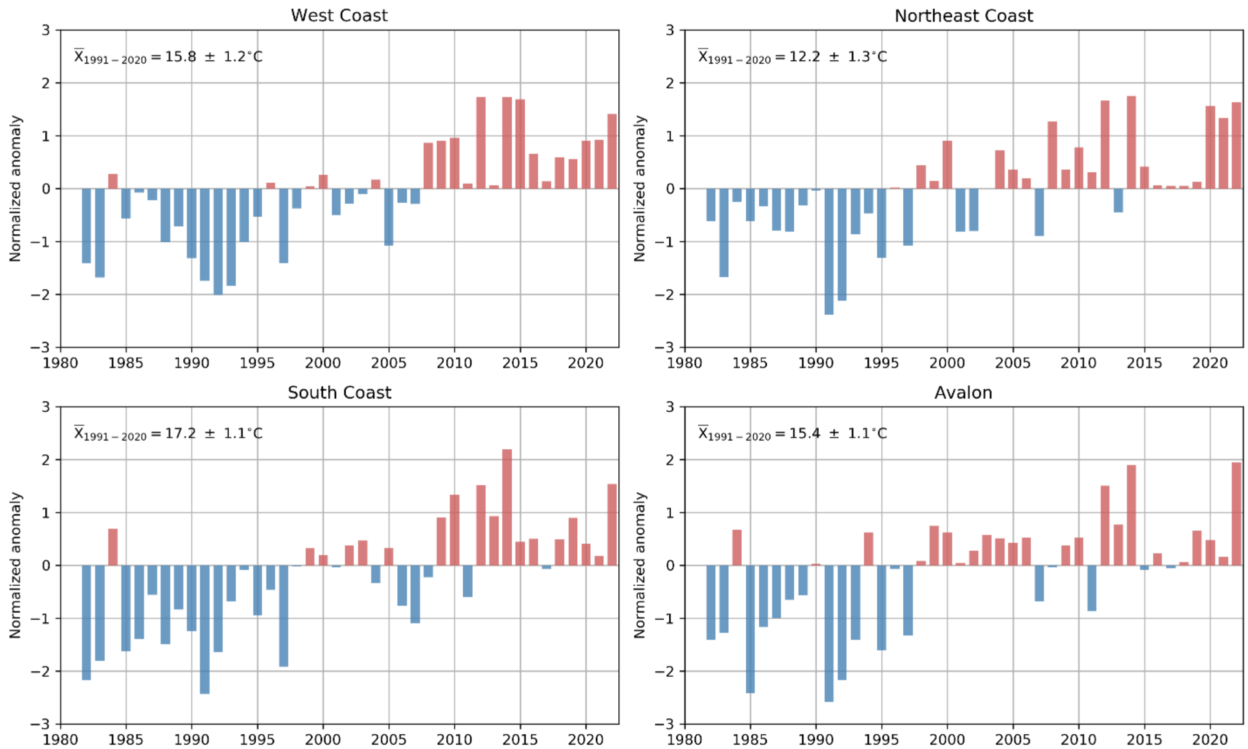

Figure 69. Normalized anomalies of the mean SST for the warmest week of the year in the four assessment regions, 1981–2022. The normalized anomalies are expressed as the departure (by standard deviation increment) from the 1981–2010 climatological average. The climatological average and standard deviation for each region is shown in the upper left of each panel. Data are from the National Oceanic and Atmospheric Administration High-resolution Blended Analysis of Daily SST on 1/4 deg. global grid (Reynolds et al. 2007). Only grid points in the regions truncated at 46°N and 51°W were considered.