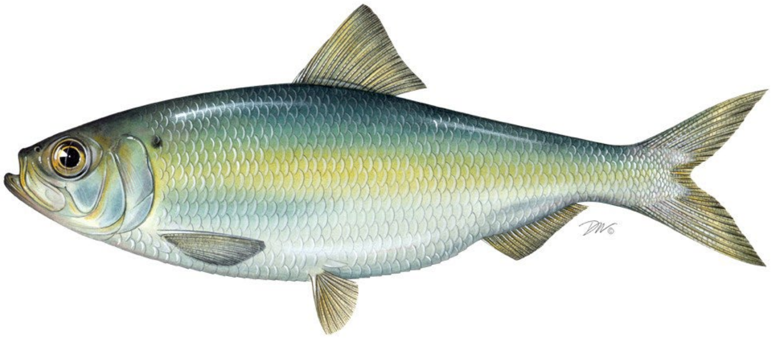
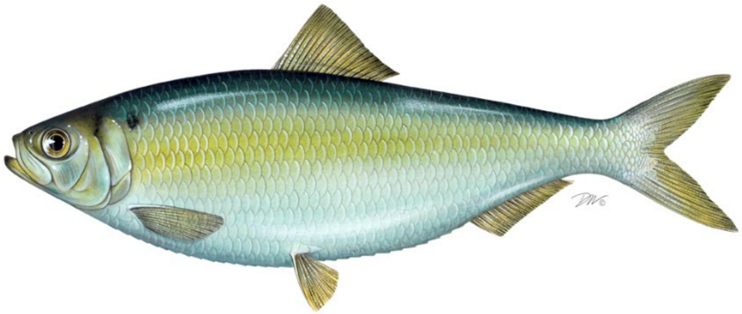
Atlantic States Marine Fisheries Commission

River Herring Benchmark Stock Assessment and Peer Review Report





Accepted for Management Use
by the Shad and River Herring Management Board
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Sustainable and Cooperative Management of Atlantic Coastal Fisheries

ACKNOWLEDGEMENTS

The Atlantic States Marine Fisheries Commission thanks all of the individuals who contributed to the development of the river herring stock assessment, specifically the ASMFC River Herring Technical Committee and Stock Assessment Subcommittee members who developed the consensus stock assessment report as well as the Atlantic Coastal Cooperative Statistics Program staff Adam Lee for validating landings.

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PREFACE

The River Herring Benchmark Stock Assessment and Peer Review Report is divided into three sections:

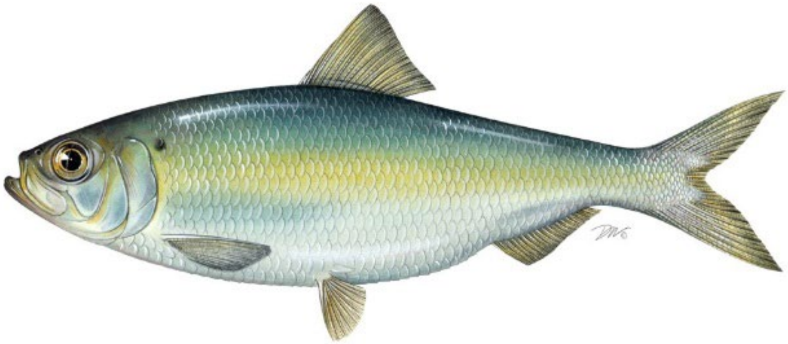
Section A – River Herring Benchmark Stock Assessment Peer Review
PDF pages 4-24
This section provides a summary of the River Herring Benchmark Stock Assessment results supported by the Peer Review Panel. The Terms of Reference Report provides a detailed evaluation of how each Term of Reference was addressed by the Stock Assessment Subcommittee and provides recommendations from the Panel for further improvement of the model in the future.

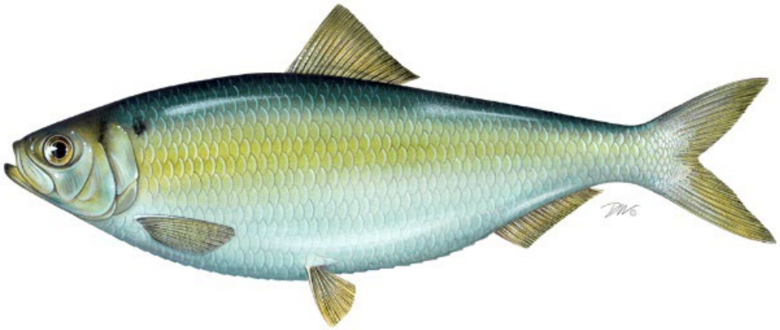
Section B – River Herring Benchmark Stock Assessment
PDF pages 25-499
This section is the River Herring Benchmark Stock Assessment report that describes the background information, data used, and analysis for the assessment submitted to the Peer Review Panel. This report begins with a Term of Reference Report which describes how the Stock Assessment Subcommittee addressed each Term of Reference followed by the more detailed assessment report.

Section C – Appendices
Appendices 1-4 provide more comprehensive descriptions of methods and results from analyses used in the assessment, including index standardization, the ARIMA analysis, the growth model, and the statistical catch-at-age models. Appendices 5-7 present analyses and information that were requested by the Peer Review Panel during the Review Workshop, including a modification to the calculation of the standard error of the total mortality (Z) estimates, a table of survey metadata, and a set of figures showing sample size for the Z calculations.

Atlantic States Marine Fisheries Commission

River Herring Benchmark Stock Assessment Peer Review





Conducted on June 4-7, 2024

Prepared by the River Herring Benchmark Stock Assessment Peer Review Panel

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Sustainable and Cooperative Management of Atlantic Coastal Fisheries

ACKNOWLEDGEMENTS

The Review Panel gratefully recognized the work conducted by the River Herring Stock Assessment Subcommittee and Technical Committee in preparing the 2024 Benchmark Assessment. The Panel also appreciated the professional, open, and constructive spirit of discussion during the review workshop. The Review Panel thanks the Science staff of the Atlantic States Marine Fisheries Commission for organizing the workshop, and providing review materials in a timely fashion.

EXECUTIVE SUMMARY

River herring stocks remain depleted from a coastwide perspective, with a decade or more of effort in restoration and moratoria not leading to improved status. Trend analysis demonstrated there has been little improvement in populations; most trajectories were flat although high variability resulted in low power to detect trends. No official statement was made regarding current rates of mortality. The assessment employed a stochastic Spawner Per Recruit (SPR) modeling framework to estimate the total mortality (Z) that would reduce the population spawning biomass to 40% of the unfished level (Z40%). Based on this reference point, the terminal year mortality rate had a 50% chance of being above the reference point for 50% of blueback populations and 65% of alewife populations. Mortality rates were high across a number of harvested runs. In addition, a forward projecting statistical catch-at-age model for Monument River (MA) alewife that predicts numbers at age by sex and maturity stage from total in-river catches, escapement counts, and escapement age composition, suggested that at-sea mortality was high. With incidental catch now representing the largest source of fisheries mortality on the population, the high mortality rates create a need to improve the monitoring and modeling of bycatch and improve the efficacy of the current catch caps. The assessment explored data-based catch-cap setting tools and the panel encourages continued effort to improve the monitoring and modeling of bycatch towards improving outcomes.

Data standardization and survey methodology, as well as species identification, and bycatch accounting remain issues and are significant impediments to producing a more data-rich assessment. The panel strongly supports expanded monitoring and effort to better track sources of mortality to region, if not river, specificity.

Overall, the review panel supports the current methodology, analyses, and interpretation of results, and recommends the assessment as the most current and best available science.

TERMS OF REFERENCE

1. Evaluate the choice of stock structure

River herring challenge many of the conventional perspectives on stock structure, since there is weak river-to-river structure based on genetic studies, state-level rule making and regional oversight through the ASMFC, while most management actions are focused at the individual river level. The panel had questions about the use of the genetic data, based on limited years and many systems located close to the same river mouth, especially in southern data. Ultimately, the structure based on genetically-defined stock regions was helpful for organizing the assessment report, but each river functionally is its own stock.

The genetic analysis suffers from a couple of issues with respect to being used to define stock management units. First, the fish collections were composed of 137 collections taken from 99 locations (n=5678). Thus, temporal replicates were available for 28 locations. While temporal stability was present for most rivers capable of being evaluated, there were generally not multi-annual samples for most sites. Still, the panel is satisfied with the level of sampling for the conclusion of genetic regional groupings. Additionally, stocking influence and lack of complete coverage of all river herring populations means that precise geographic partitioning is difficult and confounded by human interventions.

Threats to river herring and restoration of populations are river specific in nature, and as a result the genetic groupings are practical for organizing regional runs, but are not an effective scale for management actions. How to lump rivers will remain a challenge until a more robust approach for regional groupings based on genetics is completed, with expanded sampling and repeated sampling of sites. The panel had discussions around the likelihood of straying within closed bays such as Albemarle Sound, Chesapeake Bay and other particularly southern sites that all grouped together genetically. Straying remains a question in the population structuring or river herring, and has important consequences for the ability of the species to respond with potential range shifts due to climate change (Poulet et al. 2023).

It will also be important to account for the influence of recovery actions on underlying stock structure for river herring, if regional groupings continue to be based on genetic analyses. The SAS was not able to quantify transfers among rivers or regions from historical stocking as detailed information on supplementation programs was not available for the assessment. Although trap and transfer as well as hatchery programs seem to be declining due to smaller run sizes in donor rivers, these types of restoration activities can affect the strength of genetic differentiation among rivers, both by increasing straying rates and through hybridization (Quinn 1993; Koch and Narum 2021). It will be important to have more detailed accounting on donor and recipient rivers to track genetic effects of any future supplementation to ensure regional distinctions and population structure among rivers are maintained.

Thus, we support use of regional groupings based on genetic clusters but believe individual or perhaps adjacent rivers are the primary stock unit. This is consistent with how the status update tables summarize river specific trends in the assessment report.

2. **Evaluate the thoroughness of data collection and the presentation and treatment of fishery-dependent and fishery-independent data in the assessment.**
    a. Presentation of data source variance (e.g., standard errors).
    b. Justification for inclusion or exclusion of available data sources.
    c. Consideration of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivity, aging accuracy, sample size).
    d. Calculation and/or standardization of abundance indices.
    e. Estimation of bycatch.

General Statements

There were panel questions about the reporting of coefficients of variation (CVs) from the different indices, and whether they could be compared between GLMs and GAM model-based standardization or nominal indices, such as the stratified arithmetic and delta mean. Indices used for trend analysis were chosen using consistent criteria, with each survey needing consistent data collection methods over the time series, or a way to calibrate between gear, vessel, or other changes, 10 consecutive years of data, and 10% of tows/hauls/sampling events were positive for alewife or blueback herring. Overall, the SAS did well to characterize uncertainty from so many different indices with different underlying methodologies and data structures. More clarity on which standardization approach was used for each data series would be helpful. The power analysis was perhaps more informative than the prevalence-based approach. For example, zeros were common in daytime sets of a purse seine and resulted in higher variability for daytime compared to nighttime density estimates (Devine et al. 2018).

Otherwise, there is also a question of the appropriateness of the Z error calculation with both over and underdispersion found in the data. Unfortunately, species identification issues remain a problem in surveys and the various indices, while useful, have low power to detect trends. Thus, it was not surprising that trends were not evident in many datasets. Sample sizes by age were not initially provided and the panel was concerned there were likely small numbers of fish age 5 and greater for estimating Z. Small differences in a low sample size for 6- and 7-year-olds would introduce substantial variability. Sample sizes were provided during the peer review workshop and should be made available for future assessments. The detailed information supported concerns about low sample sizes in select systems at the annual scale.

Gear selectivity has not been considered, and may be important particularly in the Northeast Fishery Observer Program (NEFOP) data. Because of the deep body of river herring, they are likely retained at different sizes than Atlantic herring. Understanding selectivity would provide improved understanding of survey indices and observer data from otter trawl and midwater trawl fisheries. The panel had questions about whether ratio-based expansions to the fleet would be appropriate as bycatch estimators for pelagic schooling fish with strong seasonal patterns in availability (see more detail below).

