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Multi-Indicator Precautionary Approach Assessment Framework for Newfoundland and Labrador Lobster (*Homarus americanus*)

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Foreword

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

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ABSTRACT

Indices from the Newfoundland and Labrador (NL) American Lobster (*Homarus americanus*) fishery have shown considerable improvements in recent years, with reported landings and fisheries catch rates increasing to time-series highs. This broadly aligns with improving habitat conditions associated with progressive warming, presumably enabling growth at this northern limit of the species range. This assessment of the NL lobster population and fisheries dynamics was undertaken to support the development of a Precautionary Approach Framework (PAF) for guiding the management of this resource. We establish multiple indicators to comprehensively examine the health of the NL lobster resource, including fishing mortality (F) rates on immediate recruits, biomass of immediate recruitment into the fishery, size of egg-producing females, and standardized fishery catch per unit of effort (CPUE). These indicators are presented for each of the four Assessment Regions (ARs) delineated as Northeast Coast, Avalon, South Coast, and West Coast, with individual indicator scores combined into an overall integrated health score index (HSI) for the assessment of the resource and PAF basis. The work reveals that improving landings and fishery CPUE are associated with both improving recruitment and increasing fishery exploitation rates in all ARs, and that fishery indicator improvements are being inflated by unquantified effort creep due to a shift toward more efficient traps being used in the fishery. The work finds that growth overfishing is occurring in all ARs, such that potential resource growth is not being maximized, and highlights concerns of potential recruitment overfishing in the most heavily exploited West Coast AR due to low egg production. The NL lobster fishery has become progressively reliant on immediate recruitment in most ARs, with improving recruitment ultimately driving overall improvements in resource status despite high F. The PAF is designed to promote protection of immediate recruits and align with resource management objectives of reducing exploitation rates and increasing egg production in the population. The Limit Reference Point (LRP) is placed in context of historic stock performance levels demonstrated to enable recent improvements in recruitment, following (B_{recovery}) logic, but which could quickly capture signals of recruitment impairment should they occur. All ARs were found to be above the LRP, with a negligible probability of being in the Critical Zone. This document highlights concerns with inconsistent data collections and near-exclusive reliance on fisheries-dependent data for resource assessment. Guidance to establishing appropriate Upper Stock Reference (USR) point levels and Harvest Control Rules (HCRs) is provided. This guidance centers on being cognizant of the influence of increased use of more efficient fishing gear and associated increasing exploitation rates, along with increasing recruitment, upon establishing reference points to differentiate the Cautious Zone from the Healthy Zone. It is advised that reducing exploitation rates in heavily exploited areas toward establishing increased presence of large lobster in the population is the most direct means to offset egg production impairment, maximize resource growth potential, and improve stock outcomes to better align with overarching management objectives.

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1. INTRODUCTION

1.1. FRAMEWORK APPROACH

Recent changes to the *Fisheries Act* require Fisheries and Oceans Canada (DFO) to develop a Precautionary Approach Framework (PAF) for the management of American Lobster (*Homarus americanus*) in Newfoundland and Labrador (NL). Henceforth, the resource is termed ‘NL lobster’. Major challenges associated with developing a PAF for NL lobster are unknown stock structure, lack of time series of fisheries-independent data, incomplete and spatiotemporally disparate reporting in fisheries-dependent data, and minimal recent research on NL lobster to help support a biological knowledge base for framework development.

In line with the broader American Lobster population throughout Atlantic Canada and the eastern United States, NL lobster knowingly demonstrate a high level of resilience to fishing. The resource has recently experienced considerable improvements despite sustained high exploitation rates throughout much of its range in Newfoundland waters, in particular in the most productive fishing areas (Coughlan et al. 2023; DFO 2023a). Stock improvements are deemed largely driven by improving climatic conditions, namely warming (Le Bris et al. 2018).

Lobster assessments in other DFO Regions typically invoke a multi-indicator approach to measure resource and fishery performance and provide management advice. Major pieces of guidance for Atlantic Canada-wide (FRCC 1995, 2007) and NL-specific (DFO 2021) lobster management state increased egg production and reduced exploitation rates as focal objectives for resource and fishery management (FRCC 2007; DFO 2021). Most lobster fisheries, including throughout NL, are effort-controlled and have no quotas to limit removals. Given the confluence of factors including limited sources of data, high climate regulation of the resource, and leading guidance to promote increased egg production and reduced exploitation rates as outcomes, the approach to developing a PAF is to apply a multi-indicator assessment of resource and fishery performance incorporating egg production and exploitation rate considerations to the extent possible. Ultimately, this work produces a multivariate synopsis of stock health for integration and application within a conventional PAF featuring reference points to differentiate stock status (DFO 2006). As per DFO process, this document outlines a conceptual framework, produces a Limit Reference Point (LRP), and provides direction for establishing an Upper Stock Reference (USR) point as well as Harvest Control Rules (HCRs) toward final framework development.

1.2. EXISTING DFO PAFS FOR LOBSTER

Precautionary Approach Frameworks for lobster resources have been implemented in other DFO Regions, including the Maritimes, Gulf, and Quebec, which are generally more data rich than NL in terms of resource monitoring information. As is the case in NL, most of the data sources used in stock assessments and PAFs in those Regions are fishery-dependent; however, other regions have more fisheries-independent data. For example, in parts of the Maritimes and Southern Gulf of St. Lawrence regions, there are fishery-independent trawl surveys. The PAFs differ across Regions, but typically focus on either landings or catch per unit of effort (CPUE) along with other biological or productivity indicators depending on the data sources available and how the stock is monitored on an annual basis. Ultimately, the overall goal of each PAF is to ensure the lobster resource is maintained at a healthy level.

In the Maritimes Region, there are different stock assessment methodologies and PAFs for different Lobster Fishing Areas (management units; LFAs), reflecting differences in data availability and changing dynamics of processes applied over time as new information accrues. In the majority of LFAs, the PAFs have recently moved from landings to fishery CPUE and

exploitation rates as primary indicators (Cook et al. 2020, In prep¹; DFO 2020). Secondary and contextual indicators include landings, effort, and catch rate indices of recruitment and exploitable lobster from surveys to inform multiple PAFs. Further indicators invoked include the proportion of the exploitable stock comprised of new recruits, proportions of females mature and ovigerous (bearing eggs), egg production potential, median size, maximum sizes from at-sea and port sampling, and temperature. All inshore LFAs in the Maritimes Region have reference points based on either commercial CPUE (Cook et al. 2020, 2023) or fisheries-independent trawl survey commercial biomass (Cook et al. 2020, 2023). Meanwhile, all primary indicators for LFA 34 have reference points established based on productivity changes. Secondary indicators encompass landings, commercial catch rates, and recruitment indices. In the most recent assessment framework conducted in the Maritimes Region, for LFAs 35, 36, and 38, fishery CPUE was replaced as the primary stock status index due to hyperstability in catch rates masking resource declines. Stock size indices from surveys will be used as the primary indicator moving forward as the focus shifts from fishery-dependent to fishery-independent data (Cook et al. In prep.¹). Exploitation rate indices (ERIs) and removal references for various LFAs in the Maritimes Region are defined based on continuous change in ratio (CCIR) models from data collected in standardized traps (LFAs 27–33) or relative fishing mortality (F) indices (LFA 34).

In the Gulf Region (i.e., southern Gulf of St. Lawrence), the PAF integrates both fishery-dependent and fishery-independent data to estimate abundance indicators (DFO 2023b). These sources include landings, logbooks, at-sea sampling, and bottom-trawl survey data. Within this framework, productivity indicators, such as catch rates of pre-recruits in surveys using unvented traps or bottom-trawls, are assessed. Additionally, juvenile abundance is measured through scuba surveys, a settlement index is obtained from bio-collectors, and egg production is estimated (DFO 2023b). Fishing pressure indicators are also incorporated in the PAF and are derived from exploitation rates estimated through a recruitment-index program. The median value of landings as a proxy for biomass for maximum sustainable yield (Bmsy) is used as a reference point in the Gulf Region's PAF. The LRP and the USR were identified using median landings from 1974 to 2009 as a proxy for Bmsy (DFO 2014), with the USR and LRP set at 80% and 40% of Bmsy, respectively (DFO 2014).

In the Quebec Region, the PAF utilizes primary abundance indicators, including landings and fishery CPUE from dockside sampling and at-sea data. Reference points for these indicators are established based on landings (DFO 2019, 2024). Demographic indicators such as mean size, exploitation rate, and sex ratio are also used and provide additional insights into population structure. Productivity indicators, including ovigerous female abundance, egg production, pre-recruit abundance, temperature, and rock crab abundance, were used to assess reproductive potential and environmental impacts. Both primary and secondary indicators were used to provide advice. The LRP, USR, and stock status zones (Healthy, Cautious, and Critical) were defined from landings. Average landings for the Gaspé (1985 to 2009) (LFAs 19, 20, 21) were used as reference points which included the LRP, set at 40% of the average, and the USR, set at 80% of the average (DFO 2022).

No Region weights or integrates indicators into an overall health index. Rather, each focuses on a single indicator as the basis of reference points, wherever developed.

¹ Cook, A.M., Howse, V., Asselin, N., Armsworthy, S., Denton, C., Gurney-Smith, H., Tam, J.C., White, L., and Quinn, B. In prep. Framework Assessment of American Lobster (*Homarus americanus*) in Lobster Fishing Areas 35-38. DFO Can. Sci. Advis. Sec. Res. Doc.

1.3. LESSONS FROM OTHER REGIONS

The resilience of lobster to high exploitation rates in a fishery is a commonality of the species virtually everywhere it is fished. Exact reasons for prolonged resilience to high levels of fishing are unknown. However, there is general agreement that large lobster in the population are central to the process in several ways. Among other attributes, large lobster produce more eggs and produce superior larvae, are more robust to disease, create intrinsic competition, and can better withstand climate perturbations (DFO 2009; Comeau and Hanson 2018; Le Bris et al. 2018; Pinsky et al. 2018). Effectively, the lesson to apply herein is that moderately high exploitation rates are acceptable as long as a sufficient residual component of the population comprised of large individuals is maintained. In terms of stock status indicators to apply in a PAF, ongoing evolution of focal indicators due to progressive understanding of spatiotemporal biases in data signals associated with changing stock dynamics within the Maritimes Region in particular, highlights the need to be cognizant of hyperstability in fisheries-dependent data sources (i.e., landings and CPUE)¹, thus sole emphasis on those should be avoided.

2. METHODS

2.1. SPATIAL UNITS OF ANALYSIS

With respect to spatial stock structure, it is assumed that some level of broad-scale spatial heterogeneity occurs throughout and beyond NL waters due to larval drift connectivity patterns that exceed the size of LFAs used to manage the fishery (Quinn et al. 2017). Conversely, given that the historic distribution of NL lobster has been restricted to coastal areas, along with the assumption that NL lobster are ‘coastal lobster’, it is assumed most NL lobster exhibit overall small post-settlement movements and that seasonal migration or other movement types are largely localized (Ennis 1984).

Further complicating the decision on best approach for spatial units of analysis is the nature of most available data, with the overwhelming dominance of fisheries-dependent data showing small spatial scale (i.e., LFA) variability in both quantity and quality of collections, as well as temporal dynamics such as season dates. In-season data collections are neither systematic nor randomly distributed in time or space. Going too small on spatial analysis units would lead to outright omission of numerous LFAs from analysis.

A further consideration affecting the decision on spatial units of analysis is the ‘Rule of 5 Policy’, which restricts presentation of results when either the number of harvesters, vessels, or buyers is less than five in a given spatial area and year due to a need to safeguard proprietary anonymity (i.e., Tomasic 2023).

Ultimately, a balanced approach is needed to capture important LFA-level details in available data, maintain the ability to incorporate information from all LFAs and years into the PAF, and report on spatial scales large enough to at least partially capture ‘biological stocks’. In cases where precision is needed to build indices, data analyses are conducted on LFA-level information and subsequently amalgamated into Assessment Region (AR) outputs. Otherwise, when coarse grain analyses are sufficient, AR-level analyses are the only analytical level. This approach is in line with the stock assessment (Coughlan et al. 2023) and broadly captures fisheries and assumed biological trends occurring within and across the four ARs. The four ARs are defined as the Northeast Coast, the Avalon [Peninsula], the South Coast, and the West Coast (Figure 1). Over the past decade, primarily based on reported landings, the South and West Coast ARs have emerged as ‘Major ARs’ while the Northeast Coast and Avalon Regions remain characterized as ‘Marginal ARs’. Despite regional differences in the levels of fishery

indicators, all ARs are presently showing marked signs of increasing fishery and assumed biological productivity (Coughlan et al. 2023, 2025).

2.2. DATA SOURCES

The data sources used to estimate and develop the multiple indicators for this PAF are described below. Most of the data for this PAF come from fishery-dependent sources, collected by harvesters and Fish, Food and Allied Workers union (FFAW) technicians, along with a new short-term, fishery-independent lobster trap survey that began in 2018 and has now expanded to include four sites.

2.2.1. At-Sea Sampling

At-sea sampling data from 2004 to 2023 were utilized in the PAF. At-sea sampling programs have employed at-sea technicians who record in-season daily catches onboard fishing boats in specific locations around the province. Where possible, every trap is sampled and carapace lengths (CL) of all lobster are recorded to the nearest mm. Individual sex is recorded and female reproductive status (ovigerous or non-ovigerous) is determined based on visual assessment of the abdomen and the presence or absence of a v-notch is noted. V-notch refers to a tail marking identifying that an individual was previously captured (and released) as an ovigerous female. Where present, v-notching is also subjectively classified as being a new versus old tail notch. These at-sea sampling data are the primary data source used to produce demographic depictions of population structure.

2.2.2. Logbooks

Two sources of logbook data are available from the fishery: one from an index harvester program ('FFAW logbooks') and one from a mandatory (all harvester) DFO program ('DFO logbooks'). Both programs capture information on date of fishing activities, numbers of lobster caught, and number of traps fished.

For the FFAW logbook series, data were available from 2004 to 2023 for each AR, with representation from most LFAs in most years. Throughout the commercial lobster fishing season, harvesters participating in this program collect information on the catch from commercial traps including number of commercial lobster kept, ovigerous females, and/or v-notched and undersized.

For the DFO logbook series, logbooks detail date of fishing, number of lobster kept, and number of traps fished. This logbook program was implemented in 2010. Despite being mandatory, return rates have averaged approximately 50% since 2010.

2.2.3. Modified (unvented) Traps

Since 2006, modified (unvented: targeting pre-recruit/sublegal size lobster) traps have been distributed to index harvesters and deployed throughout various LFAs. Logbook data and at-sea data were collected and reported on all lobster caught from these traps. The data from these traps are captured (in numbers) for discrete groupings of commercial lobster kept, ovigerous females, and undersized males and females. These data are scant throughout the time series in all areas.

2.2.4. Trap Surveys

Fisheries-independent trap surveys were developed and took place in the spring and early summer from 2018 to 2023 in Conception Bay (Avalon AR), in June 2021 to 2023 in Port

Saunders (West Coast AR), in September from 2020 to 2023 in Comfort Cove (Northeast Coast AR), and in April 2022 and September 2023 in Harbour Breton (South Coast AR). At each location, approximately 50 traps were deployed daily, including commercial and modified (unvented) lobster traps, at various 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 trap 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 (unvented) and commercial traps in both survey and at-sea sampling data.

2.3. RULE OF FIVE

Two potential limitations affecting presentation of information on fisheries-dependent data are the number of buyers and the number of harvesters with registered licenses in any given LFA and year. If either such measure of proprietary business-type is less than five, data cannot be shown. The number of buyers in each LFA was provided by the Statistics Division, DFO Policy and Economics Branch, and the number of harvesters with registered licenses was obtained from DFO Resource Management. The Rule of 5 restricted presentation of data in LFAs 3, 4A, 8, 9, 14B, and 14C in some or all years. Wherever necessary, landings and fishery CPUE for each LFA were combined with adjacent LFAs. Note these types of aggregations of data sources can limit the robustness of analyses for a localized area.

2.4. MULTI-INDICATOR PAFS

The present assessment of population dynamics toward adapting a precautionary approach (PA) for NL lobster management explores numerous indicators to develop a multivariate integrated synopsis of stock health. Multi-indicator PAFs offer several potential advantages over conventional univariate, typically biomass-based, approaches (Mullowney and Baker 2023). For example, for circumstances such as those that occur for NL lobster, where few (if any) indicators are deemed to have enough efficacy to support them as a stand-alone index, the approach of comparing and integrating signals from multiple sources into a holistic synopsis strengthens the assessment of overall stock health through a weight of evidence-type evaluation. The reality of the indicators examined herein is that there are important caveats associated with the data used to form each one. Moreover, multi-indicator PA approaches promote integration and application of factors beyond just biological indicators into the process. For example, fisheries CPUE has the potential to be included as an indicator of fishery health, creating a more holistic system-level synopsis of factors affecting the resource. Finally, another advantage is that multiple indicators enable a more robust adaptation to changes in carrying capacity. For example, if the absolute level of biomass of a stock increases (or decreases) to a level not aligned with historic levels due to changes in carrying capacity, the interpretation of stock status need not be directly aligned with that outcome, with ancillary factors such as maintenance of broad stock structure or per-capita egg production enabling a synopsis inclusive of factors beyond just stock biomass.

In line with the understanding that multi-indicator PAFs should avoid inclusion of too many variables that render the interpretation of stock health convoluted (Mullowney and Baker 2023), the work presented herein explores a total of five indicators before arriving at decisions of final inclusion for individual indicators. This approach was discussed at, and supported by, the most recent stock assessment (Coughlan et al. 2025).

As detailed in Section 1.2, multi-indicator PAFs are the norm in Atlantic Canadian lobster populations, albeit none includes a quantitative integration of resource performance scores into a single health index.

2.5. BIOLOGICAL AND FISHERY PARAMETERS

2.5.1. Trap Selectivity

Biological measurements from commercial traps (at-sea sampling) collected in the fishery were the most common data available for analysis of population demographics but required a trap selectivity conversion to examine data on poorly captured sub-legal size (< 82.5 mm CL) lobster. To develop a selectivity curve for conversion of commercial trap catch rates, the methods from the most recent stock assessment were followed, with the fisheries-independent trap survey data used to develop the model (Section 2.2.4) updated to 2023. For this analysis, length bin (4 mm CL bins with sexes combined) catch rates (#/trap) were calculated by year and site, with bins ranging > 50 mm to < 89 mm isolated to fit the curve. This range represented the majority of data and captured the size spectrum within which the relative capture efficiency of commercial traps was anticipated to increase from near-zero to near-one. The observation data used to fit the curve were represented by means of the ratios of catch rates of commercial to modified (unvented) traps, with all years and sites used to develop the catch rate ratios. This approach reflected strong consistency in site-specific selectivity curves from the four survey sites (Coughlan et al. 2025). A generalized additive model (GAM) using a quasi-binomial family distribution (logit link) was fit in the *mgcv* package (Wood 2017) in R Studio version 4.4 (R Core Team 2023). Quasibinomial distributions are appropriate when data variance is larger or smaller than would be expected with binomial data and applicable to response variables consisting of proportions. Observations with catch rate means above one were set to one prior to model fitting to conform with the proportional response variable. This affected the observation data at 80 mm CL.

The selectivity model was of the form:

$$[\text{Eq. 1}] \ rCOMM \sim s(CL),$$

where $rCOMM$ is the ratio of commercial to modified (unvented) trap catch rates, CL is carapace length represented by 4 mm bins, and s denotes a thin-plate smoothing spline. Three basis knots ($k = 3$) were used in fitting the model, the minimum possible, to avoid overfitting the model. Visual analysis of residuals and interpretation of adjusted R^2 were used to confirm sufficient model fit. The model was refit with a simulated dataset comprised of a sequence of CLs ranging from 30 mm to 150 mm to estimate length-specific selectivity conversion factors. A qualitative examination of selectivity-adjusted catch rates in commercial traps to unadjusted commercial trap catch rates, as well as modified (unvented) trap catch rates, was conducted by site and year to ensure efficacy of the conversions. These conversions were applied to the time series of commercial trap data from in-season monitoring in the fishery for all subsequent analyses, where appropriate.

2.5.2. Length-Weight Relationships

For the first time in 2023, weights of individual lobster were opportunistically recorded on the fisheries-independent trap surveys. Accordingly, length-weight relationships were developed for this PAF process. A GAM was fit to the data using the R-package *mgcv*, with a scaled t family distribution (log link). The scaled t distribution is appropriate for heavy tailed data, used in lieu of a Gaussian distribution, which can occur when relatively few observations are located near the extremes of the data distribution (Wood et al. 2016). The model, predicting weights, was

originally run using survey site and sex as unsmoothed factors alongside a smoothed term of CL, but upon finding negligible differences across the four survey sites for either sex, it was condensed to a simpler version containing only sex and CL as predictor variables. Maturation-specific groupings of females were too data poor to further refine to consider maturities at this point.

The length-weight model was of the form:

$$[\text{Eq. 2}] \text{Wgt} \sim \text{sex} + s(\text{CL}),$$

where Wgt is weight in grams, sex is a factor variable, and $s(\text{CL})$ is a thin-plate smoothed term for CL, measured to 1 mm. Adjusted R^2 was used to determine adequacy of fit. Three basis knots ($k = 3$) were used in fitting the model, the minimum possible, to avoid overfitting the model. The model was refit with a simulated dataset comprised of a sequence of CLs ranging from 1 mm to 150 mm to estimate sex-specific weights. These weights were applied to the time series of commercial trap data from at-sea sampling in the fishery for all subsequent analyses, where appropriate.

2.5.3. Fecundity

There is no recent regional brood size data in females. To estimate CL-egg relationships in females we used the latitude gradient approach of Currie and Schneider (2011). In this method, the scaling of the power law relationship of egg count as a function of length decreases as latitude increases. The latitude gradient applies to b , in the fecundity relationship defined as:

$$[\text{Eq. 3}] F = aL^b,$$

where F is fecundity (number of eggs), a is a scaling factor, L is carapace length, and b is the power law exponent. Across a range of latitudes from 40 to 52°N, b is defined as:

$$[\text{Eq. 4}] b = -0.08597 * \text{Lat} + 7.0202$$

We used central latitudes of 49.5°N, 47.2°N, 47.3°N, and 49.3°N for the Northeast Coast, Avalon, South Coast, and West Coast ARs, respectively, and 48.3°N for an index for all of Newfoundland.

The scaling parameter a is defined as:

$$[\text{Eq. 5}] a = F_{85}/(L^b),$$

where F_{85} represents mean fecundity at 85 mm CL at a given latitude, L is 85 mm, and b is the power law exponent. F_{85} is defined as:

$$[\text{Eq. 6}] F_{85} = 490.6 * \text{Lat} - 12222$$

2.5.4. Size-at-Maturity

No recent data on size-at-maturity (SaM) in NL lobster were available from DFO. To estimate SaM ogives for females, we transformed CL-based probit regression equations reported in Ennis (1980) for five sites around Newfoundland into percentages mature at size. These sites included St. Chad's and Comfort Cove from the Northeast Coast AR, Arnold's Cove (Placentia Bay) from the Avalon AR, and adjacent to the South Coast AR, and Boswarlos and North Arm from the West Coast AR. The determination of mature females in the work by Ennis (1980) was based on examination of ovary color and ova size. We calculated an average proportion mature at size across the five sites for application in further analyses. A conceptual percent ovigerous curve was plotted, defined as 0.5 times the percent mature at any given size, for benchmarking ovigerous proportions in subsequent analyses. This concept was based on females being on a

two-year molt-spawn cycle after reaching sexual maturity (Aiken and Waddy 1982; Comeau and Savoie 2001) and the calculation was based on all sites (i.e., average) maturity rate curve.

2.5.5. Immediate Recruit Size

Immediate recruit size was defined as 83–95 mm CL. The upper limit of 95 mm was chosen as reflecting a typical growth increment of 15% above the 82.5 mm CL MLS (minimum legal size, note lobsters which measure 82.5 mm CL are recorded as 83 mm CL.). This growth increment estimate is consistent with the myriad of historic reports from the southern Gulf of St. Lawrence for mid-large size lobster highlighted in Comeau and Savoie (2001), which ranged 12–20% across sites and sexes. The peer review meeting agreed upon 95 mm CL as representing a typical maximum size expectation for lobster first growing into the fishable population.

2.5.6. Maximum Sustainable Yield Harvest Rate (Fmsy)

Maximum Sustainable Yield Harvest Rate (Fmsy) is the F that produces the largest yield from a stock over the long term. We used a Yield Per Recruit (YPR) model to identify Fmsy harvest rates within the size spectrum of immediate recruits (83–95 mm CL). The YPR models conceptually estimate optimal fishing rates by considering the influence of natural mortality (M) rates in balancing the trade-off between letting individuals grow further and attain more weight versus fishing them at a smaller size in the present. In lieu of the typical age-based approach, we isolated modal sizes for each sex loosely conforming to ages approximated in Ennis et al.(1986). Specifically, for males, 83 mm CL and 92 mm CL approximated age 8 and 9, while for females, 83 mm CL, 88 mm CL, and 95 mm CL approximated ages 9–11. The YPR model was programmed in the *MQMF* package (Haddon 2023) in R. Input weights at a given size for each sex were based on predicted values from the survey-derived length-weight relationships previously described. Size-specific selectivity of lobster was based on the previously described selectivity curve, annual harvest rates were simulated over a range of 1 to 99%, M was set at 5% for males and 10% for females, reflecting higher energetic demands from reproduction in females, and initial population sizes were set at 10,000 lobster at 83 mm CL.

2.6. ADJUSTED LANDINGS

In the absence of other information, landings have been deemed an indicator that could at least partially reflect stock size of the exploitable population (DFO 2023b, 2024). Given landings were among the few data sources featuring a prolonged time series of data, they were considered potentially useful as either a direct framework indicator or one that could contribute to others, such as recruitment, given the fishery is deemed a recruitment fishery.

There are recognized problems using landings as an index of stock size. Besides the potential issue of changes in landings reflecting changes in effort rather than stock size (Cook et al. 2020), there is also known systemic under reporting of the catch. This reflects reported landings data coming exclusively from sales slips of processing facilities with no accounting for lobster sold in channels outside the processing sector. To address these issues, an index of adjusted landings was developed as the basis for potential inclusion of a direct or contributing landings indicator in the PAF in lieu of reported landings.

The approach to develop an index of adjusted landings, rather than reported landings, was supported by two anticipated changes to reported landings practices moving forward, both expected to produce upward bias on proportions of landings that get reported relative to time-series norms. First, it was anticipated that application of landings within the PAF could incentivize reporting of more landings to help ensure the index remains high, and second, expected broad-scale improvements in the lobster stock moving forward are anticipated to

increase volumes of lobster caught and consequently enhance the need for individual harvesters to sell catch to processing facilities rather than through other channels.

The equation underpinning the development of an index of adjusted landings at a week- and LFA-level is structured as:

$$[\text{Eq. 7}] \text{Landings}_{(week)} = (\overline{\text{sales}}_{(week)}(\mu) * \overline{\text{trips}}_{(week)}) * (\sum \text{licences}_{(annual)} * \alpha \text{fish}_{(week)}),$$

where *Landings* is adjusted landings in tonnes, $\overline{\text{sales}}$ is average tonnage of reported sales each week, μ is an adjustment factor to account for the number of fishing trips within a given sale, $\overline{\text{trips}}$ is the average number of trips taken by a given harvester each week, $\sum \text{licences}$ is the total number of harvesters requesting trap tags each year (i.e., inferred as intending to go fishing), and αfish is the proportion of the fleet fishing each week.

Data on average weekly sales tonnage by LFA was available from the Catch and Effort (CE) database of DFO (i.e., quota and catch monitoring) and the number of harvesters requesting trap tags by LFA was available from DFO Resource Management. The average number of trips per FIN (Fisher Identification Number) per week and the proportion of the fleet fishing per week needed to be estimated to develop the adjusted landings index.

2.6.1. Weekly Trips

All sources of data to estimate the average number of weekly trips per FIN were incomplete as not all harvesters consistently reported sales or submit logbooks. The average number of weekly trips per FIN was estimated from fishery logbooks rather than CE due to consistently higher levels of reporting in logbooks. To be representative of broader fleet activity levels, this approach necessitated an assumption that harvesters that do fill out logbooks do so consistently throughout the year. This was in part examined by looking for consistency among the two logbook data series in their relationships with sales slips. It was also expected that if this assumption was valid, the number of trips per week should approach or equal six (i.e., daily excluding Sundays in some areas) in major fishing areas during at least some parts of the season and be lower in more marginal LFAs. Relationships between the average number of trips per FIN per week from logbooks (trips) versus sales slips (slips) per FIN per week from CE were plotted as seasonal path plots by year and LFA, with calendar weeks representing path increments, examining DFO and FFAW logbook series separately. Reflecting more underreporting in CE sales data than in logbooks, as well as multiple trips being contained within some sales, it was expected that the average number of slips per FIN per week in CE would be systematically lower than trips per FIN per week in logbooks. Accordingly, the data were plotted against a 45° relationship line to look for these expected patterns within them to validate the efficacy of the approach.

The calculated number of trips per FIN per week was occasionally incomplete in some weeks of the season in any given LFA and year due to missing logbook information. To estimate the number of trips per FIN per week, including unaccounted for weeks in the data, the average number of weekly trips taken by harvesters was modelled using a GAM in *mgcv*. Data prior to 2010 were exclusive to FFAW logbooks and post-2009 they were restricted to DFO logbooks. This choice was made for the post-2009 period because although there was general agreement in trends in estimated number of trips per week between the two data series, preliminary analyses showed directionality in FFAW logbooks showing tendencies toward fewer trips per week, which plausibly reflected the smaller sample sizes from that data series. The trips model was structured as:

$$[\text{Eq. 8}] \overline{\text{trips}} \sim te(\text{year}, \text{week}),$$

where \overline{trips} represents the average number of trips per FIN, and $te(year, week)$ is a smoothed interaction of year and week fit by LFA.

Year and week were both treated as continuous variables. The model was fit as a quasi-poisson distribution with an identity link function and the k parameter controlling the year * week interactions was set to 15 to keep the degrees of freedom moderate. A quasi-poisson distribution reflects the non-integer count structure of the observation data. Adequacy of model fit was judged by adjusted R^2 and model residuals were presented as scatter plots of observed versus predicted weekly values plotted by LFA and year. Marginal effect contour plots of the interaction between year and week were examined by LFA to discern spatiotemporal patterns of high and low rates of weekly fishing activity.

The final step in estimating weekly trips was to refit the trips model with a database containing annual open and closing dates, converted to calendar weeks, for each LFA and year from 2005–23 to predict values for weeks when data were missing. These data on season dates were provided by DFO Resource Management. Weekly fits from this final model run, both in weeks where observation data were present and not present, were used as the estimate of average number of trips per FIN per week in Eq. 7.

2.6.2. Proportion of Fleet Fishing

The proportion of the fleet actively fishing each week was estimated based on numbers of FINs filling out logbooks. This was done through invoking an assumption that the week with the highest number of unique FINs in logbooks represented the week of maximum activity for the fleet in any given LFA and year. During this maximum activity week, 100% of the fleet was assumed to be active. Weekly proportions of the fleet fishing were initially calculated from unique FINs in logbooks and subsequently re-scaled to reflect the activity level relative to the maximum activity week.

The modelling approach to estimate weekly proportions of the fleet fishing was similar to that taken to estimate weekly numbers of trips, with an end goal of filling in estimates in weeks when no data were present. Again, the model was fit as a GAM in *mgcv*. The proportions model was structured as:

$$[\text{Eq. 9}] \propto fish \sim te(year, week),$$

where $\propto fish$ represents the proportion of the fleet fishing, and $te(year, week)$ is a smoothed interaction of year and week fit by LFA.

The proportions model was fit as a quasi-binomial distribution (logit link) to account for the proportional form of the data. Again, year and week were continuous explanatory variables and the k parameter controlling the year * week interactions was set to 15 to keep the degrees of freedom moderate. Adequacy of model fit was judged by adjusted R^2 . Residuals were presented as scatter plots of observed versus predicted weekly values and marginal effect contour plots of the interaction between year and week were examined by LFA to discern spatiotemporal patterns of high and low rates of fleet-level fishing activity.

The final step in estimating weekly proportions of the fleet fishing was to refit the proportions model with the database containing annual open and closing dates for each LFA and year to predict values for weeks when data were missing. Weekly fits from this final model run were used as the estimate of proportion of the fleet fishing each week in Eq. 7, regardless of whether or not observation data were available for a given week.

2.6.3. Average Sales

The CE data were available as average sale weight by week and LFA. However, not all harvesters who sell to plants do so for each trip and multiple trips can be contained within any given sale. Accordingly, to convert the average sale to a per-trip basis, an adjustment factor defined as weekly slips per FIN divided by estimated number of trips per FIN was applied. This represented the μ parameter in Eq. 7.

The modelling approach to estimate average sale per trip followed a similar process to the models used to estimate numbers of trips per FIN and proportions of the fleet fishing each week. The GAM was structured as:

$$[\text{Eq. 10}] \overline{\text{sale}} \sim te(\text{year}, \text{week}),$$

where $\overline{\text{sale}}$ represents average sale per trip and $te(\text{year}, \text{week})$ is a smoothed interaction of year and week fit by LFA.

The sales model was fit as a Gamma distribution (log link) to account for the positive form of the data with sporadic high values. Again, year and week were continuous explanatory variables and the k parameter controlling the year * week interactions was set to 15. Adequacy of model fit was judged by adjusted R^2 and residuals were presented as scatterplots of observed versus predicted values. Marginal effect contour plots of the interaction between year and week were examined by LFA to discern spatiotemporal patterns of weekly sales patterns.

Average per-trip sales in weeks and LFAs when no sales data were present were predicted by refitting the sales model with the database containing annual opening and closing dates for each LFA and year. Although this final run of the sales model fit available data well, it was clear there were some anomalous fit predictions produced in LFAs where data were particularly sparse, namely LFAs 3, 8, and 9. To safeguard against grossly inflated fit predictions leading to inflated adjusted landings, a calculation to identify outliers was conducted. This calculation was defined as the ratio of the predicted weekly sales value to the median value in any given LFA and year. Upon plotting this ratio for all LFAs and years, a ratio greater than 7 was defined as constituting outliers, with this level reflecting a break under which virtually all values were below in all other LFAs, in particular those with high levels of recorded sales data. For instances where outliers were identified, weekly sales estimates and standard errors were set to the annual medians.

2.6.4. Calculating Adjusted Landings

Adjusted landings (Eq. 7) were calculated by LFA and year by inputting season-filled predicted mean weekly number of trips per FIN (Eq. 8), proportion of the fleet fishing (Eq. 9), and sales per trip (Eq. 10). Weekly estimates of landings were subsequently summed by year to the LFA and AR levels. Propagated standard errors (σ) were calculated for adjusted landings (l) for weekly point estimates of average number of trips per FIN (t), proportion of the fleet fishing (f), and average sale weight (w), as:

$$[\text{Eq. 11}] \sigma l/l = \sqrt{((\sigma t/t)^2 + (\sigma f/f)^2 + (\sigma w/w)^2)}$$

Two (1.96) propagated standard errors were used as 95% confidence intervals around adjusted landings estimates.

2.7. FRAMEWORK INDICATORS

2.7.1. Fishing Mortality in Immediate Recruits

Length frequency data were calculated from selectivity-adjusted commercial traps as well as modified (unvented) traps from at-sea sampling from the fishery on a per trap basis (#/trap, npt). Selectivity-adjusted commercial trap data were treated analogous to modified (unvented) traps. Lobster were segregated by size (1 mm CL), sex, and maturity category (males, ovigerous females, non-ovigerous females, v-notched ovigerous females, v-notched non-ovigerous females). V-notching indicates a lobster was previously marked due to being ovigerous upon initial capture.

To qualitatively examine differences in size-specific catch rates at early versus late season stages, the length-frequency data were partitioned into stages constituting measurements taken before 20% of the season effort had been expended and after 80% of the season effort had been expended in any given LFA and year. Early versus late season length frequency distributions were plotted by AR and year, limiting lobster to those able to be kept in the fishery, namely males and non-ovigerous females. This was done for two reasons; first to qualitatively infer the extent of fishing effects on population demographics, and second to investigate possible temperature-induced increases in catchability that could occur throughout the season (Comeau and Drinkwater 1997).

Upon identifying concerns for increased catchability throughout the season, as inferred by high catch rates of sub-legal-sized pre-recruits in late versus early fishery stages, a choice was made to use a CCIR method to estimate total mortality in exploitable lobster. A CCIR calculates a depletion statistic from relative catch rates of unfished (i.e., reference group) versus fished lobster throughout the season (Claytor and Allard 2003). Accordingly, since temperature-induced increased catchability concomitantly affects both pre-recruit and exploitable lobster, the comparative approach safeguards against this bias in estimating mortality.

The unfished reference group was defined as males and non-ovigerous females ranging 80 to 82 mm CL, removing data on smaller lobster that could be affected by small sample sizes, while the exploitable group was restricted to immediate recruits, or males and non-ovigerous lobster ranging 83 to 95 mm CL. The reference group only included the two analogous categories of lobster as those being fished (males and non-ovigerous females) to maintain a direct comparison across the two without potential confounds. This refinement to immediate recruits rather than all sizes of exploitable lobster reflected two considerations. First, CCIR is most effective when compared groups are relatively close to one another in size (Claytor and Allard 2003), and second, the overwhelming majority of lobster captured in the fishery are immediate recruits (Coughlan et al. 2025), with few residual lobster (larger than immediate recruit size) in the population in many areas due to high F. Given low M in large lobster (Comeau and Hanson 2018), the majority of estimated total mortality is attributed to fishing. The reference group was narrowly defined as a 3 mm size group of lobster. Iterations extending the reference group back to sizes as small as 70 mm were undertaken and it was decided at the peer review meeting to make the reference group a narrow range to safeguard adherence to the assumption of same temperature-induced effects on catchability on all lobster being examined, particularly given no substantial loss of data necessary to fit linear regressions occurred as the reference group range was narrowed.

Quantitatively, non-linear regressions are fit to depleting loss rates of exploitable lobster in CCIR. A ratio of the number of exploitable to exploitable plus reference lobster (p) at sampling events throughout the season is calculated as the response variable and is regressed against

cumulative fishery landings as the explanatory variable. The p is adjusted to the pace of fishery landings by a conversion factor based on the proportion of monitoring effort to fishery landings at any given time. Cumulative fishery landings were estimated from kept lobster identified in logbooks, with the cumulative proportion of kept lobster multiplied by adjusted landings for any given AR and year to calculate accrued landings at any given point. We binned time into five-day increments to increase sample sizes used to make the p ratios. This approach also reduced across-LFA variability within any given AR. Initial analyses showed that limited data near the beginning and end of the seasons affected p ratios on the tails of the data distributions. Thus, p ratios from the first and last 5% of the season (measured by landings) were omitted in fitting regression curves. The non-linear regressions were fit as AR-specific quasi-binomial GAMs structured as:

$$[\text{Eq. 12}] p_{[j]} \sim s(\text{year_f}_{[re]} + s(\text{cum_land}_{[j]})),$$

where $p_{[j]}$ is the ratio of exploitable to exploitable plus reference lobster ($\text{exp}/(\text{exp} + \text{ref})$) measured by npt at any given time $[j]$, with j representing five-day bins in any given AR and year, year_f is year treated as a factor and fit as a random effect $[re]$, $\text{cum_land}_{[j]}$ is cumulative fishery landings at any given time $[j]$, with j representing five-day bins in any given AR and year, and s denotes a thin-plate smoothing spline.

There was an intent to both keep the curvature of models relatively rigid while allowing enough flexibility to reflect the underlying data distribution without overfitting the models. To enable this outcome, the k parameter on the cum_land term was set to the minimum (3) to minimize degrees of freedom while the sp parameter, controlling tightness of the smoother, was set to 0.5 to allow a moderate level of tightness in fit. Adequacy of model fits was judged by adjusted R^2 and residuals were presented as scatterplots of observed versus predicted values at the AR and year level. Marginal effects of cumulative landings were examined to discern overall patterns of depletion.

The Exploitation Rate Index (ERI) at any given (j) is calculated based on the predicted p ratio (p_{pred}) in relation to the estimated initial p ratio (p_0) using the following equation:

$$[\text{Eq. 13}] \text{ERI}_{[j]} \sim 1 - \left(\left(p_{pred_{[j]}} / (1 - p_{pred_{[j]}}) \right) / \left(p_{pred_{[p_0]}} / (1 - p_{pred_{[p_0]}}) \right) \right).$$

The maximum ERI in any given year corresponded to the end of season index and was taken as the annual ERI. Two (1.96) standard errors around the fitted estimate were used as 95% confidence intervals.

2.7.2. Size of Ovigerous Females

The most recent stock assessment highlighted unusually low proportions of fecund females in immediate recruits in some ARs (Coughlan et al. 2025). We updated the Size-at-Ovigerous (SaO) model from Coughlan et al. (2025) to investigate if those patterns have persisted. Prior to updating the SaO model we plotted proportional distributions of size-specific sex and category groups of males and females to qualitatively examine population demographics by AR. This was done for all lobster caught and sampled by at-sea sampling technicians each year, regardless of date. Lobster below 70 mm CL were omitted from examination due to potential for unrealistic transformations in catch rates at smaller sizes in the selectivity-adjusted commercial traps.

The SaO model was a GAM fit using $mgcv$ that interacted CL and year as explanatory variables to predict length-specific proportions of female lobster that are mature. The model family was quasi-binomial and the k parameter on the interaction was set to 12 to help in fitting to the a

priori dynamic shape of the data distribution. Further details on the SaO model are available in Coughlan et al. (2025).

Along with the updated run of the SaO model, we plotted cumulative proportions of sample sizes of female lobster in the population by AR and year to qualitatively discern the relative amount of female lobster in the population affected by low fecundity rates.