The panel feels the SAS did as good a job as possible in accumulating all the data on river herring from both fisheries dependent and independent sources. Significant data limitations remain an issue for these stocks, particularly with the lack of standardized methods for ageing and abundance indices. There are essentially only a handful of river herring focused surveys. Species identification in reported landings, and in most historical data sources, as well as current harvested runs in Maine, remains problematic for allocating catch to each of the two species. The lack of genetic assignments of bycatch over time is also an issue with current discards.

Fishery-dependent Data

Commercial Landings

Commercial landings data for years prior to 1950 came from the US Fish Commission reports, and for 1950-2022 came from the Atlantic Coastal Cooperative Statistics Program (ACCSP). States had a variety of reporting strategies associated with river herring commercial fisheries that were initiated in different years. It was not always clear whether all data were from ACCSP, or whether they were maintained independently. The majority of States have enacted moratoria on harvest, except Maine, New York (Hudson River only) and South Carolina.

Recreational fisheries data are collected through surveys, online and intercept, through the Marine Recreational Information Program (MRIP). As a result, river and freshwater recreational catch is unmonitored, including during spawning when use of river herring as bait is most likely. While recreational harvest needs better accounting, it is not likely to be at an equivalent scale relative to marine discards or the limited directed fisheries. Riverine monitoring should be the focus of any future recreational harvest research.

Port-side sampling

Probably the most important aspect of incidental catch is that it has become the highest individual source of fishing mortality on river herring. Thus, understanding total mortality into the future will be contingent on better sampling of the fisheries with incidental bycatch of river herring. A short-term multi-year study from Massachusetts is mentioned here as recognition that, since the primary pelagic fisheries that catch river herring are full retention fisheries, there would be great value in maintaining some level of monitoring that can identify fish to species level. Genetic assignment would be an extremely valuable addition to port sampling to understand the impacts of bycatch on the regional stock groupings.

Incidental catch

Incidental catch is collected as part of the Northeast Fishery Observer Program, although sampling effort is mostly directed to the northeast multispecies groundfish complex. The lack of spatial coverage in the midwater trawl fishery, and pelagic fisheries in general, as well the resulting estimation method for bycatch (see below) were identified by the review panel and in the public comment period as a source of uncertainty. As the northeast multispecies groundfish fishery has high levels of observer coverage, more uncertainty is found in the midwater trawl pelagic fisheries. It is important to note that bottom trawl catch was a substantial source of incidental catch over the time series, with large catches in some years (Fig. 13-Fig. 14).

The SAS quantified incidental catches (retained and discarded) of alewife and blueback herring from fleets sampled by the Northeast Fishery Observer Program, considering numerous gear types and multiple mesh sizes for trawls and gillnets. There was a recent switch in data systems, with information coming from GARFO with bycatch estimated through SBRM from 1989-2019 and then using CAMS in 2020-2022. The SAS went to considerable effort to standardize the fleet definitions among the two data sources to ensure annual values were comparable. Bycatch from each fleet was estimated using the combined ratio method of Wigley et al. (2007), stratified by region, year, quarter, gear group, and mesh size, while CAMS uses the separate ratio method. In general, the ratio represented the total catch of alewife or blueback herring divided by the kept weight of all species (t/k ratio), where data were imputed from the next closest time period for each gear-region combination if there were no observed catches of river herring in a specific quarter. Total landed weight from dealer slips was used as the raising factor to expand the t/k ratios to total incidental catch, except for mid-water trawl, where the captain's hail estimate from VTR data was used. Compared to landings and recreational catches, bycatch makes up a substantial proportion of total fisheries removals in recent years.

The ratio method has a long history of application in stock assessments, so the SAS did not evaluate the appropriateness of the underlying assumptions for river herring. Specifically, whether alewife or blueback herring catches were proportional and linearly related to total kept catch for each fleet and strata (region, year, quarter, gear group, mesh size). The appendices showing validation plots from various bycatch estimators from Wigley et al. (2006) were provided to the review panel to demonstrate that the assumption of linearity tended to hold. However, the predictive ability of catch ratios for river herring was not assessed.

Since the development of the combined ratio method, there has been substantial progress applying spatial modeling or machine learning tools to observer data to estimate bycatch (Stock et al., 2019, 2020; Yan et al., 2022). Unlike ratio estimators, the more complex methods can account for non-linearity, excess zeros, as well as any underlying correlation structure in catches arising from environmental, ecological, and biological factors. Different bycatch estimators could be compared relative to predictive ability, where the preferred approach would have the lowest root-mean-square-error in cross-validation (e.g., Stock et al. 2020). For river herring, appropriate implementation of the bycatch cap as well as quantifying total fishing mortality critically depend on the precision of bycatch estimates. Therefore, we recommend the ratio estimator be validated with respect to river herring in the shorter term, and further investigation of alternative bycatch estimation approaches in the longer term. Uncertainty in the impacts of bycatch on river herring stocks remains a key issue in the assessment. Given its importance for developing catch caps, the bycatch estimation techniques should receive additional attention and review.

Fishery-independent Data

Run-counts are conducted in numerous states using either electronic fish counters or at fishways. In all but one instance (Monument River, MA), the run-count data do not represent escapement estimates given removals upstream of the enumeration site. Associated biological data collection is required to separate counts to species as well as to monitor length and weight, to take scale or otolith samples for ageing and to characterize maturity and previous spawning history from scales. The review panel appreciated the diversity of sampling programs and urged the SAS to keep working towards better standardization of sampling methods among agencies. In the current assessment, it was challenging to understand precisely how observations were scaled up to daily abundance estimates and how biological sampling was distributed over the run (e.g., proportional to daily counts?). The review panel could not comment on whether sampling was likely to be representative of run characteristics, which influences all subsequent analyses in the assessment. Continued emphasis on biological sampling in association with run counts should be prioritized, and initiating biological data collection on rivers with only counts would be beneficial to future assessment efforts.

Fishery-independent Surveys

The assessment team identified a wide variety of surveys that intercepted one or more life stages of river herring. These included ocean, estuarine, and in-river surveys using trawls, seines, and trapnets. The SAS considered overall interception rates for alewife and blueback herring when including specific surveys in the assessment, discarding ones with extremely low catches of river herring, and/or retaining a subset of the available data (e.g., strata with > 10% positive tows).

Unfortunately, the majority of fishery-independent surveys represented sampling programs that were not specifically designed for river herring. Thus, there are very likely to be undetected issues in the sampling design that do not meet analytical assumptions when calculating abundance indices. For example, the stratification scheme used in the larger oceanic surveys may not result in lower in-stratum vs. among stratum variance (Smith and Gavaris, 1993). In other instances, repeated observations from the same site were treated as independent rather than autocorrelated samples. As with the run count data, whether or not sampling was truly representative and random was not possible to determine from the information presented in the assessment, where the temporal structure of river herring runs (Gibson et al. 2016) makes true random sampling very challenging. The panel considered it likely that undetected autocorrelation, sampling biases, and undetected heterogeneity in river herring observations were prevalent in the data used to calculate abundance indices.

The SAS compared multiple analytical approaches for developing fishery-independent indices from the available data, including design-based and model-based estimators. A key criterion used to select among options was the relative magnitude of the series CV, with approaches resulting in lower CVs considered optimal. However, we consider it inappropriate in this application to base model selection on a comparison of CVs. Design-based approaches rely on a specific sampling scheme to select units of observation from the underlying population. Their implementation does not require inherent knowledge of the factors causing variability in the population (Cotter and Pilling, 2007). Model-based estimators do not make assumptions about the sampling process generating the data, but inference relies on identifying and incorporating all relevant variables that describe the population response. Models thus seek to balance an explicit trade-off between capturing the maximum amount of variability, while minimizing model complexity (i.e., the bias-variance trade-off; Dumelle et al. 2022).

In fisheries applications such as this one, knowledge and availability of important explanatory variables may be limited, and practical constraints will exert influence over any sampling design. Because the derivation of variance metrics does not encompass statistical prediction uncertainties from model mis-specifications (Hordyk et al., 2019), they are not comparable among different analytical approaches. In other words, we do not know how strongly specific assumptions are violated in the calculation of each fishery-independent index, so it becomes inappropriate to use the relative magnitude of the CV for model selection. Design-based estimators typically have lower variance as compared to model-based, which was confirmed with the SAS and demonstrated by the relative frequency that design-based indices were selected for inclusion in the assessment report.

We recommend that the magnitude of the CV should not be used for selection when both design-based and model-based approaches are compared. Instead, the SAS should attempt to evaluate the characteristics of the data arising from a specific sampling scheme to determine if design-based estimators are appropriate. Alternatively, they should consider the availability of appropriate covariates if pursuing model-based approaches. As it stands, the report inadvertently suggests that specific indices are much less variable than others, even though that impression directly depends on which analytical approach was selected.

Standardizing Techniques

There remain a number of areas in the assessment where methods lack standard protocols across the range that make comparisons difficult. There were two specific issues regarding standardized techniques. The first is species identification. A number of river herring runs still need better species assignment. The panel was concerned over the lack of individual species monitoring. We suggested more biological sampling or the use of scales for ID of species, for proper accounting as part of any sustainable harvest plan, and for State monitoring efforts. Scale collections from runs were not associated with a specific protocol. There was concern across all sites that improper sampling of the run, for example missing the first fish or few samples from mid-run, could result in a bias to smaller and younger individuals. Few details were available for the sample distribution over the spawning run.

The report states "Although used extensively, these protocols have not been validated with known-age river herring. A 2014 aging workshop for river herring found CVs greater than 5% across labs, and systematic bias across readings from paired scales and otoliths." This admission of issues with diverse ageing processes taken in every state, and the lack of agreement in ages, is of concern to the panel. It was not clear how consistent the agers were, even for each dataset.

3. **Evaluate the methods and models used to estimate population parameters (e.g., Z, biomass, abundance), biological reference points, and bycatch caps/limits, including but not limited to:**
    a. Evaluate the choice and justification of the preferred model(s). Was the most appropriate model (or model averaging approach) chosen given available data and life history of the species?
    b. If multiple models were considered, evaluate the analysts' explanation of differences in results.
    c. Evaluate model parameterization and specification (e.g., choice of CVs, effective sample sizes, likelihood weighting schemes, calculation/specification of M, stock-recruitment relationship, choice of time-varying parameters, plus group treatment).
    d. Evaluate the diagnostic analyses performed, including but not limited to:
        - Sensitivity analyses to determine model stability and potential consequences of major model assumptions.
    e. Evaluate the methods used to characterize uncertainty in estimated parameters. Ensure the implications of uncertainty in technical conclusions are clearly stated.

The SAS conducted a range of analyses to evaluate population trends and statuses. Estimation of total mortality (Z) reference points from SPR analysis (see also TOR 5) by stock region required estimates of length-, weight-, maturity-, natural mortality-, and selectivity-at-age. The SAS also conducted trend analysis on a variety of estimates, including survey CPUE and run sizes, mean length, and mean length-at-age at the river level. Trends were evaluated using two methods: the non-parametric Mann-Kendall test for monotonic trends, and auto-regressive, integrated moving average (ARIMA) models. Mann-Kendall tests were applied for the whole time series, and since 2009 or later if the time series started after 2009. ARIMA models were also applied to the catch per unit effort (CPUE) and run size estimates using the entire time series. Previously-developed statistical catch at age assessment models were updated for three rivers.

Analyses for the Estimation of Total Mortality Reference Points

Growth

The SAS developed a hierarchical Bayesian von-Bertalanffy growth model (VBGF) to estimate length-at-age at different spatial scales, including coastwide, stock region, and individual rivers, accounting for the impacts of aging method (scales or otoliths) and sex. Uncertainty in parameter estimates were derived from the posterior distributions for each parameter.

Results from the analysis indicated females were consistently larger than males at a given age, and that scales resulted in a lower maximum size ($L\infty$) compared to otoliths. While there were differences across rivers in growth estimates, there were no consistent patterns across rivers spatially.

The panel noted this was a thorough and well-done modeling effort, but suggested future exploration of changes in growth over time was warranted. Due to the current runtime of the model, the Panel recommended preliminary explorations that looked at time blocks as opposed to years, and estimating parameters initially at broader spatial scales (coastwide or stock region) to see if there is a temporal influence. It was noted that priors were based on a subset of the data, in order to improve model runtime. Specifically, in the assessment report (page 112) it reads “variances for all hyper-parameters were specified using half student-t priors with 3 degrees of freedom, a mean of zero, and a scale parameter (ν) derived from the data for each species.” The Panel questioned this approach, and worried that differences among rivers were largely an artifact of variability arising from low river-specific sample size and the effect of the assumed priors, rather than capturing real life history differences among populations. The Panel feels discussion of the potential impacts of the approach versus other priors is warranted. Sensitivity analyses could be conducted to discern the impact of this assumption.

Natural Mortality (M)

Estimates of weight-at-age were used to estimate M-at-age using the Lorenzen (1996) method. The panel noted Lorenzen was a widely-used and reasonable approach to estimate M. Uncertainty in M was based on uncertainty in weight-at-age, as well as the uncertainty in the parameters relating weight- and M-at-age estimated by Lorenzen (1996). Age-based estimators of M were also discussed by the panel. However, reliance on a maximum age estimate may be problematic based on the sampling design, the portion of the run sampled, and the magnitude of uncertainty in age assignments. The panel felt overall this was a useful approach to calculate M with uncertainty. However, the panel also noted the details were limited in the assessment report on the estimation of the length-weight relationship and uncertainty in the parameters.

Maturity

Proportion mature-at-age was estimated following the approach of Maki et al. (2001) that is based on spawning marks in scales. The approach requires assumptions about ages of full maturity and immaturity, and the SAS assumed all fish younger than 3 were immature, and all fish older than 5 were mature. Thus, the proportion mature at ages 3-5 was estimated for each species by sex at the area grouping level. The SAS noted the method assumes equal survival between mature and immature fish.

However, the assumption is likely violated given the different sources of mortality faced by mature fish that return to freshwater to spawn. Uncertainty in maturity ogives by region were derived by bootstrapping of the Maki et al. (2001) approach, which produced standard errors for the proportion mature for ages 3-5. Overall, the panel felt this was a suitable approach for deriving sexual maturity ogives for alewife and blueback herring.

Selectivity

Estimation of selectivity-at-age by region was not possible at the river or stock region level due to limited information on in-river removals, as well as uncertainties in how the coastwide catch is distributed across individual stocks and ages within stock. As a result, selectivity-at-age was derived from the maturity-at-age estimates. The SAS assumed fully mature fish were fully selected in the fishery, and partially mature ages (3-5) had a selectivity proportion that was ≥ the maturity proportion for a given age. The SAS generated random selectivities by first drawing random maturities at age, then adding a uniform random variable to this proportion that was bounded to keep selectivity between the random maturity proportion and 1 for a given age. Then, they fit a logistic curve to approximate selectivity, and associated variability, for immature fish. While unconventional, the panel felt this was a reasonable attempt to characterize mortality for immature fish.

Z SPR-based Reference Points

The SAS developed stochastic SPR models to estimate the total mortality (Z) that would reduce the population spawning biomass to 40% of the unfished level (Z40%). The SAS discussed the possibility of other percentages, and based their selection of 40% on previous studies evaluating the question in a simulation framework. For each species and area grouping, 5,000 sets of parameters were drawn for M-, maturity-, selectivity-, and weight-at-age, and Z40% was calculated for each set. The parameter draws were independent and did not account for potential covariation among parameters. The panel noted that accounting for covariation might reduce the extreme right-skew in the distribution of the reference points and give a more representative estimate for the upper confidence interval. Parameter draws were based on joint distributions from individual rivers within the regional groupings, which resulted in some unusual distributions for some inputs (e.g., bimodal L_∞ for an area), and also provided even weight to rivers within the regional groupings. Although the panel had concerns about these issues, overall, they concluded it was a reasonable approach to calculate Z reference points with uncertainty.

Z Estimates

The SAS calculated total mortality (Z) over time across rivers with sufficient age information for comparison with the Z40% reference points. They explored using the Chapman Robson method for estimating Z, but ultimately used a Poisson GLM model based on the analysis of Nelson (2019) who showed it was one of the least biased methods under multi-stage cluster sampling. They assumed the first age at full selection was five, corresponding to the age of full maturity, and included rivers that had at least 3 ages with a minimum of 30 fish total. Uncertainty in Z estimates were based on the standard error estimated from the Poisson model.

The panel felt this was a useful approach overall, but there were some concerns identified. First, the Poisson model included a correction for overdispersion that occasionally resulted in infinite standard errors, when data were actually underdispersed rather than overdispersed. The SAS attempted to address the issue and ultimately utilized an approach that ignored the correction factor when underdispersion occurred. The net result of the change was that standard errors were lower for both alewife and blueback, on average. The panel also noted the method of using catch-at-age in a given year is sensitive to cohort effects, which could result in estimates of Z biased either high or low. Also, due to run sampling timing, later sampling of younger spawners could produce Z estimates that were positively biased. The panel suggested exploration of the Sinclair (2001) method, to estimate Z across cohorts by aggregating data across three to five years and calculating a common slope and different intercepts for each cohort. Being able to use all of the age data rather than having to exclude information below the age of full selectivity could also be beneficial, particularly because sample sizes were low in some rivers. This was particularly important in the terminal year where small changes in numbers would have greater influence. The GLMM method developed by Billard (2020) that fits a catch curve using the number of previous spawnings, rather than age class, as the predictor variable in the regressions, and factoring the data by age at maturity. Applicability of the method would require non-negligible numbers of fish spawning three or four times to reliably fit the curve, similar to how the original catch curve method used at least three fully-selected age classes.

Last, by using data based on age 5+ fish, the analysis becomes restricted to only fully mature fish when natural mortality is expected to be at its lowest (Fig. 91-98). Mortality during younger age classes that contributed most to the observed run count is not able to be estimated, as the proportion of the adult spawning population is composed mostly of first-time spawners (Fig. 113-115, Fig. 132, Fig. 144, Fig. 174, Fig. 178, Fig. 191, Fig. 197, Fig. 215). Thus, the mortality rate represents only the oldest ages, and not the peak abundance exposed to bycatch.

Trend Analyses

The SAS conducted trend analyses on different sources of information using the Mann-Kendall non-parametric test for monotonic trends, and the auto-regressive integrated moving average (ARIMA) model. Both methods were applied to indices of abundance from surveys and run count data, and the Mann-Kendall method was also applied to mean length and length-at-age trends, and proportion of repeat spawners. For a given data set the Mann-Kendall test was applied for the full time series, and from 2009 onwards, to look at overall versus recent trends. Uncertainty was incorporated in the ARIMA model via bootstrapping to calculate the percentage of times the terminal year smoothed value was above the 2009 value, as well as the 25th percentile for the entire time period (reference points are discussed in more detail in ToR 5). Overall, the Panel felt the Mann Kendall and ARIMA methods were suitable for looking at trends over time.

Index Standardization

Survey indices-of-abundance were included in the trend analysis for surveys with consistent methodology over time, at least 10 years of consecutive data, and ≥ 10% positive tows for river herring in suitable strata, months, and stations. For stratified random design surveys, the stratified arithmetic mean was calculated for each year. For other surveys, the SAS explored the use of GLMs and GAMs with different covariates, as well as the delta and geometric mean. The SAS selected the delta mean over the geometric mean due to lower bootstrapped means overall, and only considered the model-based estimates if they reduced the interannual variability in the estimates. The Panel had some concerns about comparing CVs as a model selection tool, detailed under TOR 2.

Correlation Analysis

With indices of abundance, the SAS conducted pairwise Spearman's correlations by species and rivers within the regional grouping areas to look for consistent trends over time in indices used for trend analysis. Overall, there were few correlations within regions. The panel felt this was an interesting and useful analysis. There was some discussion that comparisons across all rivers and different indices might be interesting. One might expect rivers that are far apart, yet have similar remediation efforts, to be correlated in time.

MARSS Model

In addition to the pairwise correlation analysis, the SAS conducted a multivariate auto-regressive state space model (MARSS) to explore common trends in indices by region. Limited detail was provided regarding the model development and fitting. It was noted the MARSS approach was not pursued in great detail due to model fitting issues, including inconsistent trends within regions. The panel agreed that trying to identify patterns in rivers within regions was of great interest. However, an analysis that looked for trends across the entire region is also of interest, in part due to adjacent rivers being split between regions. Also, other factors may play a role at broader spatial scales (e.g., restoration efforts or development trends across rivers).

Power Analysis

The SAS conducted a power analysis following the method of Gerrodette (1987) to calculate the probability of detecting trends in abundance indices from the surveys. Specifically, they looked at the probability of detecting a ≥ 50% change over a 10 year period for both linear and exponential trends. The SAS noted this is not a retrospective power analysis often done after testing for a trend. Rather, it is a measure of the possibility of identifying a trend if one were to occur. The panel felt this was a very useful analysis, as it revealed a very low probability to detect significant trends if they were to occur over 10 years.

Trends in Maximum Age, Mean Length, Length-at-age, and Proportion of Repeat Spawning

The SAS explored trends in age, length, and repeat spawning over time where possible. The panel felt the analyses were interesting and useful. However, care was needed when using trends in the data to make inferences about stock status, as other dynamics including the sampling design and changes in personnel may be influencing the observed data.

Trends in maximum age by species and sex were explored across rivers where age information was available. Trend analyses were not conducted on maximum age, and trends were evaluated visually. Rivers where changes in ageing method changed over time were split. Maximum ages ranged between 4-9 across rivers with ages 6-7 most common. Over time values fluctuated. In general, there was no discernible trend across the majority of rivers. The panel noted that observed maximum age for a given river may be influenced by the timing of the sampling relative to the run timing, and therefore may not be reflective of the true maximum age returning to a river.

Length data from fishery-independent and -dependent sources were collected to calculate trends in overall mean length and length at age for individual spawning populations. Time series with at least 10 years of data and with at least five years of continuous data were used in Mann-Kendall tests for a monotonic trend. The SAS noted that year-class effects can influence trends in mean length (but not mean length-at-age), particularly for shorter time series. The panel also suggested looking at changes in mean length in the NMFS offshore trawl survey to get a more coastwide look at changes in size, as there are some length-based data limited methods that could be explored for adjusting the bycatch cap.

The percentage of repeat spawners was calculated as the percent of fish sampled with one or more spawning marks divided by the total sampled in a given year. The Mann Kendall test was applied for rivers for 10+ years of data, with at least five continuous years. A few rivers stood out as they had large increases towards the end of the time series, with very high percent repeat spawners. Although this seemed to be a positive result at first glance, the panel noted it could also be the result of successive year class failures. In response, the SAS conducted a simulation of the data and demonstrated that indeed year class failure could be responsible for such changes. It might be useful in the future to structure the data so that figures showing each river or regional grouping could allow for visual evaluation of the various indices and facilitate attempts to make inferences about biological processes. The aging of scales and detection of repeat spawning events using them remains a source of variability that is hard to quantify. Last, the panel was concerned with the very low number of repeat spawners in some years (eg. 2018 in CAN-NNE, Fig. 174).

Statistical Catch-at-Age Models

Statistical catch-at-age (SCAA) models were updated for stocks in three rivers. Catch-at-age models are discussed in detail below in response to ToR 4.