To develop an index of SaO for application within the PAF, we calculated the weighted mean size of ovigerous lobster in the population, with the weighting factor being the number per trap of captures for ovigerous lobster. This was done by AR and month to investigate spatiotemporal patterns in SaO lobster. However, due to high variance around point estimates and in consideration of poor sampling of lobster in some ARs in recent years, we applied a GAM to predict the mean sizes of ovigerous females. This estimation model was fit individually by AR as follows:

$$[\text{Eq. 14}] CL_{(month)} \sim te(year, month),$$

where CL is mean carapace length of ovigerous lobster sampled in the fishery, and te is an interaction smoother.

Non-ovigerous v-notched lobster were included as ovigerous, thus the analysis ultimately examined mean size of female lobster able to reproduce. The month term was fit as a thin-plate spline with $k = 4$ to give a basis knot for each month present in the data (April–July). The year term was fit with a thin-plate smoother with $k = 3$ basis knots, to minimize overall degrees of freedom in the model. Residuals were plotted as scatterplots of observed minus predicted values and marginal effect interactions of year and month were plotted for each AR. Upon finding differences in SaO by month, which showed patterns of increasing size from April to July, June was isolated as the temporal unit to predict into and report on as the mean size index because it featured relatively large sizes but was also a month in which sampling data were present in all ARs and years, thus the predictions into June statistical space were associated with fits to observation data everywhere. Two (1.96) standard errors of the predicted mean lengths were used as 95% confidence intervals around predicted point estimates of SaO.

2.7.3. Recruitment Biomass

Herein, recruitment refers to immediate recruits to the fishery. This component of the population comprises a high proportion of the landings and biomass in all ARs. An index of recruitment biomass was developed from integration of size composition sampling from the fishery to adjusted landings. Both data sources were binned to weekly increments before calculating proportions of contributions of recruits (83–95 mm CL males and non-ovigerous females) to the total catch sampled by at-sea sampling technicians, and by extension proportions of the overall adjusted landings occurring in each week, based on weekly levels of kept catch reported in logbooks versus total season adjusted landings for each AR. Upon merging the weekly catch compositions and landings, weekly estimates of the weight of recruits caught in the fishery were derived. Upper and lower estimates of captured recruit biomass were based on upper and lower 95% confidence interval estimates from adjusted landings. The weekly estimates of recruit biomass caught in the fishery were subsequently summed to annual levels, before developing the recruitment biomass index as annual biomass of recruits caught divided by the ERI of immediate recruits.

Upper and lower estimates of annual recruitment biomass (RB) were based on propagated standard errors (σ) from estimated catches of recruits (RC) and exploitation rate indices (ERI), as:

$$[\text{Eq. 15}] \sigma_{RB} = \sqrt{(\sigma_{RC}/RC)^2 + (\sigma_{ERI}/ERI)^2}$$

Two (1.96) propagated standard errors were used as 95% confidence intervals around recruitment biomass estimates.

2.7.4. Fishery CPUE

The most recent stock assessment introduced a standardized fishery CPUE index into the assessment of fishery performance. This index includes year and calendar day as explanatory variables and the non-smoothed effects of LFA and source (i.e., DFO versus FFAW logbooks) in a GAM fit with *mgcv*. However, there was a recommendation from the 2022 assessment meeting to explore including an additional term of vessel or FIN into the model. Accordingly, we undertook exploration of a suite of models including a random effect of FIN alongside existing model terms, comparing Akaike information criterion (AIC) to select a model that featured FIN as a standalone random effect without interactions with other terms. Additionally, in exploring changes to the existing CPUE standardization model, two streams of analogous models were examined, one maintaining the existing Tweedie family distribution and one featuring a quasi-poisson family distribution to more closely align with the count data form of the response variable. The quasi-poisson models consistently yielded higher deviance explained statistics than their Tweedie counterparts, and quasi-AIC fit assessment patterns mirrored the AIC patterns, thus quasi-poisson family was chosen to update the model. The updated standardized fishery CPUE model, fit as a generalized additive mixed model (GAMM) by individual ARs, is as follows:

$$[\text{Eq. 16}] CPUE_{[j]} \sim LFA + Source + s(year) + s(cday) + ti(year, cday) + s(FIN_{[re]}),$$

where *CPUE* is mean fishery catch rate (number per trap) for the fishing event, *j* denotes individual fishing events (i.e., daily trip), *LFA* is Lobster Fishing Area, *Source* is DFO or FFAW logbook series, *cday* is calendar day, *FIN* is a factor effect of Fisher Identification Number, *s* denotes a thin-plate smoothing spline, *ti* denotes a thin-plate interaction smoother, and *re* denotes a random effect.

There was no manipulation of *k* or other default model parameters, the model was fit with a quasi-poisson distribution with a default log link, and model residuals were presented as observed minus predicted values plotted against model fit. This approach for presentation of residuals was taken due to a high volume of data concentrated near low values in the typical presentation of linear fits of observed versus predicted values used for other analyses thus far. Marginal effect interaction plots of year and calendar day were presented for each AR to discern temporal changes in fishery CPUE throughout the data time series, and seasonal distribution patterns of model fits by year and calendar week were shown for LFAs within each AR. Finally, to derive an index creating comparable performance across and within ARs and years that incorporated any changes in temporal fishing dynamics, a mid-point for each season within each AR was calculated. This mid-point week was based on cumulative sum of kept catch in the logbooks, selecting the week whereby a proportion closest to 0.5 occurred in any given AR and year. Two (1.96) standard errors of the model fit were used as 95% confidence intervals for these mid-point weeks.

2.8. CHOICE OF INDICATORS AND SCORING

Correlograms of each of the five developed indicators considered for inclusion in the PAF (adjusted landings, F in immediate recruits, recruit biomass, mean size of ovigerous females, and mid-season fishery CPUE) were plotted for each AR to investigate relationships among them. The intent was to identify problematic relationships that could produce undesirable results in scoring the final framework. For example, in all ARs there was a strong and positive correlation between adjusted landings and the ERI in immediate recruits. Given that it would be

inappropriate to attribute a strong positive score to adjusted landings that are being progressively driven by increasing exploitation rates in the fishery, adjusted landings were removed from inclusion in the final framework indicators. The strong positive relationships between fisheries exploitation rates and recruitment levels were deemed non-problematic, given they were considered conceptually independent of one another. Removal of adjusted landings eliminated potential for a correlation between it and the conceptually-linked fishery CPUE index to be redundant in final indicators selection.

From a biological mechanistic perspective, there was potential for redundancy (i.e., a negative relationship) between size of ovigerous females and the exploitation rate on immediate recruits. However, the data showed no such consistent pattern across ARs, thus both indicators were kept. That this relationship could be affected by management interventions, such as v-notching and prohibition of ovigerous females, was thought to be a strength in the decision to keep both variables. There were no consistent relationships between ovigerous female size and the biomass of recruits across ARs, thus they were deemed sufficiently independent from one another for final inclusion in the framework.

Of the four indicators chosen for final inclusion in the framework, fisheries CPUE may be most problematic. This reflected both ongoing practices in the fishery, specifically an unaccounted for shift in gear type being used, and directional relationships with recruitment and exploitation rate. Interestingly, the directional relationship between CPUE and exploitation rate (positive) was not one that would be expected to hold in the long run. This partially offset concerns of the decision to retain CPUE. Further, the positive relationship with recruitment was deemed one that should conceptually hold and work together to shape the results of the framework (i.e., go up and down together). From a general perspective, recruitment was deemed a biological health indicator and CPUE deemed a fishery health indicator. Furthermore, it is recognized that the intent of this process is to build a collaborative system amenable to all parties, and that CPUE effectively represents the harvester's currency on data inputs into the PA system.

To score the F indicator, an index of F/F_{msy} was calculated, applying the annual estimated harvest rate for each AR to F_{msy} derived from the YPR model. Annual F rates were plotted along the YPR curve and scores were simply calculated as the fraction of F_{msy} the fishery was operating at, expressed as a proportion, thus potential scores ranged from zero (fishing at 100% annual mortality rate) to one (fishing at or below F_{msy} (39%)). Values below F_{msy} were all given a score of one, as it would be inappropriate to penalize the fishery for operating at low exploitation rates on immediate recruits. This scoring approach was deemed to align with overarching fishery management goals of reducing exploitation rates.

The size of ovigerous females indicator was scored within a size range corresponding to sizes at which 50% and 100% of females would be expected to be mature on average from all sites. These sizes were represented as 73 mm and 96 mm CL. Values including and between these two extremes were scored along a zero to one continuum following a linear regression of the form $[\text{score} = 0.0435 * \text{CL} - 3.1739]$, which was simply fit to the two endpoints. This approach of basing scoring on expected rates of SaM was deemed to align with fishery management objectives of enhancing egg production.

Percentiles above baseline values were used to score the immediate recruitment and fishery CPUE indicators. For each indicator, the baseline values were set at averages of annual values for the pre-2016 period within each AR, with the underlying philosophy that 2015 was the point at which notable and now sustained improvements began. Effectively, this approach is rooted in the time series performance of each indicator and identifies a point at which below/above stock growth would be assumed to be impaired/enabled in the future judging from past performance. Values below pre-2016 means were set to zero, while subsequent ones were scored as their

percentile above the defined level. This approach means that if new highs are reached in either indicator, new upper limits defining scores of one will be established.

Error terms for each of the four indicators included in the final Health Score Index (HSI) were developed using a propagated additive approach from the standard deviations (σ) of the individual indicators used to make it (mortality [M], ovigerous [O], recruitment [R], CPUE [C]), as follows:

$$[\text{Eq. 17}] \sigma_{HSI} = \sqrt{(\sigma M)^2 + (\sigma O)^2 + (\sigma R)^2 + (\sigma C)^2}$$

Two (1.96) standard deviations around the HSI were used as 95% confidence intervals.

2.9. SETTING OF LIMIT REFERENCE POINT

Setting LRPs in PAFs is both a very important and difficult process. This is effectively the most critical operational element of a PAF as legislation to enhance or reduce controls on fisheries, in particular landings, depends on stock performance in relation to LRPs. Unfortunately, there are no consistent or firmly established best-practice approaches used in setting LRPs (Marantette et al. 2021). A high percentage of DFO PAFs revert to setting LRPs at 40% of a given stock performance measure, in line with advice to use this approach if no other philosophy is invoked.

Setting a LRP for NL lobster is difficult due to several factors. First, in line with most other PAFs for Canadian lobster resources, the available data do not allow for development of conventional ‘finfish type’ frameworks, which normally quantify a time series of spawning stock biomass through an index or model as the singular basis of stock performance upon which to establish reference points. In adaptation to the available data, like other lobster PAFs, a multi-indicator approach was applied here to assess resource health, albeit taking the process one step further in developing an integrated HSI. Second, beyond data, there are biological and circumstantial factors to consider. For example, a central tenet of establishing LRPs is to place them at a level below which serious harm is thought to be occurring (DFO 2023c). If such harm is due to fishing, remedial actions can be taken to address it if stocks are placed in the Critical Zone. Interference to reproductive processes, such as impaired fecundity rates associated with fishing, could constitute serious harm. However, to broaden this, it must be considered if such conceptual serious harm is in fact impairing the resource being assessed. Ideally, outcomes could be quantitatively measured to establish the cause-effect relationship. American Lobster populations are known to show persistence in their resilience to high rates of fishing throughout much of their stock range, albeit in the context of biological concerns over aggressive fishing practices (Comeau and Hanson 2018). Moreover, larval drift dynamics are known to connect populations throughout Atlantic Canada, particularly within the Gulf of St. Lawrence (Quinn et al. 2017), thus the extent to which localized egg production affects localized recruitment is poorly understood. Nonetheless, broad-scale resource performance patterns would suggest broad-scale stock-recruitment processes.

In consideration of all aforementioned factors associated with setting a LRP, our approach was to place it, based on the integrated HSI, at a level from which broad-scale resource growth has been demonstrated, following the logic of B_{recover} , which is defined as a level of biomass (or proxy) that produced recruitment that led to stock recovery (DFO 2023c). This invoked a consideration on what constitutes recovery. Historic landings in the lobster fishery have been documented as being much higher in the past than during the period preceding the recent stock growth (Coughlan et al. 2025). Accordingly, the review meeting agreed some measure of stock health preceding recent broad-based stock growth appropriately fit within the definition of B_{recover} . However, the issue of low ovigerous rates in females in heavily exploited areas was also deemed necessary to consider in setting a LRP, and that the LRP level should be sensitive to quickly capture measured resource productivity impacts of potential harm stemming from low

ovigerous rates if they become apparent. To be specific, the intent was to ensure the LRP was set within one health score unit of the recent and present assessment of the West Coast AR due to concerns of egg production impairment most obviously occurring in that AR (see Section 3.3.2 for details), with the one health score unit intended to capture a signal of recruitment failure should it occur.

The LRP was set at the lowest of the average score for the integrated HSI across ARs during the pre-2016 period (West Coast AR = 1.78, LRP set at 1.75), after which demonstrated and sustained resource growth has occurred everywhere. This is proposed in consideration of the fact that it is within one health score unit of present and recent West Coast AR assessments.

2.10. ANCILLARY ANALYSES

2.10.1. New Versus Conventional Trap Catch Rate Experiment

In recent years, harvesters in NL have been replacing the standard commercial size traps (36" long, 12" high, and 18" wide) with larger commercial traps (known as Nova Scotia [NS] traps) (48" long, 14" high, and 21½" wide). Two major differences are that these traps have two entrance holes, one on either end of the trap, and typically use twice the bait as conventional traps. Although unquantified, use of these traps is now widespread and common. To investigate the difference in catch rates between the larger traps and conventional commercial lobster traps, ten of the new larger traps were integrated within the lobster trap surveys in Comfort Cove and Harbour Breton in September 2024. Soak times were the same as in conventional traps. To follow the practices of the fishery, the amount of bait (herring) was doubled (i.e., two skivers [tool used to hold bait] per trap) in the larger traps. Another caveat is that at the initial Comfort Cove site, only shallow depths within the depth-stratified design were occupied with large traps, whereas all depths were occupied in Harbour Breton. The data collected from these traps included the total catch, measurements of all lobster caught (CL), and reproductive status and egg stages (of ovigerous females).

A GAM was used to model catch rates of legal-size lobster in new versus conventional traps. This model was of the form:

$$[\text{Eq. 18}] \text{CPUE} \sim \text{Site} + \text{TType} + s(\text{depth}) + s(\text{soak}),$$

where *CPUE* is number of legal-size lobster per trap, *Site* is survey location (i.e., Harbour Breton or Comfort Cove), *TType* is trap type (i.e., conventional commercial or large NS-style), and *s* denotes a thin-plate smoothing spline on the depth (m) and soak time (hours) terms. The *k* parameter for each smoothed term was set to 5. The model family was Tweedie to accommodate the normal data containing zeros. Boxplots of catch rates for each trap type were produced from the data used in the analysis and marginal effect smooths for each fitted-model term were plotted. The weights of all lobster captured were also examined, using boxplots and interpreting differences in medians, to investigate if there was a difference in the size of animals captured by each trap type.

3. RESULTS

3.1. BIOLOGICAL AND FISHERY PARAMETERS

3.1.1. Trap Selectivity

There was a high level of variance around mean point estimates of the ratio of size-binned catch rates in modified (unvented) versus regular commercial traps in the surveys. However, the point

estimates formed the anticipated logistic shape, with the ratios near one over the 76–88 mm CL range (Figure 2). The selectivity model fit the observation data well, with an adjusted R^2 of 0.938 and no systematic pattern in residuals (Figure 2). Capture efficiency estimates ranged from 0.03 at 60 mm CL to 0.99 at 88 mm CL. At 83 mm CL, just above MLS, the capture efficiency estimate was 0.96.

Overall, the transformed commercial trap catch rate data closely mirrored the modified (unvented) trap catch rate data at sizes at and above 70 mm CL across all survey sites and years (Figure 3). Below 70 mm CL there was more variability, with selectivity-adjusted catch rates above the modified (unvented) trap catch rates in Port Saunders and Harbour Breton and below modified (unvented) trap catch rates in most years in Comfort Cove. Nonetheless, data transformations in commercial traps were deemed reliable at and above 70 mm CL and were applied to the at-sea sampling data for the majority of analyses herein, none of which included lobster below 70 mm CL.

3.1.2. Length-Weight Relationships

The length-weight models fit the survey data well for both males and females, with an overall adjusted R^2 of 0.914 (Figure 4). Males and females were estimated to have similar weights at 50 mm CL (105 g for females versus 114 g for males) with divergence progressively occurring between the lighter females and heavier males over the remainder of the size distribution. At 100 mm CL, females were estimated at 838 g while males were estimated at 903 g. At legal size (i.e., 82.5 mm CL, but measured as 83 mm CL), females were estimated at 462 g and males were estimated at 498 g.

3.1.3. Fecundity

There was tight agreement in fecundity at size across all ARs (Figure 5). The power-law relationship estimated a legal-size female lobster (i.e., 83 mm CL) to have 10,717 eggs on average across ARs, while a 140 mm CL female was estimated to carry 47,996 eggs on average.

3.1.4. Size-at-Maturity

The historic data on SaM from sites around Newfoundland showed tight conformity in maturity rates in small size (< 70 mm CL) female lobster, but diverge above about 70–75 mm CL, at which point approximately 50% of females were mature at all sites (Figure 6). There was no clear spatial pattern in the data, with separate sites in both the Northeast Coast AR and the West Coast AR showing divergence in maturation rates after 70–75 mm CL. On average, 2.5% of females were mature at 60 mm CL, 50% were mature at 73 mm CL, and 100% were mature at 96 mm CL. The conceptual percent ovigerous curve, defined as half the rate of maturity, showed 45% of females to plausibly be carrying eggs at legal size (i.e., 83 mm CL) and 50% to plausibly be carrying eggs at sizes above 90 mm CL.

3.1.5. Maximum Sustainable Yield Harvest Rate (Fmsy)

The YPR models assumed a M of 0.05 for males and 0.10 for females. Model runs on both females and males in the immediate recruit size range were conditioned on trap selectivity (Figure 2) and length-weight (Figure 4) data from the surveys. At initial size (83 mm CL), the modeled males produced slightly higher yield than females due to heavier weights (Figure 7), and modes in parabolic shapes systematically shifted left as sizes increased, reflecting benefits of letting lobster live and accrue more weight before fishing them. High F rates were associated with negligible contributions of large immediate recruits to the long-term yield in both sexes

(Figure 7). The optimal fishing intensity rate, deemed F_{msy} , on this group of lobster was 37% per year in females, 42% in males, and 39% with both sexes combined (Figure 8). At 39% annual harvest rate, all age-proxies of lobster of both sexes within the immediate recruit group made substantial contributions to the overall fishery yield (Figure 7).

3.2. ADJUSTED LANDINGS

3.2.1. Weekly Trips

Both logbook data series showed similar seasonal patterns in the relationships between average numbers of weekly trips per FIN in logbooks versus average numbers of weekly sales per FIN in CE (Figures 9a–d). There was a systematic pattern of higher numbers of trips per FIN in logbooks than weekly sales per FIN in CE, particularly in the marginal fishery ARs in the Northeast Coast (Figure 9a) and Avalon (Figure 9b) ARs. However, the relationship between the two indicators became closer to a 1:1 ratio in major fishing areas, such as LFA 11 in the South Coast AR (Figure 9c) and particularly so in LFAs 13A, 13B, and 14A on the West Coast (Figure 9d). In most West Coast LFAs, there were clear consistent declining patterns in both the number of weekly trips and weekly sales throughout the season in most years. Although present in some LFAs and years, the synchronous drop in weekly trips and weekly sales were often less clear in the more marginal LFAs such as those in the Avalon AR (Figure 9b). In the West Coast AR, the maximum number of weekly trips at the start of the season, was often six, and only one trip per week occurred by the end of the season in many years. Conversely, in marginal fishing areas such as LFAs 4, 5, 6, and 7, there was an overarching pattern of just one or two sales per week throughout much of the season in most years (Figures 9a–b). Similar to the major fishing areas, there was a suggestion of declining numbers of trips throughout the season in some years, but overall the patterns remained more centralized toward about two to five trips per week in most seasons. Interestingly, in recent years there has been an increase in the number of weekly trips, with a shift toward five to six trips per week in several of these marginal LFAs (i.e., LFA 4A, Figure 9a).

Frequency distributions of weekly number of trips per FIN from logbooks showed overall normal distribution patterns in Northeast Coast and Avalon LFAs, centered on three to four trips per week (Figure 10). In the South Coast AR, the distributions of weekly fishing trips were left-skewed, centered on five to six trips per week in the two LFAs. In the West Coast LFAs, the distribution patterns were overall broadly distributed and platykurtic across a range of about two to six trips per week in any given LFA and year.

The total trips GAM estimating the number of weekly trips per FIN fit the data well overall with an adjusted R^2 of 0.762 (Table 1). Overall, residual patterns were non-dynamic and indicative of representative model fits (Figure 11). However, there were some issues of occasional flat patterns in the residuals, generally in marginal LFAs (i.e., LFAs 8 and 9 in 2019). Nonetheless, the residuals confirmed a sufficiently fitting model capturing the dynamic suite of spatiotemporal data.

Marginal effect interaction plots were presented to visualize the spatiotemporal predictive patterns of the model (Figure 12). Generally, in most LFAs, the model predicted positive forcing on the number of trips in the mid-portions of the season while fishing was occurring in any given LFA and year. Generally, in areas where data were sparse or not present and the model interpolated or extrapolated into statistical space, negative forcing on the effect of number of predicted trips occurred, reflecting reduced activity at or near the start and end of the fishing seasons.

Overall, in most LFAs and years, the model fit the data on weekly number of trips per FIN, and interpolated or extrapolated into areas with missing data, with a horseshoe-type pattern characterized by fewer trips at the beginning and end of the season than at mid-points of it (Figure 13). Although the Rule of 5 precluded presentation of the data in some LFAs and years, model fits for all LFAs and years were plotted and showed relative consistency in patterns over the 18-year time series plotted in any given LFA (Figure 14). Despite overall consistency in pattern, magnitude shifts were evident in some LFAs, such as an overall increase in number of weekly trips in most West Coast LFAs in recent years.

The final model predictions reflected the observation data in producing frequency distributions indicative of normal distributions centered on three trips per week in the Northeast Coast and Avalon ARs (Figure 15). A left-skewed distribution centered at five to six weekly trips per FIN in the South Coast AR was predicted, and a distribution centered at about four trips per week in the West Coast AR with a shift to the right in the mode in more recent years. Overall, the average number of weekly trips in the Northeast Coast AR has been showing a gradual increase since 2011, approaching four in 2023, while other ARs have been more consistent, notwithstanding a sharp increase in the average number of weekly trips in the Avalon AR in 2023, to 3.5. The high level of variance around the means reflects the horseshoe-shaped pattern of the process, featuring fewer trips at the start and end of the seasons.

3.2.2. Proportion of Fleet Fishing

The data on calculated proportions of the fleet fishing were scaled to a maximum of one based on maximum activity weeks, defined as the week with the highest number of unique FINs in logbooks in any given LFA and year. The data distribution reflected a one-inflated pattern in any given LFA, dominated by a proportion of one (100% of the fleet fishing) and a secondary incidence of zero (none of the fleet fishing), with intermittent observations between zero and one (Figure 16).

The proportion fishing GAM was able to fit the data well, with an adjusted R^2 of 0.888 (Table 2). There were no apparent problems in the residuals, with observed versus predicted values following a linear pattern everywhere (Figure 17). The marginal effect interaction plots consistently predicted high positive forcing on the effect of proportion of the fleet fishing in the mid-portions of the season in all LFAs and years and generally predicted a strong negative forcing on the effect when extrapolating into statistical space near or beyond the beginning and end portions of the season in any given LFA and year (Figure 18).

Similar to the number of weekly trips, the overarching pattern for weekly proportion of the fleet fishing was a horseshoe-type pattern, in which the model was able to both fit to the data and predict into statistical space with missing data (Figure 19). It was deemed appropriate to plot model predictions for all LFAs and years regardless of the Rule of 5 precluding plotting data, which revealed the horseshoe pattern in fleet activity levels was present across all LFAs and years (Figure 20). A second overarching consistency across LFAs was that in the mid-portions of the season, 100% of the fleet was consistently fishing everywhere in any given year. Despite these consistent patterns, there were AR and LFA-specific patterns. For example, the increase from zero to one proportion fishing was more gradual at the beginning of the season in the Avalon AR than in the South Coast AR. Similarly, the rate of decline in activity at the end of the season was more gradual in the West Coast AR than in others in some years.

The final model predictions reproduced the underlying one-inflated data pattern well. In all ARs, the data were dominated by peaks at or near one in levels of weekly fishing activity proportions for the fleet (Figure 21). On average, 70 to 90% of the fleet would be predicted to be fishing in any given week and AR, typically highest in the South Coast AR. Again, the high variability

around mean estimates reflected the horseshoe pattern in the process, with weekly proportions below one countering the central tendency of a proportion of one for activity levels in the fleet in most weeks when the fishery was open.

3.2.3. Average Sales

The weekly average reported sales in CE were converted to a per-trip basis based on the ratio for weekly sales slips per FIN to weekly trips per FIN (Figure 9). The resulting data patterns reflected a Gamma data family distribution comprised of positive and continuous values (Figure 22), albeit within a relatively constrained level of tonnage with relatively few values beyond 0.25 t (250 kg).

The average sales GAM fit the sales data well, with an adjusted R^2 of 0.821 (Table 3). The overall tight fit of the residuals reflected the clumped nature of the data near the lower range of the distribution (Figure 23), but there was some deviance from atypical high observations occurring in any given LFA and year, with a tendency to overestimate these infrequent anomalous values.

The marginal effect interaction plots revealed numerous intriguing patterns in their prediction surfaces (Figure 24). First, there has been an increased incidence of recorded sales data occurring in some LFAs in recent years, such as LFAs 3 and 14C. Second, there has been an increased level of positive forcing on the effect of sales levels in most LFAs in recent years, particularly notable since about 2020, in numerous LFAs (3, 4B, 5, 6, 7, 10, 13B, 14A, 14B, 14C). Third, the high level of inconsistency in recorded sales in LFAs 8 and 9 led to an incoherent prediction surface in those areas. Finally, there was an overall increasing tendency for the model to predict a positive forcing effect on sales volumes when extrapolating into statistical space with no data in many LFAs in recent years. In some areas the increasing positive predictive pattern could be seen in the early portion of the season (LFAs 3, 4A, 4B, 14C), while in numerous LFAs a pattern of increasing predicted sales levels could also be seen in the late season (LFAs 5, 6, 10, 12, 13A, 14A, 14B, 14C). Overall, the patterns were indicative of gradual broadening in both spatial and temporal increases in sales amounts in recent years.

Relative to the overarching horseshoe-type patterns seen in the number of weekly trips and the weekly proportions of the fleet fishing analyses, there was more LFA-specific variability in sales amount patterns (Figure 25). For example, numerous LFAs showed flat line patterns throughout the season for much of the time series (i.e., LFAs 4A, 4B, 5, 6, 13A, 13B, 14B), while some showed dynamic patterns such as a horseshoe-shaped temporal pattern (i.e., LFA 14C) or late season increases (i.e., LFA 11). Numerous LFAs showed patterns indicative of increasing sales amounts throughout the season in recent years (i.e., LFAs 5, 7, 10). Again, no data on LFAs and years when the Rule of 5 applied were plotted but model predictions for all LFAs and years were deemed appropriate to plot (Figure 26). These plots revealed some anomalous high predictions in some weeks in several LFAs and years (Figure 26). However, the issue was not systemic and was associated with select LFAs with limited data (LFAs 3, 8, 9, 14C). To address these anomalies, the identification test of the ratio of weekly sales predictions to the annual median in any given LFA and year was applied and a ratio of seven was chosen as the breakpoint to identify outliers because it isolated unusually high predictions from these four select LFAs from all data from other LFAs (Figure 27). These outliers and their standard errors were converted to season medians for any given LFA and year in which they occurred.

Ultimately, the final model predictions produced right-skewed data distributions on sales amounts in each AR, generally centered near 0.05 t (i.e., 50 kg) (Figure 28). However, in all LFAs there were underlying patterns of the mode of the distribution shifting to the right in recent years, with predicted sales amounts of 0.2 t relatively common in the South Coast and West

Coast ARs, and modes successively creeping toward 0.1 t in the Northeast and Avalon ARs. These patterns of modes shifting right over the time series in any given AR reflected average estimates of sales amounts in any given AR, which have progressively increased throughout the time series everywhere and are presently at or near historic highs.

3.2.4. Adjusted Landings Calculation

Although the Rule of 5 affected presentation of data for all LFAs and years, two patterns were clear in the adjustment of reported landings to model predicted landings. Namely LFAs in the Northeast Coast and Avalon ARs substantially under recorded landings relative to those in the South Coast and West Coast ARs, and there was a recent increase in predicted landings virtually everywhere throughout the province (Figure 29). When the piecewise LFA-level predicted landings were additively summed to the AR-level (Figure 30), point estimates of adjusted landings in 2023 for each AR totaled 2,386 t, 1,154 t, 2,690 t, and 5,088 t for the Northeast Coast, Avalon, South Coast, and West Coast ARs, respectively. These all constituted historic highs. Interestingly, there was a pattern of reported landings nearing or meeting predicted landings in the South and West Coast ARs in years associated with the COVID-19 pandemic (i.e., 2019–21). Note the limited time series in predicted landings, starting in 2014, reflected availability of trap tag data, which formed the basis of fleet size in the predicted landings calculation.

3.3. FRAMEWORK INDICATORS

3.3.1. Fishing Mortality in Immediate Recruits

The length frequency data from early versus late season sampling in each AR showed spatiotemporal dichotomies in relative abundance and inferred F both within and across ARs and years (Figure 31). However, the primary intent of identifying increased catchability of lobster throughout the season was met. For example, in all ARs there was an overarching pattern of catch rates of sub-legal-sized pre-recruits being higher in relative abundance in the late part of the season in some or most years. This affirmed the efficacy of applying an approach to estimate mortality that was sensitive to within-season changes in catchability such as CCIR.

Each of the AR-specific CCIR models fit the p -statistic depletion data adequately. Adjusted R^2 statistics were greater than 0.30 in all but the Avalon AR (Tables 4–7). Despite the low adjusted R^2 in the Avalon AR (0.180, Table 5) the model residuals that misfit were attributable to only five select weekly observations over the 2014–23 time series (Figure 32) and confirmed as in all ARs that there was no systematic misfit of the model to data. The smooths applied to the cumulative removals effect terms in each AR were negative across the entire range of cumulative landings distribution in each AR, and showed general linear patterns in all ARs (Figure 33).

Overall, the CCIR model curves fit the depletion data well in most years within ARs (Figure 34). However, temporal deficiencies in sampling data in some years forced the model to predict into statistical space with no observation data to confirm predictions. For example, no early or mid-season sampling in the Avalon and South Coast ARs in 2020 forced the regression back to the intercept with no comparative observation data. This issue became more problematic in recent years, in particular in the Avalon AR in 2023 and the West Coast AR in 2021 and 2023. More broadly, the general lack of initial season sampling in the West Coast AR since 2020 is concerning given the importance of estimating p_0 at the x -intercept to calculate F .

The patterns of F showed systematic tendencies toward an asymptote as exploitation rates became elevated as fishing removals progressed throughout the season (Figure 35). In

particular, when F becomes extremely high (i.e., above 50%), the incremental rate of mortality slows. The annual F estimated from CCIR shows a pattern of rapidly increasing mortality in exploitable lobster in all ARs since about 2015, with historic high estimates exceeding 50% of the population in all ARs in 2023 (Figure 36). The very high levels in the West Coast AR since 2019, near or exceeding 90% per year, are concerningly high. This reflects a virtual absence of legal-size lobster in the population at the end of the season in most recent years (Figure 31).

3.3.2. Size of Ovigerous Females

The examination of demographic proportional sex and maturity frequencies showed a relatively fixed (~50:50) sex ratio between males and females within the pre-recruit and immediate recruit groups since 2004 in all ARs (Figure 37). Beyond immediate recruit sizes, the proportions of females in the population increases, with lobster that are either v-notched or ovigerous comprising the majority of residual lobster in the surviving population. However, an examination of proportional demographics isolated to females revealed concerning patterns in some ARs and years. Most specifically, the proportions of females in the immediate recruit size that are ovigerous occasionally show dampening relative to pre-recruit and residual lobster in some ARs and years (Figure 38). This pattern was most prominent in the West Coast AR in recent years. Upon an updated run (Figure 39), the SaO model estimated that only about 15% of the female lobster sampled have been ovigerous. These levels are extremely low. For example, the roughly 15–40% of females estimated as ovigerous over the 70–80 mm CL range in most ARs and years is consistent with the conceptual values calculated from halving the percent maturity curve to conform to a two-year molt-spawn cycle (Figure 6). In comparison, this conceptual model would suggest roughly 40–50% of immediate recruit-sized female lobster might typically be expected to be ovigerous (Figure 6). In recent years, only about 20% of females in the immediate recruit size range in the Northeast Coast AR were ovigerous while levels approximating 10–15% of females of that size being ovigerous have persisted in the West Coast AR for about a decade.

There were no concerning residual patterns in the GAM model fit to weighted mean CL of ovigerous females (Figure 40) and the model overall fit the data well in each AR with adjusted R^2 ranging from 0.469 to 0.814 across ARs (Tables 8–11). Marginal effect contour plots of the effects of month and year showed some interesting patterns both across months and years. First, it was apparent that sizes generally increased throughout the season where the effect was not overridden by a strong influence of year, most clearly seen in the Northeast Coast and South Coast ARs where July samples were predicted to be largest but were not associated with consistent sampling in the South Coast AR (Figure 41). For consistently collected June samples, sizes were predicted to be larger than May samples in all ARs. However, clarity in the monthly size increase pattern has been overridden by a downward trend in size of ovigerous females by year in the Avalon and, most strongly, West Coast ARs in recent years.

The weighted mean size of ovigerous females in June has shown varying levels of rigidity for prolonged periods within the time series within each AR (Figure 42). A gradual decline from 89 mm CL has occurred in the Northeast Coast AR since 2014 with predicted mean size now at 84 mm CL. The Avalon AR has shown a similar pattern but has remained above legal size throughout the time series. In the South Coast AR, there has been a prolonged gradual increase in predicted mean sizes of ovigerous females, but the index has remained effectively centered at legal size since 2009. In the West Coast AR, a notable downward shift occurred in 2016 and the predicted mean size of ovigerous females has remained at or below 80 mm CL since.

3.3.3. Recruitment Biomass

A high proportion of the weekly catch sampled by at-sea sampling technicians was comprised of immediate recruits in all ARs and years (Figure 43). Among the data were several overarching spatiotemporal patterns. First, generally the proportion of lobster larger than immediate recruit size increased as the season length extended. Second, the Avalon AR consistently had higher proportions of larger lobster in the catch than the other ARs, with 25% or more of the catch comprised of lobster larger than immediate recruit size from the mid (i.e., ~ calendar weeks 22–23) to late stages of the fishery in some years. Third, there was an overall shift toward higher proportions of immediate recruits in the catch in all ARs in recent years, least extreme in the Avalon AR and most extreme in the West Coast AR, whereby the majority (i.e., greater than about 95%) of the catch was comprised of immediate recruits throughout the season.

In line with immediate recruits fueling much of the landings, trends in the recruitment biomass index (Figure 44) reflected adjusted landings and have increased progressively since about 2015 in all ARs. In 2023, recruitment in all ARs was at or near time-series highs, with point estimates approximating 3,000 t in the Northeast Coast AR, 900 t in the Avalon AR, 3,000 t in the South Coast AR, and 4,500 t in the West Coast AR.

3.3.4. Fishery CPUE

The standardized fishery CPUE model captured an adequate amount of variability in each AR, ranging from a low adjusted R^2 of 0.30 in the Avalon AR to a high of 0.53 in the West Coast AR (Tables 12–15). The addition of the FIN term contributed moderately to improving model fit in any given AR, overall featuring low-moderate F statistics relative to other smoothed terms in the model in any given AR.

Model residuals revealed how dynamic the CPUE data are across and within years, weeks, LFAs, and ARs. Nonetheless, overall they showed no systematic patterns of concern and were able to standardize estimates across LFAs relatively well in all ARs (Figures 45–46). However, some patterns were occasionally evident within some ARs. For example, at low CPUE values in the West Coast AR there was a tendency for the model to overestimate CPUE in some years, evident by a lack of negative residuals in model fit estimates below about 1.0 lobster per trap in some years, while in the South Coast AR during some early years the model showed some tendency to underestimate high CPUE values, evident by lack of positive residuals above about 1.5 lobster per trap up until about 2013 (Figure 46). Nonetheless, given these points of potential concern would be expected to primarily occur at the beginning and end of seasons, reflecting consistent seasonal depletion patterns in the fishery, they were not of major concern, particularly given a seasonal mid-point is applied for inclusion in the PAF.

The marginal effect interactions of year and calendar day revealed some subtle patterns of improvements occurring throughout the season across years in multiple ARs (Figure 47). For example, the latter parts of the season have begun to show slight positive forcing within the predictive space in the Northeast Coast and Avalon ARs since about 2012, while the South Coast AR has shown predicted improvements in weeks where late season (i.e., above about day 165) data were present (since 2016). In the West Coast AR, a contour of positive forcing in the early weeks of the season (i.e., below day 150) during 2004–10 has gradually shifted into the seasons since, being centered near day 150 since 2017.

Two overarching patterns were evident in seasonal predicted values in fishery CPUE in any given LFA and year; namely depletion consistently occurred after the first few weeks of fishing in any given area and season, and that overall magnitudes of CPUE were increasing over the time series in most LFAs (Figure 48). Collectively, these patterns suggest that this recruitment-driven fishery is broadly benefiting from progressively increasing recruitment into it

over the time series. However, other factors such as progressive changes in fishing gear to more efficient traps over the time series are also likely contributing to these patterns.

The mid-season CPUE has increased in all ARs since 2005 (Figure 49). Historic highs of 0.60, 0.42, and 2.23 lobster per trap are predicted in the Northeast Coast, Avalon, and West Coast ARs, respectively. The 1.21 lobster per trap in the South Coast AR is slightly below recent levels but is preliminary and recognized to be well above time series norms.

3.4. CHOICE OF INDICATORS AND SCORING

The cross-correlation analysis showed very strong positive relationships between adjusted landings and exploitation rate on immediate recruits in all ARs (Figures 50–53), with coefficients of determination at or above 0.917 in all ARs. This is concerning as it shows the recent increasing landings in the fishery are largely being driven by increasing exploitation rates. For this reason, adjusted landings were removed from inclusion in the PAF.

The strong positive relationships between ERI and the recruitment index across all ARs (minimum coefficient 0.922 South Coast AR [Figure 52], maximum 0.962 Northeast Coast AR [Figure 50]) indicate that strong recruitment into the biomass is persisting, despite high exploitation rates. This is somewhat counter-intuitive from a mechanistic perspective but is reassuring both from a resource outcome perspective as well as in enabling a decision to maintain both indicators in the final framework given that they can be viewed as being at least partially quantitatively independent of one another. This relationship, indicative of resilience to fishing, is consistent with what is observed in other American Lobster populations (Comeau and Hanson 2018).

The Northeast Coast and West Coast ARs showed significant correlations between ERI and size of ovigerous females (Figures 50 and 53, coefficients of determination = -0.937 and -0.734, respectively). The negative forms of these relationships is consistent with biological reasoning on a cause-effect relationship in this process. However, lack of significant relationships among these variables in other ARs suggests some independence between them, or that some other factor that enables large females to remain in the population (such as v-notching), is helping to affect the process more strongly in other ARs. However, the negative direction of the relationships in most ARs suggests top-down fishing effects have meaningful impact on the index of mean size of ovigerous females in the population.

The strong positive relationships between ERI and fishery CPUE were significant in all ARs (minimum coefficient 0.600 in Avalon AR [Figure 51], maximum 0.900 Northeast Coast AR [Figure 50]). Given depletion in CPUE is consistently known to occur in the fishery (i.e., Figure 48), albeit to different degrees across areas and seasons, it would appear some latent factor helps offset the dampening of CPUE, or potentially even increases it, as ERI levels accrue.

There was inconsistency across ARs in the direction and strength of relationships between recruitment levels and the size of ovigerous females in the population. However, the negative relationship between the two variables in all but the South Coast AR, coupled with significance in correlations in the Northeast Coast (coefficient -0.877, Figure 50) and West Coast (coefficient -0.636, Figure 53) ARs suggest bottom-up recruitment effects have meaningful impact on the index of mean size of ovigerous females in the population.

The positive relationships between recruitment and fishery CPUE in all ARs underscore the reliance on recruitment to sustain this fishery. Interestingly, the relationship was not significant in the South Coast AR (coefficient 0.424, Figure 52), potentially suggesting a higher level of

contribution from residual lobster in the population helping to support the fishery there relative to other ARs.

There was no consistency in relationships between size of ovigerous females and fishery CPUE across ARs. Data patterns ranged from random (Northeast Coast AR [Figure 50], Avalon AR [Figure 51]) to significantly positive (South Coast AR [Figure 52]) to significantly negative (West Coast AR [Figure 53]).

There was consistency in the direction of scores obtained in F on recruit indicators across ARs, with all receiving progressively lower scores in recent years, with time-series lows in all ARs in 2023 (Figure 54). However, the extent of deviance from fishing near an Fmsy level was highly variable, with the Northeast Coast AR still prosecuting an efficient fishery and the West Coast AR being most inefficient. The highest scores occurred in the Northeast Coast AR (0.90), with moderate scores in the Avalon (0.59) and South Coast (0.44) ARs, and a very low score occurred in the West Coast AR (0.08).

Moderate scores relative to time series norms for size of ovigerous females occurred in all but the West Coast AR in 2023. In the West Coast AR, the index score was 0.28 for each of the last three years (2021–23, Figure 54). Moderate scores occurred in all other ARs in 2023, ranging from 0.42 in the South Coast to 0.66 in the Avalon.

The maximum score of 1.0 for recruitment into the exploitable biomass was achieved in all ARs in 2023, except for the West Coast which was also high (0.89) reflecting a continuous trend of progressively higher recruitment levels in all ARs in recent years (Figure 54). There are no concerns over recruitment performance in any AR.

The maximum score of 1.0 for fishery CPUE was achieved in all ARs except the South Coast in 2023 (Figure 54). In the South Coast AR, the score of 0.83 remained high relative to time series norms. There are no concerns over fishery CPUE in any AR.

All ARs were assessed as being above the proposed LRP in 2023 with a negligible (< 0.05) probability of being in the Critical Zone (Figure 55). The highest health scores in the Northeast Coast and Avalon ARs versus lowest scores in the West Coast AR ultimately reflected better performance conforming with fisheries management objectives of reducing exploitation rates and increasing egg production.

3.5. ANCILLARY ANALYSES—NEW VERSUS CONVENTIONAL TRAP CATCH RATE EXPERIMENT

The trap type catch rate model fit the data well with an adjusted R^2 of 0.428. The new larger traps captured substantially more legal-sized lobster than the conventional traps at both survey sites (Figure 56). Median catch rates in Comfort Cove nearly doubled in large traps compared to conventional traps, while in Harbour Breton the difference was more pronounced with a quadrupling in median catch rates to four legal-sized lobster per trap in the larger traps. Overall, across sites, catch rates more than doubled in larger traps compared to conventional traps (Figure 57). The positive shape of the soak time smooth is intuitive with accruing catches as gear fishing time accrued, while the positive depth smooth likely reflects the lack of deep sampling in Comfort Cove. Finally, with respect to size, the median weights of all lobster caught in the larger traps was higher than in conventional commercial traps at both survey sites (Figure 56), with commercial traps most commonly capturing lobster slightly below 500 g and large traps capturing lobster slightly above 500 g in Comfort Cove, and a marginal increase from a median of 470 to 475 g in the conventional versus large traps in Harbour Breton.

4. DISCUSSION

4.1. KEY FINDINGS

The examination of various biological and fisheries indicators from NL lobster ARs reveal two overarching concomitant processes shaping trends in stock status, namely increasing recruitment into the exploitable biomass and increasing fisheries exploitation rates. Leading causes explaining these two dominant processes regulating resource and fishery productivity are improving habitat conditions from climate warming, promoting recruitment (Le Bris et al. 2018; Goode et al. 2019), and increasing effort creep from a shift toward more efficient traps being used in the fishery enabling abrupt increases in landings and fishery CPUE.

Although recent fishery indicators of landings and CPUE are very positive on the broad-scale, the research herein raises concern that improvements in fisheries data indicators could be masking underlying stock performance issues and obscuring the alignment between resource outcomes and management objectives. Despite positive landings trends, it is apparent that growth overfishing is occurring in most ARs. Growth overfishing occurs when a resource is harvested at sub-optimal rates that preclude it from achieving efficient YPR, which balances the trade-off between harvesting individuals at a smaller size in the present versus letting them grow and harvesting at a larger size (FRCC 1995). The present dynamics of the fishery, featuring steadily increasing F on immediate recruits, is progressively distancing the resource and, in turn the fishery, from its maximum growth potential. This outcome is counter to the management objective of reducing, or even effectively controlling, fisheries exploitation rates. In recent years, the Northeast Coast and Avalon ARs were most consistently maintaining exploitation rates near long-term optimal levels (although are now going beyond it) while the South Coast and West Coast ARs were fishing at very high levels of exploitation, far beyond optimal levels. Particular concern is raised for the West Coast AR where F now approximating or exceeding 90% of immediate recruits per year has become the norm. It is clear F is largely going unabated (no reduction in intensity) in many areas. This issue extends into potential interference with reproductive dynamics. Although concern of low fecundity rates in immediate recruit-sized females presently appears most paramount in the West Coast AR, it also appears to apply to other ARs to different degrees (e.g., in the Northeast Coast AR where proportions of size at ovigerous in the immediate recruit-sized females has been low in recent years).

Given the two processes of rapidly increasing recruitment and exploitation rates are occurring simultaneously, it is intriguing to ask which is the more dominant forcing. Unfortunately, it is not an easy question to address from a regression modeling perspective because the explanatory terms are not independent of one another nor the response variable (adjusted landings). Recruitment is calculated based on both landings and exploitation rates. Nonetheless, an examination of correlation strength between landings and the two explanatory variables suggests both are strong determinants of landings, with similar coefficients of determination between adjusted landings versus both variables across all ARs over the past two decades. Effectively, the data depict a scenario where 'recruitment gives it, and the fishery removes it', in terms of determining annual landings. This is termed a recruitment fishery. Unfortunately, beyond distancing the resource and fishery from achieving or even nearing growth potential in many areas, there is little management or industry can do to mitigate the fishery from impacts of a weak recruitment event once it becomes near-fully reliant upon immediate recruitment to sustain it. Moreover, at least conceptually from a population biology perspective, engineering a population deplete of large individuals is inherently risky.

4.2. APPLYING LESSONS FROM OTHER REGIONS

The confluence of increasing recruitment in the presence of high F is not unique to NL. This has been the reality for lobster populations throughout most of Atlantic Canada for decades. Factors contributing to promoting species resilience to fishing include favourable environmental conditions, low predation pressure, and protection of ovigerous females (Gaudette et al. 2014) and large lobster in the population (Comeau and Hanson 2018).

Favourable environmental conditions and relaxed predation pressure are not directly controllable in resource management, but all NL lobster ARs would appear to be benefitting from both processes with a general lack of large predators consistently occupying shoreline areas for most parts of NL for decades. Effectively, lobster are deemed to have little predation on them in NL, particularly after early ontogeny, and a warming climate is likely underpinning resource growth. Like other regions, ovigerous females are prohibited from retention in the NL lobster fishery, but there is no immunity for large lobster beyond being a v-notched or egg-bearing female. These avenues of protection are evident in size proportion demographics in the population, whereby most lobster remaining in the population above immediate recruit size are either v-notched or ovigerous females in most ARs and years. Unfortunately, v-notching rates in NL lobster are relatively low and consistently trending down since 2010. About 5% of females were v-notched in all but the Avalon AR in 2021, with 13% v-notched in the Avalon AR in that year (Coughlan et al. 2025). This controllable conservation measure is not being applied in a manner consistently promoting maximization of production potential. Moreover, as can be seen in size frequency distributions of populations in heavily exploited ARs, in particular the West and South Coast ARs, despite high proportions of lobster above immediate recruit size being comprised of v-notched or ovigerous females there are in reality very few lobster of this size left in the residual population.

Despite climate-driven improvements in habitat, NL lobster remains on the fringe of the species range distribution. As a general rule, life on the fringes can be taxing on organisms from an energy budgeting perspective. They often need to invest more energy in somatic maintenance than growth or reproduction relative to organisms occupying best habitats (i.e., Kleiber 1961). Interestingly, a study from what is progressively becoming the opposite fringe for lobster range distribution, the warming waters off Maine, detailed how maintaining large female lobster in the population enhanced resilience to warming (LeBris et al. 2018; Pinsky et al. 2018). Mechanistic population-level benefits of conserving large lobster include higher resilience to disease, lower impacts of predation, stability in egg production, genetic safeguarding against fisheries-induced evolution, and better ability to withstand climate perturbations. Within Canada, it is also purported that maintaining large lobster in the population is a central tenet of enabling lobster populations to exhibit ongoing resilience to intense fishing (Comeau and Hanson 2018).

Relative to other regions, a fundamental difference in NL, most specifically the West Coast AR, is that persistently high fishing exploitation rates, now exceeding 90% of immediate recruits, are becoming normalized and are beyond levels typically imposed on lobster populations. In extension of this, to the best of our knowledge, evidence of impaired egg production via low proportions of females in the population becoming ovigerous is a novel finding. Our supposition is that this observation reflects high mortality on females while they are immediate recruit size. Specifically, in conjunction with a two-year molt-reproduction cycle, females growing into immediate recruit size do so as non-ovigerous animals. In turn, most are caught in their year of recruitment, with few surviving to be afforded the ability to become egg-bearing in the subsequent year. Despite concern of low rates of ovigerous females in the West Coast AR, it must be noted that there are indications a similar pattern is occasionally present to a less extreme degree in other ARs, thus we cannot be definitive on exact causal mechanisms. We highlight this is an issue requiring research given it may constitute documentation of serious

harm through fishing. Whatever the underlying cause (e.g., F), it is evident that outcomes in egg production potential are distant from overarching fishery management objectives.

Overall, the highest health scores in the Northeast and Avalon ARs are in line with exploitation rates being lower than in the West and South Coast ARs, and more comparable to other regions fishing lobster. We presented evidence that the larger traps being used in the fishery are not only much more efficient at capturing exploitable-sized lobster, but also appear to be more efficient at capturing larger (heavier) lobster, adding to potential biological implications stemming from this gear shift.

4.3. UPPER STOCK REFERENCE AND HARVEST CONTROL RULE GUIDANCE

Defining an appropriate LRP for NL lobster was difficult. Evidence of demonstrated resource ability to grow from historic baseline health status, supplemented by consistent and progressive recruitment increases, effectively opposed concerns of progressively high exploitation potentially extending into biological harm through fishing. This disconnect is associated with a poor understanding of larval drift or other associated stock-recruitment dynamics. Effectively, the extent to which localized processes affect localized outcomes is unclear. Ultimately, it was decided to place the LRP in a position to both recognize the baseline health level from which the resource demonstrated broad-scale ability to grow as well as be able to readily capture impacts of forthcoming recruitment impairment, should they occur.

We suggest similar extensive thought be put into where to draw USR lines from management and industry partners. Specifically, we suggest directly addressing the question of whether or not prosecuting a fishery at such high exploitation rates in the West and South Coast ARs is truly healthy. It is clear resource and fishery growth potential is not being maximized in most ARs. There will almost certainly be widespread perception, based on direct observations of landings and fishery CPUE which are undoubtedly progressively positive, that the resource is in a very healthy state. However, we urge recognition that this is at least partially an artefact of fishing gear changes, along with the measured improvements in recruitment. Effectively, we offer that the spirit of determining a USR should reflect one of cautious optimism. That the final PAF resulted in higher health scores in the Northeast Coast and Avalon ARs reflects more consistency to positive signals across the four focal indicators including those more focused on biological (egg production, mortality) rather than fishery (landings, CPUE) outcomes.

The biological indicators examined herein have direct means to control them and measures to do so would ultimately result in an outcome of establishing a consistent residual component of large lobster in the population, which is a tenet of a healthy population that would be anticipated to help contribute to continued resource resilience to fishing moving forward.

In terms of the PAF, the direct lever to pull toward establishing a residual biomass in the population is reduced exploitation on immediate recruits. This also serves to promote an ancillary benefit of promoting resource and fishery growth to be at a level closer to its potential. This should be focal in developing HCRs. Measures directed toward controlling the level of effort creep occurring in the fishery, enhancing the survival of lobster to large sizes, and increasing egg production in the population would all constitute meaningful HCRs. History has shown that through practices such as v-notching that the demographic composition of the population can be engineered.

5. RECOMMENDATIONS

Overall improving fisheries monitoring would be beneficial, including ensuring compliance with the logbook return requirements to help improve and maintain logbook return rates. A central

recommendation stemming from this work is to start quantifying the amount of the new fishing gear (large traps) being used in the fishery. This can be accomplished through identifying the gear type and size being used in logbooks (FFAW and DFO) and in the at-sea sampling data collection. Along with this, a broadening of comparative studies on differences in catch rates around the province should be undertaken to better understand variability in gear performance differences.

In extension of the need to begin quantifying trap type usage, efforts should be undertaken to estimate the historic rate of increase in use of these traps in the fishery toward refining the fishery CPUE standardization model toward a more stationary time series. It is also recommended that fishing locations and depths be included in the data available from logbooks to help with future research and modelling capabilities for this increasingly vital fishery resource.

It is recommended that the potential link between excessively high harvest rates and low ovigerous rates in females be further investigated to more concretely establish if a cause-effect relationship is present. Potential identification of biological harm through fishing necessitates research from DFO or other institutions as it counters sustainable fishing practices. Likewise, dismissal of a cause-effect relationship is important if it is not present toward better understanding levels of acceptable risk in fishery resource management.

In terms of indicators included in the PAF, it is recommended to investigate the possibility to develop and incorporate an egg production index as a focal indicator in lieu of mean size of ovigerous females. Concerns were raised during the peer review that the mean size of females index could be reflecting increasing recruitment as much as top-down removal of large females by the fishery. The data show both recruitment and F to be correlated with ovigerous female size in multiple ARs. A post-hoc check on only legal-size females (82.5 mm CL [recorded as 83mm] or greater) was done to ensure consistency in trend with the included index of all females (70 mm CL or greater) to ensure interpretation of low mean size reflecting top-down removal of large females in the population held, but it is nonetheless recognized that an egg production index would be a better measure of the process intending to be addressed in the PAF. As part of this, efforts should be taken to update length-egg relationships with more recent data than examined herein.

The time series of trap tag request data used to interpret the number of harvesters actively fishing each year is limited to beginning in 2014 and affects numerous time series indices. Efforts should be undertaken to extend the time series of tag issuance data further back into the time series.

Based on the current data, efforts should be taken to ensure at-sea sample collections are distributed in a representative fashion across both time (i.e., weeks) and space (i.e., LFA). This can occur within either systematic or random sampling designs. Predictive modelling can help offset some impacts of poor sampling designs, but it is not a long-term solution nor effective as a representative sampling program. A major issue of uncertainty in F in the AR of most concern in recent years is an outcome of poor sampling levels and distribution in the fishery.

Finally, an expansion of fisheries-independent surveys would help move resource assessments and future refinements to the PAF toward fishery-independent survey information, which is typically preferred for stock assessment.

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7. FIGURES

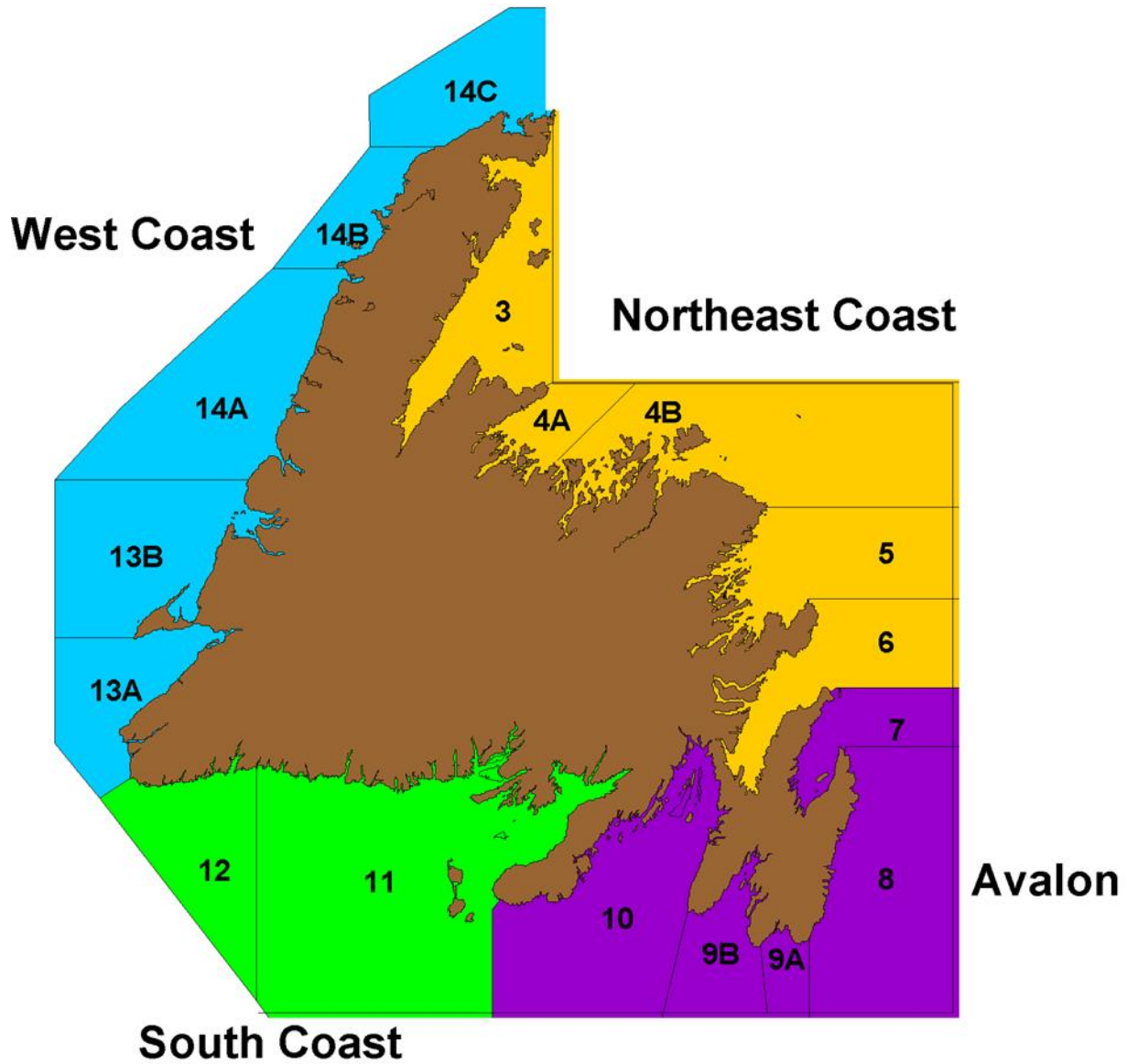


Figure 1. Map showing Newfoundland's Lobster Fishing Areas (LFAs 3–14C) within the four Assessment Regions (Northeast Coast, Avalon, South Coast, and West Coast).

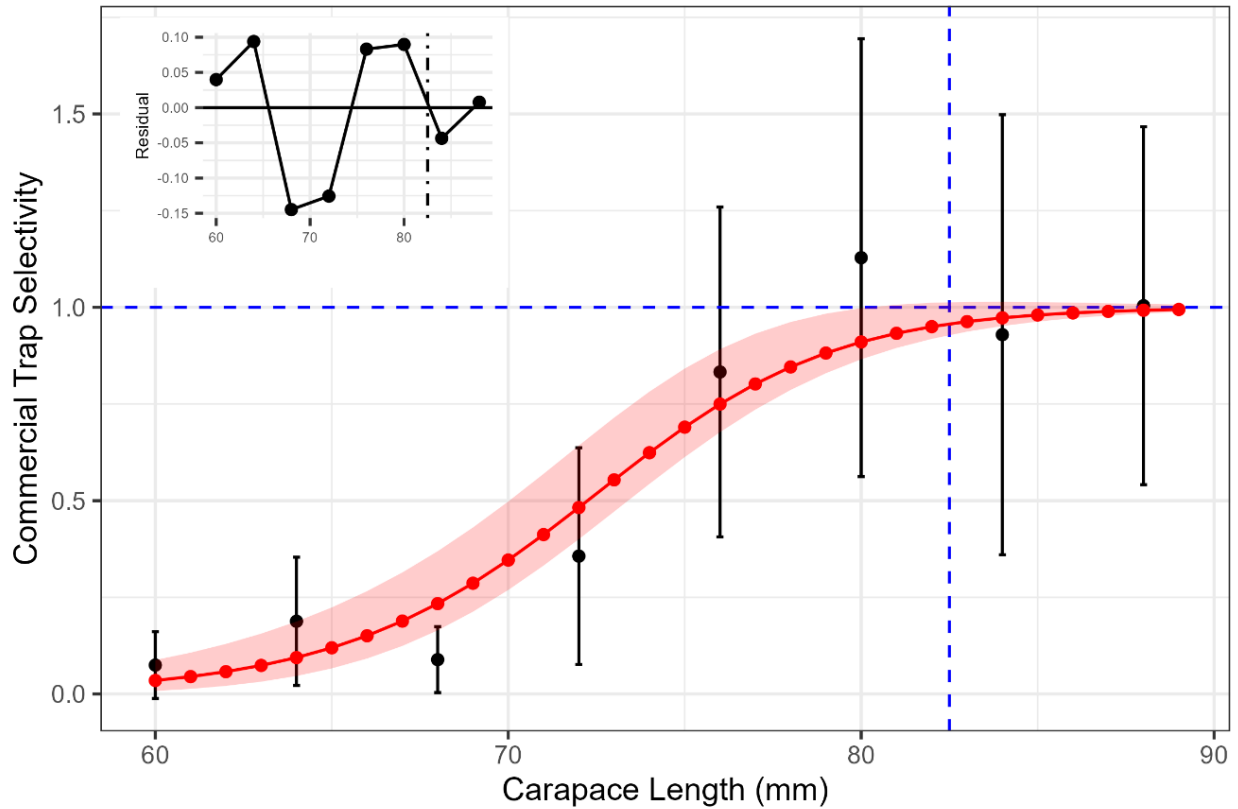


Figure 2. Trap selectivity curve from lobster trap survey catch rates of commercial versus modified (unvented) traps. Carapace lengths binned to 4 mm increments. Black dots are mean estimates of catch ratios and black lines are 2 standard deviations. Red dots show model predicted values and red shaded areas show 2 standard errors. Residual plot of model fit in upper left corner.

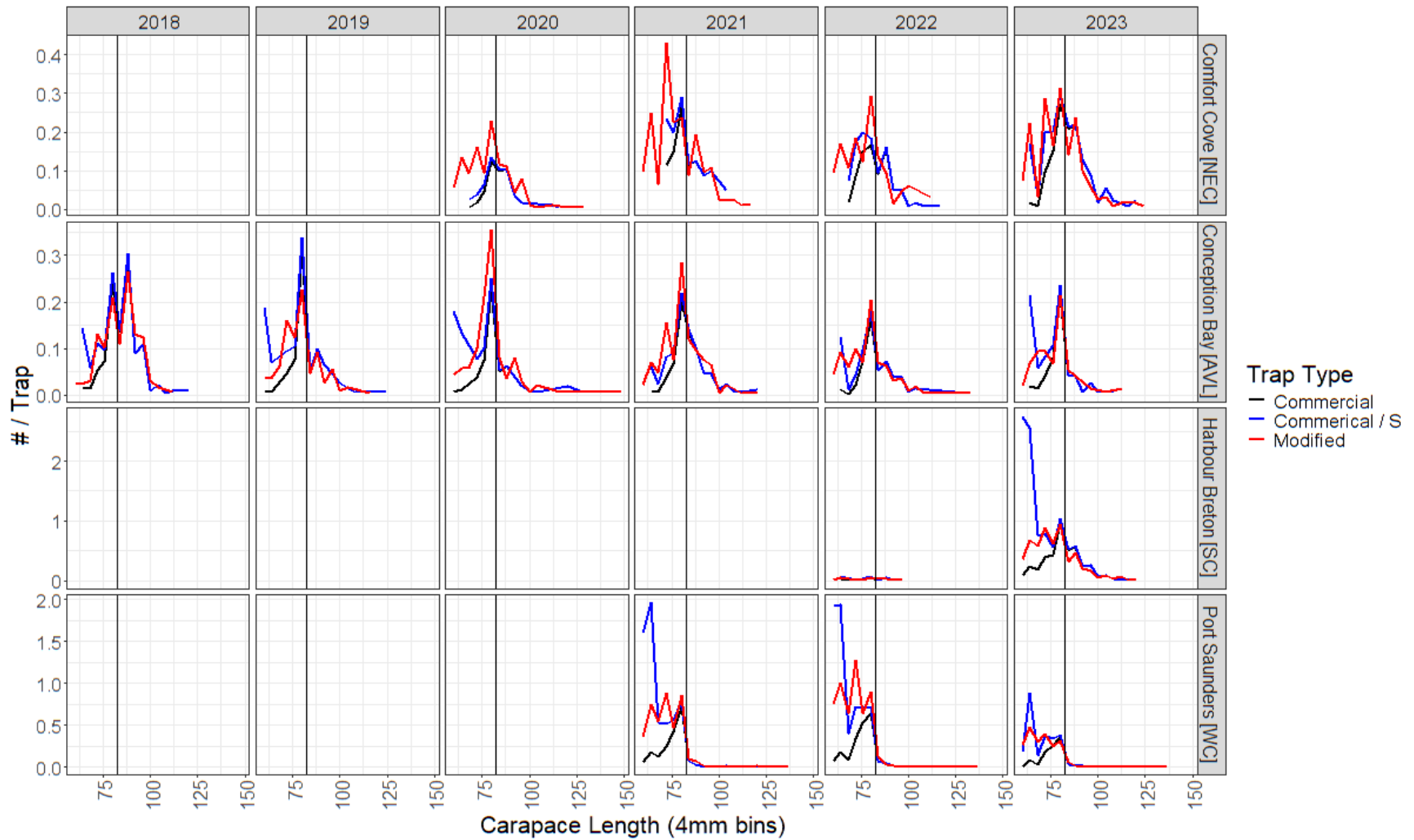


Figure 3. The trap selectivity transformed commercial catch rate data (commercial/S) from 2018 to 2023 compared to the commercial and modified (unvented) trap data over the size range (carapace length [CL]) for each of the lobster survey sites. The black vertical line represents minimal legal size (MLS, 82.5 mm CL).

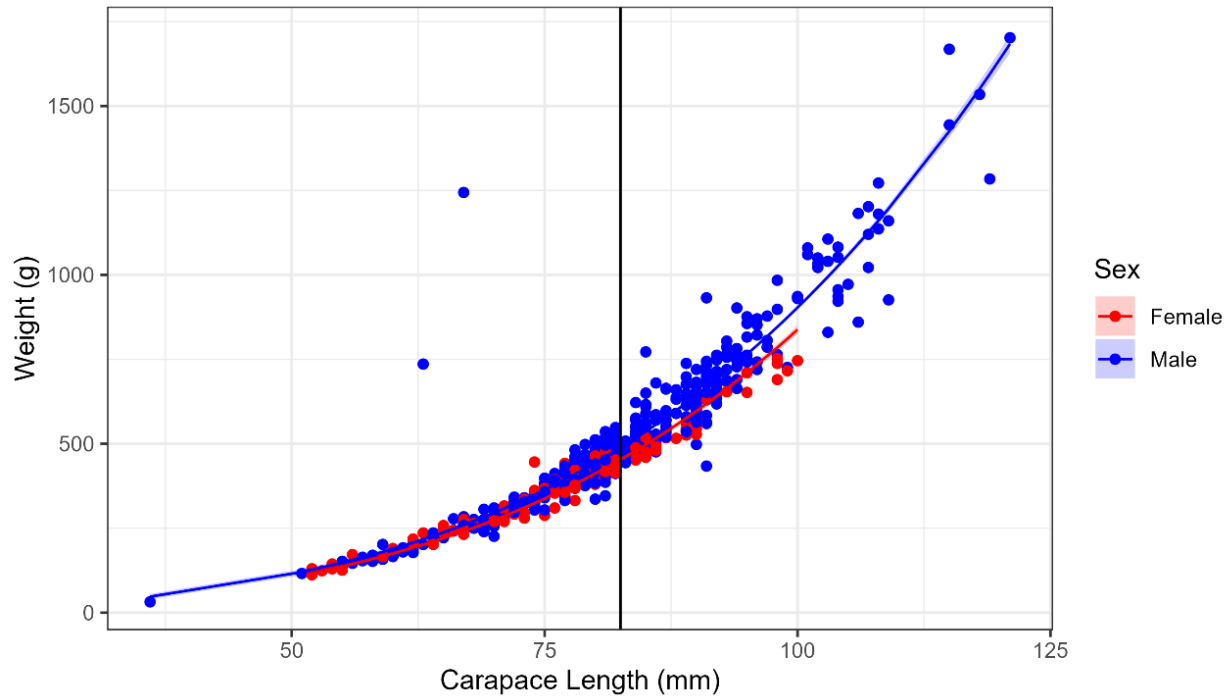


Figure 4. The length (CL, mm) to weight (grams) model based on the lobster trap survey data for both males and females. The black vertical line represents minimal landing size (MLS, 82.5 mm CL). Shading around models show 95% confidence intervals.

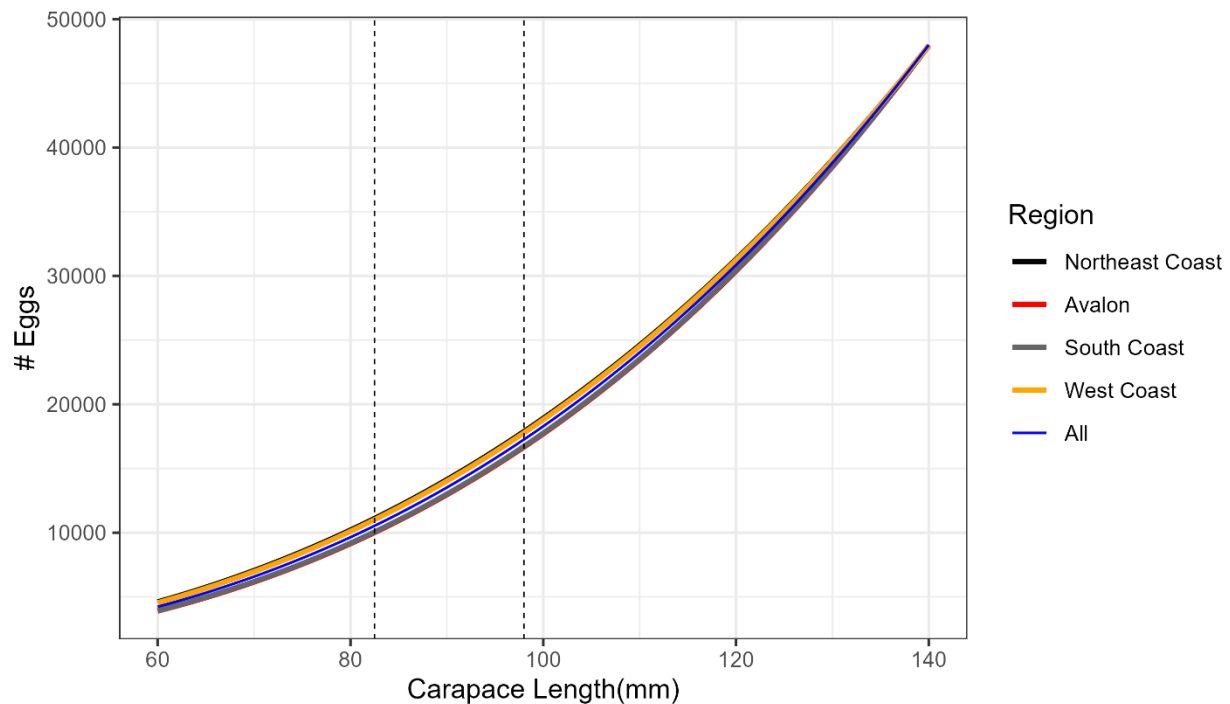


Figure 5. The power-law relationship of fecundity (number of eggs) at CL (mm) for each AR and all ARs combined (All). The black vertical dashed lines represent 83 mm and 98 mm CL.

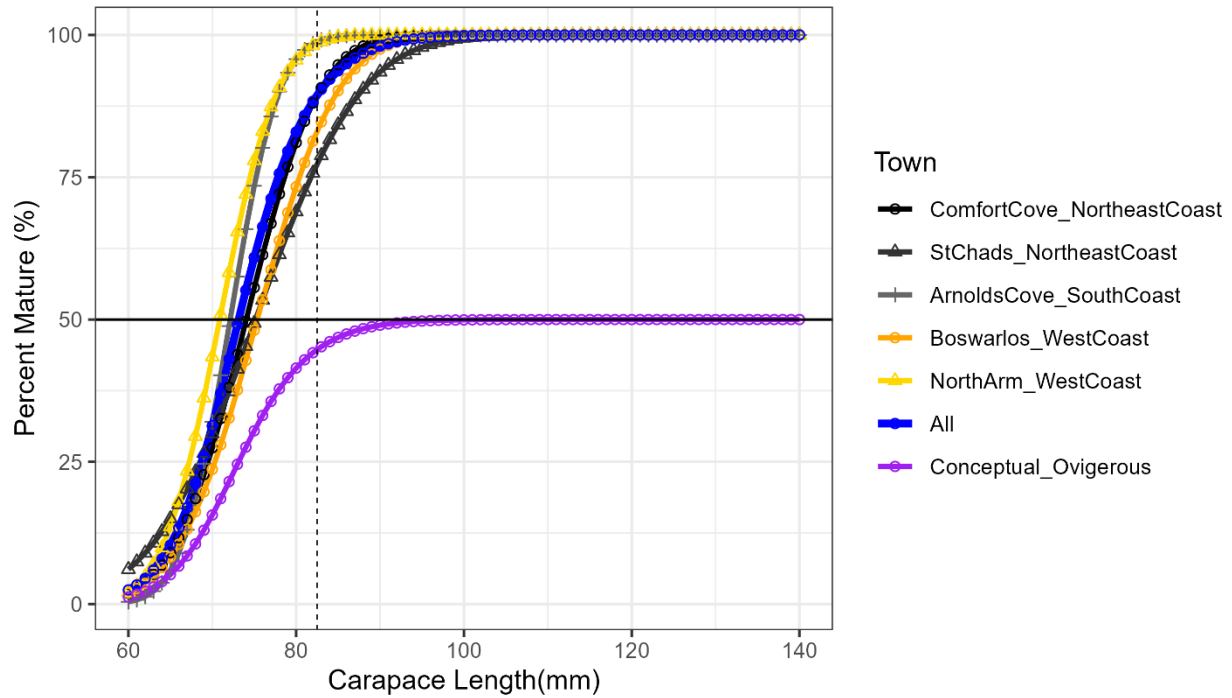


Figure 6. Size at maturity relationships for females from Ennis (1980) for five individual towns/sites (including Comfort Cove, St. Chad's, Arnold's Cove, Boswarlos, and North Arm) as well as pooled sties (All). Solid horizontal line corresponds to sizes at which 50% are mature at any given size. Vertical black dash line represents 82.5 mm CL. Conceptual percent ovigerous-at-size defined as the all sites ovige * 0.5 based on a two-year molt-reproductive cycle.

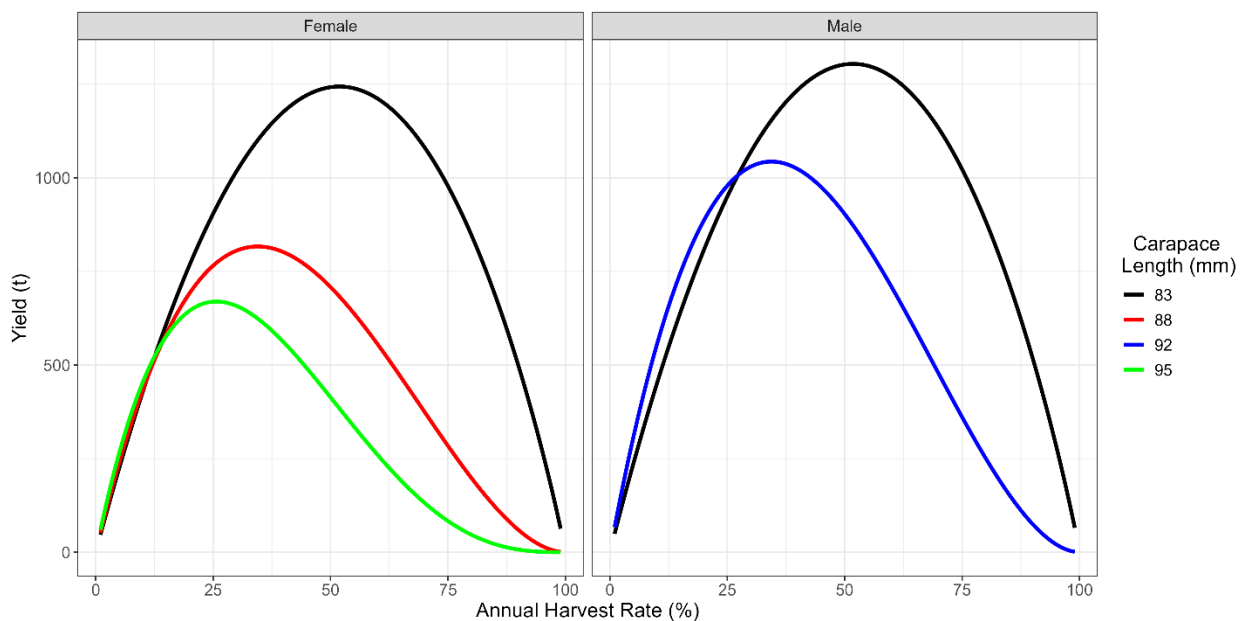


Figure 7. Yield Per Recruit (YPR) model for both sexes over the size range of immediate recruits (83–95 mm CL). Individual sizes represent age-proxies for each sex. Natural mortality set to $M = 0.05$ for males and $M = 0.10$ for females. Model conditioned on 10,000 animals starting at 83 mm CL for each sex.

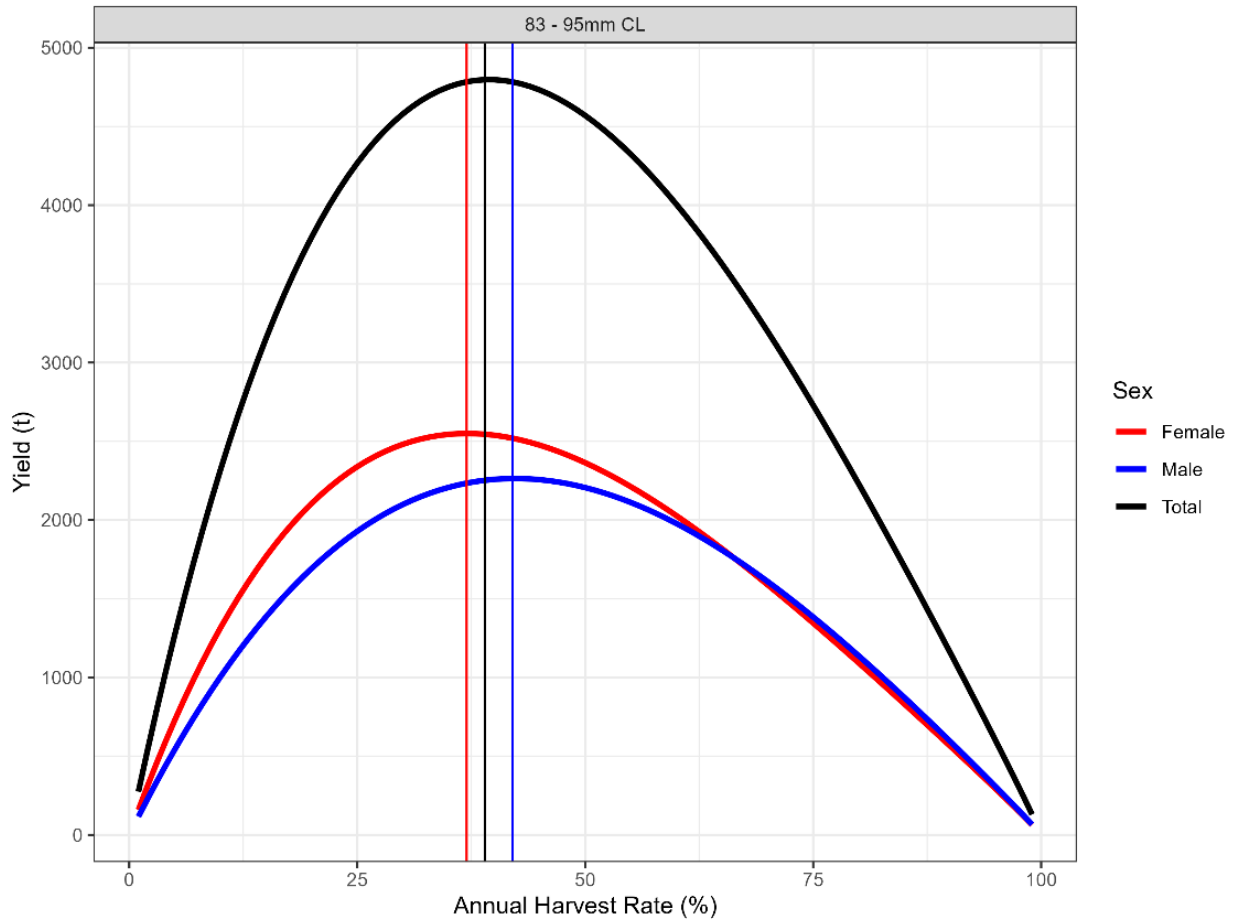


Figure 8. Yield Per Recruit model (Yield (t)) for each sex with age-proxy groups combined, and both sexes combined (total) over the 83–95 mm CL size range. The vertical lines represent peak values for each grouping and corresponds to F_{msy} (optimal fishing mortality rate in both sexes).