Bycatch Cap Limit

The SAS explored the use of data-limited methods to estimate a bycatch cap based on trends in abundance. The SAS clearly indicated this was a proof-of-concept analysis and not being recommended for management purposes. Five methods were explored: the iSmooth method, used to adjust the ABC for a number of stocks in New England, and four variations of the iSlope method. Both the iSmooth and iSlope methods were selected because they performed well in simulation testing conducted by an Index-Based Methods Working Group (NEFSC 2020). Both iSmooth and iSlope adjust recent average catches based on trends in abundance. The SAS used recent bycatch estimates, and explored adjusting the catch using two indices of abundance: the NMFS trawl survey (ME-NC), and summed run counts from the SNE stock region for alewife and from the MAT region. The SAS also conducted a retrospective analysis to quantify the interannual change in bycatch cap that would have resulted if each method had been applied previously.

The panel felt this was a useful exploration and worthy of further consideration. There was some concern about the interannual variability in cap estimates, particularly for the iSmooth method. The iSlope variations were less variable than iSmooth, although there was considerable variation for blueback herring in some years. The variability was largely due to spikes in bycatch in certain years. There was discussion that using bycatch magnitude as the catch cap could be problematic. If this approach were to be used, the current bycatch cap should be adjusted up or down (and not the recent average bycatch) based on trends in the index. The panel was also unsure how the approach could be operationalized to set a bycatch cap that includes four species (also American and hickory shad), and feels that further consideration of how to do so is needed.

Spatial Distribution Models

The SAS also presented the potential use of habitat models to predict species distribution in the marine environment and identify bycatch hotspots. The models would inform future development of time-area closures and could be explored as an alternative to management using a bycatch cap. The panel agreed the methods held promise and supported continued exploration, while cautioning that a fully spatial approach would not inherently track the magnitude of bycatch. Thus, there is the potential that some type of bycatch cap would need to be implemented concurrently with spatial management. The panel also noted there are numerous steps to developing and validating various options for time area closures, and these require clear management objectives to be defined *a priori* (Bowlby et al. 2024).

4. For each stock, identify best estimates of biomass, abundance, and exploitation from the assessment for use in management, if possible, or specify alternative estimation methods.

Despite the diversity of data available, it was difficult for the SAS to use conventional fish population modeling to estimate biomass or abundance of river herring, either by river system or by region. For the majority of river systems, only one type of monitoring data existed that could be used as an abundance index. And, the available catch data were difficult to partition to species level due to challenges in biological sampling. There were only three rivers where a statistical catch-at-age model could be developed to estimate biomass/abundance and fishing mortality.

Monument River Statistical Catch-at-Age Model

The statistical catch-at-age (SCA) model for the Monument River (MA) alewife was a forward projecting population model that predicts numbers at age by sex and maturity stage from total in-river catches, escapement counts, and escapement age composition. The SCA incorporated the updated estimates of natural mortality (M) by age derived from weight at age (Lorenzen 1996) and used the age and repeat-spawner frequency to derive annual proportions of fish mature at each age and sex following Maki et al. (2001). The structural difference from the last assessment was to incorporate a multiplier on M, to give a coefficient for two time periods: 1980-1999 and 2000-2022. Fishing mortality is currently extremely low and known (only research catches), making it possible to evaluate changes in M over time because escapement was monitored.

Model diagnostics were adequate, yet there were retrospective patterns in several parameters, notably total population abundance and female SSB. The river system is currently under moratorium, so there is limited management application for the results other than determining a relative current mortality rate. The biomass predictions in the terminal year for female SSB are below both the $F_{40\%}$ and $F_{20\%}$ reference points, suggesting recent abundance is low. The panel noted the increase in the M multiplier (1.67 to 2.68) was interesting, as it suggests other sources of anthropogenic mortality (not F) have substantially increased in this population in recent years.

Nanticoke River and Chowan River Statistical Catch-at-Age Model

Age-structured SCA models for alewife and blueback herring were developed for both rivers. Models were fit to total in-river catches, observed proportions at age and repeat spawner data, and fishery-independent indices. Unlike the Monument River model, additional anthropogenic mortality (e.g., multipliers on M) could not be estimated concurrently with fishing mortality due to the lack of information on escapement. Both rivers are currently under moratorium and recent estimates of F were minimal. Sensitivity runs indicated that biomass predictions were sensitive to the scale of removals, limiting the management utility of both models now that there are no directed fisheries. The influence of bycatch, other sources of anthropogenic mortality, or environmental effects due to climate change could not be evaluated from the available data. Any assumptions made as to their magnitude would rescale abundance estimates from the models.

Overall

Predicting biomass or abundance for alewife and blueback herring depends on having substantial extant monitoring effort in a single river. Given the sheer number of river systems, it is unlikely that future monitoring will ever be increased across systems to enable the development of additional SCA models. Furthermore, age-structured SCA approaches are not applicable at the regional level, given the diversity in population dynamics among river systems, coupled with separability issues for aggregated species data such as bycatch information. The review panel sees limited value in future model development and validation of the SCA models for management advice.

In future, the SAS could explore using population dynamics models within a Population Viability Analysis (e.g., Reid et al. 2002, Legault 2005), particularly for the Monument River. This type of an approach would shift the focus from stock status towards conservation questions and recovery planning. For example, the predominance of in-river as opposed to at-sea mortality affecting the population trajectory (e.g., Gibson et al. 2009), the potential utility of stocking (e.g., Bowlby and Gibson 2011), or the probabilities of recovery and/or extinction under various mortality scenarios (e.g., Gibson et al. 2015) could be explored. However, the assessment team noted this suggestion is effectively a simpler version of the habitat model discussed below, albeit implemented at a river-specific level.

Habitat Model

The habitat model presented for river herring was an extension of the one previously developed for American shad (Zydlewski et al. 2021) and is available via open source software. It is an age and sex structured projection model that uses current biological parameters (here regional, not river-specific values) to predict survival, maturity and productivity through time (here 50 years), conditional on the distribution and accessibility of freshwater habitat. Density dependence via a Beverton-Holt recruitment function relates the number of spawners to subsequent larval recruitment. Upstream passage and downstream mortality rates govern the probabilities of reaching suitable habitat (i.e., in freshwater for adult spawners and in ocean environments for larval recruits).

The model was initialized at a large starting population size, with the number of individuals in an age class determined by age-specific natural mortality rates and a random probability of being female drawn from a beta distribution. The amount of freshwater habitat in a river system was calculated for each reach segment using stream discharge-width relationships and summed with lake area to get the total. The position of dams in combination with modeled upstream passage and downstream survival rates affected the accessibility of freshwater habitats. The model was run for alewife and blueback herring in each region identified by the genetic analyses (see TOR 1), comparing a no-dam (1.0 upstream passage and downstream survival), a current (0.5 passage and survival), and a no-passage (0 passage and survival) scenarios.

The habitat model conclusively demonstrated the impact of accessibility on the expected productivity of different regions for river herring, with the magnitude of habitat reduction within a region reflected by decreases in predicted spawner abundance (in millions of fish). For alewife, all of the regions had 65% or more of the habitat located above first dams. For blueback herring, the proportions of habitat above dams tended to be slightly lower by region; however, for both species there was a gradient in habitat accessibility from South to North, with Northern rivers being more impacted by dams. The current model is sensitive to the amount of habitat that would remain after dam removals, and assumes all habitat to be of equal quality. These assumptions currently limit the applicability of the model, as it is known that all habitat is not equal (Monteiro Pierce et al. 2020, Devine et al. 2021), and choices between fish passage and dam removal will have significant impacts on habitat availability and quality.

For the habitat model to be used to develop explicit management advice, it would be necessary to account for the influence of fisheries, both in-river as well as ocean bycatch, as well as to compare abundance predictions to observed data to ensure sources of mortality and life history dynamics are adequately represented. Ideally, landings and bycatch would be ascribed to individual river systems to understand the combined influence of freshwater habitat loss and fishing mortality on underlying population productivity. By capturing the main sources of freshwater and at-sea mortality, the abundance predictions (estimates of numbers) could then be assessed relative to run count and escapement data to see if the modeling approach is able to approximate observed patterns. This would help validate the predictions, particularly if there is the intention to explore other sources of anthropogenic mortality (e.g., the influence of climate change) using the modeling approach. Overall, we encourage the SAS to continue development of the habitat modeling approach.

5. **Evaluate the choice of reference points and the methods used to determine or estimate reference points. Determine stock status from the assessment, or, if appropriate, specify alternative methods/measures for management advice.**

The SAS developed reference points for total mortality (Z) and for the ARIMA-smoothed time series. The reference points were then used to compare terminal estimates of Z and smoothed abundance to quantify the probability of a stock being above or below the reference point. Uncertainty was accounted for in both the terminal estimate and the reference point.

For the Z reference point, the SAS used the SPR target of 40%. Their justification for using 40% was based on a number of simulation studies that showed 40% was a robust proxy for MSY. The Panel discussed the possibility of other target SPR percentages, but also noted 40% is widely used across stocks in the U.S., and that it was reasonable for river herring.

Regarding status relative to Z, results varied by river. For blueback herring, 4 of 11 rivers had a greater than 50% chance of Z being above the reference point. For alewife, 28 of 43 rivers had a greater than 50% chance of Z being above the reference point. Although the Panel felt this approach was suitable, there was discussion over using only the terminal year estimate of Z to compare with the reference point. There is considerable interannual variation in Z, and averaging multiple years (e.g., the most recent three) may be more appropriate. Also, as noted earlier the mortality being estimated for each river is based on fully recruited 5+ year fish and thus does not represent the mortality rate of younger age classes. Ages 3 and 4 are the predominant contributors to annual variability in the run count, as most populations consist of a majority of first-time spawners. Although mortality affecting the older age groups is an accumulated metric over multiple factors (harvest, incidental catch, and fish passage), mortality is generally expected to be higher in younger and small ages. This is made slightly more complicated by a lack of mortality as a result of river use such as through fish passage during younger ages. However, length data collected in the observer program (Fig. 17-Fig. 18) demonstrate there is significant catch of young (immature) river herring as judged by the growth curves (Fig. 91-98). In fact, there are very few fish in bycatch at lengths that are consistent with age 5+ fish (approximately 275-300mm, Fig. 91-98). Thus, the calculated mortality rates are not truly indicative of all sources of mortality river herring are exposed to throughout ontogeny. Using the catch curve analysis method based on previous spawning history (Billard 2020) would better characterize mortality in earlier years as data from age 3 and 4 fish would be included in the estimation. Even though mortality is likely underestimated, the mortality rate had a 50% chance of being above the reference point for 50% of blueback populations and 65% of alewife populations. What is clear is that mortality remains high, and given the level of historical depletion throughout their respective ranges, does not bode well for recovery of either alewife or blueback herring. It is important to note the mortality rates were over the reference point in many harvested runs as well.

For the ARIMA trend analysis the SAS used two reference points – the 25th percentile from the entire smoothed time series, and the 2009 smoothed value. The 25th percentile was selected based on the work of Helser and Hayes (1995). The 2009 value was based on changes in management related to FMP Amendment 2. The Panel felt the focus should be more on the 2009 index value, in part because the 25th percentile can change over time and the 2009 value tended to be higher than the 25th percentile value. The 2009 smoothed index is fixed in time. It has relevance to known changes in management and should be considered a limit reference point. Therefore, comparisons of the current year to 2009 provide evidence if interventions are having a positive impact. With regard to status relative to reference points, the majority of rivers for both species had a greater than 50% chance of the index terminal year being above the 25th percentile and the 2009 value.

6. **Review the research, data collection, and assessment methodology recommendations provided by the TC. Make additional recommendations as necessary. Clearly prioritize the research needed to inform and maintain the current assessment, and provide recommendations to improve future assessments.**

The panel suggested de-prioritizing research questions that would not lead to information used to assess status. The panel categorized research priorities as short-term high priority that are possible now without additional data collection, and medium priority that would require additional planning, new data collection, or additional time to implement.

High Priority

The panel recognizes the need for improved estimation of bycatch and discard mortality. Exploring different estimation methods among fisheries is a high priority as it can be done now with no new data. Different analytical techniques could be compared in a sensitivity analysis to assess their relative predictive ability for estimating total bycatch. The manner in which iSlope or other methods could be implemented as catch caps should be explored. Since incidental catch seems to comprise the largest source of ongoing fishing mortality, and mortality remains high for many populations, the focus on bycatch is urgent.

Another high priority research need is to improve the habitat model by incorporating all major sources of mortality, and then to use observed data to ground truth the outputs. This does not imply a fit to data, but rather the results should be tethered to reality in that predicted run sizes are of a realistic magnitude relative to what has been observed. There were a number of unrealistic outputs in the current implementation. Future iterations should work to include fishing mortality, including bycatch, and measures of habitat quality in freshwater.

Of equal priority, but with implementation over a longer time period, is improved monitoring via port sampling to collect morphological and species data from bycatch. This would require portside monitoring to be reinstated and expanded for full-retention fisheries. However, it would appear to be a relatively low-cost solution compared to increasing at-sea observer coverage. The variability in bycatch estimate CVs relative to a target of 30% suggests increases in at-sea observer coverage would have to be substantial. During subsampling of catch, samples should be taken for genetic analysis of bycatch, even if the samples are stored for analysis at a later date. A better accounting of incidental catch is critical to improving the status of coastwide stocks.

The panel also sees a high priority in continued improvement of enumeration techniques, including hydroacoustics, eDNA, and run count video image processing with machine learning. Current fish counting technologies are phasing out. The advance of many alternatives offers the opportunity to calibrate methods and continue long-term monitoring datasets.

Medium Priority

The panel recognized the need to implement sampling programs where data are collected over the whole life stage on a single river. Such data can be input into models to allow the partitioning of mortality into different components of life history, increasing understanding of the impacts of different sources (in-river, downstream passage, incidental catch).

A detailed river history and inventory that captures current population numbers, details of restoration, and documents data collection methods would be very informative when trying to interpret current status. This could include a landscape database of threats, documenting their location, type, and magnitude along the river network. Such a baseline would help evaluate whether the environment of the river has changed. The status of current environmental monitoring, prior or subsequent run monitoring, as well as other information could help in prioritizing the collection of new data. It would also provide a platform for research and engagement.

River herring specific surveys would be of great benefit to the assessment, and the panel suggests interspecies and interstate collaboration on survey design. The low power of surveys in the assessment can, in part, be linked to the dependence on a variety of surveys not developed for river herring. At the very least, new workshops to standardize data collection and explore expanding the designs to better sample river herring in current surveys, or implementing additional methods to complement existing efforts, would be extremely useful. Angler surveys in freshwater or in spawning reaches, currently not the focus of MRIP, would fill some data holes. However, recreational harvest is probably not resulting in significant mortality.

The panel considered most of the other medium and high priority research objectives identified by the SAS (short and long term) to be less important, primarily because they would have a lower likelihood of leading to information useful for status assessment or management.

7. Recommend timing of the next benchmark assessment and assessment updates, if necessary, relative to the life history and current management of the species.

The review panel took into consideration the life history of river herring, the available assessment methods, and current management when recommending the timing of the next benchmark and update assessments. The review panel agreed with the SAS that an assessment update in 5 years and a benchmark assessment in 10 years would be appropriate.

Relative to life history, 5 years represents approximately 1 generation for river herring, based on the average age of spawners. There would be sufficient time for recruits in 2024 to contribute to the spawning population prior to the next benchmark. However, the current assessment demonstrates the power to detect trends in monitoring data can be quite low given the variability characteristic of river herring, particularly with shorter time series. Thus, continued improvement of the habitat model and linking of the results to ground-truthing data would be logical steps.

In the assessment, 10 years was used as a cut-off when identifying the time series data appropriate for trends analyses. Holding the next benchmark assessment in 10 years should allow for measurable population response to management actions, particularly from those implemented following the previous benchmark in 2012.

The complexity of river herring assessment largely stems from the diversity of organizations involved in monitoring, data collection, and management, as well as the numerous anthropogenic activities affecting each population. More frequent assessments would take substantial effort on behalf of numerous agencies with little expectation of measurable population response. An update or a benchmark on a shorter time-scale is likely to lead to the same biological conclusions and management advice as the current assessment. The panel also suggests additional inter-assessment coordination amongst states to develop as many standardized approaches (ageing, spawning checks, indices) as possible.

8. Prepare a Review Panel terms of reference and advisory report summarizing the panel's evaluation of the stock assessment and addressing each peer review term of reference. Develop a list of tasks to be completed following the workshop. Complete and submit the report within 4 weeks of workshop conclusion.

The panel was generally content with the current assessment report. However, documentation of sample sizes for catch curve estimation should be included. In future assessments, the SAS should also work to explore time blocks in simplified growth models, and evaluate the assumptions underlying the catch ratio estimator for bycatch. We thank the SAS for recalculating mortality estimates, and providing additional figures and spreadsheets describing sample sizes, at the request of the panel during the peer review workshop.

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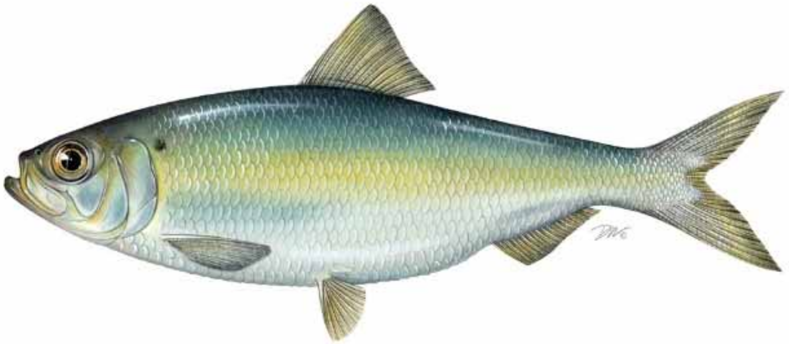
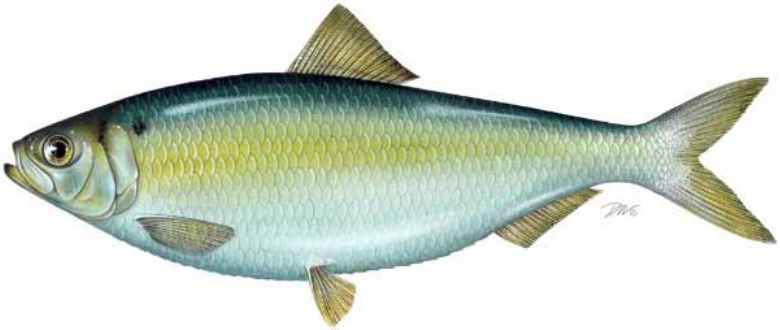
Atlantic States Marine Fisheries Commission

River Herring Benchmark Stock Assessment





Prepared by the
ASMFC River Herring Stock Assessment Subcommittee

In Collaboration with
Daniel Stich, SUNY Oneonta

And

Approved by the Shad and River Herring Technical Committee
May 8, 2024

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

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TERMS OF REFERENCE

For the 2024 ASMFC River Herring Benchmark Stock Assessment
Board Approved November 2022

1. Define and justify stock structure

River herring stock structure was identified genetically by Palkovacs et al. (2014) and later refined by Reid et al. (2018). A robust baseline collection that covered the range of both species indicated four regional genetic groups of alewife (one in Canada (CAN), and three in the US, Northern New England (NNE), Southern New England (SNE), and Mid-Atlantic (MAT)) and five of blueback herring (Canada-Northern New England (CAN-NNE), Mid-New England (MNE), Southern New England (SNE), Mid-Atlantic (MAT), and South Atlantic (SAT)). Within regional genetic groups there was much weaker genetic differentiation between rivers; there were indications that genetic isolation by distance was highly affected by stocking. The stock assessment conducted analyses at the individual river level where possible, and used the genetic stock-regions of Reid et al. (2018) to pool data and summarize results across rivers.

2. Characterize precision and accuracy of fishery-dependent and fishery-independent data used in the assessment, including life history data (e.g., age and repeat spawner data) and nontraditional data (e.g., entrainment, impingement, passage)

Commercial landings data for 1881-1949 came from the US Fish Commission reports. Data for 1950-2022 came from the Atlantic Coastal Cooperative Statistics Program (ACCSP), which compiles fisheries data from state and federal databases along the Atlantic coast. The ACCSP database was queried for landings records of alewife, blueback herring, and river herring, and ACCSP staff validated the data with the states. Reported commercial landings averaged 1,016 mt (2.24 million lbs) from 2013-2022, compared to 27,923 mt (61.6 million lbs) from 1950-1969, the height of the directed fishery.

The earliest historical data is likely an underestimate of coastwide landings, as it relies on opportunistic canvassing of the fisheries, concentrating on the mid-Atlantic states. Although reporting has become more standardized and mandatory in recent years, identification to the species level remains unreliable. The vast majority of river herring landings are reported as alewife, even for states or rivers where blueback herring dominate the runs.

Estimates of incidental catch of river herring (both retained and discarded) in non-directed ocean fisheries were developed from the Northeast Fishery Observer Program (NEFOP) data, which observes catches on federally-permitted vessels in the Mid-Atlantic and New England region. Observer data for the gillnet and bottom trawl fleets goes back to 1989, but incidental catch estimates for the midwater trawl (MWT) fleets are only provided for 2005-2022 because marked improvements to NEFOP sampling methodologies occurred in the high-volume MWT fisheries beginning in 2005.

Estimates of river herring bycatch are frequently imprecise, with CVs ranging from 0.2 to over 1.0 at the annual level. This is due to the overall low observer coverage, which has declined in recent years due to budget issues; coverage in nearshore/state waters is even lower due to the federal nature of the observer program. In addition, in high volume fisheries, it is difficult to identify river herring to the species-level.

Estimates of recreational harvest and live releases for river herring on the Atlantic coast come from the NOAA Fisheries Marine Recreational Information Program (MRIP), which uses a combination of effort surveys and angler-intercept surveys to develop those estimates. MRIP estimates of river herring recreational catch are highly variable from year to year, ranging from a minimum of less than 1,000 fish for alewife and zero for blueback herring in several years to maximums of 1.3 million alewife and 3.4 million blueback herring. The percent standard error (PSE) of the estimates are also high, with most years having a PSE of greater than 50%, and several years having a PSE of greater than 100%, even at the coastwide level. The MRIP angler-intercept survey that estimates catch per trip of each species does not occur above the head-of-tide, so in-river catches, where the directed fishery is most commonly prosecuted, are not captured by MRIP, contributing to the low precision of the estimates.

From 2013-2022, estimates of total river herring removals on the US Atlantic coast from all sources averaged 1,213 mt (2.67 million lbs) or approximately 4% of the average reported landings at the peak of the directed fishery (Figure 1). This represented an average of 6.83 million fish per year.

Fishery-independent data sets that caught river herring were evaluated and accepted or rejected for assessment use based on established criteria, including the length of the time series (at least ten consecutive years of data; surveys with 7-9 years of data were accepted for use in future updates but not included in the trend analysis results for this assessment) and the proportion of sampling events that were positive for alewife or blueback herring, when subset to the most representative strata, stations, months, etc. (at least 10% positive tows/hauls). A total of 43 fishery-independent surveys met the criteria for one or both species. Surveys ranged from Maine to Florida and included young-of-year surveys and age-1+ surveys (Figure 2). Young-of-year or spawning stock surveys that occurred in the nursery grounds or rivers were assigned to the stock-region that the river or estuary was in; surveys that occurred in the ocean were assigned to the coastwide mixed stock for each species. Gears included trawls, seines, gillnets, and electrofishing. The SAS explored using GLMs and GAMs to incorporate environmental information into the calculation of the abundance indices. If the model-based standardization reduced interannual variability or the CVs of a dataset or could account for changes in sampling methods that would otherwise require dropping years of data, the standardized index was used. Otherwise, the nominal index was used.