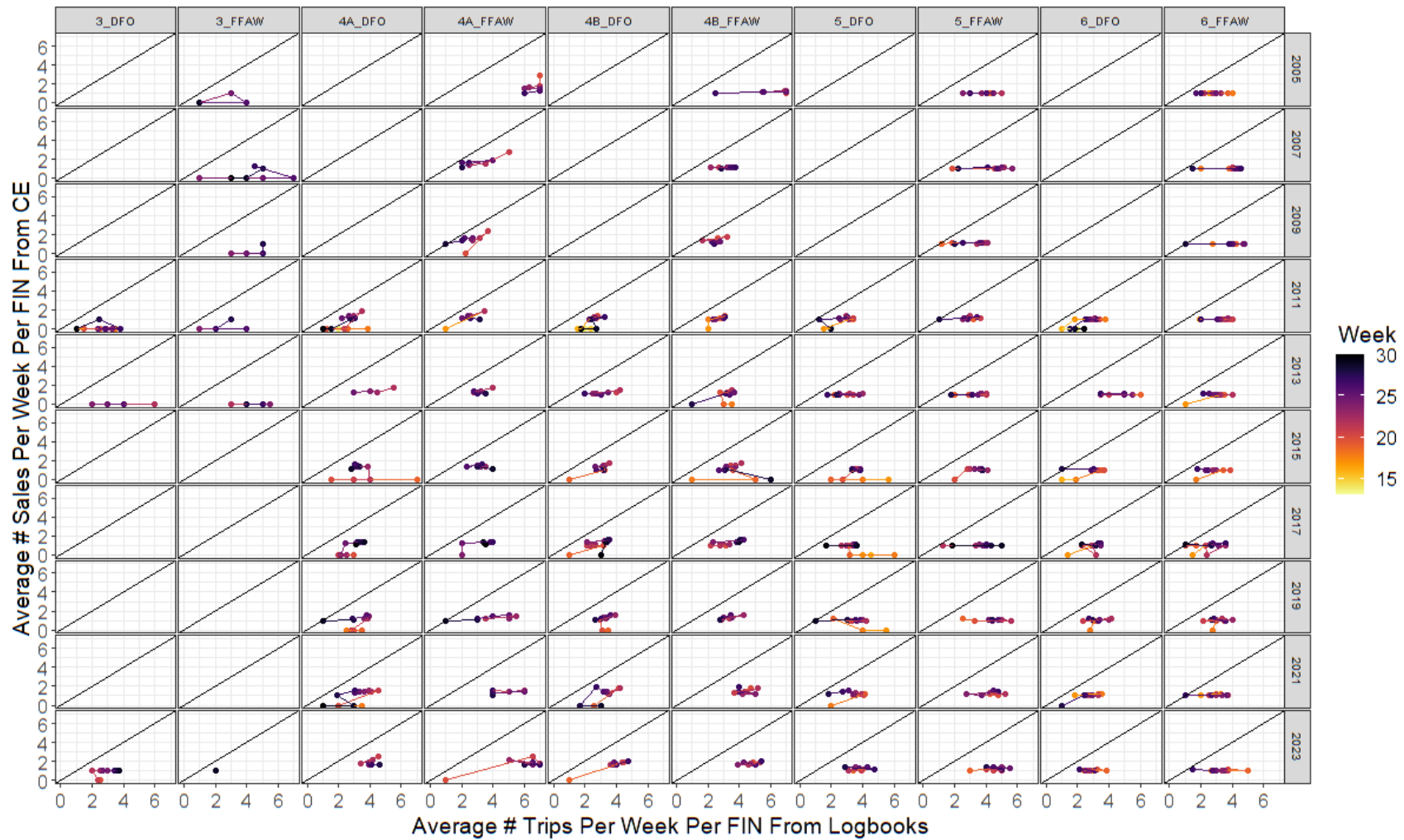


Figure 9a. Seasonal patterns in the relationships between average numbers of weekly trips per FIN in logbooks (x-axis) versus average number of weekly sales per FIN in CE (y-axis) for both logbook data sources within each respective LFA for the Northeast Coast Assessment Region from 2005 to 2023. Panels affected by the Rule of 5 not shown. Only odd years in 2005–23 time series shown.

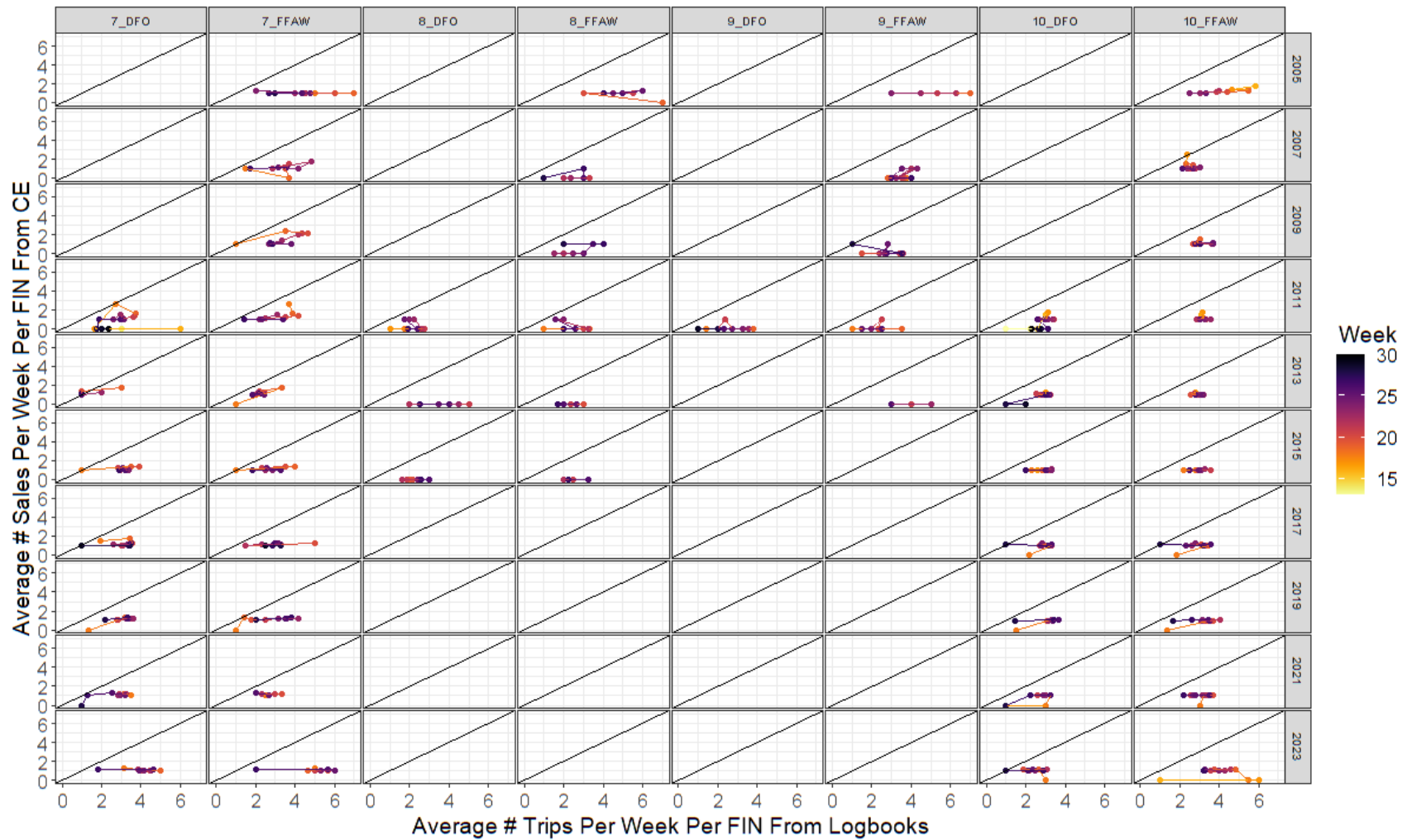


Figure 9b. Seasonal patterns in the relationships between average numbers of weekly trips per FIN in logbooks (x-axis) versus average number of weekly sales per FIN in CE (y-axis) for both logbook data sources within each respective LFA for the Avalon Assessment Region from 2005 to 2023. Panels affected by the Rule of 5 not shown. Only odd years in 2005–23 time series shown.

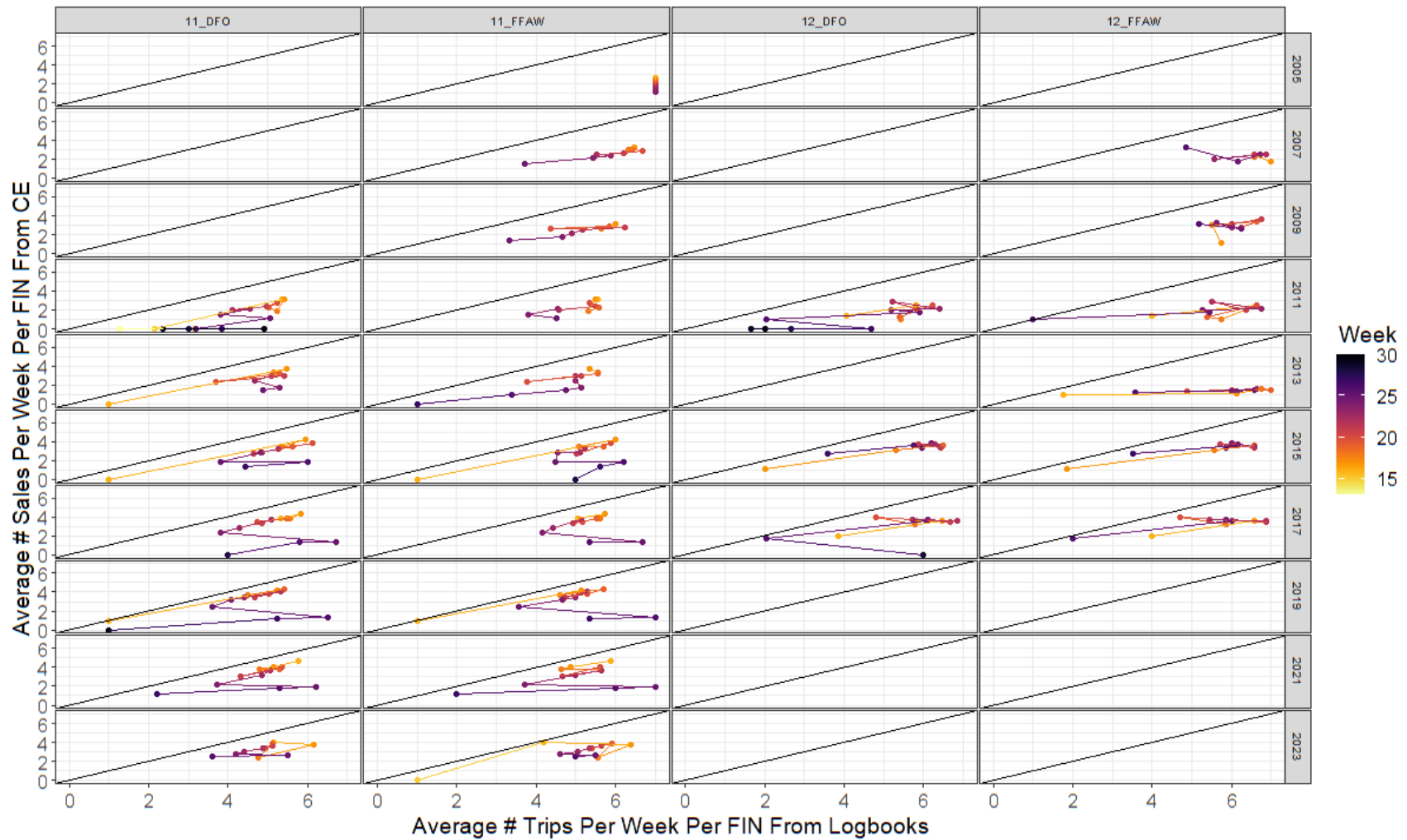


Figure 9c. Seasonal patterns in the relationships between average numbers of weekly trips per FIN in logbooks (x-axis) versus average number of weekly sales per FIN in CE (y-axis) for both logbook data sources within each respective LFA for the South Coast Assessment Region from 2005 to 2023. Panels affected by the Rule of 5 not shown. Only odd years in 2005–23 time series shown.

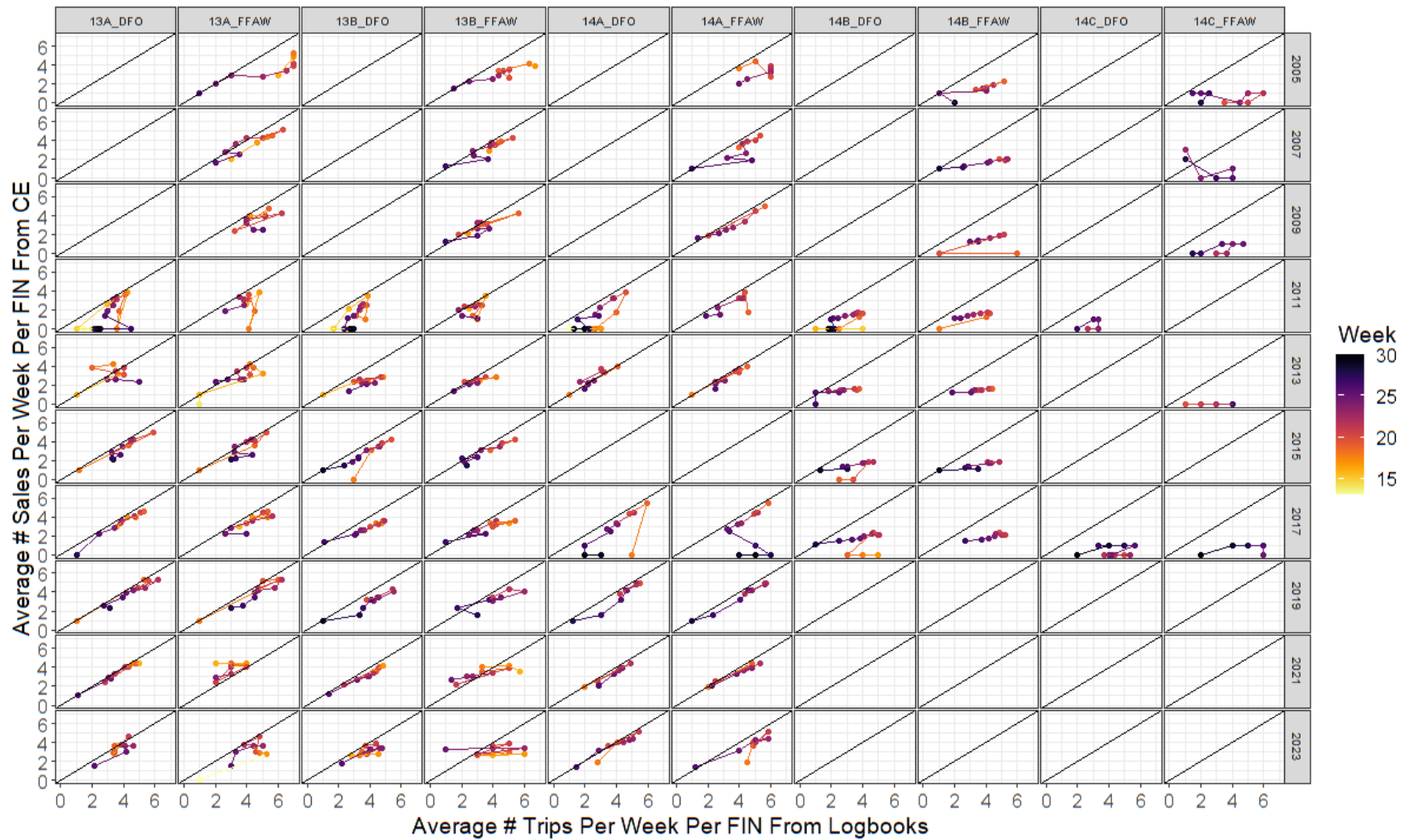


Figure 9d. Seasonal patterns in the relationships between average numbers of weekly trips per FIN in logbooks (x-axis) versus average number of weekly sales per FIN in CE (y-axis) for both logbook data sources within each respective LFA for the West Coast Assessment Region from 2005 to 2023. Panels affected by the Rule of 5 not shown. Only odd years in 2005–23 time series shown.

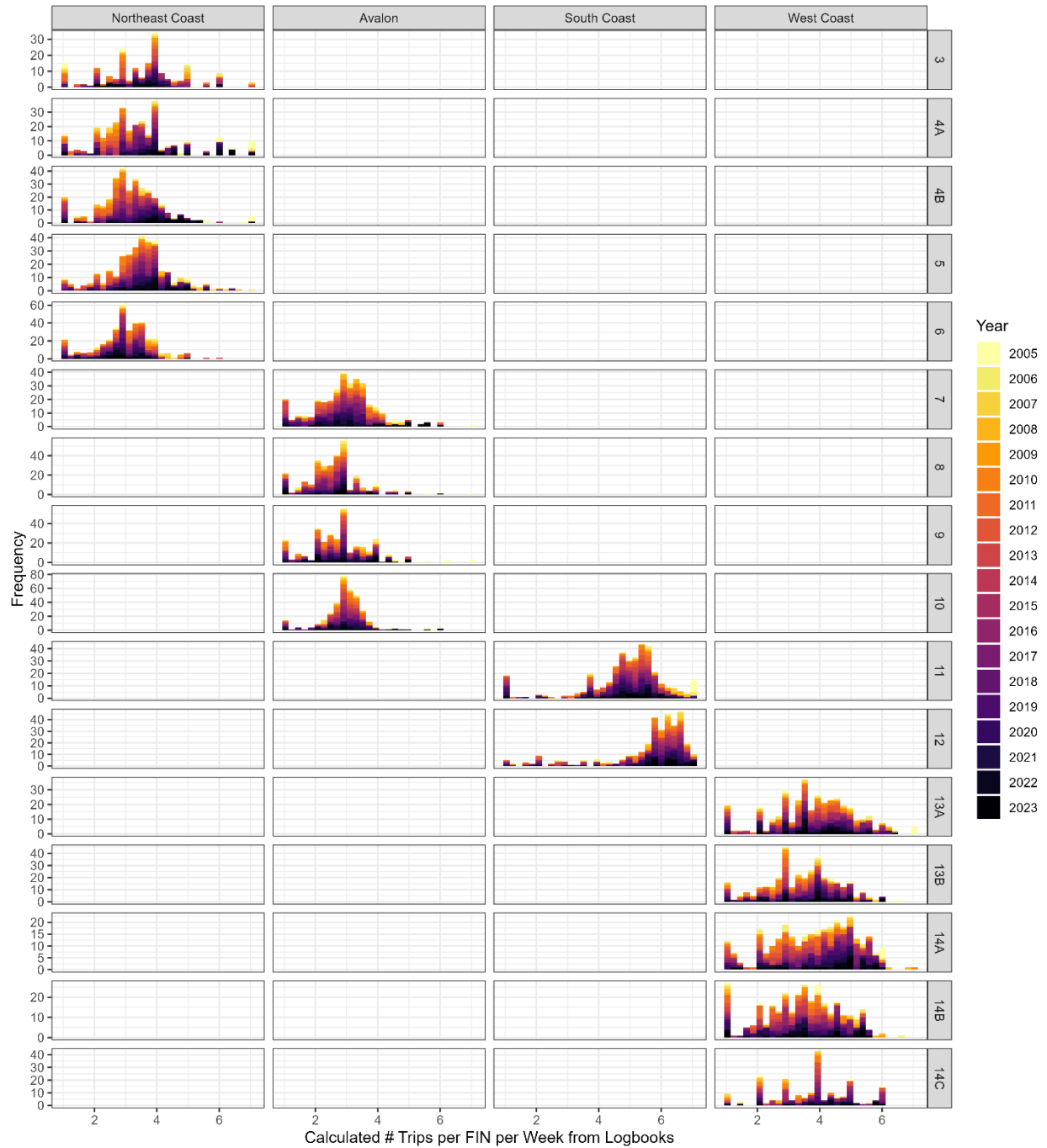


Figure 10. Frequency distributions of weekly number of trips per FIN from logbooks within LFAs 3–14C in each respective AR from 2005 to 2023.

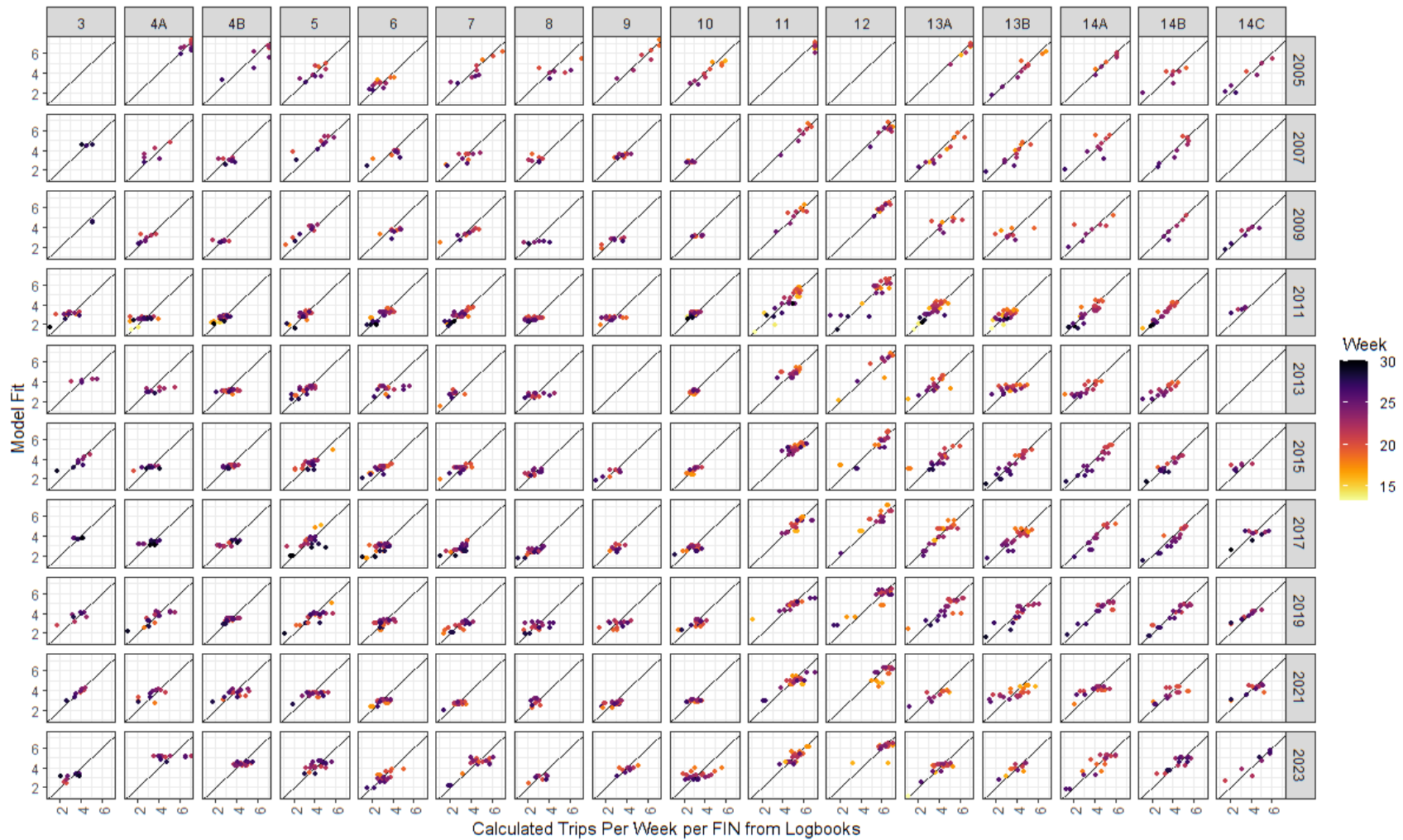


Figure 11. Predicted (Model Fit) versus observed (Calculated Trips Per Week per FIN from Logbooks) values from model estimating total weekly trips per FIN for LFAs 3 to 14C, from 2005 to 2023. Only odd years in 2005–23 time series shown.

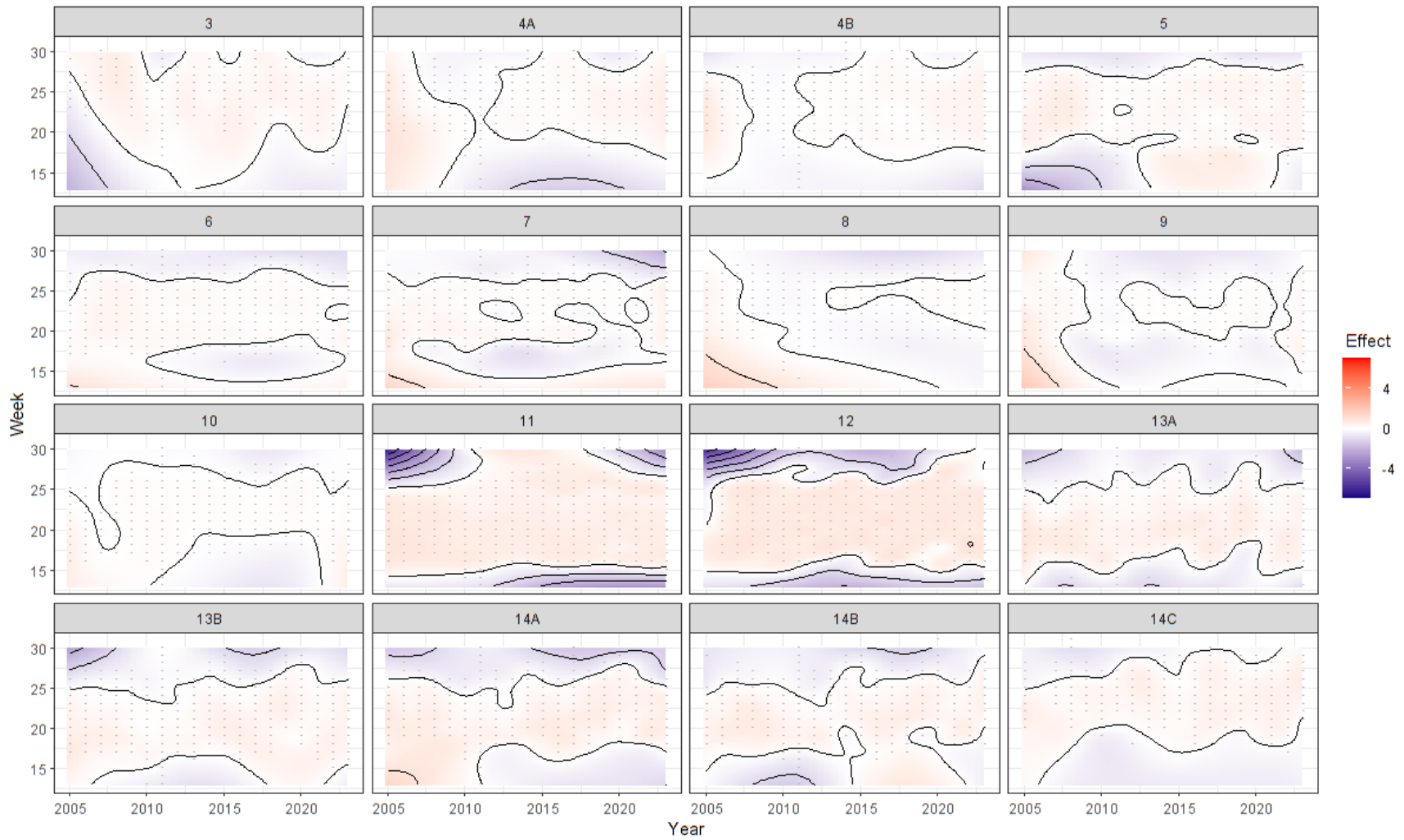


Figure 12. Marginal effect interaction plots between year and week for model estimating number of trips per week per FIN for LFAs 3–14C from 2005 to 2023.

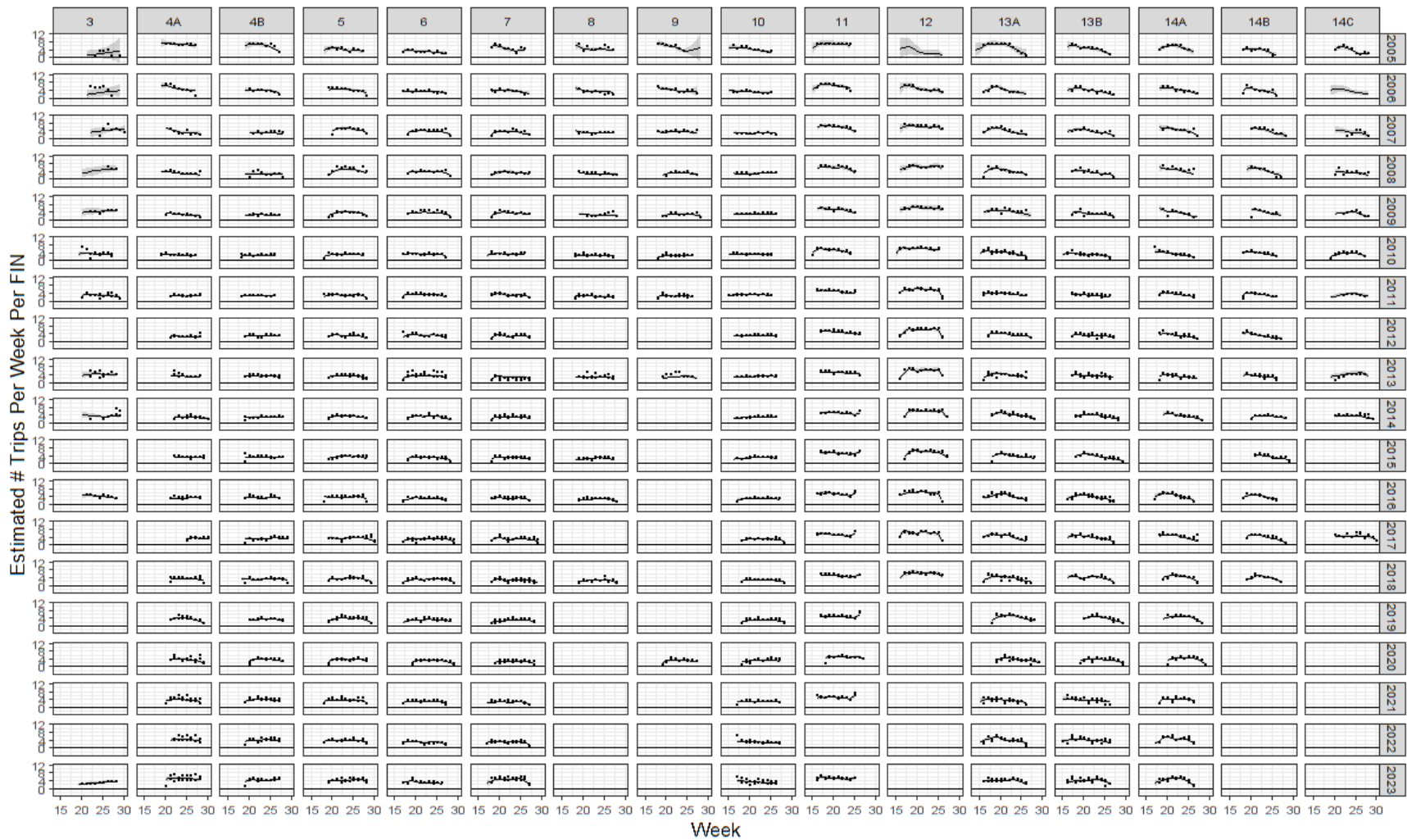


Figure 13. Season-filled model estimated number of trips per week per FIN over the weeks of the fishery fit to logbook-estimated data in LFAs 3–14C from 2005 to 2023. Panels affected by the Rule of 5 not shown. Shading around points shows 95% confidence intervals.

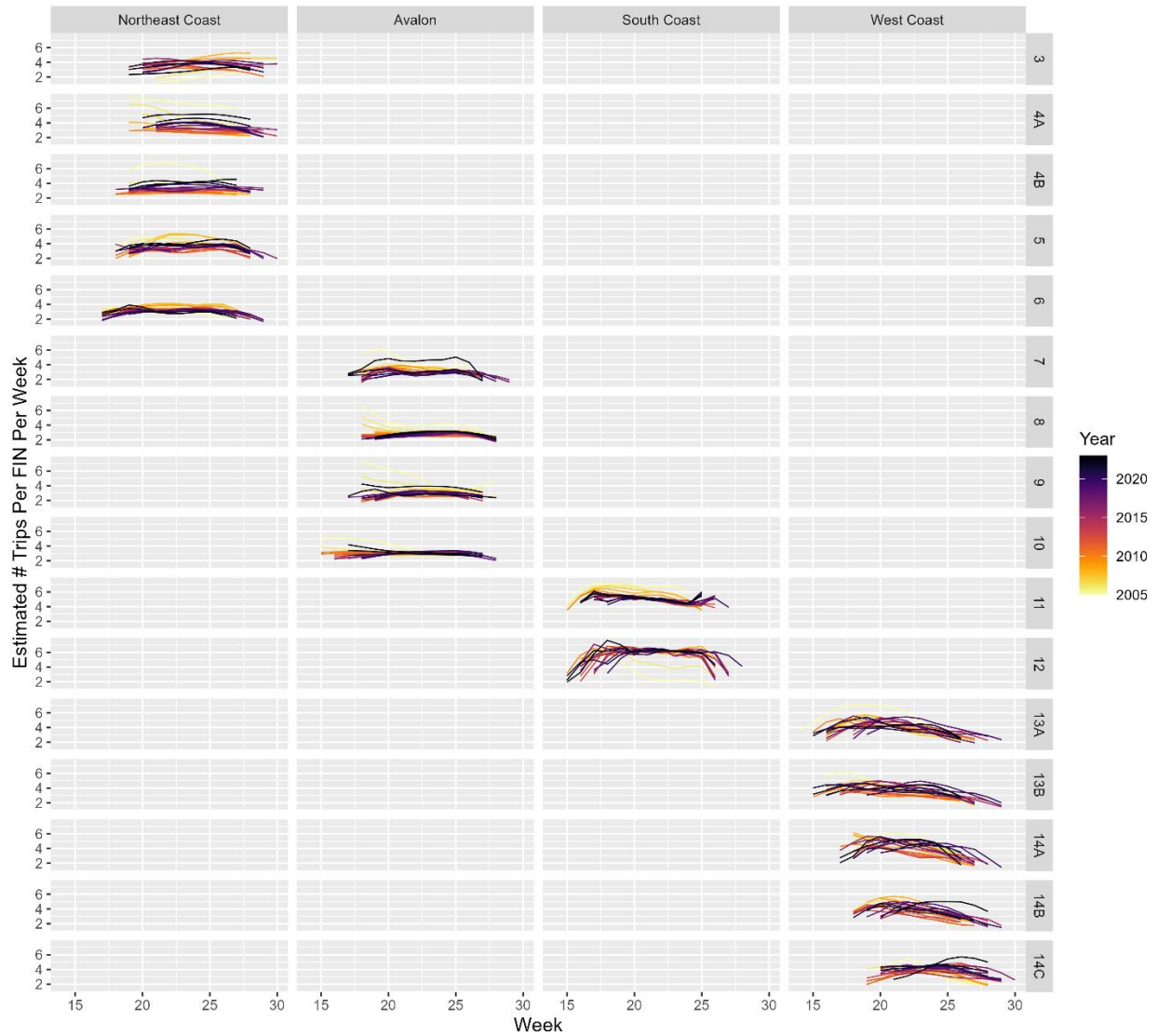


Figure 14. Season-filled model-estimated number of trips per week per FIN over the weeks of the fishery in LFAs 3–14C from 2005 to 2023.

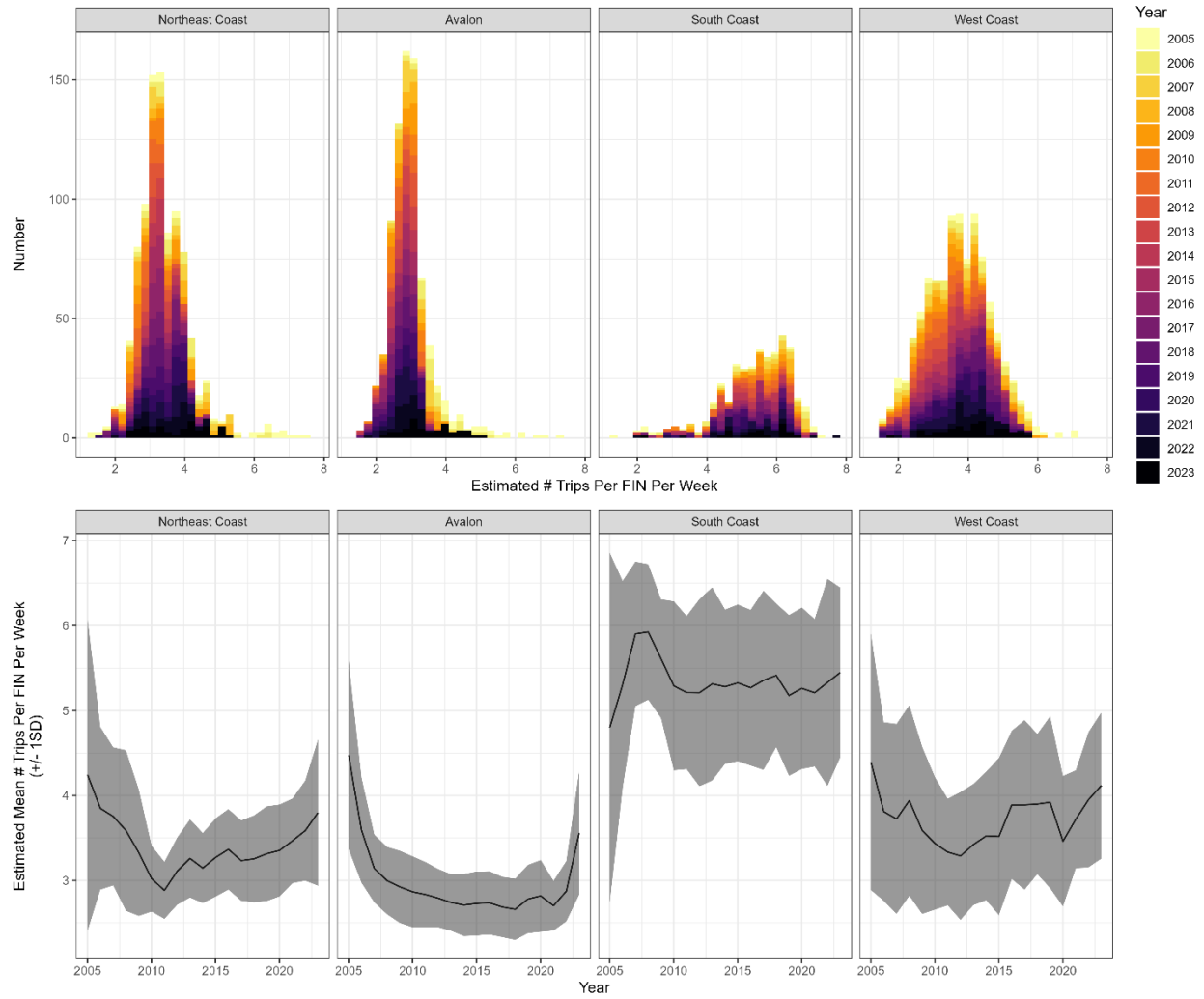


Figure 15. Top panels: Frequency distributions of model-estimated weekly number of trips per FIN from logbooks within LFAs 3–14C in each respective AR from 2005 to 2023. Bottom panels: Model-estimated mean number of trips per FIN per week from 2005 to 2023 for each AR.

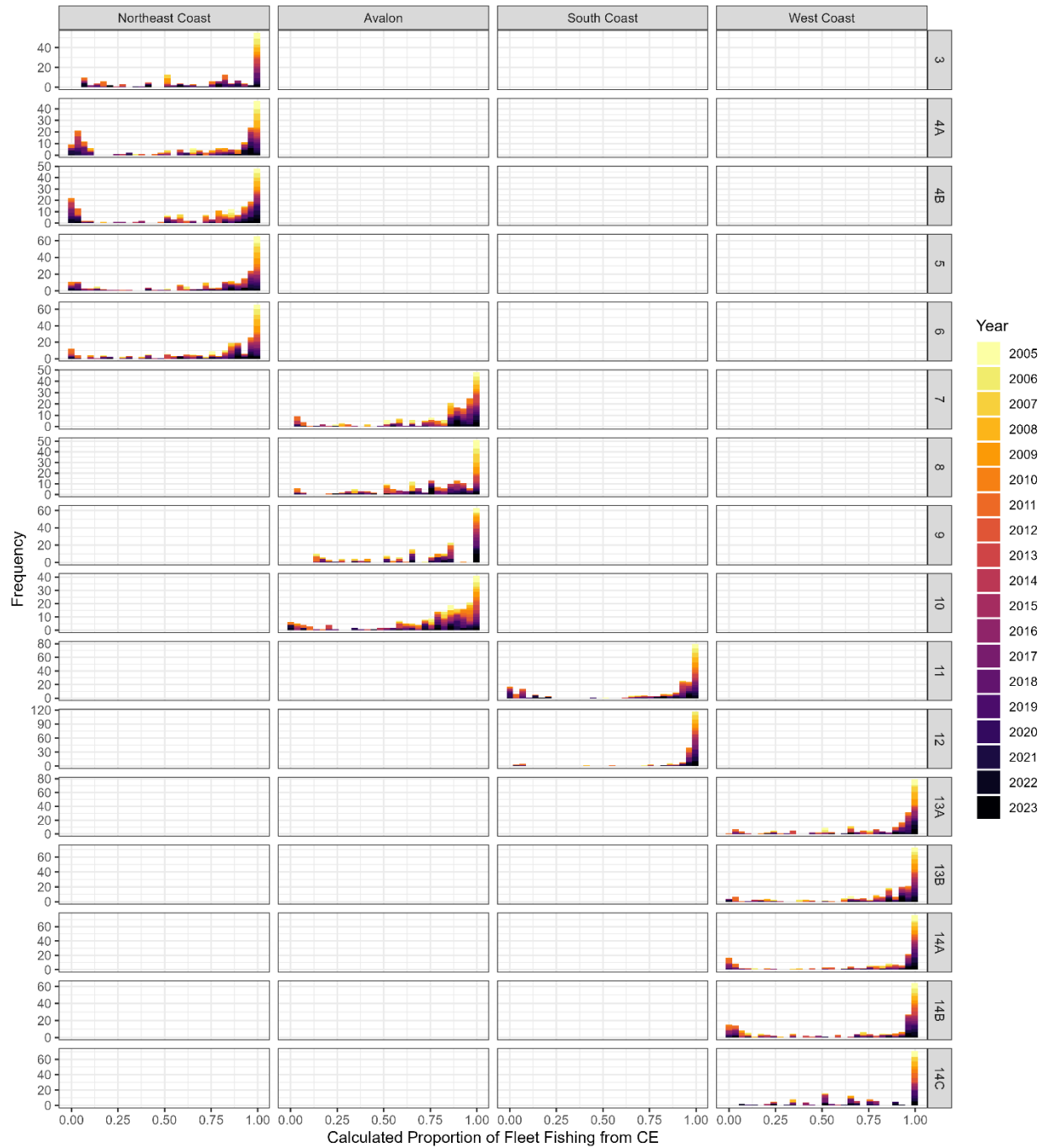


Figure 16. Frequency distributions of weekly proportion of the fleet fishing from logbook data within LFAs 3–14C in each respective AR from 2005 to 2023.