The major sources of uncertainty in the surveys were (1) the lack of a targeted design, with majority of the surveys being multispecies monitoring projects that did not target river herring, resulting in a high proportion of zero tows in the datasets, and (2) time-series length, with virtually all surveys starting in the 1980s or later, after the significant decline in the directed fishery.

Two fishery-dependent CPUE datasets were also included; the length of the time-series and consistent methods of sampling provided useful contrast in the trends in abundance, but the ability to define effort in a detailed, consistent way over the time-series did increase uncertainty for those indices.

In addition to fishery-independent surveys, run counts were used as indices of abundance for river herring. Run counts were available from Maine through South Carolina for both species, although the majority of counts were from the northern end of the range. The major source of uncertainty for the run counts was the potential for changes in passage efficiency over time, due to factors like deliberate passage improvements or improvements in counting methodology, degradation of passage, or interannual variability in flow or other environmental factors. In addition, for a number of run counts, river herring were not identified to the species level for part or all of the time series. While the SAS attempted to restrict the years in the analysis to years of consistent methodology, it was not possible to account for all sources of variability. The SAS considered run counts to be indices of relative abundance rather than estimates of absolute abundance.

Biological data including lengths, weights, ages, and repeat spawner marks were available from fishery-dependent and fishery-independent sources. River herring have historically been aged using scales, using protocols first developed by Cating (1953) for American shad and Marcy (1969) for river herring. Although used extensively, these protocols have not been validated with known-age river herring. A 2014 ageing workshop for river herring found CVs greater than 5% across labs, and systematic bias across readings from paired scales and otoliths. Collection of otoliths has increased since the last benchmark, and several thousand otolith ages were available across multiple stock-regions for both species.

3. Estimate bycatch where and when possible

Estimates of incidental catch of river herring (both retained and discarded) in non-directed ocean fisheries were developed from the NEFOP data, at both the annual level and stratified by gear and region. From 2005-2022, the total annual incidental catch of alewife ranged from 22.7-537.8 mt in New England and 6.5-295 mt in the Mid-Atlantic. The dominant gear varied across years between paired midwater trawls and bottom trawls. Corresponding estimates of precision (coefficients of variation, CVs) exhibited substantial interannual variation and ranged from 0.01-10.61 across gears and regions. Total annual blueback herring incidental catch from 2005-2022 ranged from 8.2–186.6 mt in New England and 1.4-388.3 mt in the Mid-Atlantic. Across years bottom trawl, paired and single midwater trawls exhibited the greatest blueback herring catches. Corresponding CVs ranged from 0.01 – 3.56.

Total incidental catch estimates from 2020-2022 were among the lowest in the time series (2005-2022) for both alewife and blueback herring. From 2005-2019, incidental catch made up 27% of total removals in weight and 35% of total removals in numbers, but from 2020-2022, incidental catch was 7.5% of total removals in weight and 10% of total removals in numbers. These lower estimates of bycatch are related to the lower effort in the Atlantic herring and mackerel fleet in recent years, but are also affected by the lower levels of observer coverage and port sampling in those years.

4. Summarize data availability and trends by stock

Information on abundance and/or total mortality were available from 75 rivers or river systems, as well as the Atlantic Ocean, for one or both species, across all stock-regions.

Indices and run counts were analyzed with the non-parametric Mann-Kendall trend analysis (Mann 1945, Kendall 1975) to determine if a monotonic trend was present in each series. The autoregressive integrated moving average (ARIMA) approach (Box and Jenkins 1976) was used to minimize measurement error in the survey estimates and to infer population status relative to an index-based reference point for both abundance indices and run counts. The reference points used were the 25th percentile of the time series, and the index value in 2009, the year when Amendment 2 to the Shad and River Herring Fishery Management Plan was implemented.

There was no clear trend signal for either species across the coast. Even within the genetic stock-regions, individual rivers often differed in recent and long-term trends for both abundance and mortality. Overall, the northern most stock regions (NNE for alewife, CAN-NNE for blueback herring) had more rivers with significant positive trends than the other stock-regions.

For alewife, in the NNE stock-region, there were eight species-level time series: six run counts and two young-of-year surveys. ARIMA results indicated five of the six run counts and both young-of-year indices had a greater than 50% chance of being higher than they were in 2009. Four of the eight time-series showed an increasing trend over the full time series, while two of eight showed an increasing trend since 2009. The rest of the trends were non-significant. In the SNE region, there were eight species-level time series: seven run counts and one young-of-year survey. ARIMA results indicated four of the seven run counts had a greater than 50% chance of being higher than they were in 2009; the young-of-year index only had a 6% probability of being higher than it was in 2009. None of the time-series had a significant trend in recent years; four runs had had a long-term decreasing trend and one run had a long-term increasing trend. In the MAT stock-region, there were 21 species-level time series: eleven age-1+ indices and ten recruitment (young-of-year or age-1) indices. ARIMA results indicated five of the eleven age-1+ indices and six of ten recruitment indices had a greater than 50% probability of being higher than they were in 2009. None of the time-series showed a significant trend in recent years. One age-1+ index and three recruitment indices showed a decreasing trend over the full time series. Three age-1+ indices, all in North Carolina, and one recruitment index showed an increasing trend over the full time series.

For blueback herring, in the CAN-NNE stock-region, there was one species-level time series, a young-of-year index. ARIMA results indicated it had a very high probability of being above the 2009 index value, and showed an increasing trend in both recent years and over the full time series. In the MNE stock-region, there were five species-level time-series: four run counts and a young-of-year index. ARIMA results indicated that three of the four run counts had a greater than 50% probability of being higher than they were in 2009. None of the time-series showed a significant trend in recent years. The Oyster River run count had a decreasing trend over the full time series, and only a 16% probability of being above the 2009 value. The young-of-year index also had a significant decreasing trend over the full time series, but had a high probability of being above the 2009 value in the most recent year. There were no species-level time-series for the SNE stock-region (all run counts for this region were reported as mixed river herring). For the MAT stock-region, there were 27 species-level time series: 16 age-1+ surveys and 11 recruitment indices. ARIMA results indicated that seven of sixteen age-1+ indices and nine of the eleven recruitment indices had a greater than 50% probability of being higher than they were in 2009. Only one time series, the NC Albemarle Sound Gillnet Survey of age-1+ abundance had an increasing trend in recent years; the rest were non-significant. Over the full time series, four recruitment indices and two age-1+ indices showed decreasing trends, while one recruitment index and three age-1+ indices showed increasing trends. For the SAT stock region, there were three species-level time series: one run count, one age-1+ survey, and a young-of-year index. ARIMA results indicated that the age-1+ surveys and the young-of-year survey had a greater than 50% probability of being higher than they were in 2009, while the Santee-Cooper River run count had only a 3% probability of being above the 2009 value. The Santee-Cooper River run count showed a decreasing trend over the full time series and in recent years. The young-of-year index showed an increasing trend over the full time series, but the age-1+ index had no significant trend over either time period.

5. **If possible, develop models used to estimate population parameters (e.g., Z, biomass, abundance) and biological reference points, and analyze model performance.**

This assessment updated and refined the trend analyses, total mortality (Z) estimates, and Z reference points from the 2012 benchmark assessment. New analyses included the exploration of a MARSS model in an attempt to identify underlying trends within stock-regions, and the development of a habitat model to understand the importance of habitat loss and restoration on river herring population trends at the watershed level.

Indices of abundance were developed and correlation of the indices within region was measured with Spearman's Rank Correlation. Power analysis was used to calculate the probability of detecting trends in the abundance indices developed from fishery-independent data using the methods of Gerrodette (1987). Indices and run counts were analyzed with the non-parametric Mann-Kendall trend analysis (Mann 1945, Kendall 1975) to determine if a monotonic trend was present in each series. The autoregressive integrated moving average (ARIMA) approach (Box and Jenkins 1976) was used to minimize measurement error in the survey estimates and to infer population status relative to an index-based reference point (25th percentile and fitted 2009 value respectively) for both abundance indices and run counts.

Trends in maximum age, mean age-at-length, mean length, and repeat spawner percentage were tested for by species and sex where the data existed.

A Poisson log-linear model was used to estimate total instantaneous mortality (Z) rates (Millar, 2015) for each species and year combination for two different spatial scales: at the river level and at the regional level. A stochastic spawning stock biomass per recruit model (SPR) was developed to estimate a total mortality threshold of $Z_{40\%SPR}$ for each stock-region to evaluate the estimates of Z against; the stochastic approach allowed a more comprehensive inclusion of uncertainty for the key life history and fishery parameters in the model.

A Multivariate Auto-Regressive State-Space (MARSS) model was explored for each stock-region which analyzed river-level surveys and run counts in an attempt to identify underlying trends across rivers within each stock-region. However, the overall performance of this model was poor, indicating an inability to isolate a single consistent trend in abundance across rivers within stock-regions.

Statistical catch-at-age (SCA) models developed during the last benchmark were updated and refined for the Monument (alewife), Nanticoke (alewife and blueback herring), and Chowan (blueback herring) rivers.

A habitat model was developed which modeled population abundance of anadromous river herring as a function of freshwater habitat availability throughout their native ranges (habitat model). This model relies on a combination of biological parameters and habitat distribution in freshwater spawning and rearing environments to project populations through time similar to the American shad model (ASMFC 2020).

6. **If possible, develop methods to calculate a biologically-based cap or limit on bycatch of river herring in ocean fisheries.**

The SAS developed a proof-of-concept example for a bycatch cap based on the data-limited index-based methods simulation-tested as part of the 2020 SAW/SARC Research Track "Topics" Assessment, specifically the iSmooth (aka Plan B Smooth) and iSlope approaches (NEFSC 2020). In the simulations, these approaches were able to rebuild stocks above SSB_{MSY} on average in the long term, and also had the highest median catch among the methods that achieved rebuilding more than 50% of the time (NEFSC 2020). The NEFSC and NEAMAP surveys were used as ocean/mixed-stock indices, and an index from run counts from stock-regions identified as significant contributors to bycatch in the midwater trawl fishery by Reid et al. (2022) was used as a sensitivity run (SNE for alewife, MAT for blueback herring).

The estimated catch caps were lower than both the estimated bycatch and the current bycatch cap across species and fisheries. The total cap for all river herring and shad across the mackerel and Atlantic herring fleets was 490 mt per year over the last three years. The estimates of the alewife catch cap for the coast ranged from a high of 85.2mt for the iSmooth approach with the mixed stock index to a low of 34.4mt for the iSlope approach with the run count index (Table 31). Coastwide bycatch of alewife has averaged 91.7 mt over the last three years. The blueback herring catch cap for the coast ranged from a high of 41.4mt for the iSmooth approach with the mixed stock index to a low of 20.9mt for the iSlope approach with the run count index (Table 31). Coastwide bycatch of blueback herring has averaged 42.5 mt over the last three years.

The iSmooth and iSlope approaches utilize available information on river herring abundance to adjust the bycatch caps instead of using a fixed, historical level. This allows the caps to decrease when river herring abundance is decreasing and increase as river herring abundance increases, making them more responsive to trends in the river herring population. However, there is no mechanistic population model underlying these methods to provide an estimate of what a sustainable level of removals for these populations are. In addition, declines in river herring are only partially driven by ocean bycatch, so reducing incidental catch may not lead to increases in abundance and the TAC would continue to be reduced if the population continued to decline.

Furthermore, the bycatch fishery is operating on the mixed stock population, and the proportion of each run or genetic stock-region that is present in the bycatch is a function of the abundance of each run as well as the time and area where the fishery is operating. The genetic composition of the bycatch is not currently monitored, so even if population-level estimates of bycatch limits could be developed from population models, the current sampling framework could not accurately monitor removals against those caps.

The SAS recommended developing a species-distribution model to determine time-area closures as an alternative or complement to the catch cap approach to reduce river bycatch, which would require less intensive observer sampling to implement. However, the development of that kind of model was beyond the scope of this assessment.