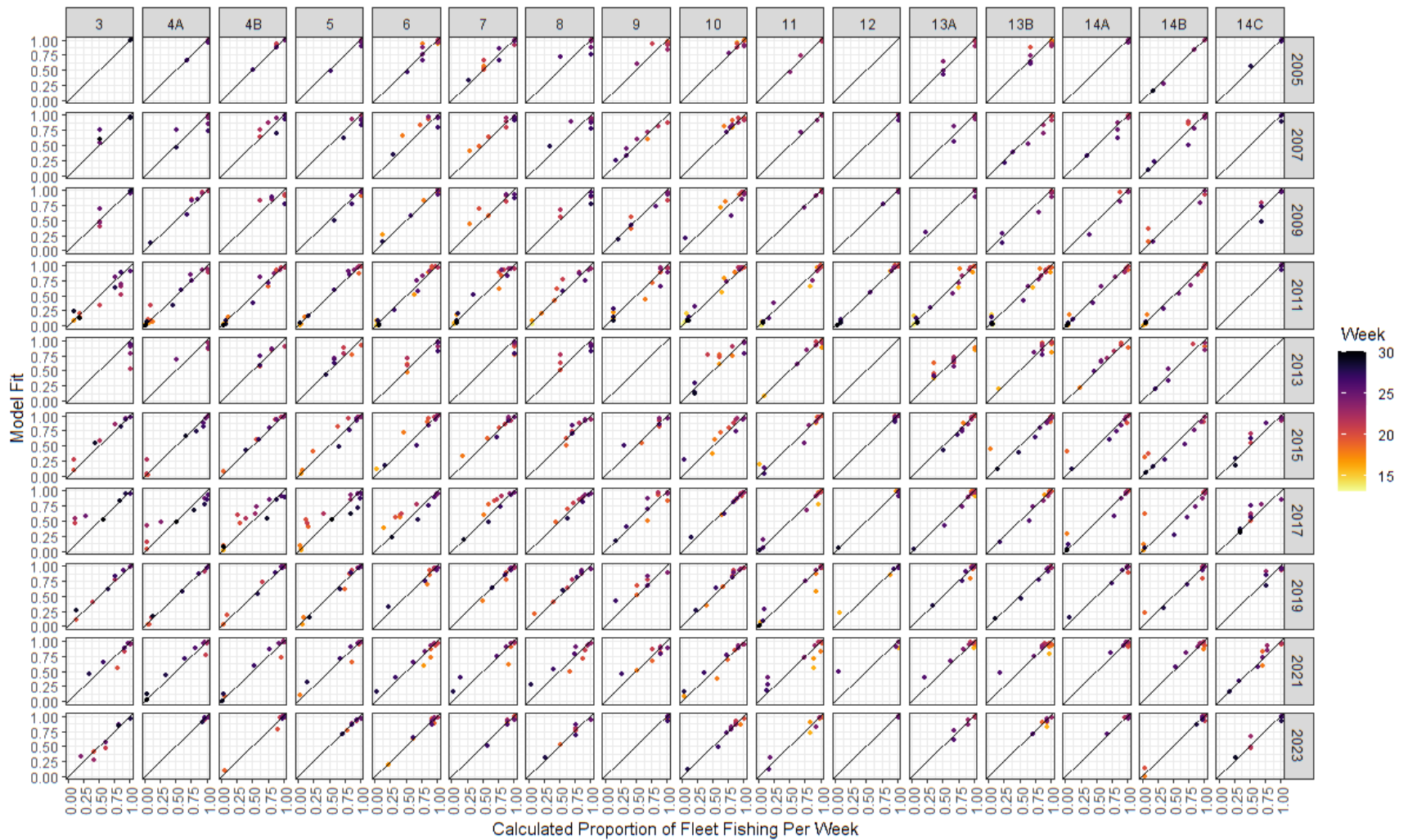


Figure 17. Predicted (Model Fit) versus observed (Calculated Proportion of Fleet Fishing Per Week) values from model estimating weekly fleet activity levels for LFAs 3 to 14C from 2005 to 2023. Only odd years in 2005–23 time series shown.

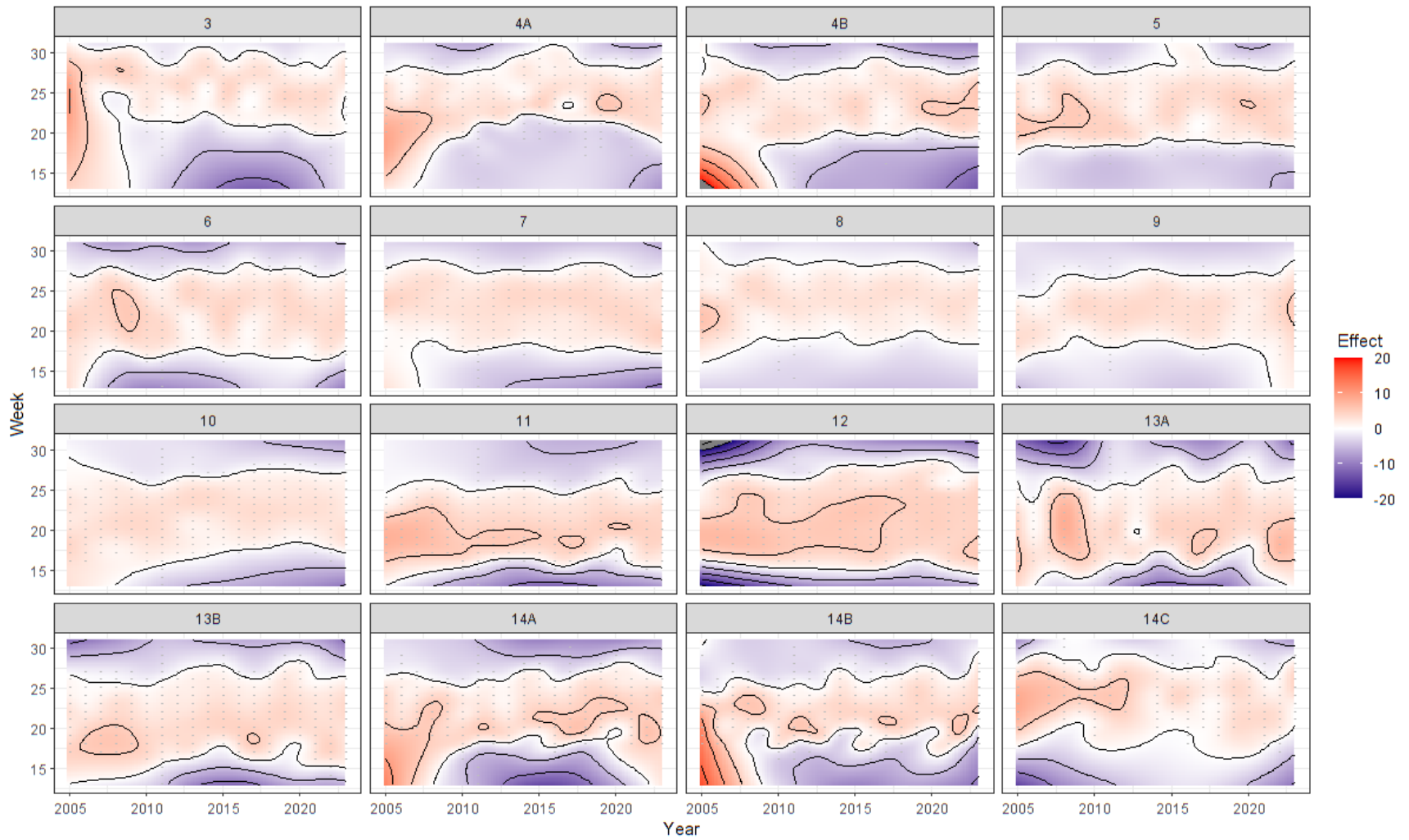


Figure 18. Marginal effect interaction plots between year and week for model estimating proportion of fleet fishing for LFAs 3–14C from 2005 to 2023.

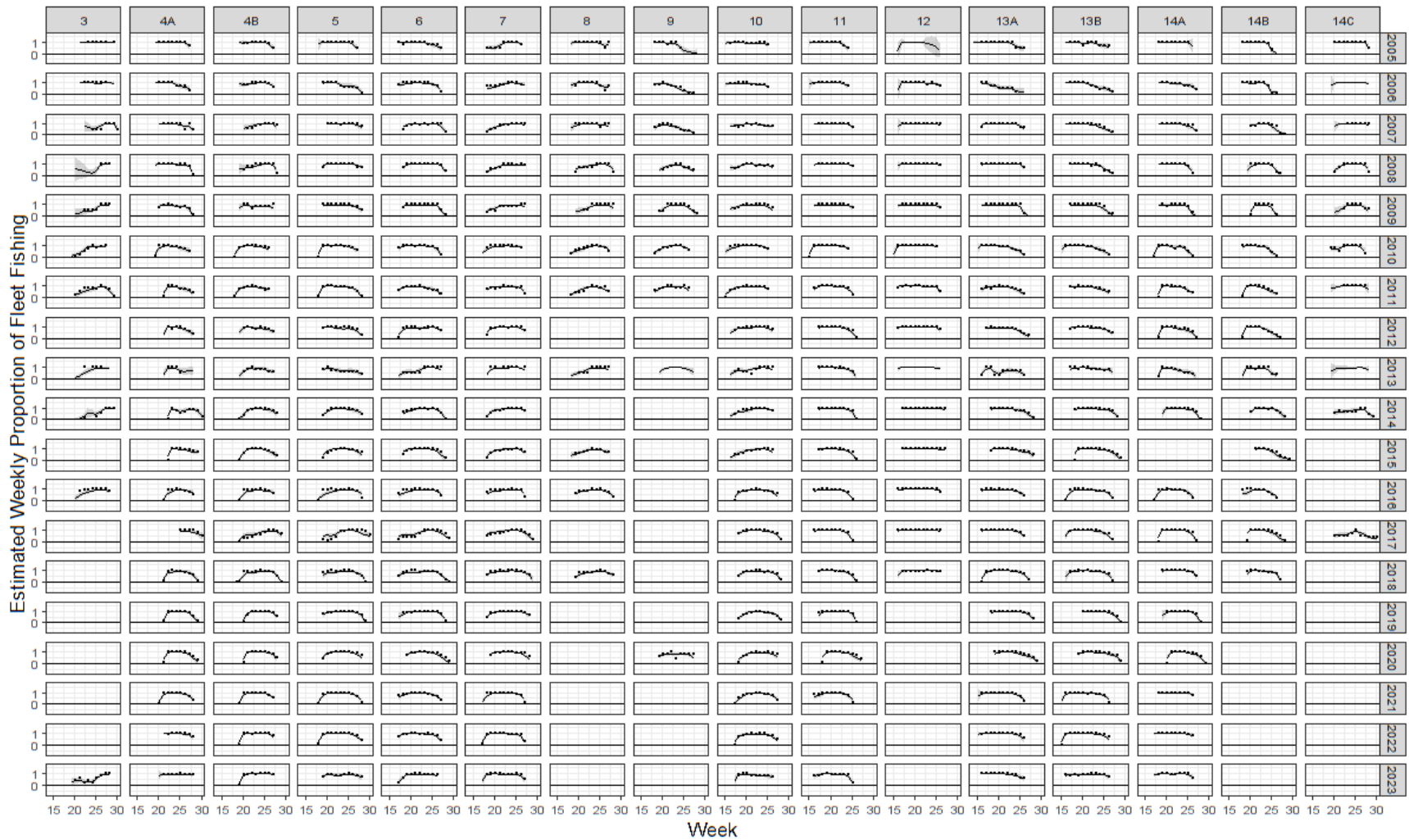


Figure 19. Season-filled model estimated proportion of the fleet fishing over the weeks of the fishery fit to logbook-estimated data in LFAs 3–14C from 2005 to 2023. Panels affected by the Rule of 5 not shown. Shading around points shows 95% confidence intervals.

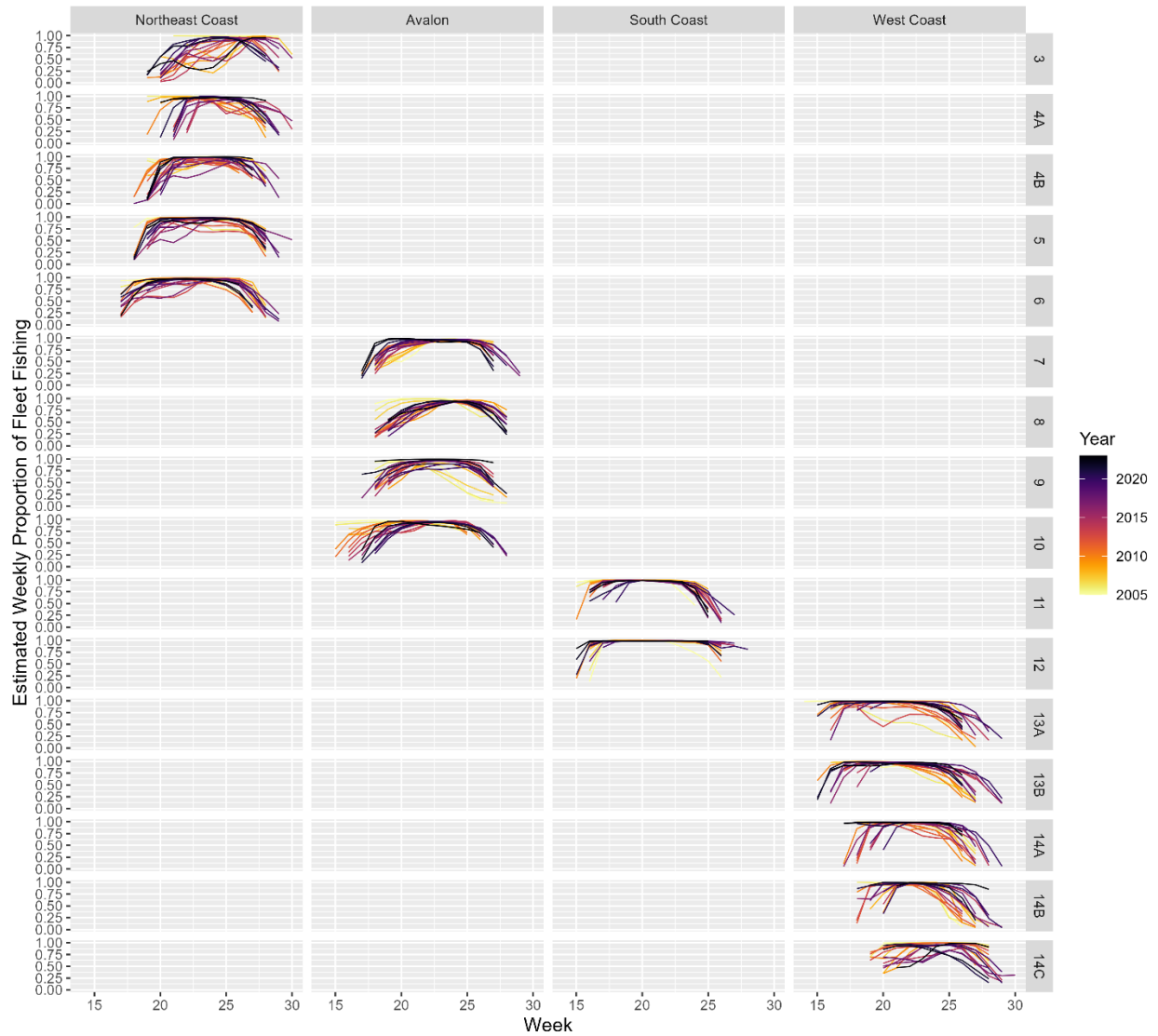


Figure 20. Season-filled model-estimated proportion of the fleet fishing over the weeks of the fishery within LFAs 3–14C in each respective AR from 2005 to 2023.

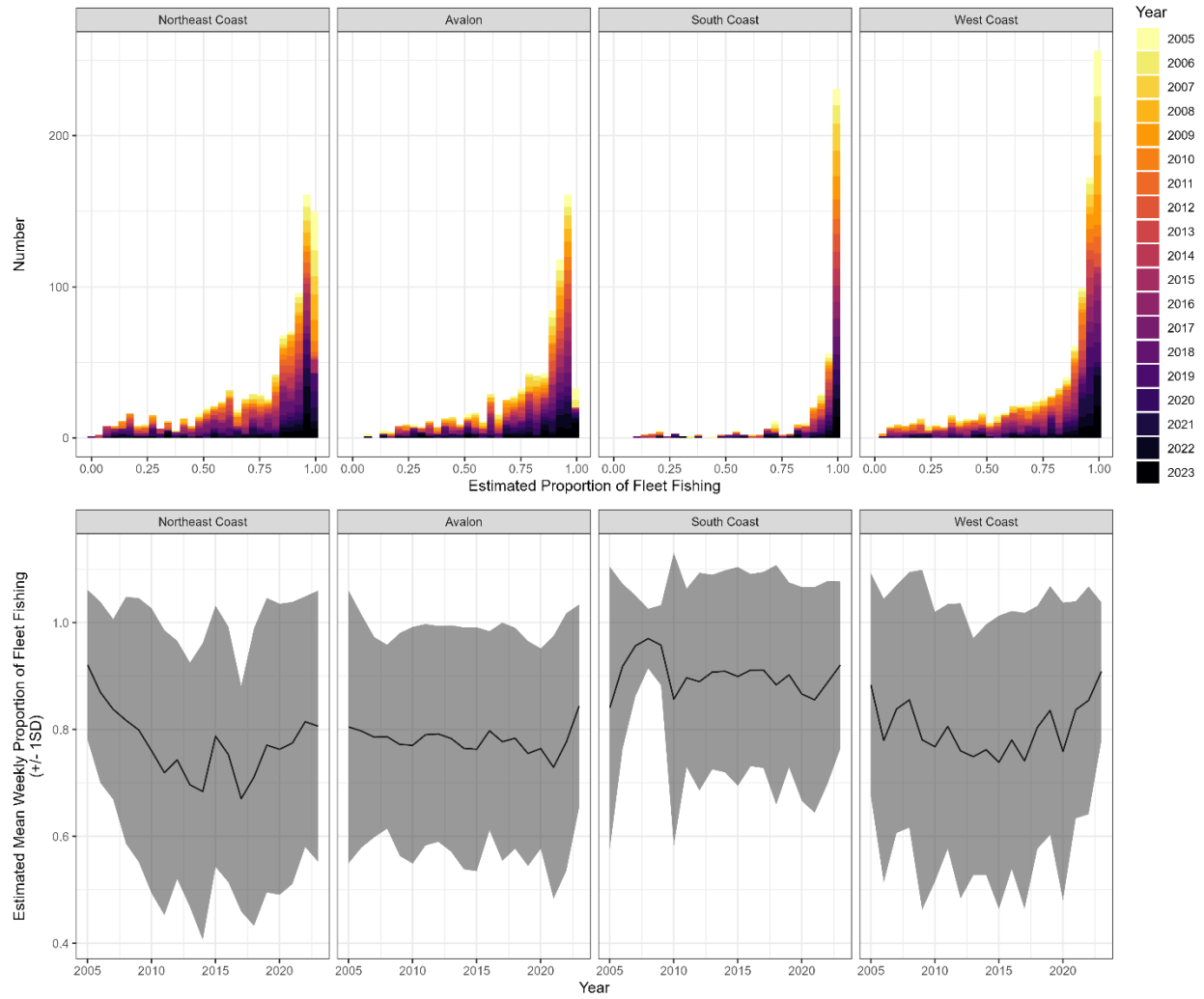


Figure 21. Frequency distributions of model-estimated weekly proportions of the fleet fishing within LFAs 3–14C in each respective AR from 2005 to 2023. Bottom panels: Model-estimated mean proportions of the fleet fishing per week from 2005 to 2023 for each AR.

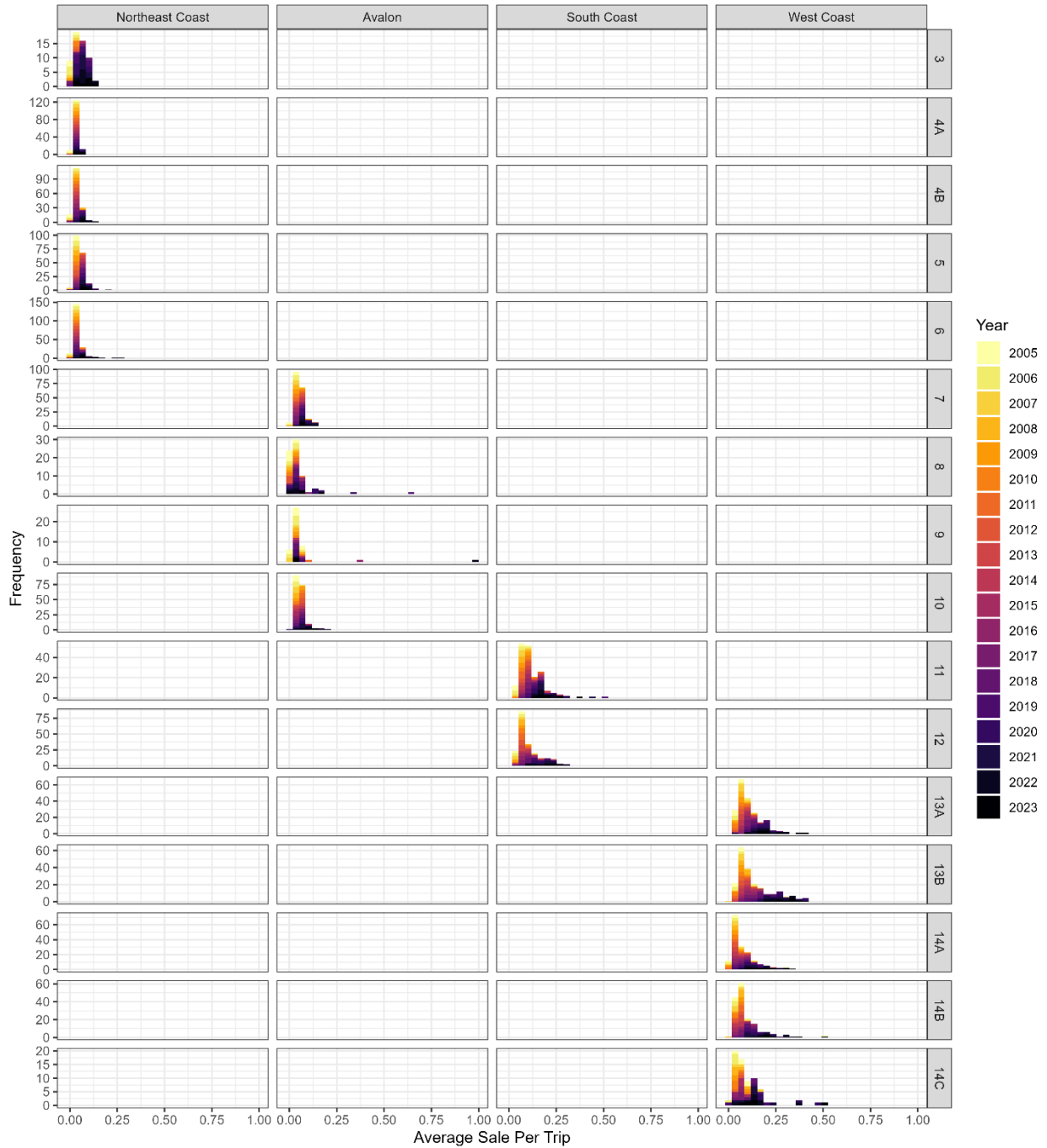


Figure 22. Frequency distributions of weekly average sales per trip from Catch and Effort data within LFAs 3–14C in each respective AR from 2005 to 2023.

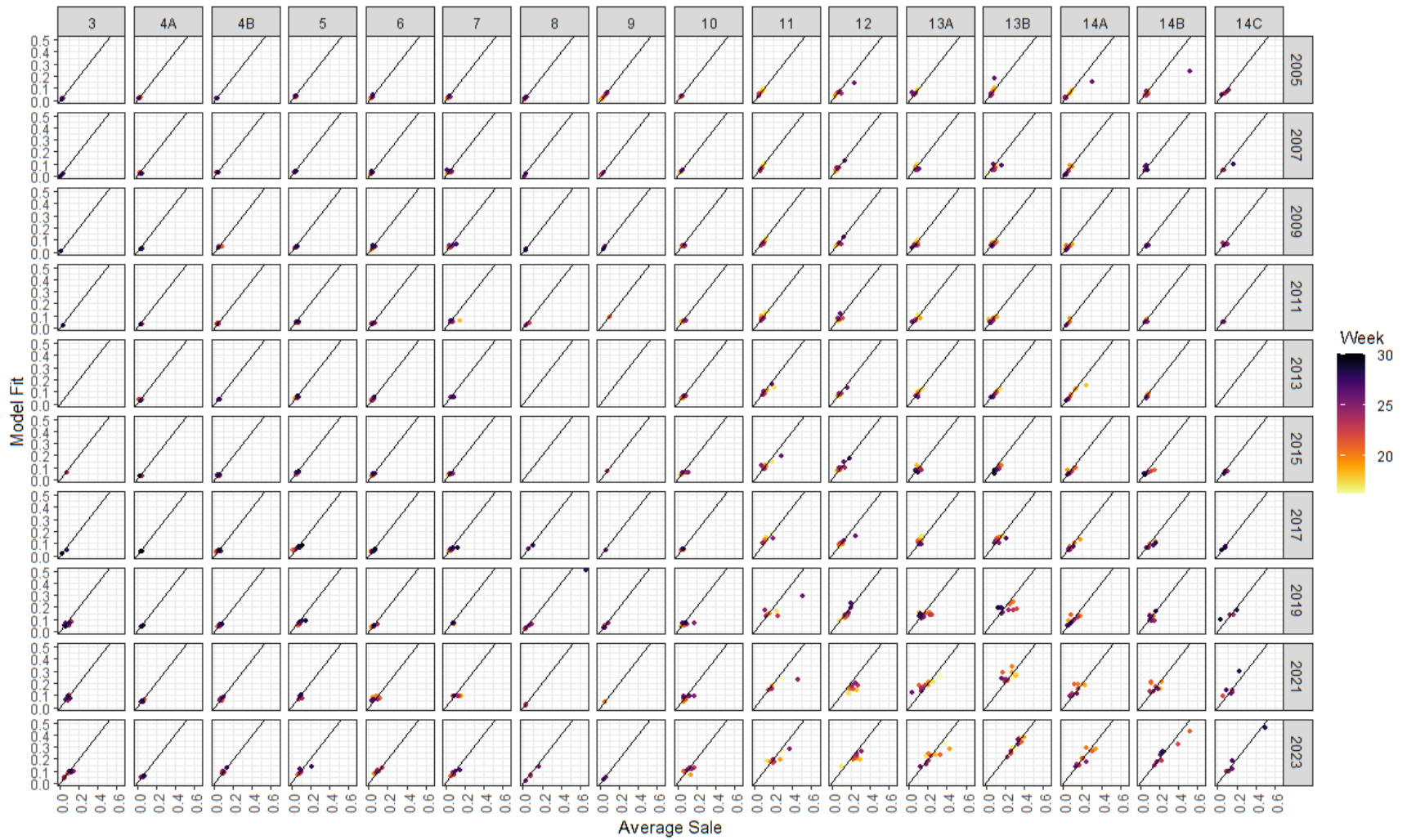


Figure 23. Predicted (Model Fit) versus observed (Average Sale) values from model estimating average weekly sales amounts for LFAs 3 to 14C, from 2005 to 2023. Only odd years in 2005–23 time series shown.

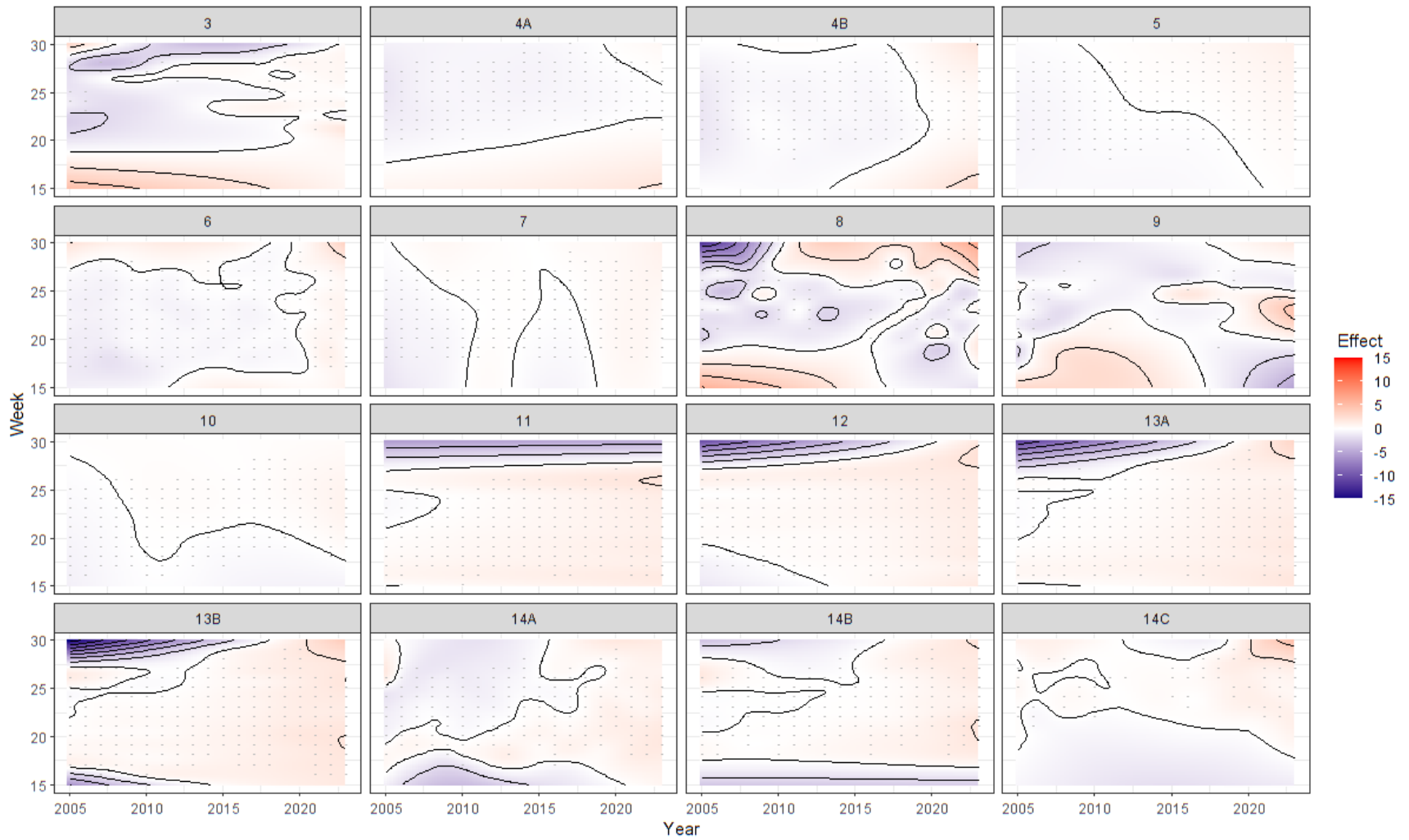


Figure 24. Marginal effect interaction plots between year and week for model estimating average weekly sales for LFAs 3–14C from 2005 to 2023.

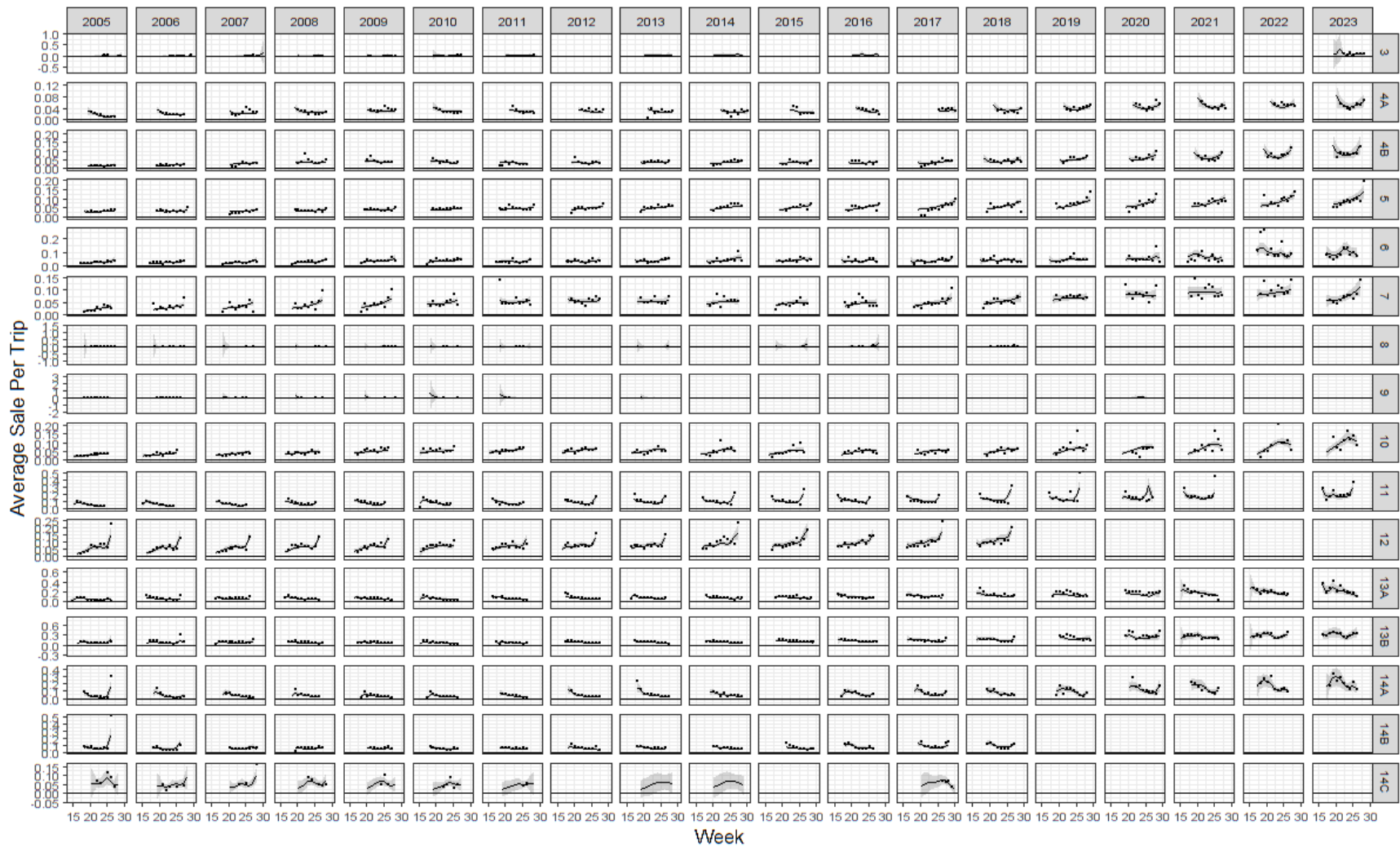


Figure 25. Season-filled model estimated average sales amount over the weeks of the fishery fit to Catch and Effort-estimated data in LFAs 3–14C from 2005 to 2023. Panels affected by the Rule of 5 not shown. Shading around points shows 95% confidence intervals.

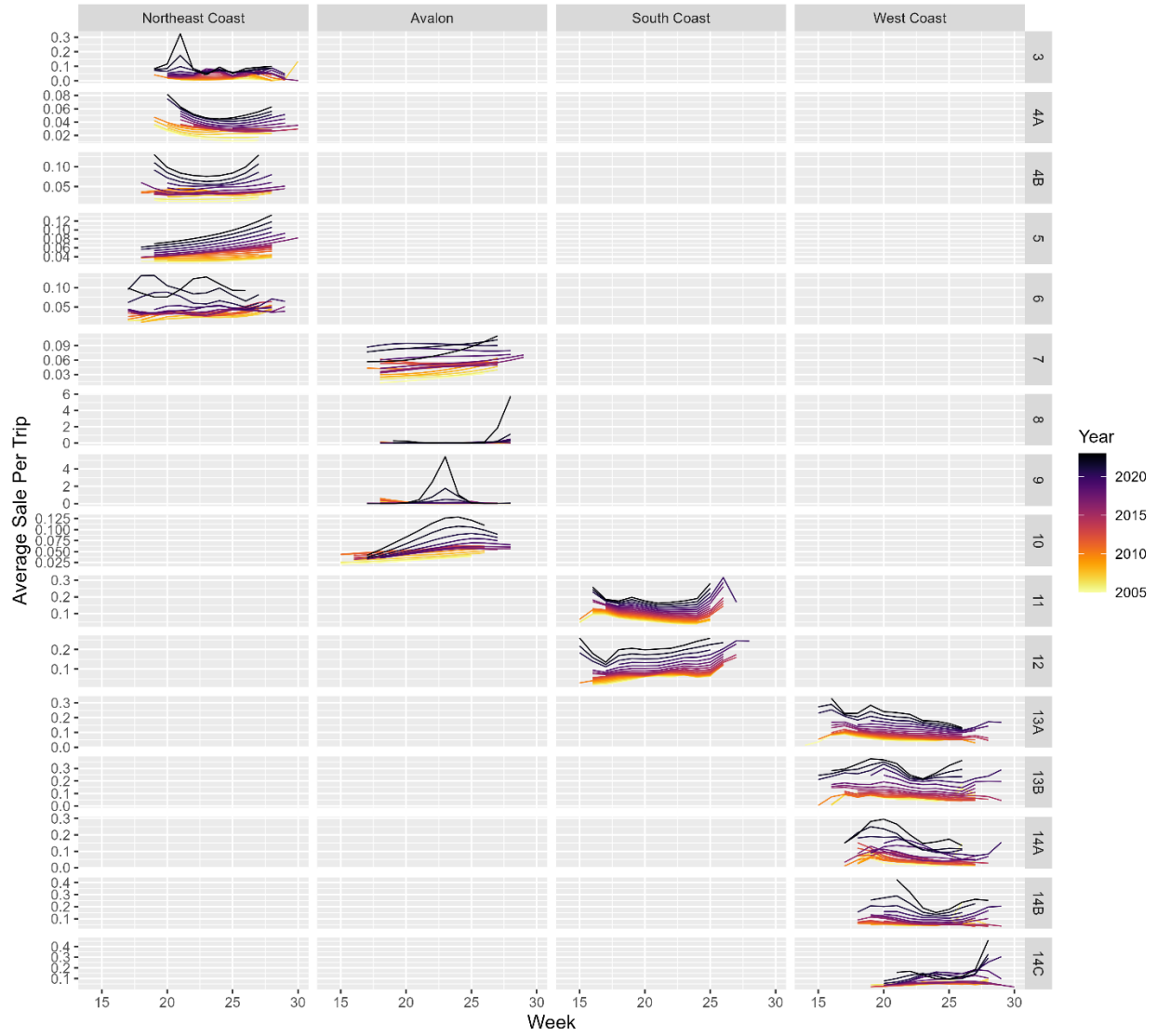


Figure 26. Season-filled model-estimated average sales amounts over the weeks of the fishery within LFAs 3–14C in each respective AR from 2005 to 2023.

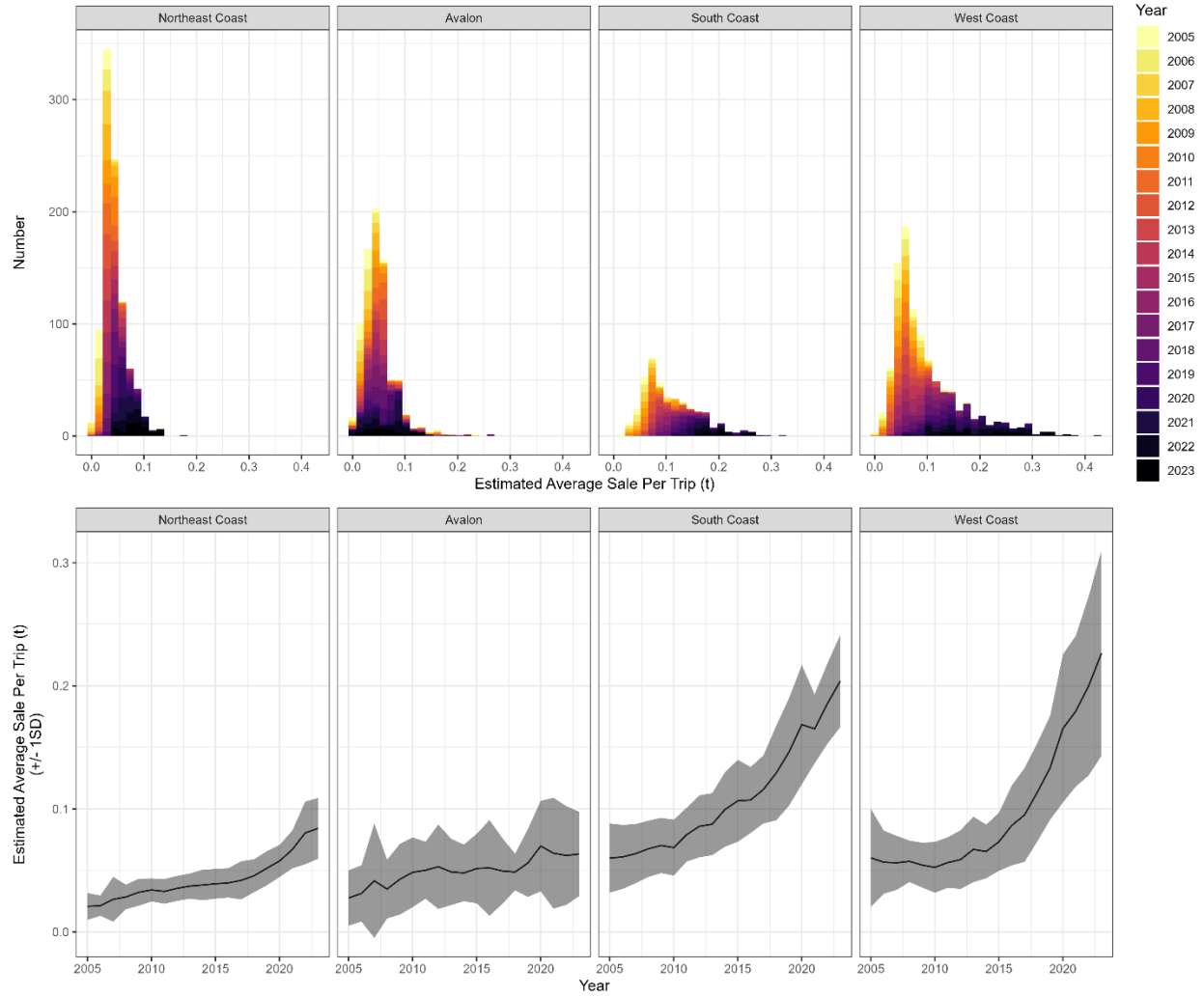


Figure 28. Top panels: Frequency distributions of model-estimated average weekly sales amounts within LFAs 3–14C in each respective AR from 2005 to 2023. Bottom panels: Model-estimated average weekly sales amounts from 2005 to 2023 for each AR.