7. Recommend stock status as related to reference points, if available

The coastwide populations of both alewife and blueback herring were still depleted relative to historic levels. The habitat model indicated that overall productivity of all stock-regions for both species is lower than would be expected under virgin habitat conditions. In terms of recent trends, there is no clear signal for either species across the coast. Even within the genetic stock-regions, individual rivers often differed in recent and longer-term trends for both abundance and mortality, with some rivers showing increasing trends and low mortality rates, and others showing flat or declining trends and total mortality rates above the $Z_{40\%SPR}$ reference point.

While the NNE and CAN-NNE stock-regions showed the highest proportion of rivers with positive abundance trends, there were rivers in these stock-regions with high Z rates and/or no sign of increases since 2009. Meanwhile, some rivers in other stock-regions did show positive trends, and the MAT stock-region for both species had the highest proportion of rivers with a low probability of being above the $Z_{40\%SPR}$ reference point. See Table 28 and Table 39 for a river-by-river summary of stock status.

8. Other potential scientific issues

Where available, the SAS compared trends in *Z* estimates to trends in abundance, and found that in most cases, the trends were inversely related, as would be expected if *Z* is affecting abundance. I.e., most rivers with an increasing *Z* trend showed a decreasing abundance trend, and rivers with increasing abundance trends showed a decreasing trend in *Z*. A few rivers showed declines in abundance even though *Z* was stable. However, the majority of rivers with data did not have both a *Z* estimate and an abundance trend.

The habitat model indicated that habitat loss was greatest for the CAN-NNE and NNE stock-regions, but those regions had the highest number of increasing trends along the coast. The northern states have done extensive work to restore access to habitat in multiple stock-regions, but not all rivers have responded. Habitat restoration may be part of the reason the northern stock-regions are showing positive trends, but other factors may be hindering rebuilding in other stock-regions. Reid et al. (2022) noted that bycatch in ocean fisheries is comprised mainly of alewife from the SNE stock-region and blueback herring from the MAT stock-region, areas that have undergone habitat restoration but do not show the same positive trends as the more northern stock-regions.

The literature on the effects of climate change on river herring is not extensive, even less so for blueback herring than for alewife. Alewife and blueback herring have been ranked as “Very High Risk” to climate change by Hare et al. (2016) and as “Vulnerable” by Galbraith and Morelli (2017). This is due to their exposure to multiple factors of climate change impacts and their life history (i.e., temperature-driven spawning runs to their natal freshwater spawning grounds) that make it more difficult for them to adapt to these changes. The direct effects of climate change are difficult to measure. The Gulf of Maine is one of the fastest warming areas in the ocean, but the trends in that region are more positive than in other locations on the coast. Staudinger et al. (2024) found that evidence of changes in the timing (initiation and peak) of spawning runs was mixed, with some populations shifting earlier in recent years, some shifting later, and some not changing. Alewife’s center of biomass has been shifting further north in the NEFSC trawl survey. However, without genetic composition data, it is difficult to determine whether the biomass of the total coastwide population is shifting north, or whether the change in the center of biomass is driven by different patterns in abundance trends in northern vs. southern populations of alewife.

9. If a minority report has been filed, explain majority reasoning against adopting approach suggested in that report. The minority report should explain reasoning against adopting approach suggested by the majority.

No minority report has been filed.

10. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology

High priority short-term recommendations for research and data collection included develop consistent ageing protocols across all states; establishing a database of existing data sources with comprehensive metadata and recommendations for use; expand observer and port sampling coverage including genetic sampling to better quantify incidental catch of river herring; studies to quantify, improve, and implement standard practices for fish passage efficiency; and evaluating and validating hydroacoustic methods to quantify river herring spawning run numbers in major river systems. Continued development of the habitat model or similar models to predict the potential impacts of climate change on river herring distribution and stock persistence and develop targets for rivers undergoing restoration (dam removals, fishways, supplemental stocking, etc.) was a high-priority short term research recommendation for assessment methodology.

High priority long-term recommendations were to conduct regular exchanges or workshops to monitor the precision of ageing across states and maintain or implement river herring-specific surveys, particularly in rivers without run counts or rivers where restoration efforts (e.g., dam removal) will break or end the time series of run counts.

11. Recommend timing of next benchmark assessment and intermediate updates, if necessary relative to biology and current management of the species

The SAS recommends that an assessment update be conducted in five years and a benchmark assessment in ten years. Due to the high variability of fisheries independent surveys, an assessment update at a shorter timeframe will likely not show any significant changes in indices of abundance. New datasets which would warrant a benchmark would require a time-series of at least seven years. If significant improvements to the habitat or other models are achieved before ten years, the benchmark could be accelerated.

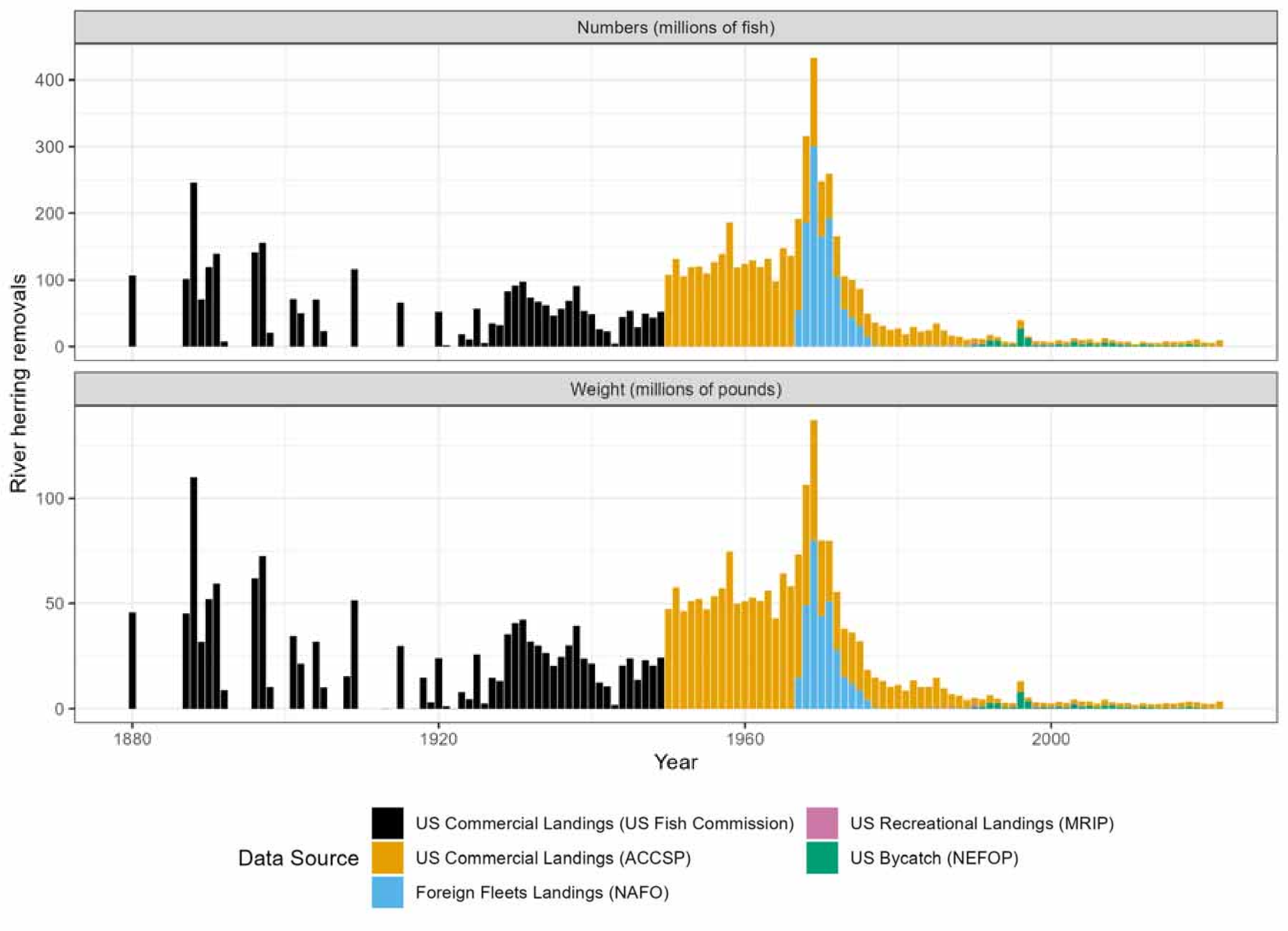

Figure 1. Total removals of river herring by data source, 1880-2022.

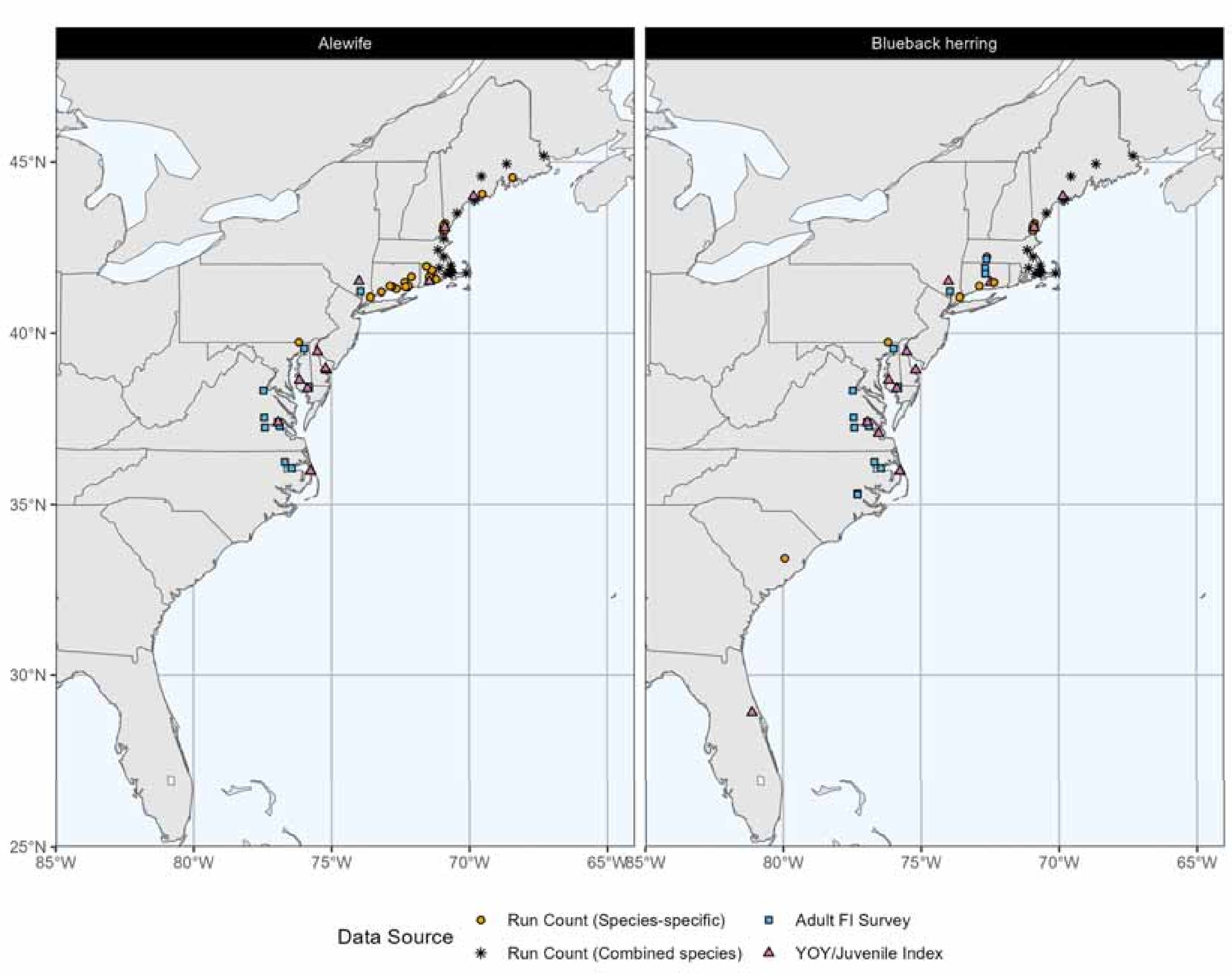

Figure 2. Map of river herring data sources by river and data type.