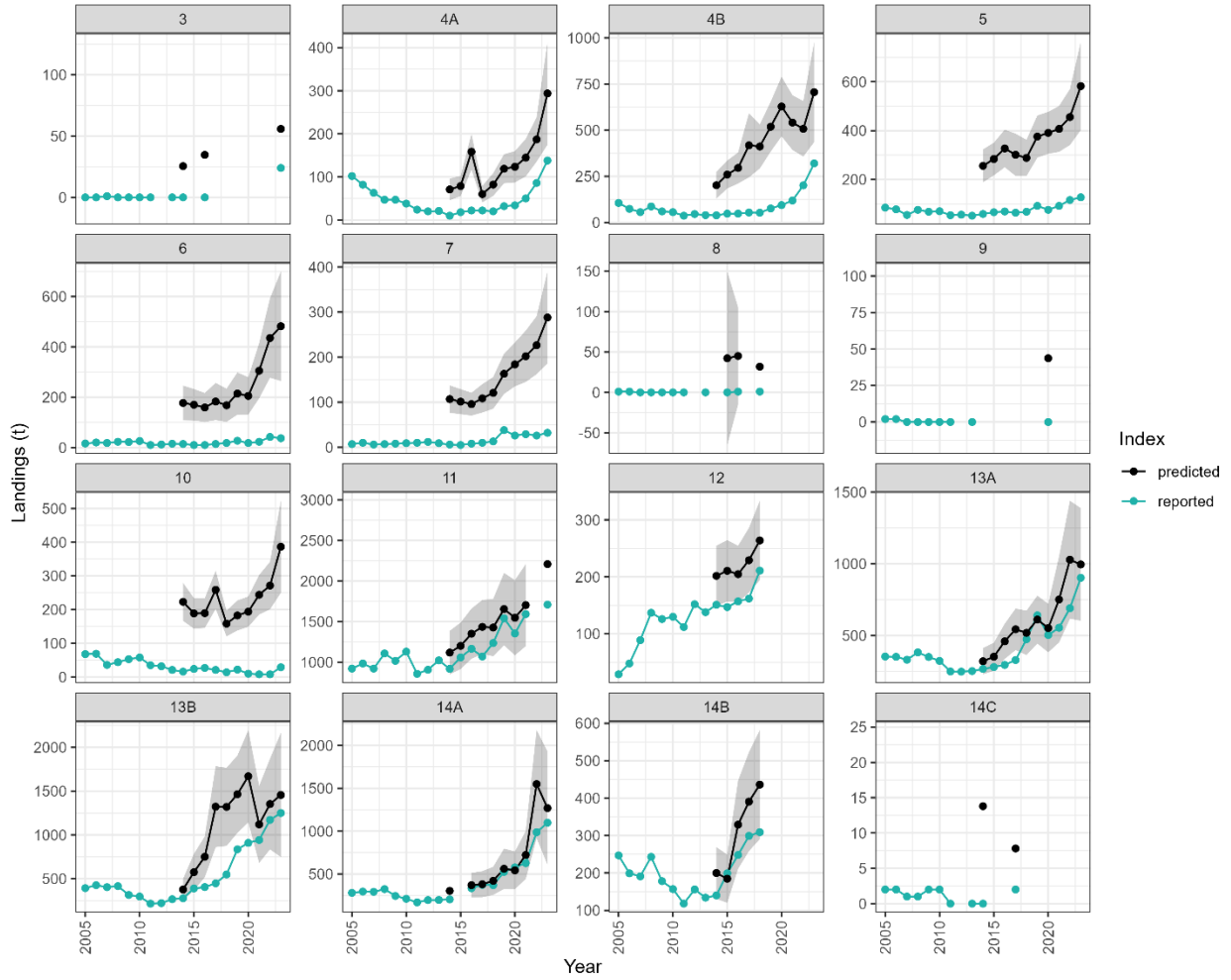


Figure 29. Predicted (black line) and reported (blue) landings (t) between 2005 and 2023 in LFAs 3–14C. Note: Northeast Coast (3–6), Avalon (7–10), South Coast (11–12), and West Coast (13A–14C). LFAs and years affected by the Rule of 5 not shown.

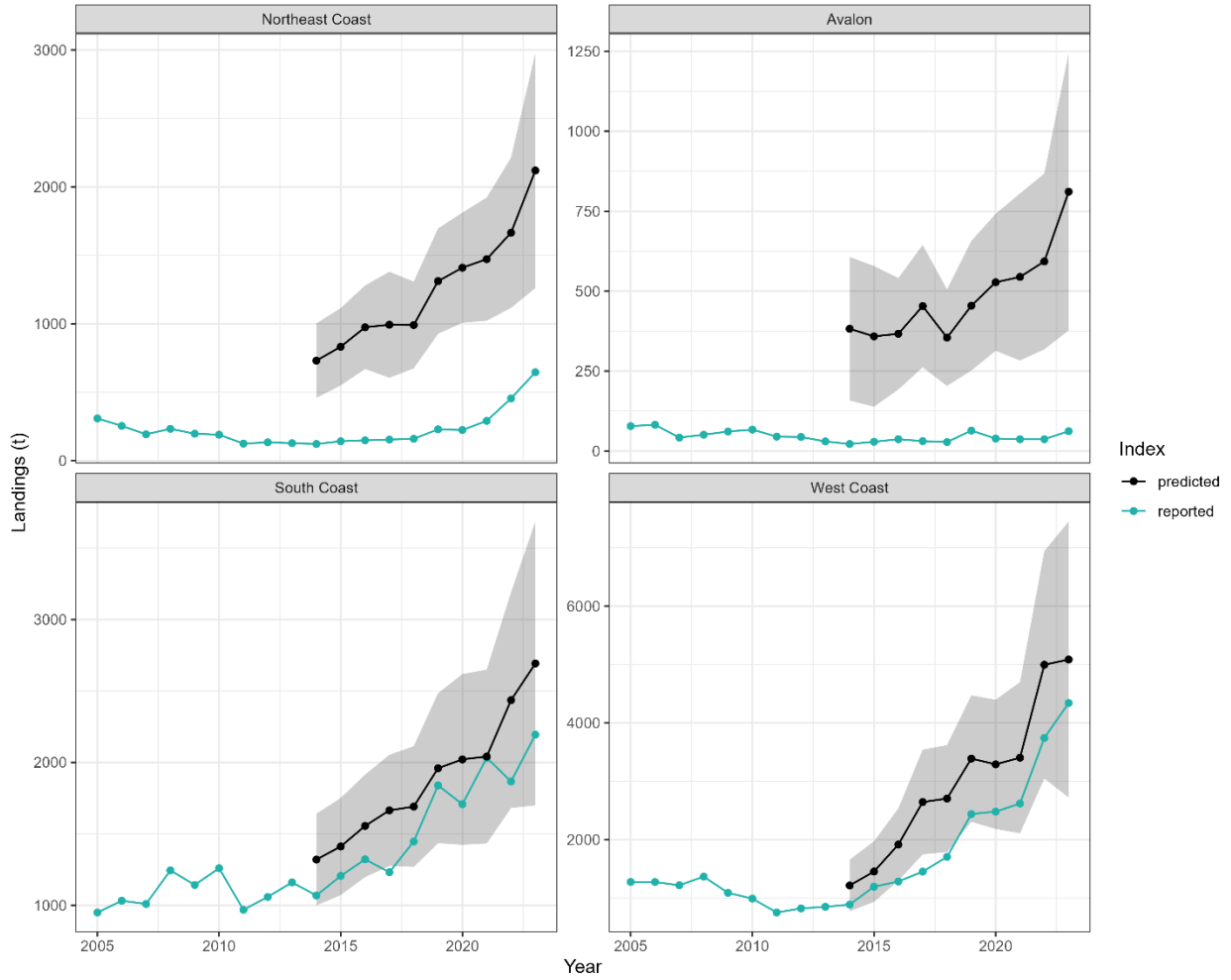


Figure 30. Predicted (black line) and reported (blue) landings between 2005 and 2023 for each AR.

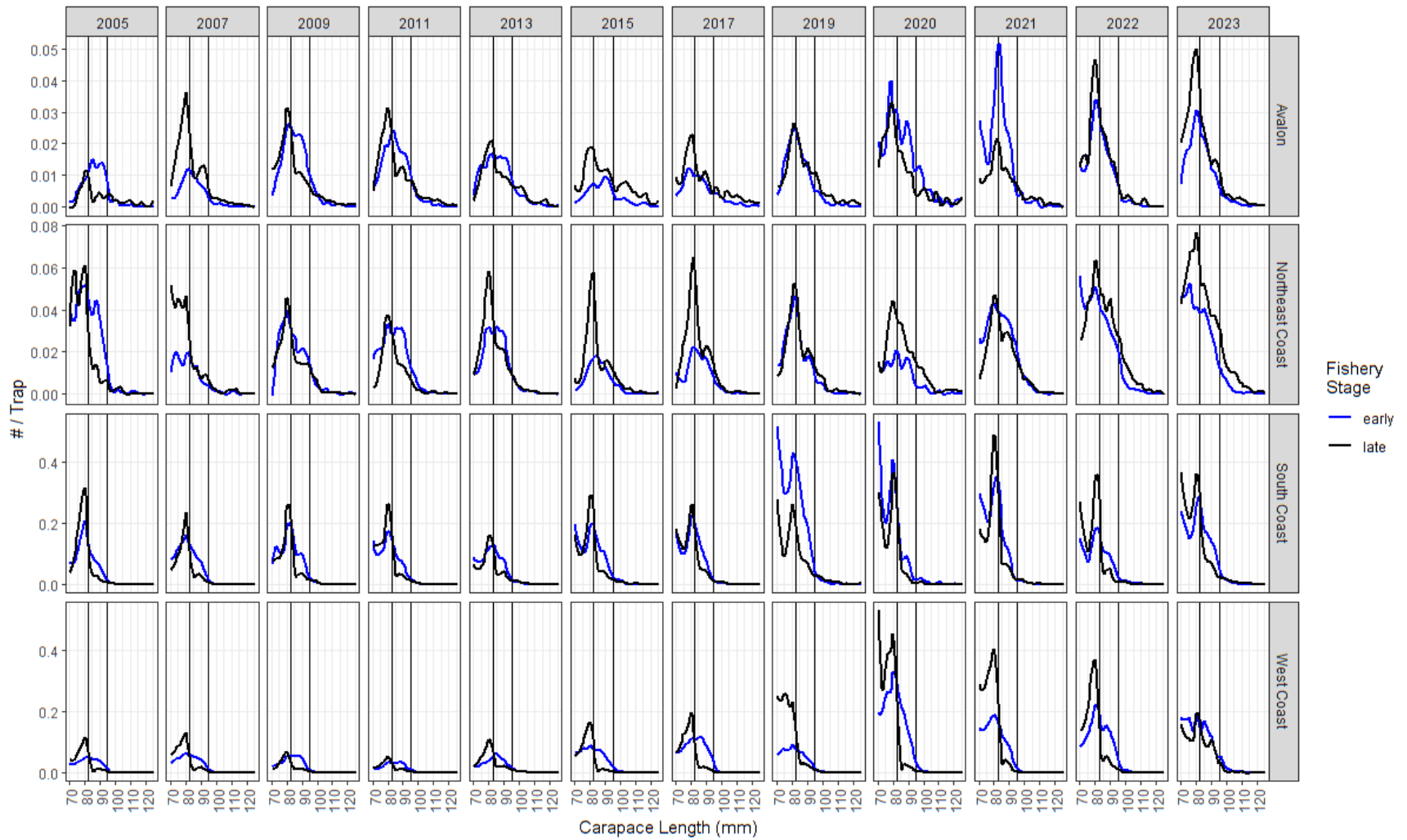


Figure 31. Length frequency data from early versus late season sampling in each AR by year. Vertical grey lines show legal size (82.5 mm CL) and upper end of immediate recruit size range (98 mm CL). Only odd years shown prior to 2020.

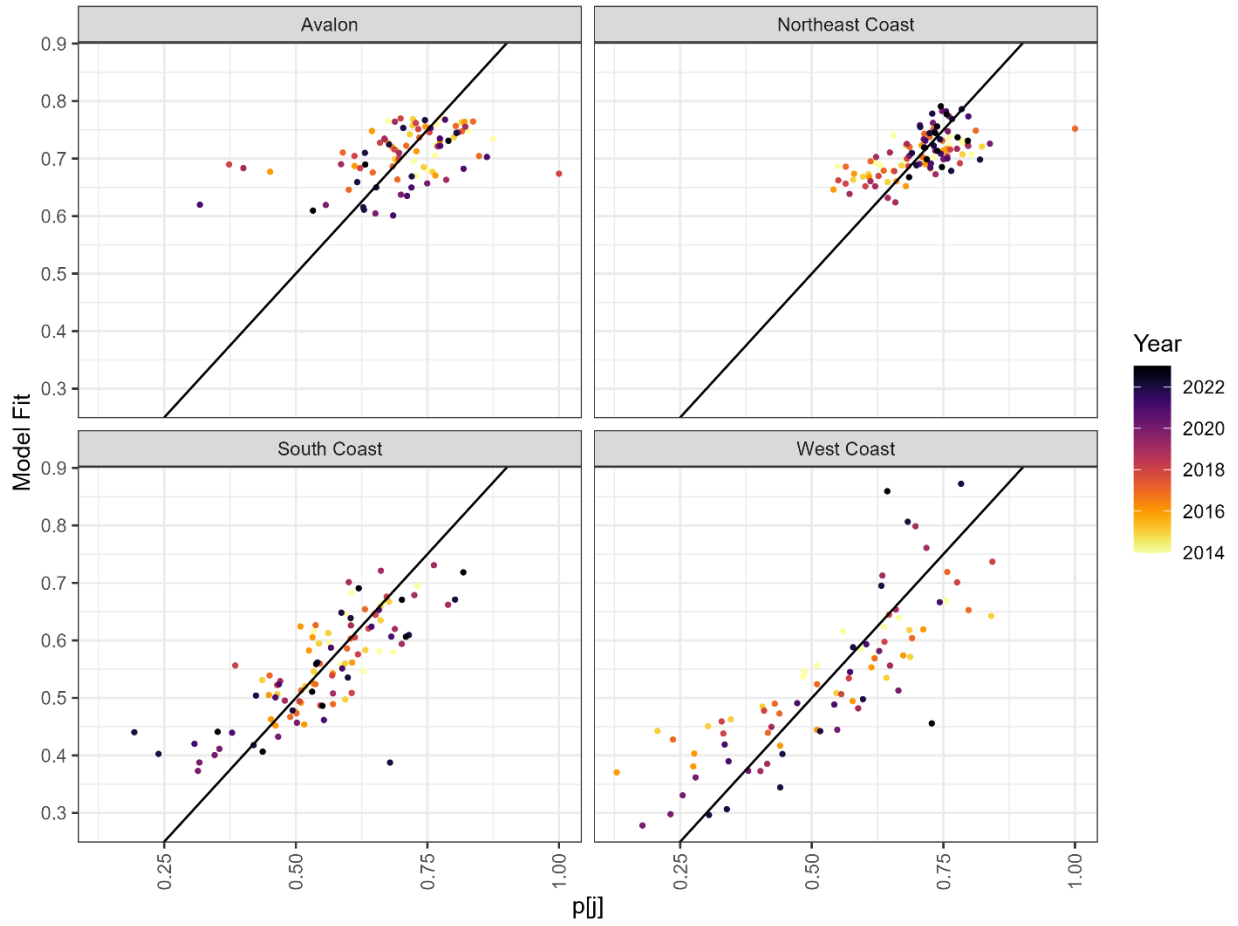


Figure 32. Predicted (Model Fit) versus observed ($p[j]$) values from CCIR mortality model for each AR from 2014 to 2023.

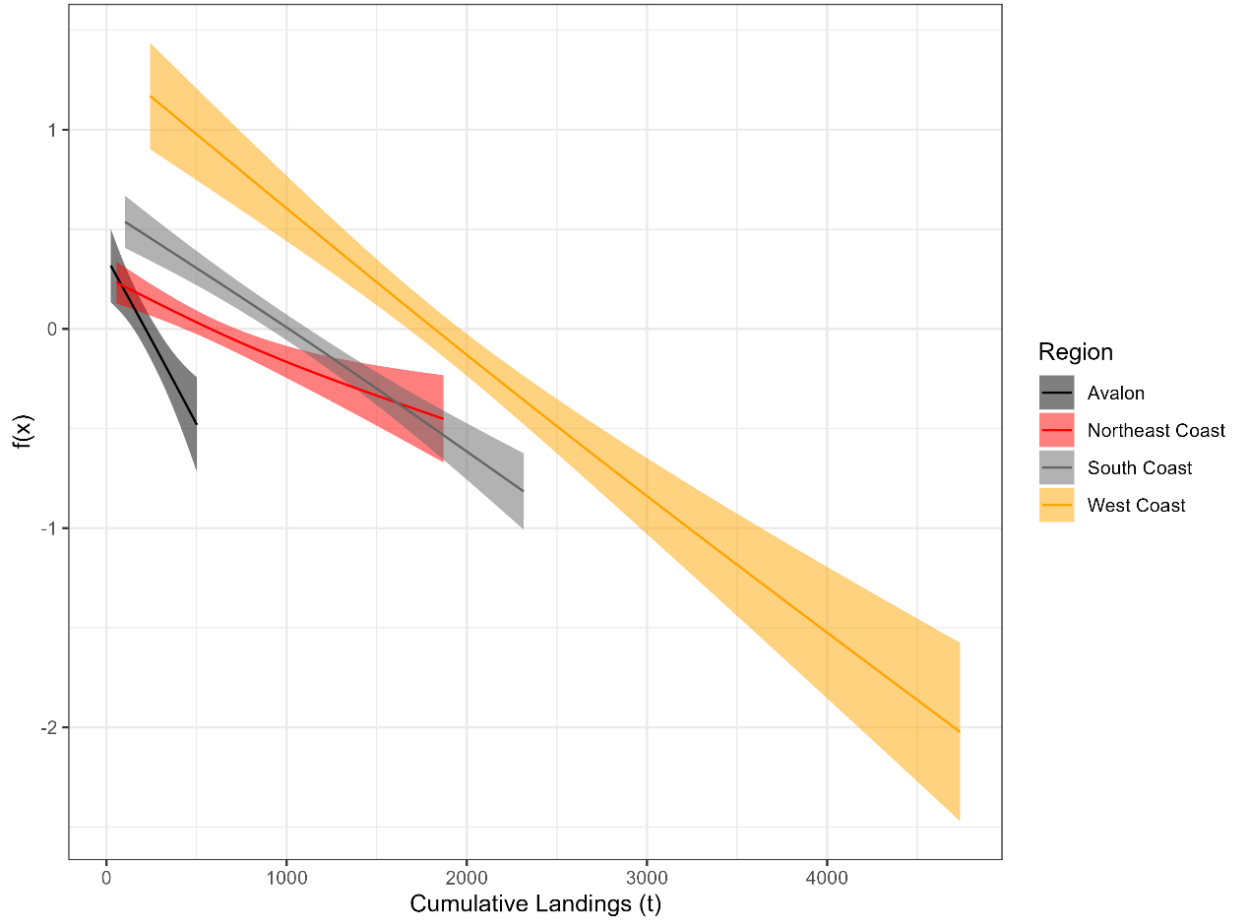


Figure 33. Marginal effect smooths for cumulative landings from the CCIR mortality model by AR. $f(x)$ denotes y-axis effect size is a function of x-axis variable (cumulative landings).

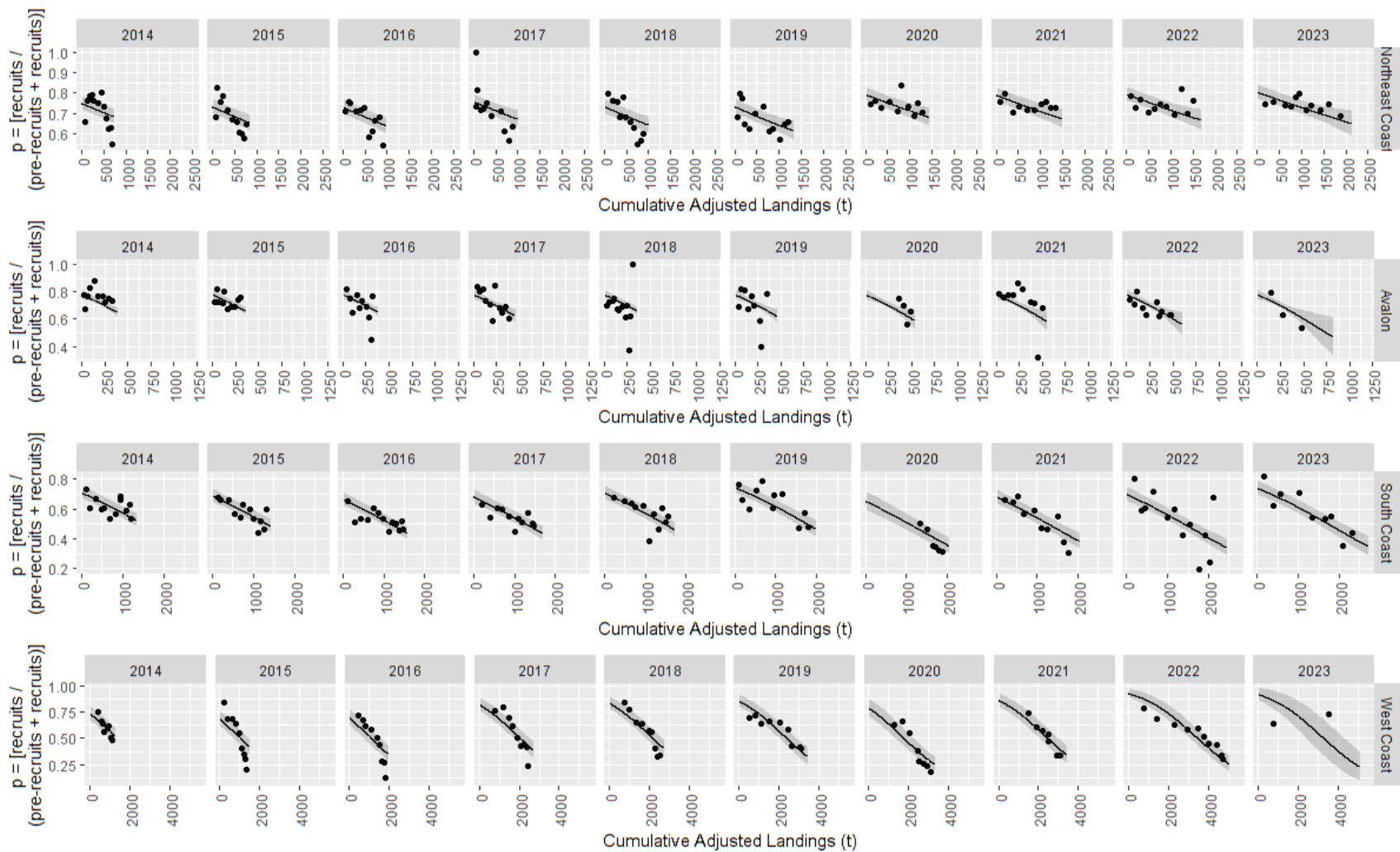


Figure 34. Continuous change in ratio model by AR and year. Points show five-day bins of ratios of recruits (exploited group) versus recruits plus pre-recruits (total catch) versus cumulative landings in the fishery. Lines show non-linear regressions fit to data and shaded areas denote 95% confidence intervals.

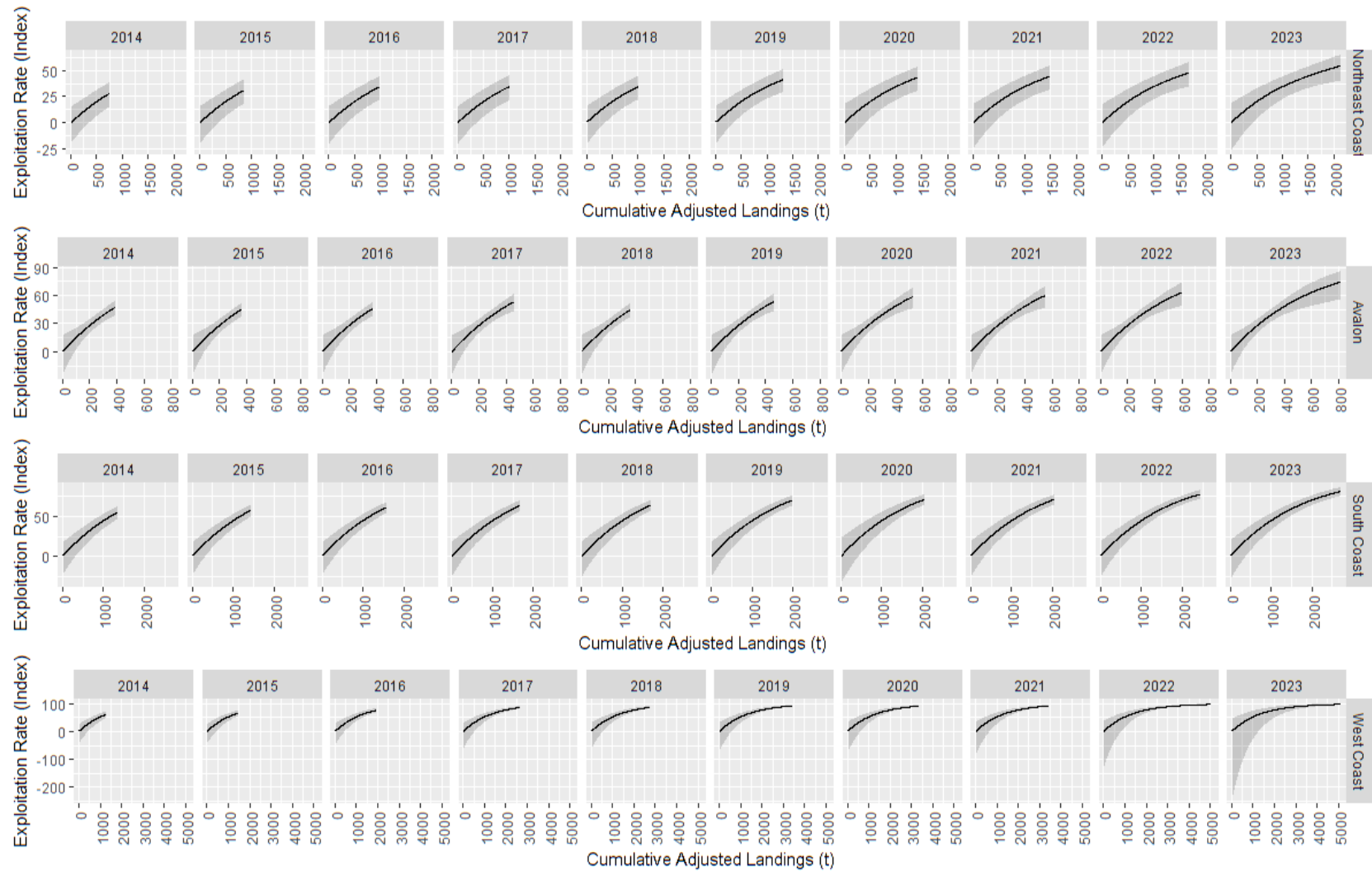


Figure 35. Seasonal exploitation rates in immediate recruits estimated from CCIR morality model for each AR from 2014 to 2023. Shaded areas denote 95% confidence intervals.

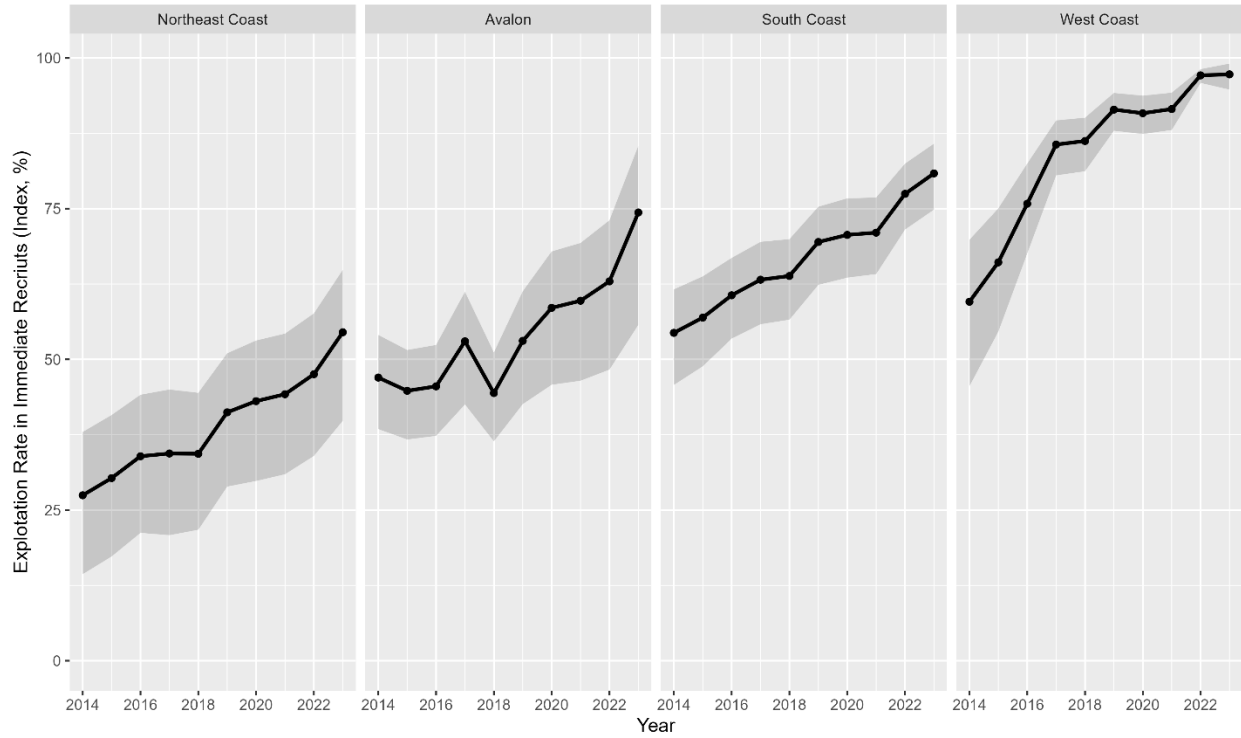


Figure 36. Annual exploitation rates in immediate recruits estimated from CCIR morality model for each AR from 2014 to 2023. Shaded areas denote 95% confidence intervals.

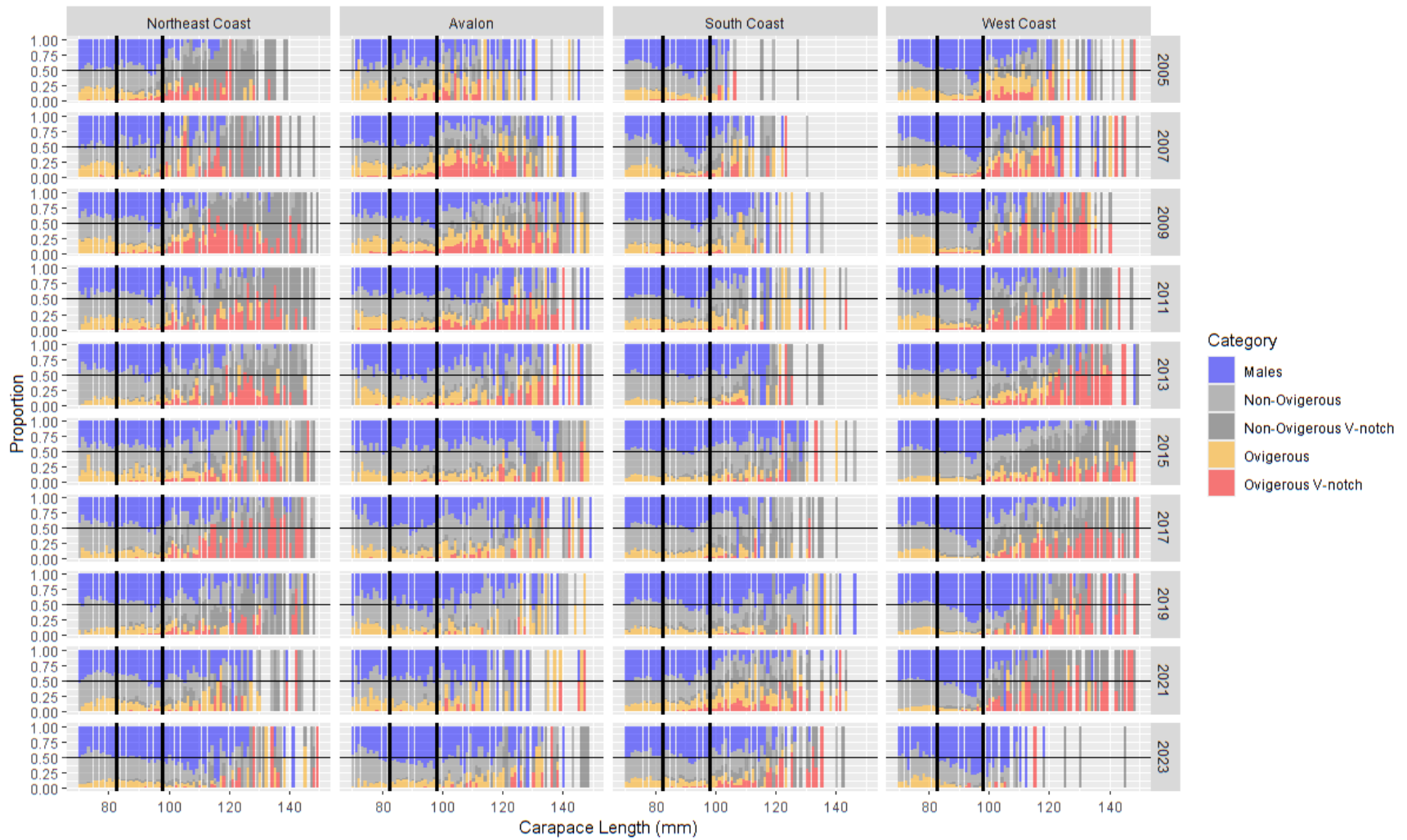


Figure 37. Proportion of both male and female lobster by maturity category and size (1 mm CL bin) in each AR from 2004 to 2023. The black vertical lines represent 83 mm CL, and 98 mm CL (immediate recruits). Only odd years shown in 2005–23 period.

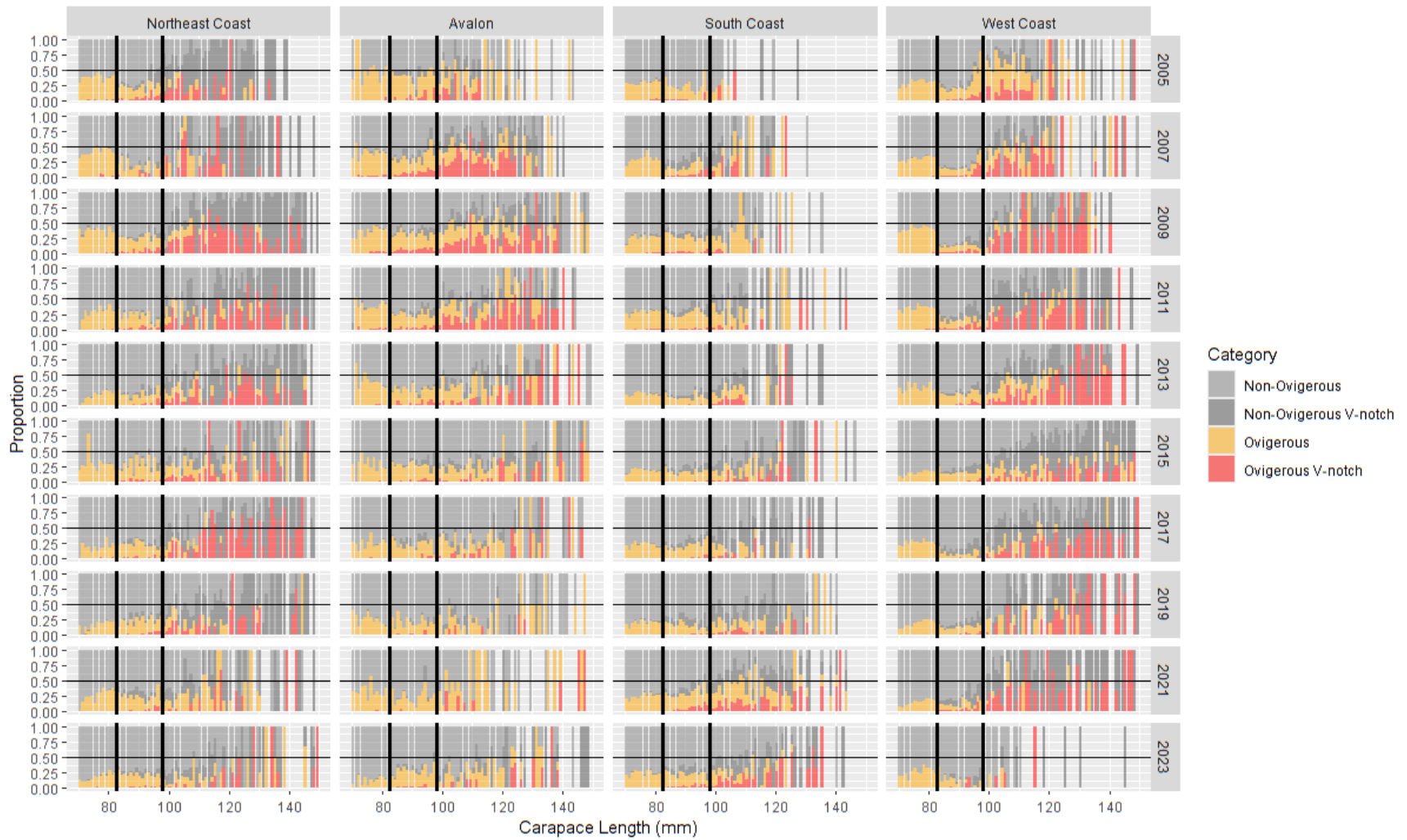


Figure 38. Proportion of female lobster by maturity category and size (1 mm CL bin) in each AR from 2004 to 2023. The black vertical lines represent 83 mm CL, and 98 mm CL (immediate recruits). Only odd years shown in 2005–23 period.

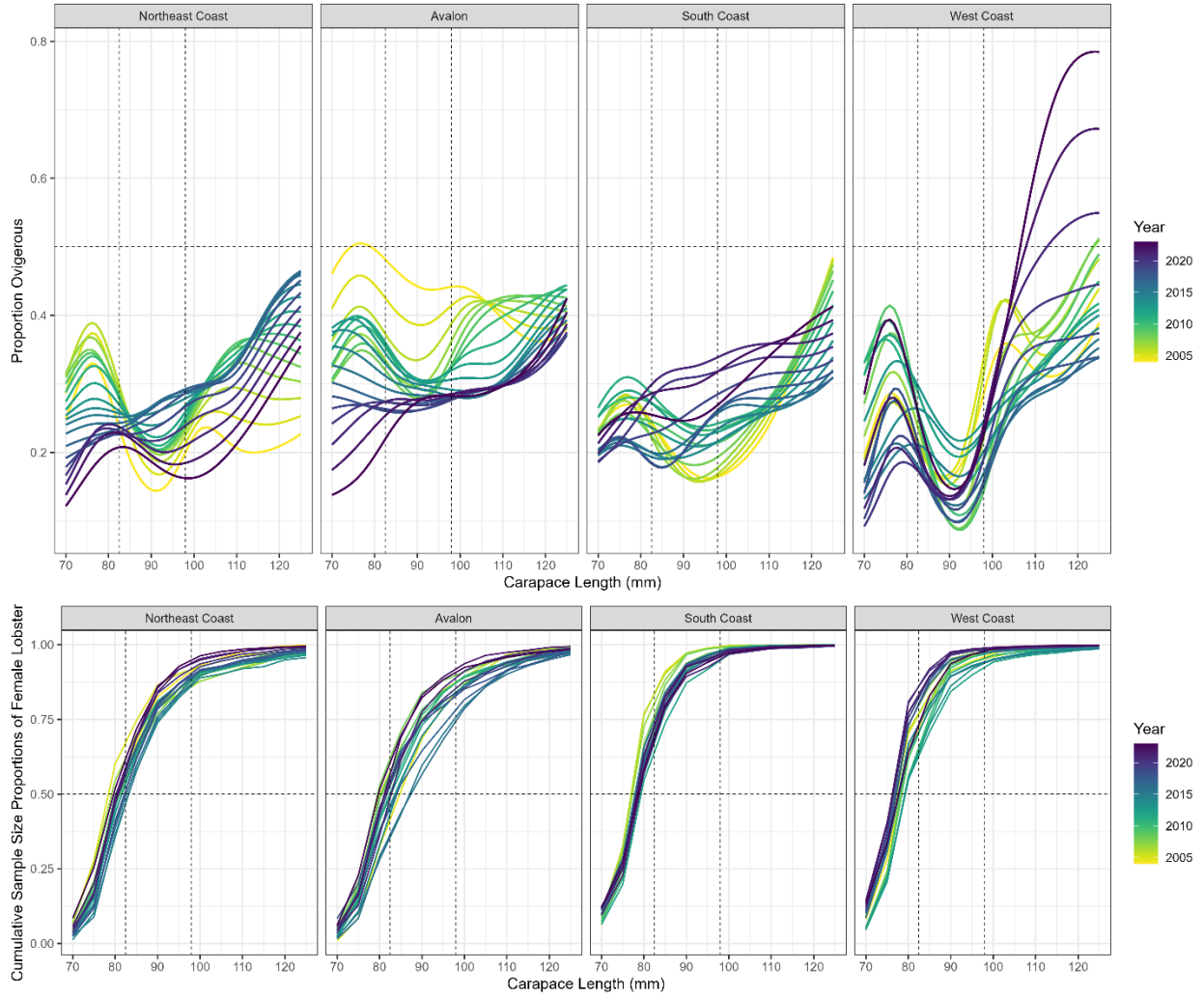


Figure 39. Top panels: Size-at-ovigerous model showing estimated proportion of female lobster that are ovigerous by size (1 mm CL bin) and year for each AR. Bottom panels: Cumulative proportions of females by size in the population by AR and year. Vertical dotted lines show MLS (82.5 mm CL) and upper range of immediate recruit group (98 mm CL).

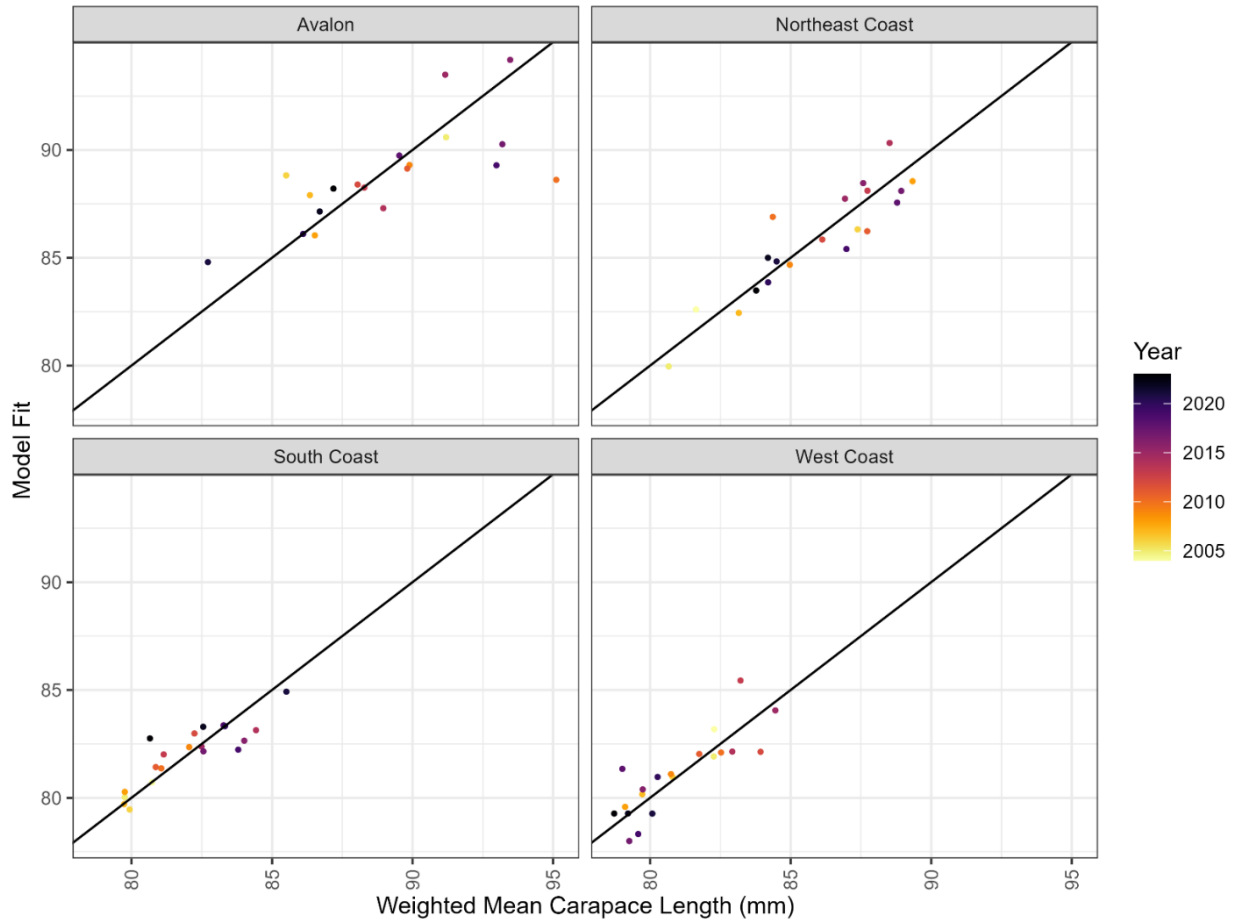


Figure 40. Predicted (Model Fit) versus observed (Weighted Mean Carapace Length (mm)) values from Ovigerous Size model for each AR from 2005 to 2023.

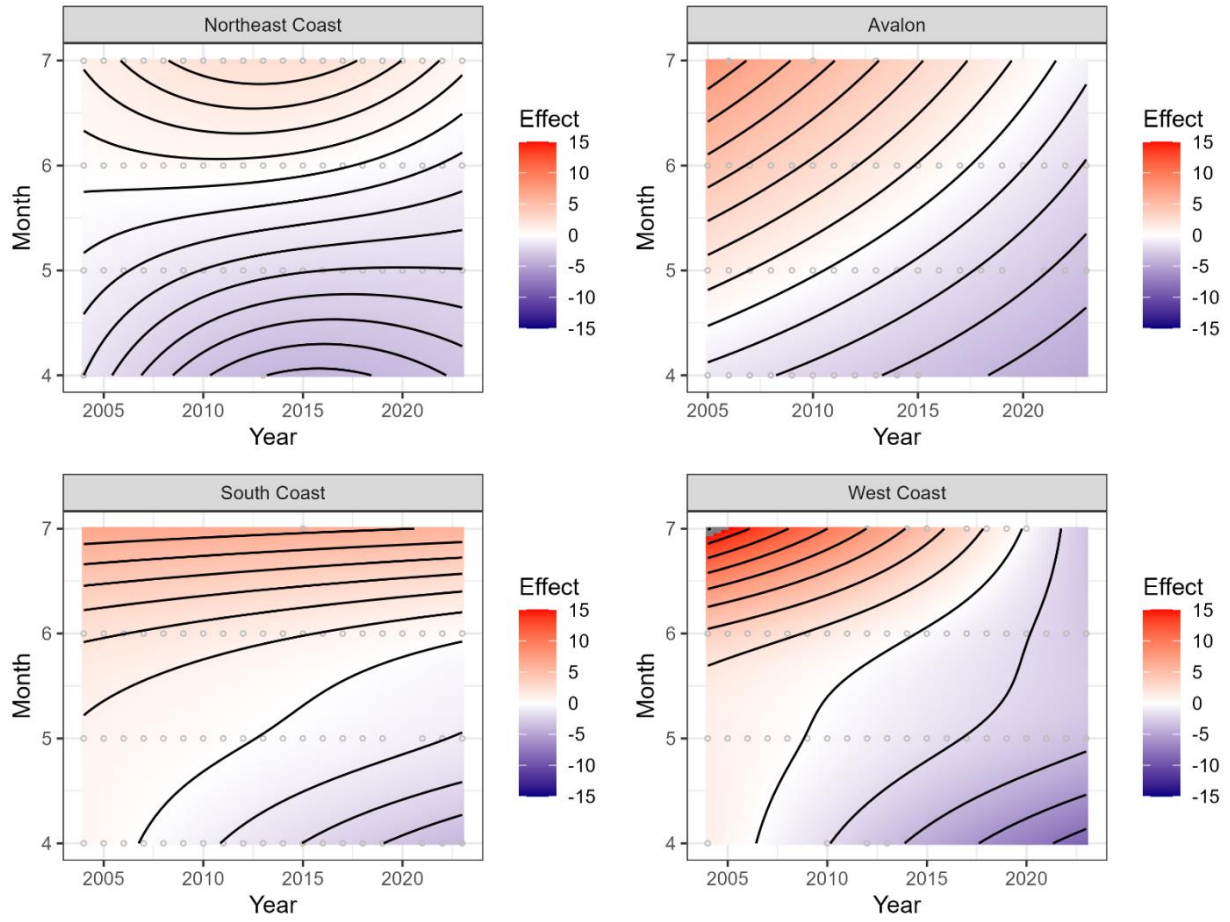


Figure 41. Marginal effect interaction plots between month and year for models estimating sizes of ovigerous females for each AR from 2005 to 2023.

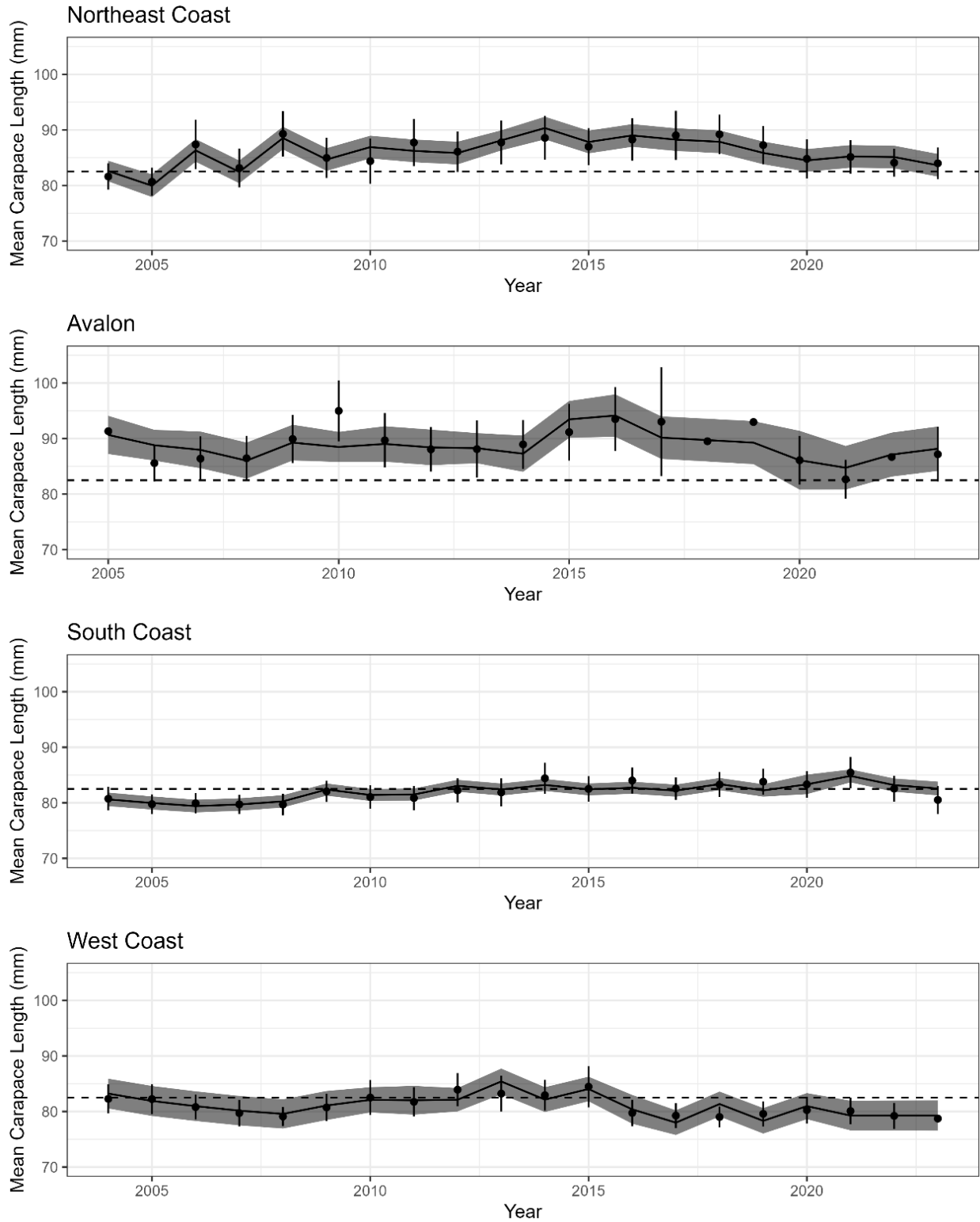


Figure 42. Weighted mean CL (mm) of ovigerous females in each AR from 2005 to 2023. Points and vertical error bars show data and lines and shaded bands show model fit and 95% confidence intervals. Black dashed line represents 82.5 mm CL (MLS).

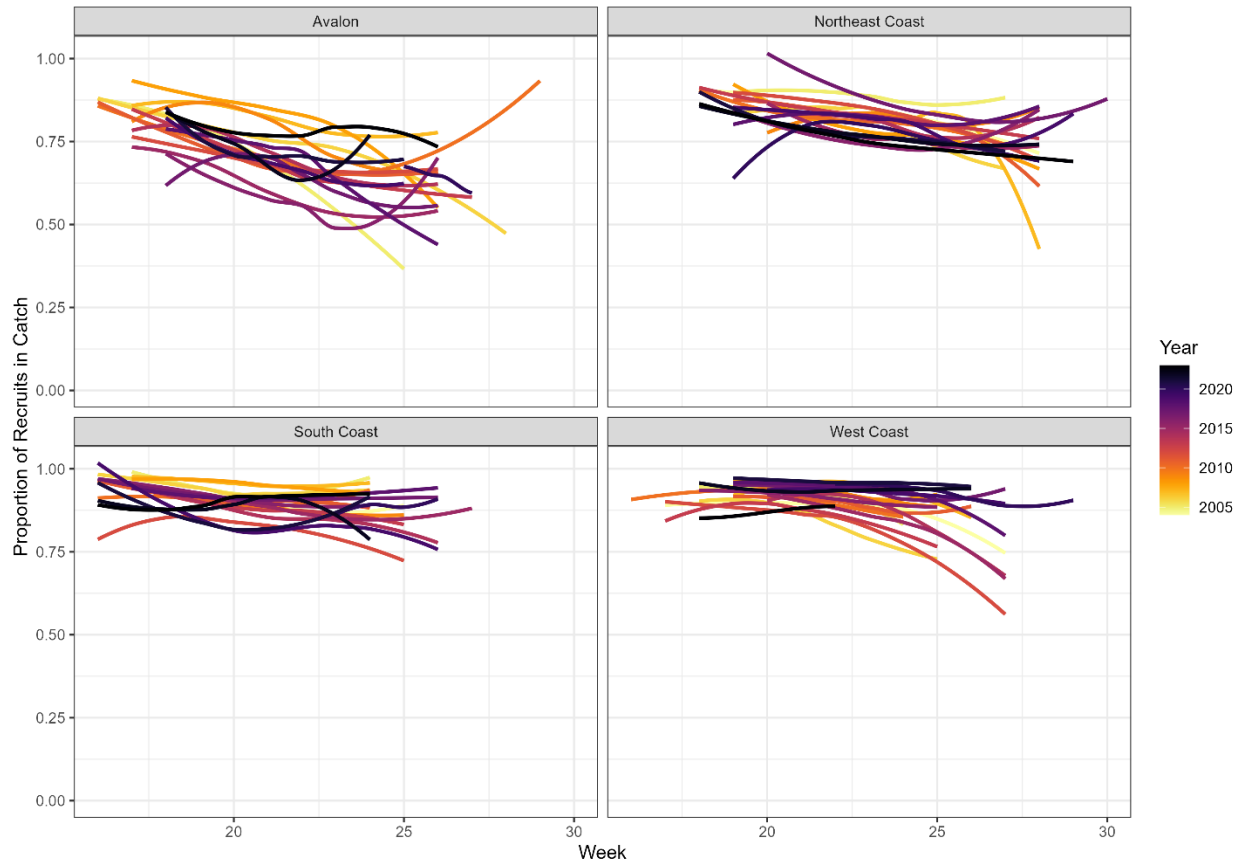


Figure 43. The proportion of recruits in catch per year (2005–23) by week of the year for each of the ARs.

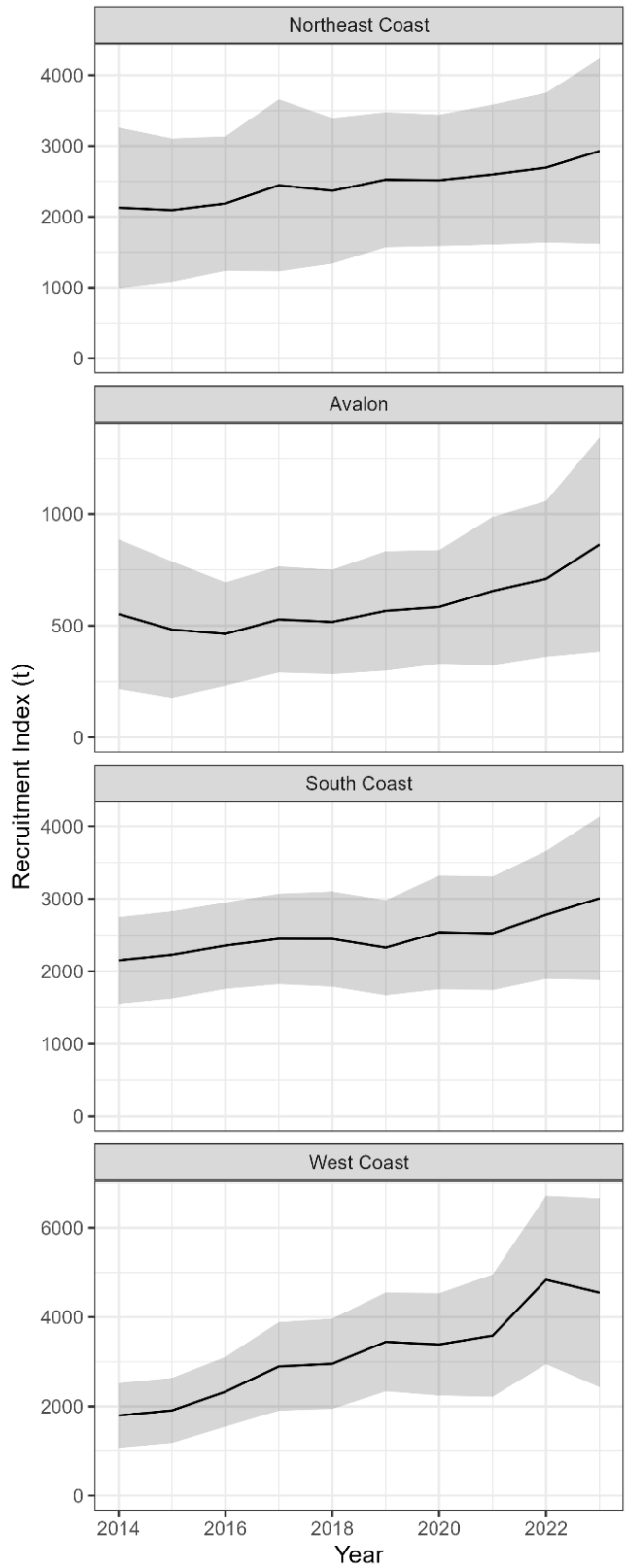


Figure 44. Recruitment index (t) from 2005 to 2023 in each AR. Shaded bands show 95% confidence intervals.

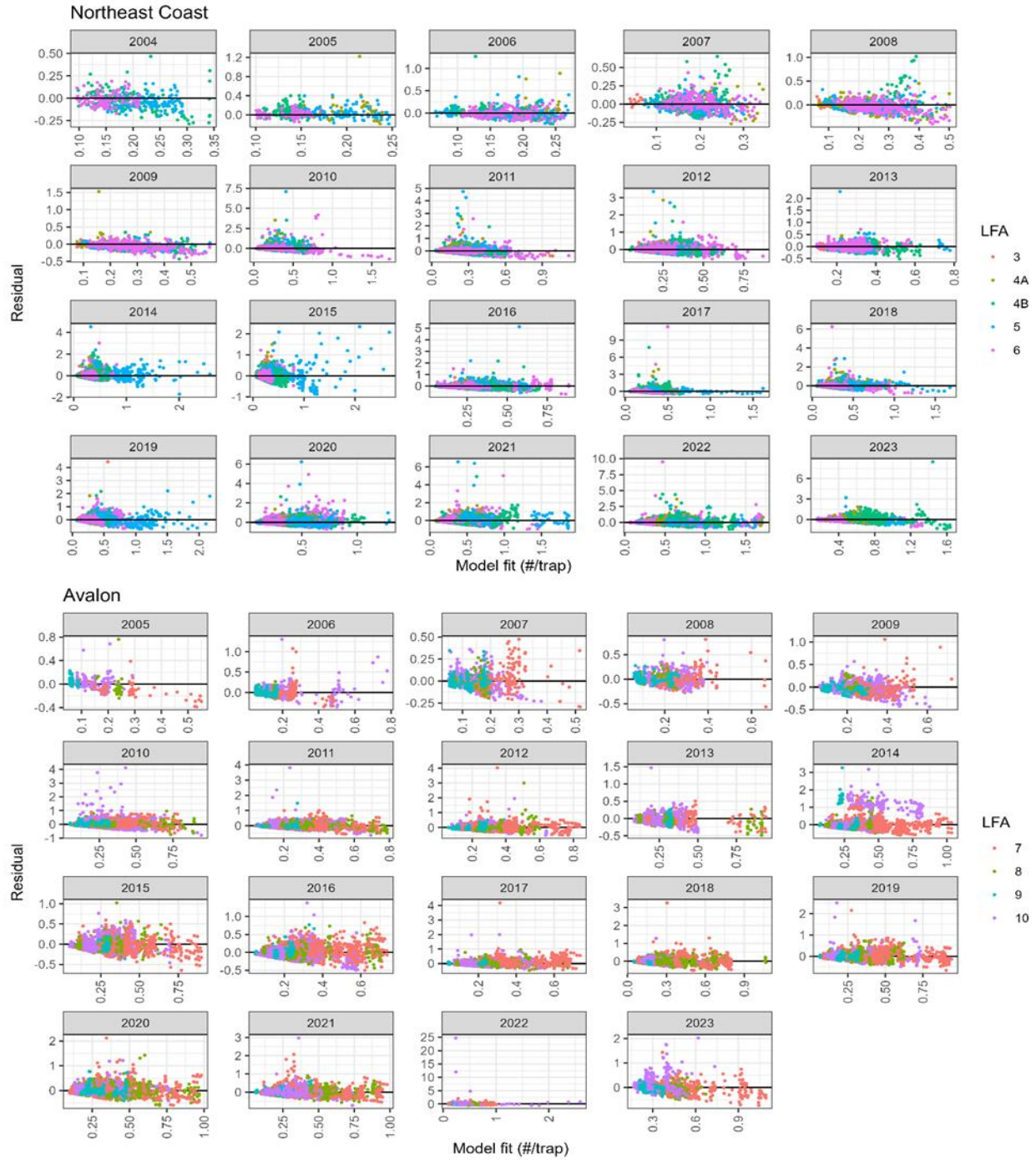


Figure 45. Residual plots for the CPUE model (presented as observed minus predicted values plotted against model fit) for each LFA and year in the Northeast Coast AR (top) and Avalon AR (bottom).

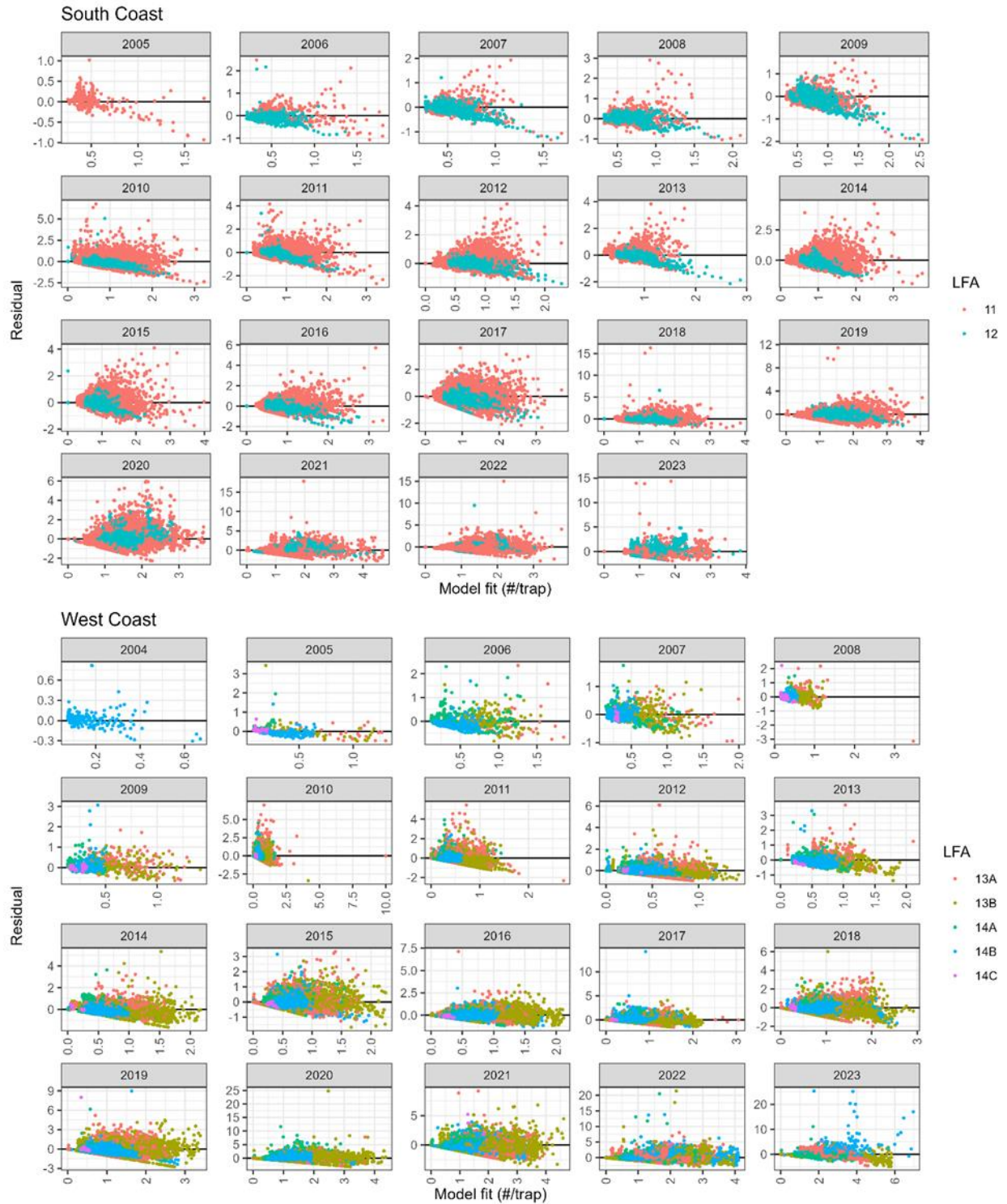


Figure 46. Residual plots for the CPUE model (presented as observed minus predicted values plotted against model fit) for each LFA and year in the South Coast AR (top) and West Coast AR (bottom).

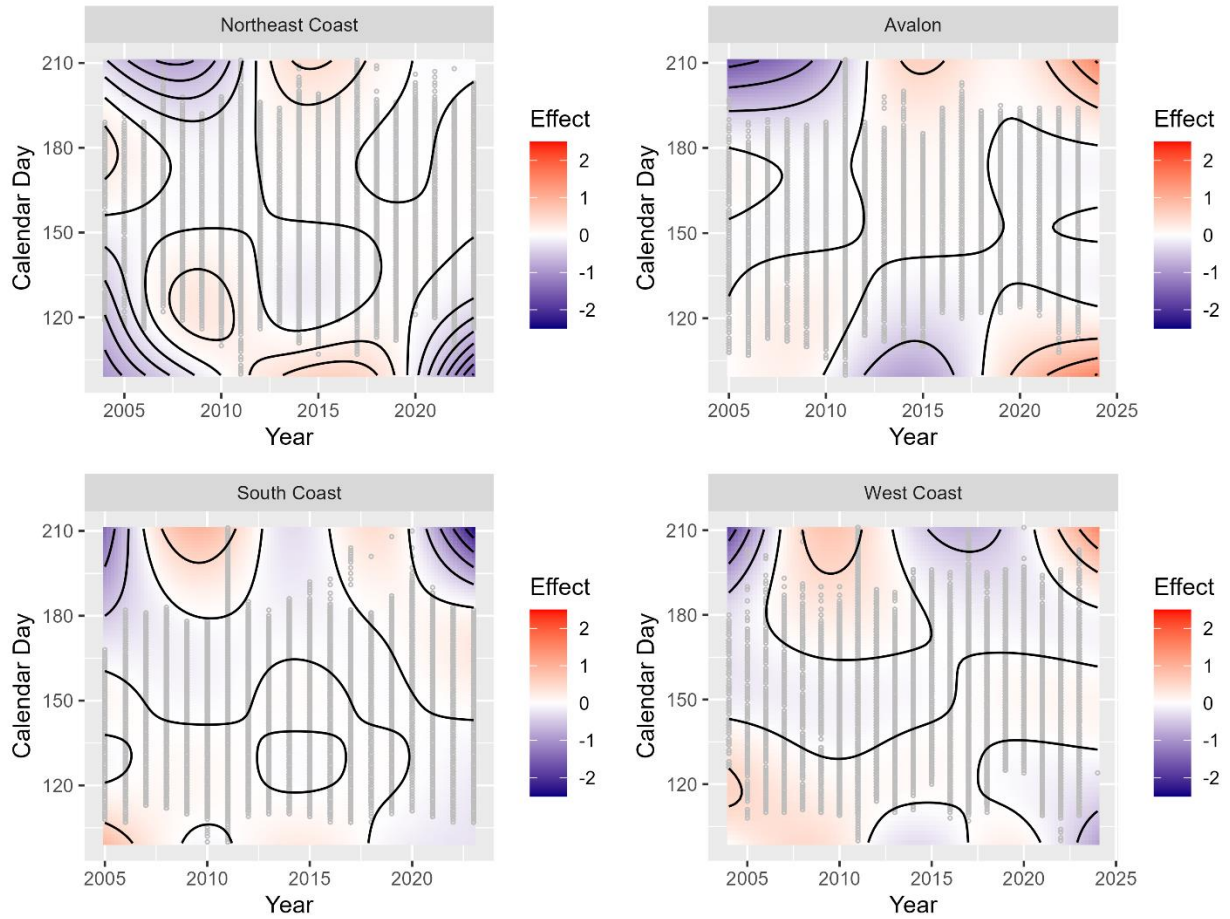


Figure 47. Marginal effect interaction plots between year and day for model estimating fishery CPUE for each AR from 2005 to 2023.

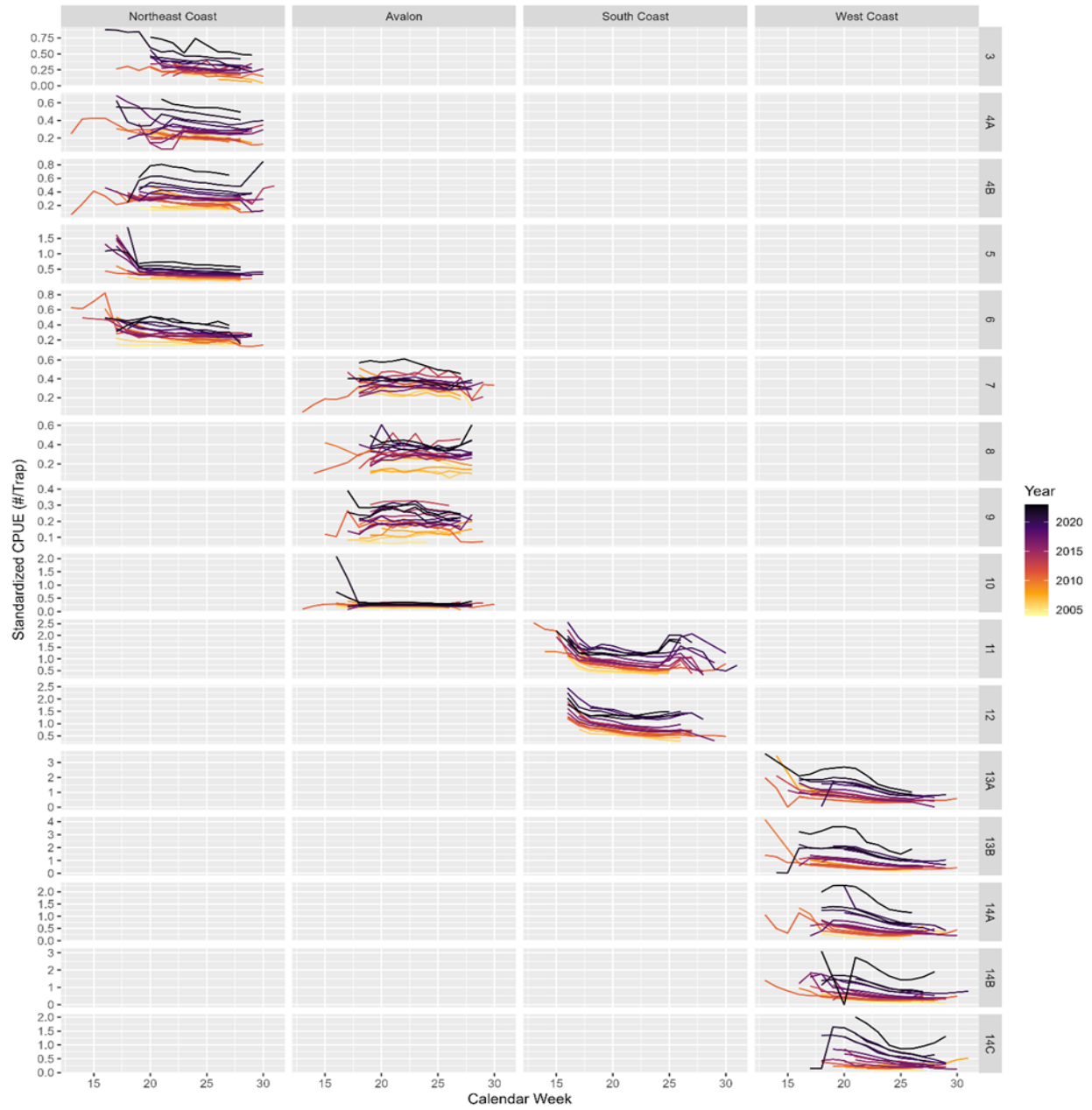


Figure 48. Standardized catch per unit effort (CPUE, number per trap) by week within LFAs 3–14C in each respective AR from 2005 to 2023.

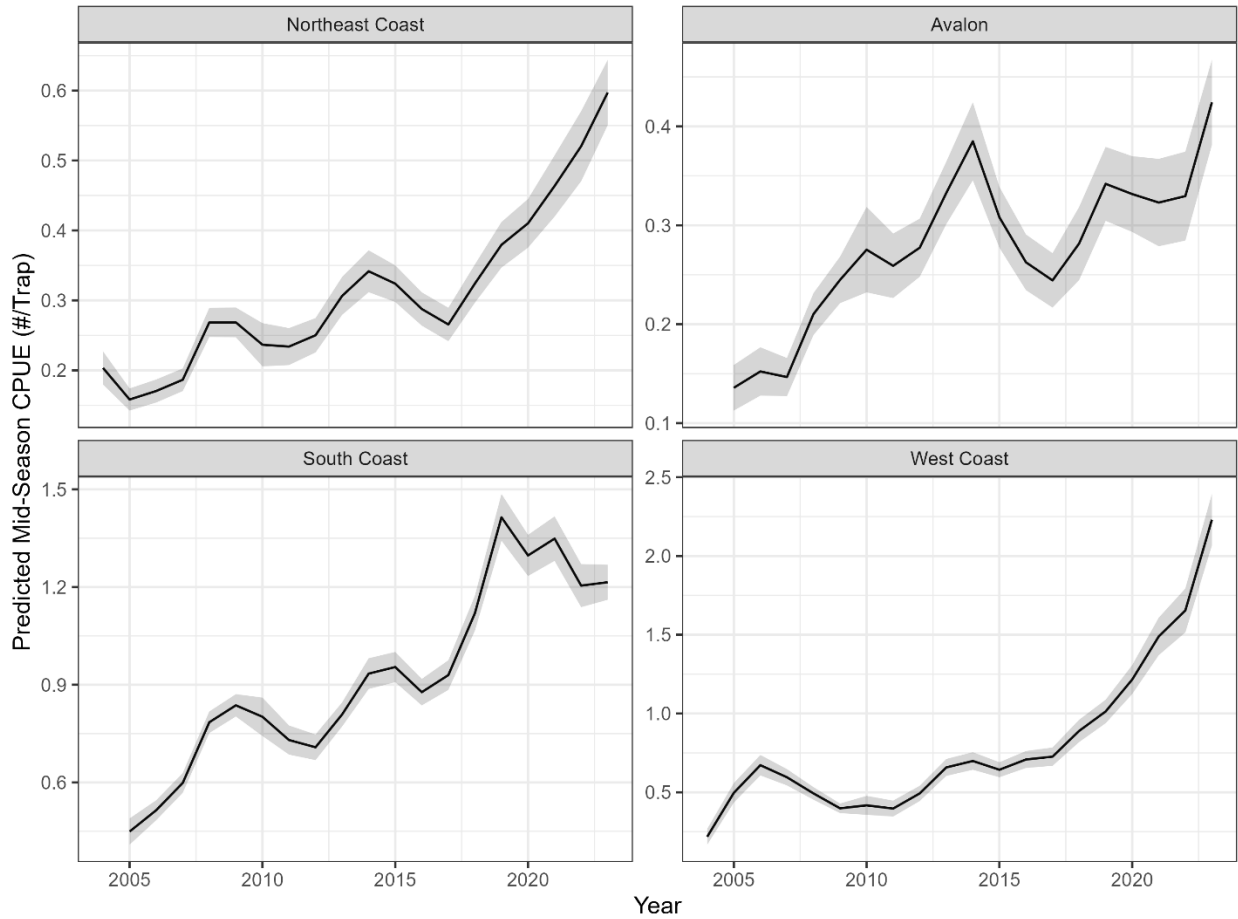


Figure 49. Standardized catch per unit effort (CPUE, number per trap) at season mid-points for each AR from 2005 to 2023. Shaded bands show 95% confidence intervals.

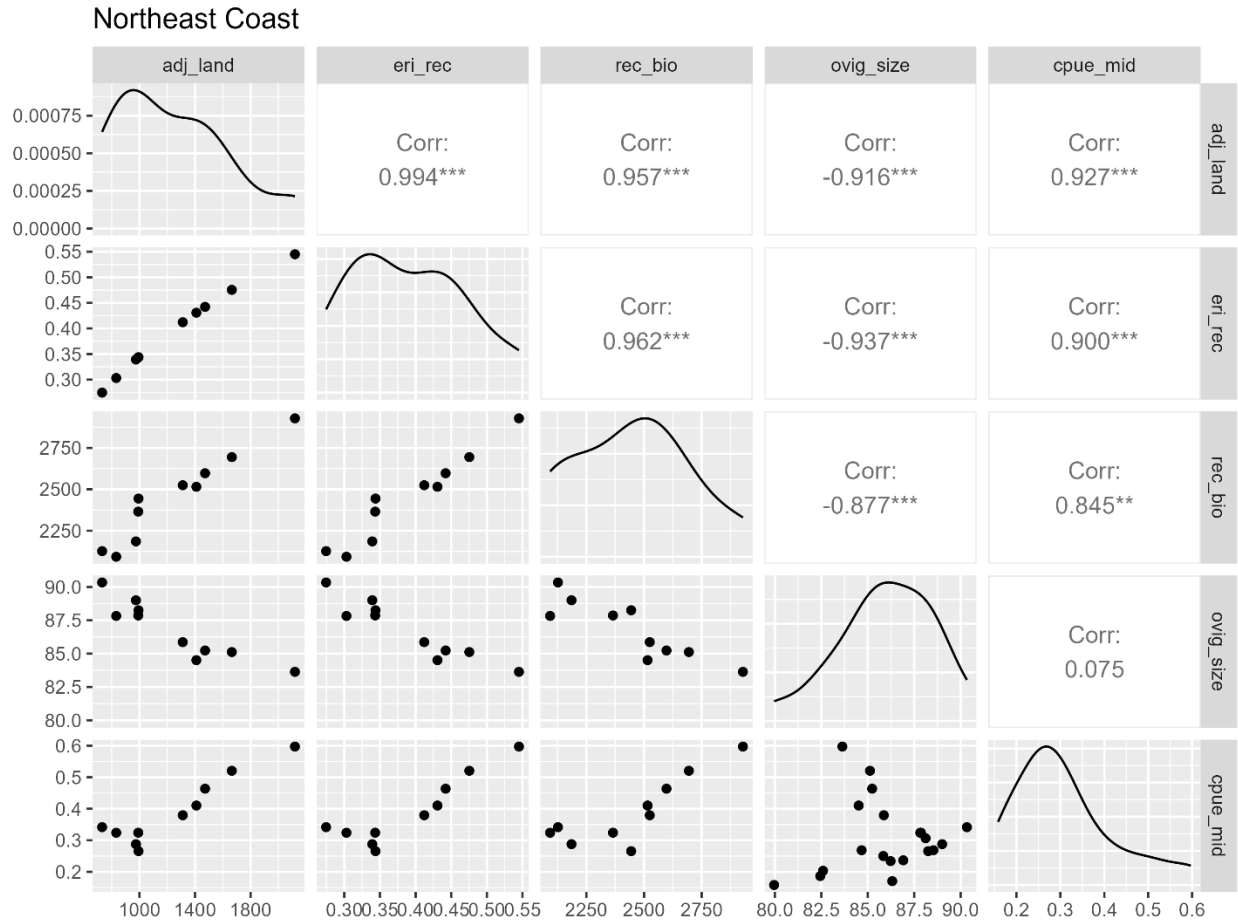


Figure 50. Correlograms of the five developed indicators (adjusted landings – *adj_land*, fishing mortality in immediate recruits – *eri_rec*, recruit biomass – *rec_bio*, mean size of ovigerous females – *ovig_size*, and mid-season fishery CPUE – *cpue_mid*) considered for inclusion in the PAF for the Northeast Coast Assessment Region from 2005 to 2023. Asterisks denote level of significance in the correlations (***) $p < 0.001$, (**) $p < 0.01$, (*) $p < 0.05$).

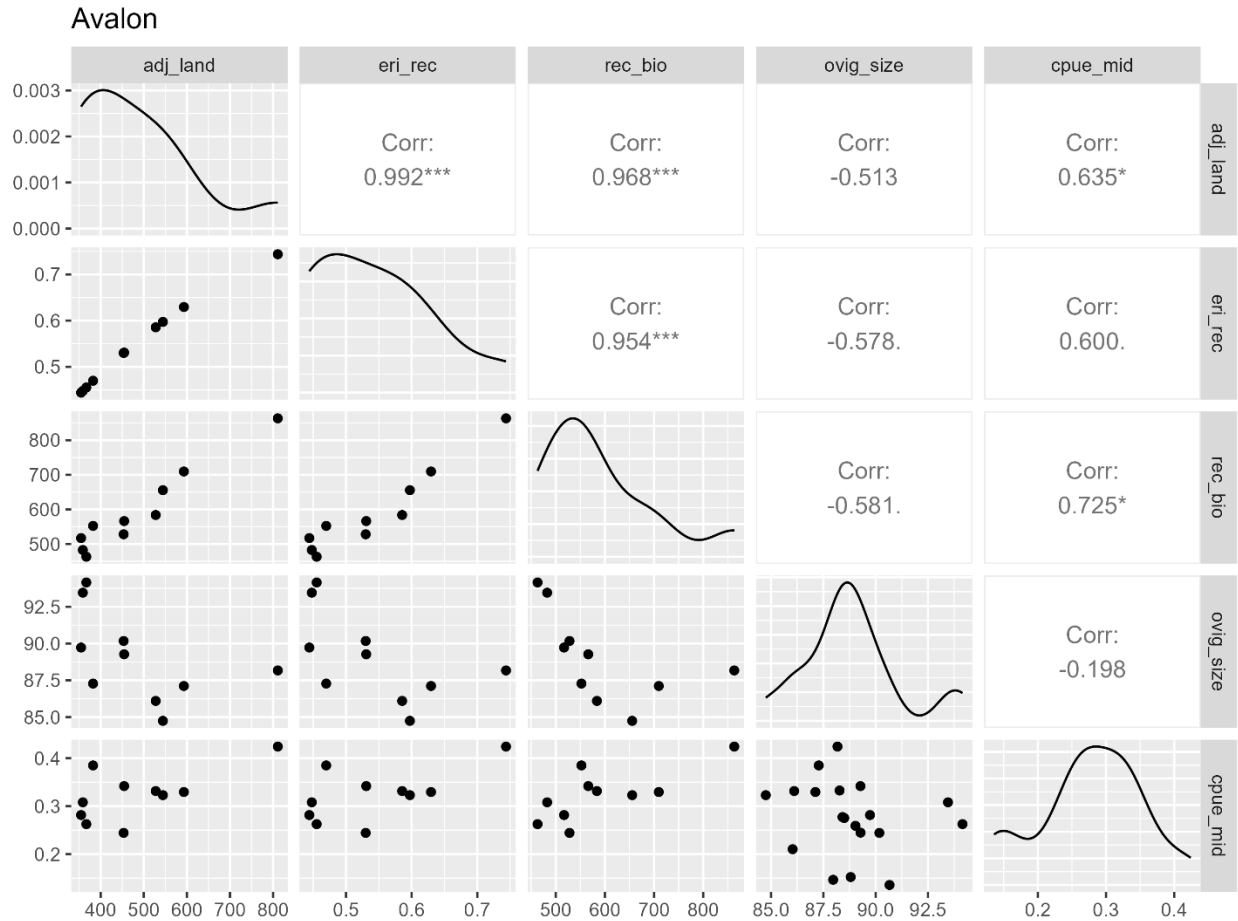


Figure 51. Correlograms of the five developed indicators (adjusted landings – *adj_land*, fishing mortality in immediate recruits – *eri_rec*, recruit biomass – *rec_bio*, mean size of ovigerous females – *ovig_size*, and mid-season fishery CPUE – *cpue_mid*) considered for inclusion in the PAF for the Avalon Assessment Region from 2005 to 2023. Asterisks denote level of significance in the correlations (*** ~ $p < 0.001$, ** ~ $p < 0.01$, * ~ $p < 0.05$).

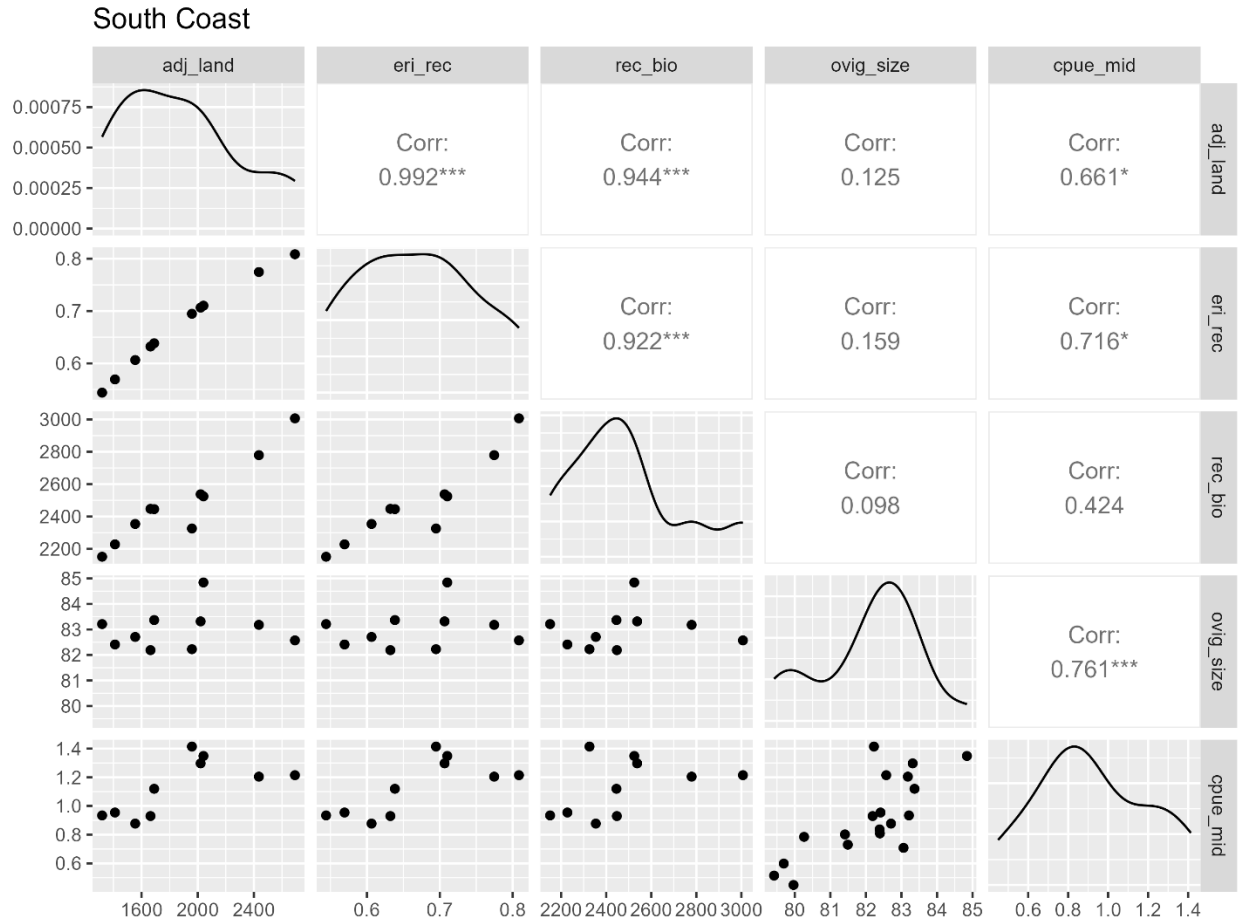


Figure 52. Correlograms of the five developed indicators (adjusted landings – *adj_land*, fishing mortality in immediate recruits – *eri_rec*, recruit biomass – *rec_bio*, mean size of ovigerous females – *ovig_size*, and mid-season fishery CPUE – *cpue_mid*) considered for inclusion in the PAF for the South Coast Assessment Region from 2005 to 2023. Asterisks denote level of significance in the correlations (***) ~ $p < 0.001$, ** ~ $p < 0.01$, * ~ $p < 0.05$).

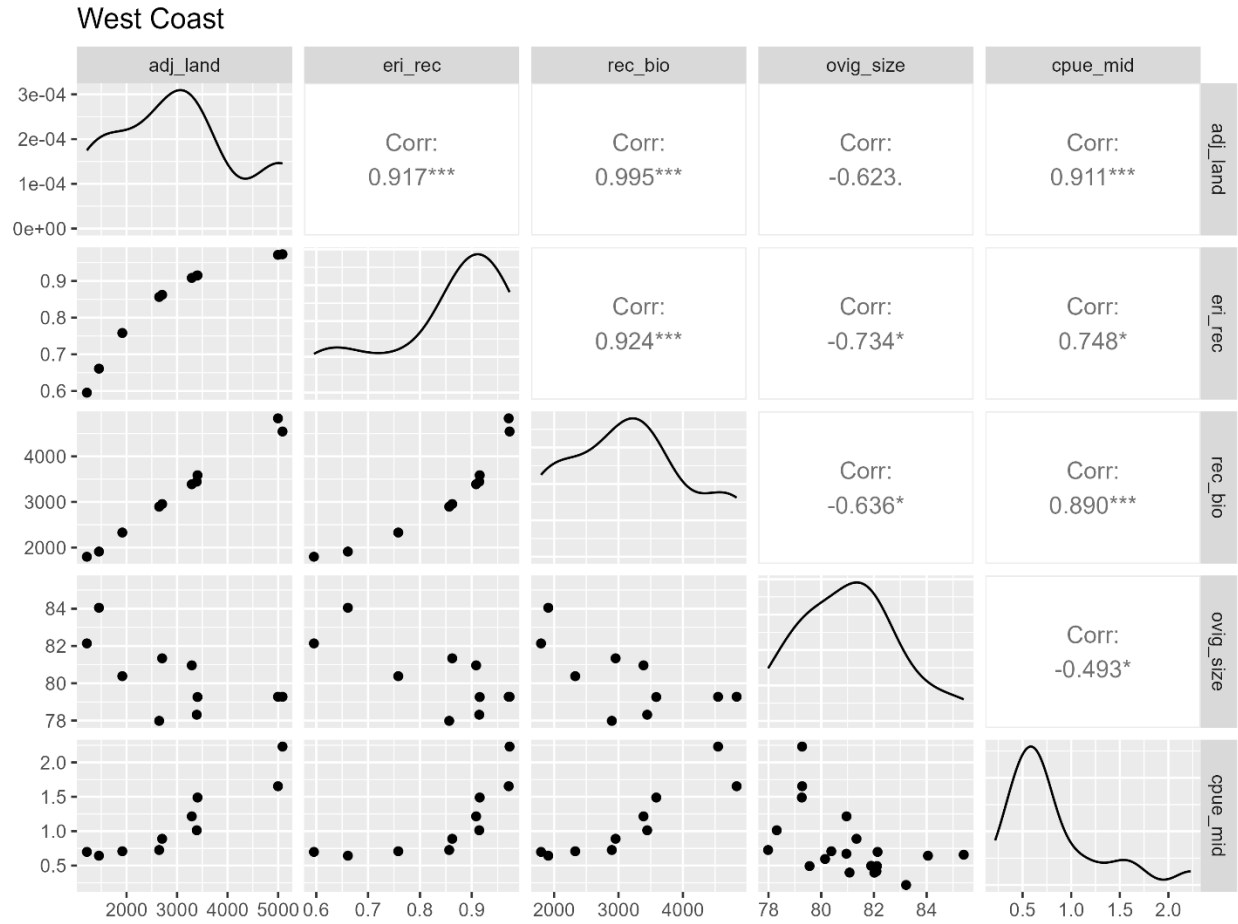


Figure 53. Correlograms of the five developed indicators (adjusted landings – *adj_land*, fishing mortality in immediate recruits – *eri_rec*, recruit biomass – *rec_bio*, mean size of ovigerous females – *ovig_size*, and mid-season fishery CPUE – *cpue_mid*) considered for inclusion in the PAF for the West Coast Assessment Region from 2005 to 2023. Asterisks denote level of significance in the correlations (**~ $p < 0.001$, **~ $p < 0.01$, *~ $p < 0.05$).

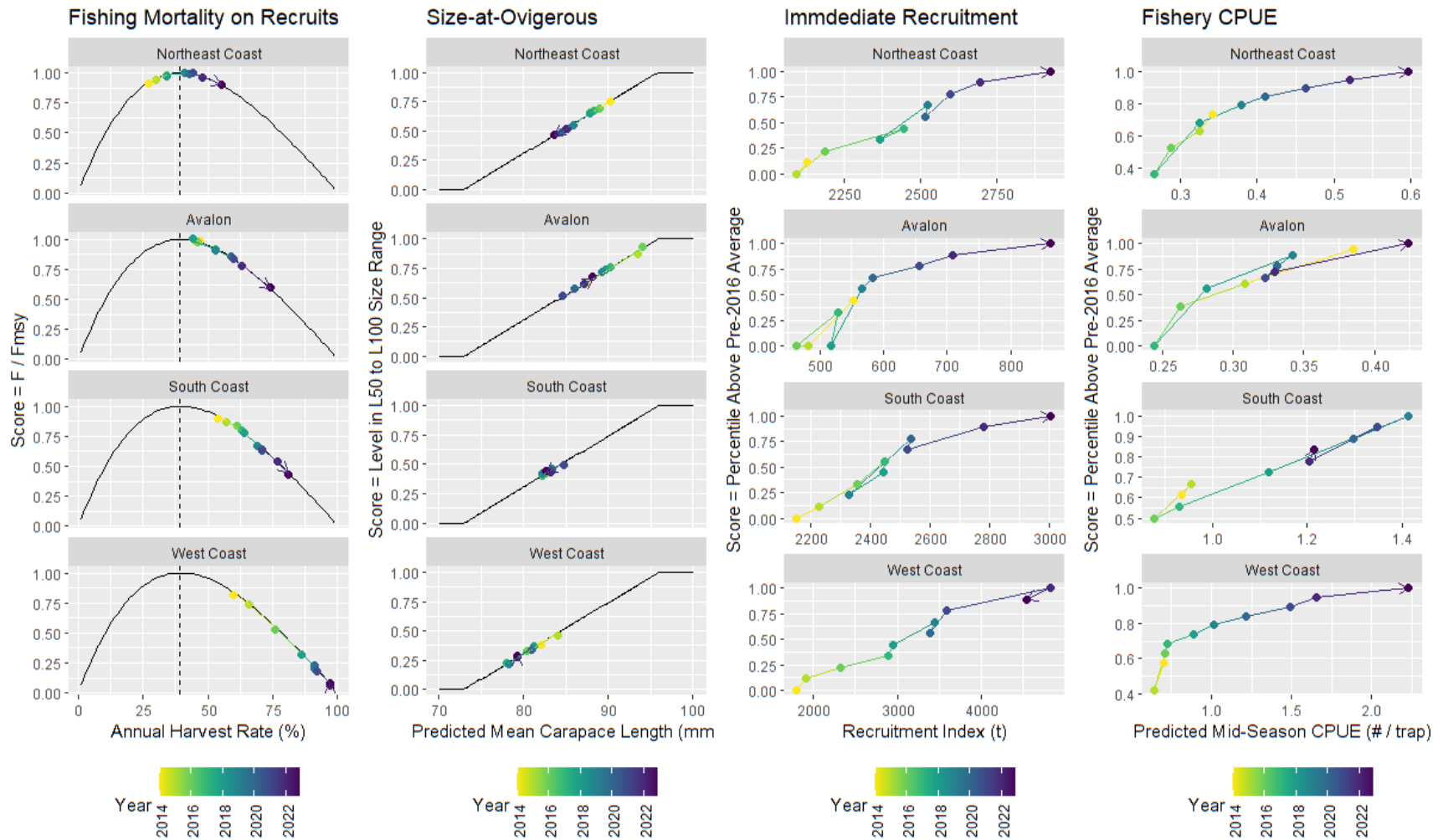


Figure 54. Four indicators of lobster stock health, left to right: fishing mortality of recruits, predicted mean carapace length of size at ovigerous (mm), immediate recruitment index (t), and mid-season CPUE (#/trap) from 2005 to 2023 in each of the four Assessment Regions off Newfoundland (Northeast Coast, Avalon, South Coast, and West Coast). Each indicator is shown in relation to its health score through time.

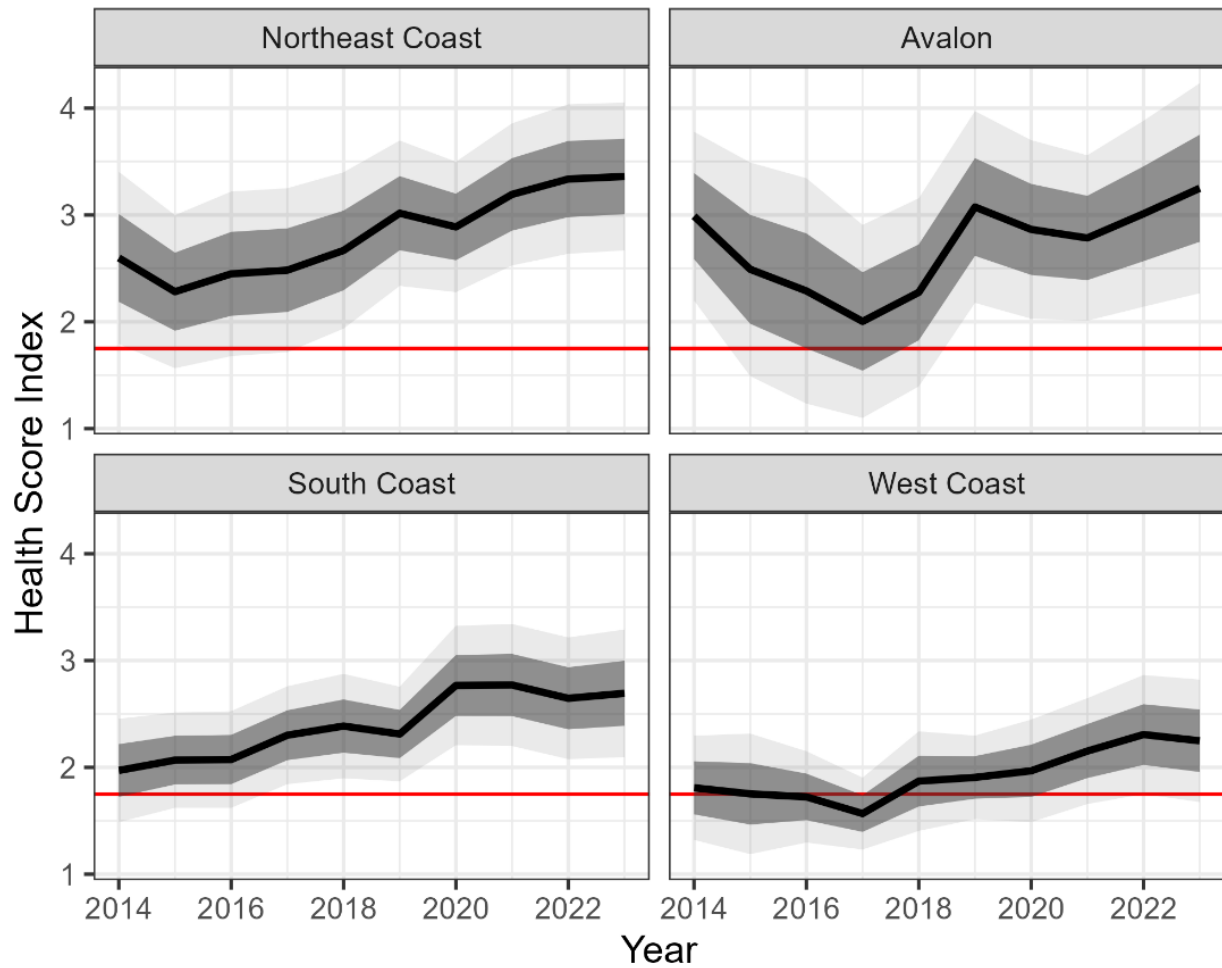


Figure 55. The health score index (HSI) of American Lobster (solid black line) throughout the four Assessment Regions of Newfoundland (Northeast Coast – top left, Avalon – top right, South Coast – lower left, and West Coast – lower right) from 2005 to 2023. The horizontal red line depicts the limit reference point (LRP) and the shaded areas represent one and two standard deviations around the mean of the confidence interval of the HSI.

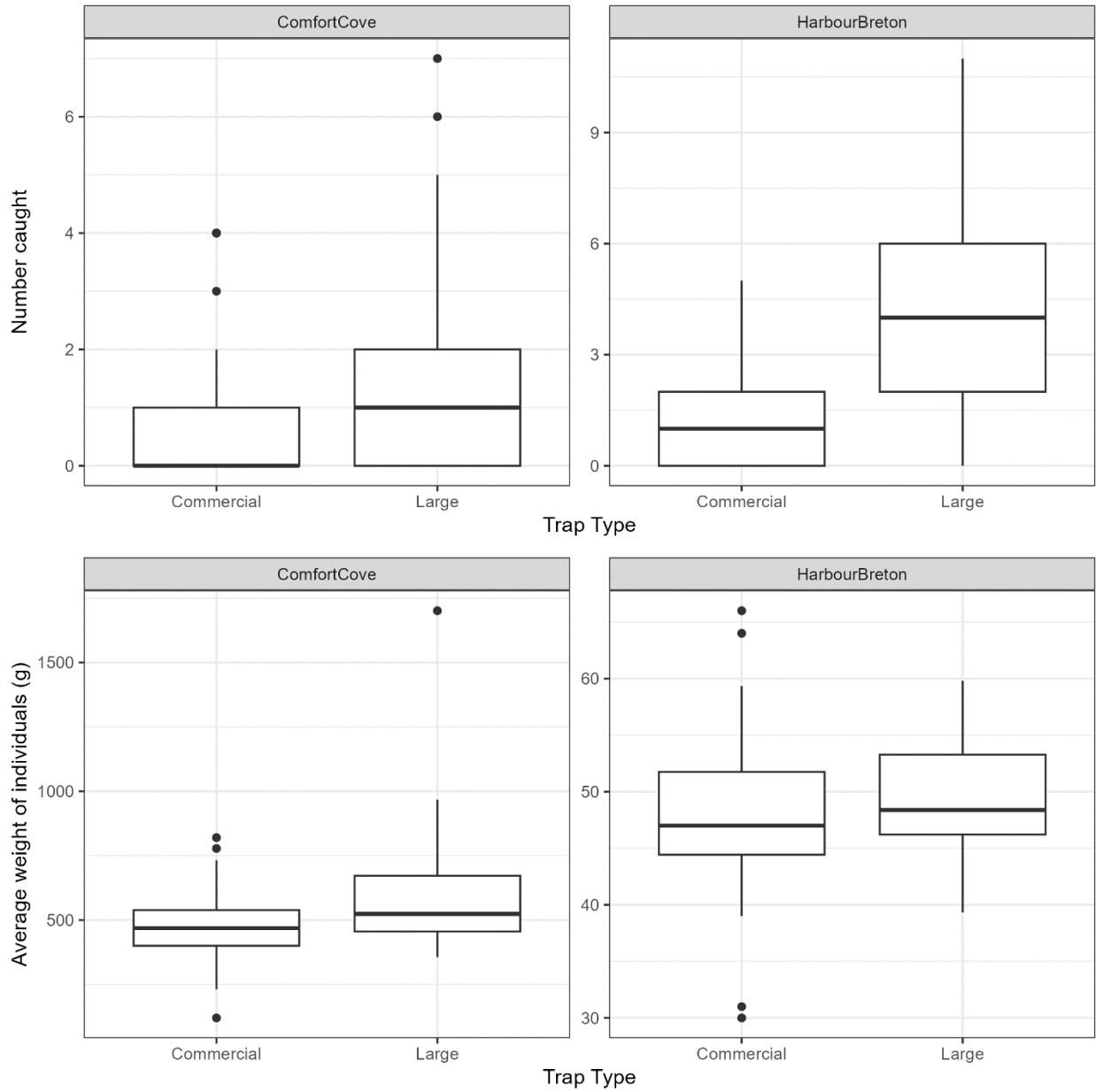


Figure 56. Boxplots of data from DFO lobster surveys completed during 2024 in Comfort Cove and Harbour Breton. Top row: Number of legal-sized lobster in conventional commercial traps and large (Nova Scotia) traps in Comfort Cove (left) and Harbour Breton (right). Bottom row: Average weight (g) of all lobster caught in conventional commercial traps and large traps in both bays.

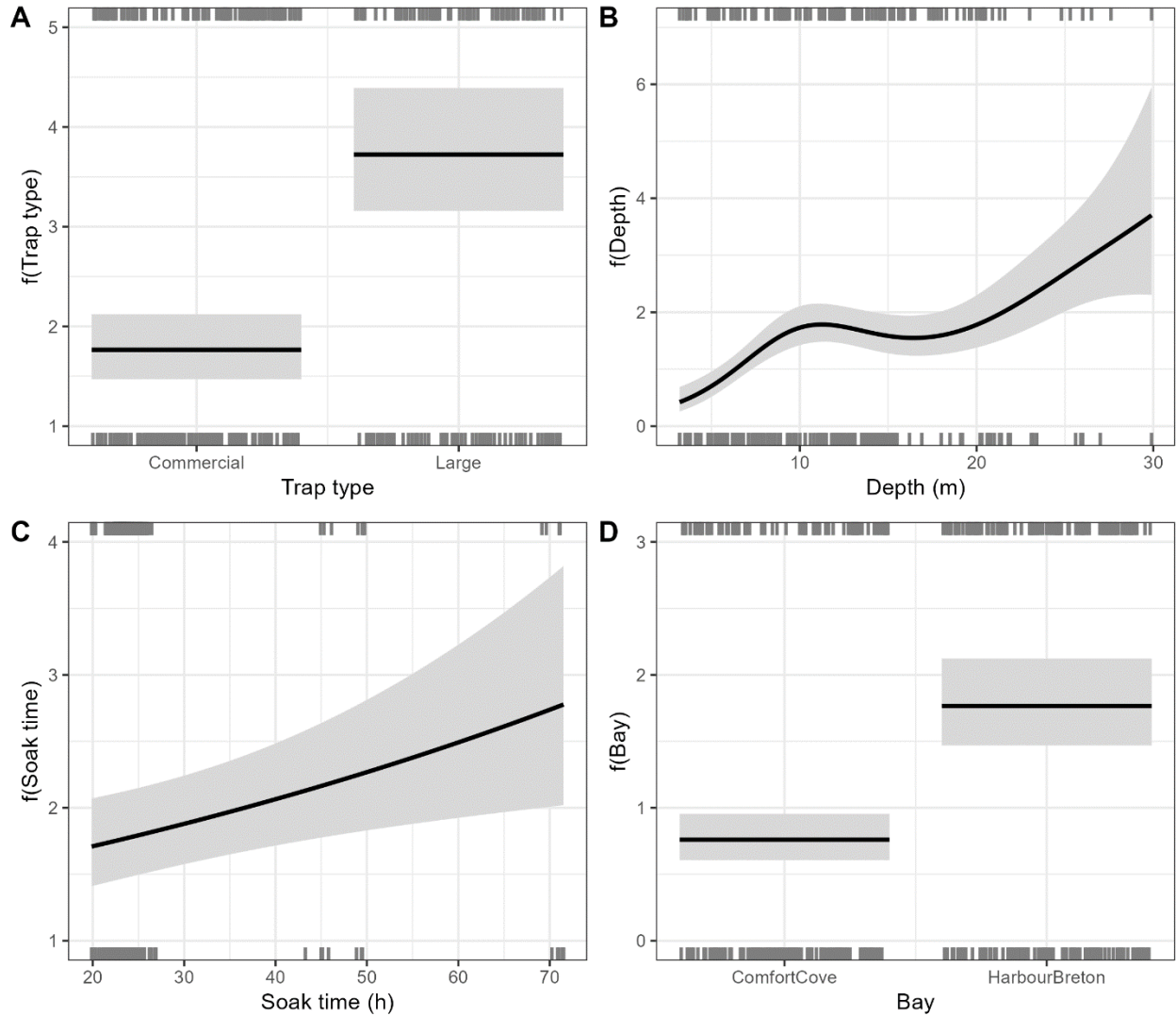


Figure 57. Conditional effect plots from the model predicting the number of legal-sized lobster caught in Comfort Cove and Harbour Breton surveys (2024). Trap type, depth (m), soak time (h) and Bay are shown. Conditional effects are depicted based on setting other categorical variables to their most common levels and other continuous variables to their median values. 95% confidence intervals include uncertainty of the intercept and rug lines highlight available predictor data.

8. TABLES

Table 1. Statistical output for total weekly trips per FIN model. R² is adjusted R² and RMSE is Root Mean Square Error. Total Trips GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	1.031	0.017	61.43	<0.01	-
te(year,week) x lfa3	-	-	5.57	<0.01	29.94
te(year,week) x lfa4A	-	-	13.63	<0.01	37.65
te(year,week) x lfa4B	-	-	8.61	<0.01	37.78
te(year,week) x lfa5	-	-	6.14	<0.01	65.49
te(year,week) x lfa6	-	-	3.75	<0.01	52.68
te(year,week) x lfa7	-	-	4.94	<0.01	67.89
te(year,week) x lfa8	-	-	4.31	<0.01	29.52
te(year,week) x lfa9	-	-	5.93	<0.01	48.33
te(year,week) x lfa10	-	-	3.36	<0.01	32.19
te(year,week) x lfa11	-	-	13.67	<0.01	79.04
te(year,week) x lfa12	-	-	17.14	<0.01	102.80
te(year,week) x lfa13A	-	-	10.33	<0.01	75.46
te(year,week) x lfa13B	-	-	8.26	<0.01	59.93
te(year,week) x lfa14A	-	-	11.73	<0.01	67.46
te(year,week) x lfa14B	-	-	9.15	<0.01	64.30
te(year,week) x lfa14C	-	-	6.77	<0.01	43.03
Num.Obs.	4618	-	-	-	-
R ²	0.762	-	-	-	-
RMSE	0.57	-	-	-	-

Table 2. Statistical output for weekly proportions of the fleet fishing model. R^2 is adjusted R^2 and RMSE is Root Mean Square Error. Proportion Fishing GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	-0.34	0.11	-3.22	<0.01	-
te(year,week) x lfa10	-	-	9.47	<0.01	53.87
te(year,week) x lfa11	-	-	9.36	<0.01	59.13
te(year,week) x lfa12	-	-	9.00	<0.01	43.65
te(year,week) x lfa13A	-	-	7.18	<0.01	72.10
te(year,week) x lfa13B	-	-	8.15	<0.01	67.31
te(year,week) x lfa14A	-	-	7.42	<0.01	66.66
te(year,week) x lfa14B	-	-	7.37	<0.01	81.55
te(year,week) x lfa14C	-	-	6.03	<0.01	56.32
te(year,week) x lfa3	-	-	6.58	<0.01	63.45
te(year,week) x lfa4A	-	-	7.44	<0.01	73.08
te(year,week) x lfa4B	-	-	7.67	<0.01	68.17
te(year,week) x lfa5	-	-	7.75	<0.01	72.08
te(year,week) x lfa6	-	-	8.28	<0.01	65.87
te(year,week) x lfa7	-	-	9.28	<0.01	50.62
te(year,week) x lfa8	-	-	7.67	<0.01	51.17
te(year,week) x lfa9	-	-	8.34	<0.01	50.88
Num.Obs.	3165	-	-	-	-
R^2	0.888	-	-	-	-
RMSE	0.09	-	-	-	-

Table 3. Statistical output for average weekly sales model. R^2 is adjusted R^2 , AIC is Akaike information criterion, BIC is Bayesian information criterion and RMSE is Root Mean Square Error. Average Sales GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	-3.012	0.019	-155.30	<0.01	-
te(year,week) x lfa10	-	-	9.10	<0.01	17.89
te(year,week) x lfa11	-	-	45.80	<0.01	20.30
te(year,week) x lfa12	-	-	26.08	<0.01	31.39
te(year,week) x lfa13A	-	-	24.32	<0.01	34.24
te(year,week) x lfa13B	-	-	24.70	<0.01	55.51
te(year,week) x lfa14A	-	-	13.03	<0.01	67.97
te(year,week) x lfa14B	-	-	15.36	<0.01	40.34
te(year,week) x lfa14C	-	-	10.81	<0.01	31.31
te(year,week) x lfa3	-	-	12.90	<0.01	34.39
te(year,week) x lfa4A	-	-	15.43	<0.01	18.91
te(year,week) x lfa4B	-	-	11.57	<0.01	27.79
te(year,week) x lfa5	-	-	17.76	<0.01	10.90
te(year,week) x lfa6	-	-	7.53	<0.01	61.42
te(year,week) x lfa7	-	-	12.51	<0.01	22.35
te(year,week) x lfa8	-	-	16.29	<0.01	59.59
te(year,week) x lfa9	-	-	9.58	<0.01	34.88
Num.Obs.	2469	-	-	-	-
R^2	0.823	-	-	-	-
AIC	-12269.3	-	-	-	-
BIC	-8777.0	-	-	-	-
RMSE	0.03	-	-	-	-

Table 4. Statistical output for CCIR mortality model in Northeast Coast AR. R^2 is adjusted R^2 and RMSE is Root Mean Square Error. Northeast Coast CCIR GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	0.904	0.065	13.86	<0.01	-
s(yearf)	-	-	3.73	<0.01	7.26
s(cumland)	-	-	25.89	<0.01	1.09
Num.Obs.	110	-	-	-	-
R^2	0.316	-	-	-	-
RMSE	0.06	-	-	-	-

Table 5. Statistical output for CCIR mortality model in Avalon AR. R^2 is adjusted R^2 and RMSE is Root Mean Square Error. Avalon CCIR GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	0.892	0.048	18.53	<0.01	-
s(yearf)	-	-	0.00	0.48	0.00
s(cumland)	-	-	15.81	<0.01	1.16
Num.Obs.	89	-	-	-	-
R^2	0.180	-	-	-	-
RMSE	0.09	-	-	-	-

Table 6. Statistical output for CCIR mortality model in South Coast AR. R^2 is adjusted R^2 and RMSE is Root Mean Square Error. South Coast CCIR GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	0.230	0.062	3.69	<0.01	-
s(yearf)	-	-	2.57	<0.01	6.75
s(cumland)	-	-	78.65	<0.01	1.15
Num.Obs.	107	-	-	-	-
R^2	0.581	-	-	-	-
RMSE	0.07	-	-	-	-

Table 7. Statistical output for CCIR mortality model in West Coast AR. R^2 is adjusted R^2 and RMSE is Root Mean Square Error. West Coast CCIR GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	0.20	0.27	0.72	0.47	-
s(yearf)	-	-	6.95	<0.01	8.56
s(cumland)	-	-	85.59	<0.01	1.07
Num.Obs.	81	-	-	-	-
R^2	0.638	-	-	-	-

-	Est.	Std.Error	f-value	p-value	Error.DF
RMSE	0.10	-	-	-	-

Table 8. Statistical output for size at ovigerous model in Northeast Coast AR. R^2 is adjusted R^2 , AIC is Akaike information criterion, BIC is Bayesian information criterion and RMSE is Root Mean Square Error. Ovigerous Mean Size Northeast Coast GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	82.50	0.54	153.58	<0.01	-
te(month,year)	-	-	12.73	<0.01	3.49
Num.Obs.	62	-	-	-	-
R^2	0.702	-	-	-	-
AIC	268.1	-	-	-	-
BIC	318.6	-	-	-	-
RMSE	1.43	-	-	-	-

Table 9. Statistical output for size at ovigerous model in Avalon AR. R^2 is adjusted R^2 , AIC is Akaike information criterion, BIC is Bayesian information criterion and RMSE is Root Mean Square Error. Ovigerous Mean Size Avalon GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	85.95	0.85	101.41	<0.01	-
te(month,year)	-	-	11.47	<0.01	2.98
Num.Obs.	51	-	-	-	-
R^2	0.469	-	-	-	-
AIC	263.0	-	-	-	-
BIC	305.9	-	-	-	-
RMSE	2.06	-	-	-	-

Table 10. Statistical output for size at ovigerous model in South Coast AR. R^2 is adjusted R^2 , AIC is Akaike information criterion, BIC is Bayesian information criterion and RMSE is Root Mean Square Error. Ovigerous Mean Size South Coast GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	78.48	0.37	213.70	<0.01	-
te(month,year)	-	-	24.27	<0.01	6.16
Num.Obs.	59	-	-	-	-
R^2	0.814	-	-	-	-
AIC	173.8	-	-	-	-
BIC	228.6	-	-	-	-
RMSE	0.68	-	-	-	-

Table 11. Statistical output for size at ovigerous model in West Coast AR. R^2 is adjusted R^2 , AIC is Akaike information criterion, BIC is Bayesian information criterion and RMSE is Root Mean Square Error. Ovigerous Mean Size West Coast GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	79.55	0.51	157.08	<0.01	-
te(month,year)	-	-	11.66	<0.01	6.01
Num.Obs.	51	-	-	-	-
R^2	0.653	-	-	-	-
AIC	223.4	-	-	-	-
BIC	274.1	-	-	-	-
RMSE	1.29	-	-	-	-

Table 12. Statistical output for fishery CPUE standardization model in Northeast Coast AR. R^2 is adjusted R^2 and RMSE is Root Mean Square Error. Fishery CPUE Standardization Northeast Coast GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	-1.187	0.054	-21.97	<0.01	-
lfa_f4A	-0.113	0.052	-2.18	0.03	-
lfa_f4B	0.014	0.053	0.27	0.79	-
lfa_f5	-0.024	0.056	-0.42	0.67	-
lfa_f6	-0.075	0.054	-1.37	0.17	-
sourceFFAW	-0.0664	0.0069	-9.66	<0.01	-
s(year)	-	-	2466.83	<0.01	8.98
s(cday)	-	-	520.45	<0.01	8.92
ti(year,cday)	-	-	79.44	<0.01	14.61
s(fin_f)	-	-	36.85	<0.01	1191.11
Num.Obs.	136673	-	-	-	-
R^2	0.383	-	-	-	-
RMSE	0.21	-	-	-	-

Table 13. Statistical output for fishery CPUE standardization model in Avalon AR. R^2 is adjusted R^2 and RMSE is Root Mean Square Error. Fishery CPUE Standardization Avalon GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	-1.504	0.048	-31.08	<0.01	-
lfa_f7	0.20	0.07	2.87	<0.01	-
lfa_f8	0.305	0.078	3.90	<0.01	-
lfa_f9	-0.46	0.12	-3.79	<0.01	-
sourceFFAW	-0.023	0.011	-2.05	0.04	-
s(year)	-	-	146.25	<0.01	8.96

-	Est.	Std.Error	f-value	p-value	Error.DF
s(cday)	-	-	29.36	<0.01	8.98
ti(year,cday)	-	-	20.25	<0.01	15.14
s(fin_f)	-	-	32.99	<0.01	452.43
Num.Obs.	54168	-	-	-	-
R ²	0.298	-	-	-	-
RMSE	0.22	-	-	-	-

Table 14. Statistical output for fishery CPUE standardization model in South Coast AR. R² is adjusted R² and RMSE is Root Mean Square Error. Fishery CPUE Standardization South Coast GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	-0.27	0.94	-0.29	0.77	-
lfa_f12	0.0051	0.0140	0.36	0.72	-
sourceFFAW	0.0155	0.0048	3.23	<0.01	-
s(year)	-	-	3998.40	<0.01	8.96
s(cday)	-	-	3485.27	<0.01	8.97
ti(year,cday)	-	-	147.01	<0.01	15.20
s(fin_f)	-	-	109.12	<0.01	543.42
Num.Obs.	136243	-	-	-	-
R ²	0.497	-	-	-	-
RMSE	0.52	-	-	-	-

Table 15. Statistical output for fishery CPUE standardization model in West Coast AR. R² is adjusted R² and RMSE is Root Mean Square Error. Fishery CPUE Standardization West Coast GAM.

-	Est.	Std.Error	f-value	p-value	Error.DF
(Intercept)	-1.00	0.78	-1.28	0.20	-
lfa_f13B	-0.128	0.032	-4.04	<0.01	-
lfa_f14A	0.108	0.055	1.95	0.05	-
lfa_f14B	0.087	0.042	2.05	0.04	-
lfa_f14C	0.163	0.046	3.53	<0.01	-
sourceFFAW	0.2122	0.0078	27.17	<0.01	-
s(year)	-	-	6193.43	<0.01	8.98
s(cday)	-	-	1753.07	<0.01	8.91
ti(year,cday)	-	-	113.08	<0.01	15.75
s(fin_f)	-	-	43.08	<0.01	894.33
Num.Obs.	142872	-	-	-	-
R ²	0.533	-	-	-	-

-	Est.	Std.Error	f-value	p-value	Error.DF
RMSE	0.59	-	-	-	-