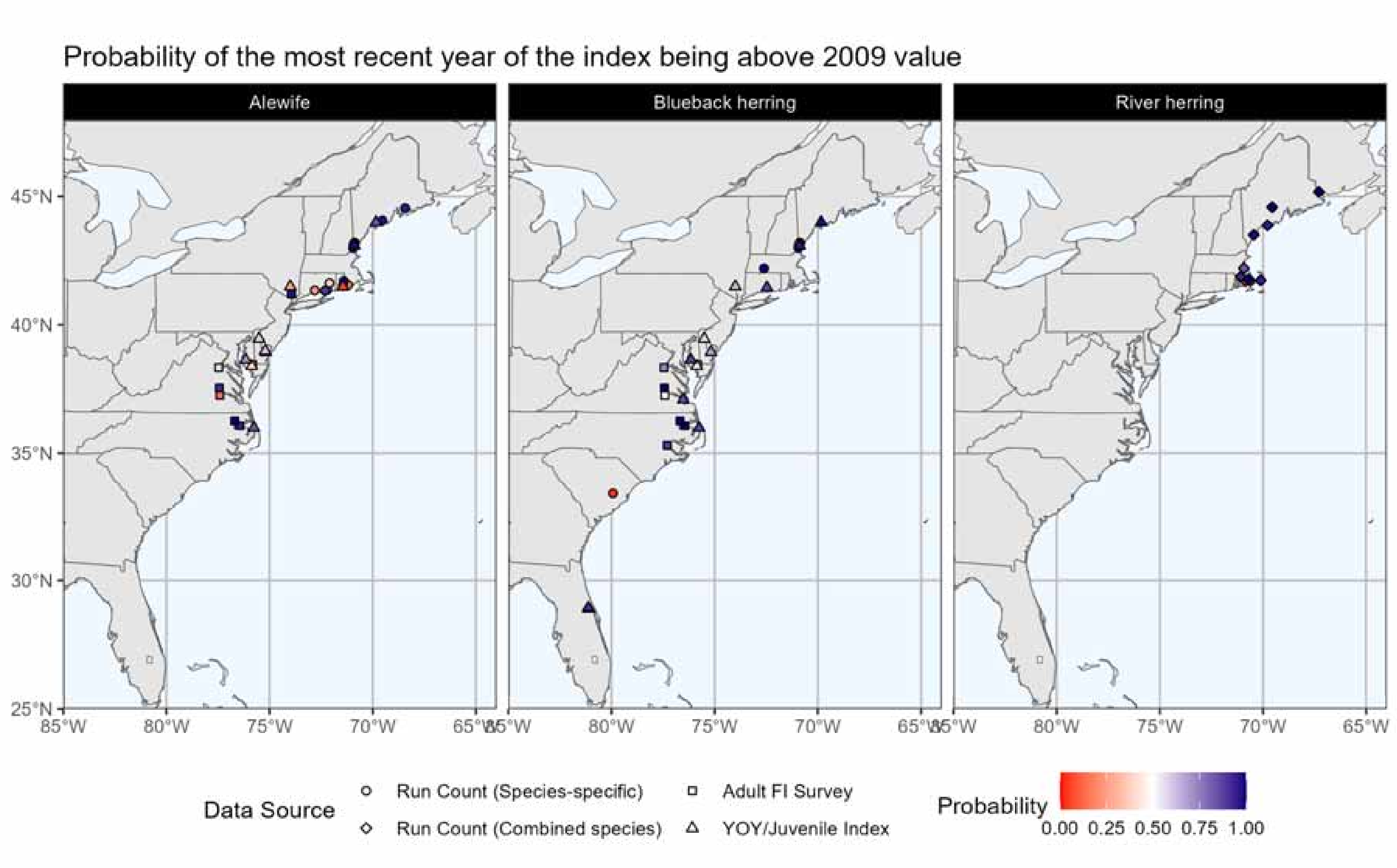

Figure 3. Map of the results of the ARIMA analysis showing the probability that the terminal year of the index is greater than the 2009 value. "River herring" indicates run counts that are not differentiated by species.

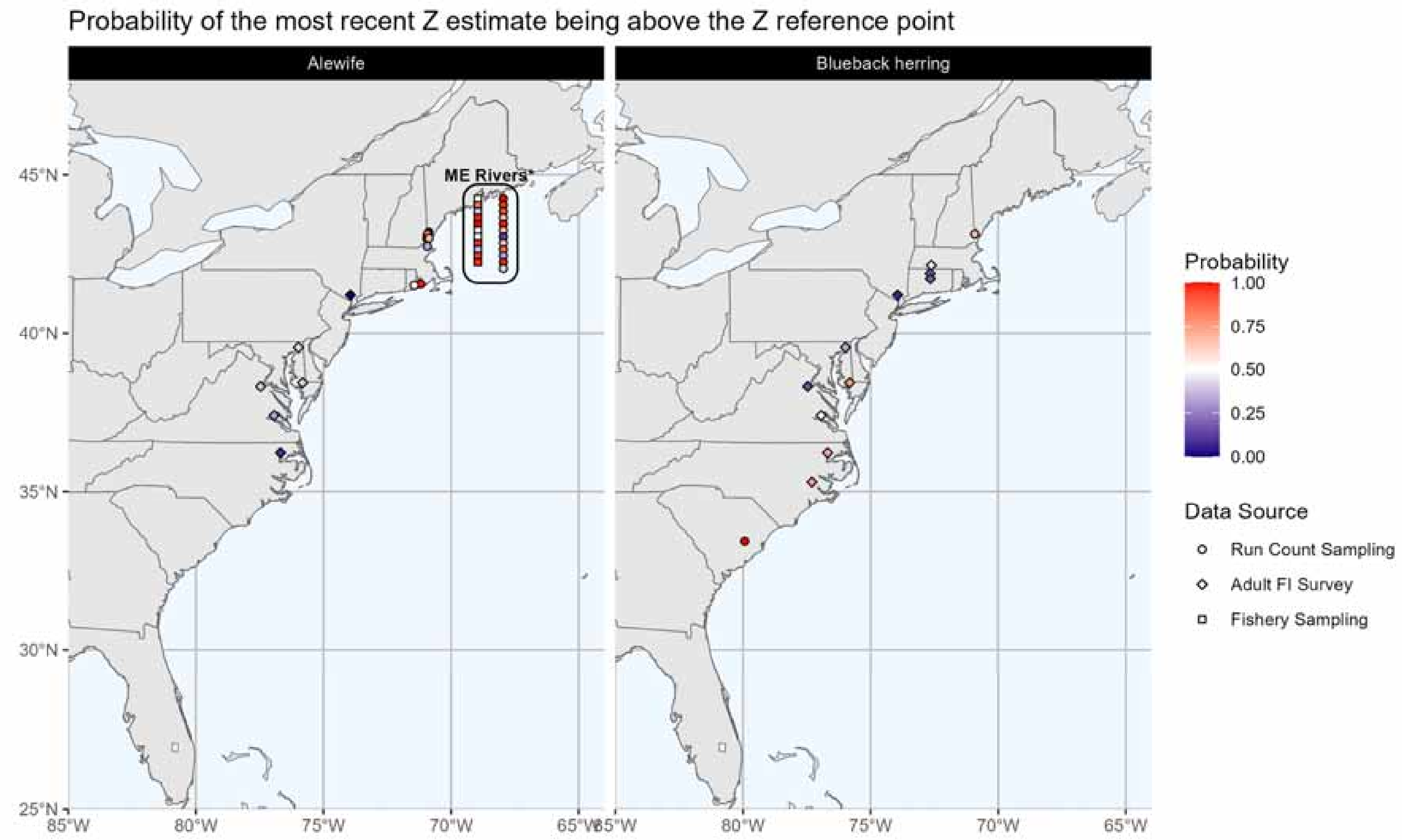

Figure 4. **Map of the probability that the most recent Z estimate is above the $Z_{40\%SPR}$ reference point. *ME Rivers: Maine rivers are not plotted geographically to preserve confidentiality.**

1 INTRODUCTION

1.1 Biology and Life History

1.1.1 Distribution and Migration

River herring is a collective term that is used to refer to alewives (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). The species are distinct and can be distinguished by cutting the abdomen and examining the pigmentation of the peritoneum, the membrane that lines the abdominal cavity. In alewife, the peritoneum is pale or white; in blueback herring, the peritoneum is sooty dark or black. This dissection is not a routine procedure in most commercial fisheries. When fresh specimens of both species are in hand, the alewife has a much larger eye and is deeper bodied than blueback herring. Despite these clear differences, the species are often misidentified and mixed in fishery statistics. To further complicate assessments of abundance and stock status, river herrings can be confused with young American shad (*A. sapidissima*), hickory shad (*A. mediocris*), Atlantic menhaden (*Brevoortia tyrannus*), Atlantic herring (*Clupea harengus*), and other similar species. As a result, these species are often misidentified and mixed in reports of harvest and landings.

Both species are anadromous, highly migratory, schooling, pelagic fishes that spend most of the annual cycle at sea, but migrate to fresh water to spawn in the spring. Alewives are distributed from the Gulf of St. Lawrence and northern Nova Scotia south to North Carolina (Berry 1964; Rullifson et al. 1982; Rulifson 1994). Blueback herring are distributed from Nova Scotia to the St. John's River in northern Florida and are most abundant in waters from the Chesapeake Bay south (Bigelow and Schroeder 1953; Hildebrand 1963; Leim and Scott 1966; Scott and Crossman 1973; Williams et al. 1975; Manooch 1988; Scott and Scott 1988). Landlocked stocks for both species occur (Klauda et al. 1991; Waldman and Limburg 2003), but this occurrence is much rarer for blueback herring (Schmidt et al. 2003).

While most river herring return to their natal rivers to spawn, some individuals have been found to stray to adjacent streams or colonize new areas; others have even reoccupied systems from which they were previously extirpated (Havey 1961; Thunberg 1971; Messieh 1977; Loesch 1987). Most river herring reach sexual maturity between 3 and 6 years of age. The onset of spring spawning is related to temperature and varies with latitude. Alewives spawn at lower temperatures than other alosine fishes and typically migrate earlier (Schmidt et al. 2003). At the southern end of their range, alewives spawn from late February to June (Marcy 1976b; Neves 1981; Loesch 1987). Further north, alewives typically spawn from June through August. Blueback herring begin spawning as early as December or January at the extreme southern end of their range (McLane 1955; Marcy 1976a). At the northern end of the range, blueback herring may not spawn until June and spawning can continue through August (Leim and Scott 1966; Marcy 1976b). Both species are broadcast spawners, releasing their eggs over a variety of substrates. Adults leave the spawning grounds immediately after spawning, reaching deep water by fall.

Eggs hatch between 50 and 360 hours (2 to 15 days) after spawning, depending on water temperature (Fay et al. 1983), but most often hatch within 80 to 95 hours (3 to 4 days; Edsall 1970). Larvae begin to feed externally three to five days after hatching and transform gradually into the juvenile stage. Juvenile alewives and blueback herring begin migrating from their nursery areas as water temperatures decline in the fall. Other factors that trigger downstream migration include changes in water flow, water levels, precipitation, and light intensity. There is some evidence that a high abundance of juveniles may trigger a very early (e.g., summer) emigration of large numbers of small juveniles from the nursery area (Richkus 1975). Little information is available concerning the life history of sub-adult and adult river herring once they migrate to the sea.

1.1.2 Metapopulation and Stock Structure

Multiple genetic studies have found significant isolation by distance and population structuring within the coastwide metapopulation of both alewife and blueback herring (McBride et al. 2014; Palkovacs et al. 2014; Reid et al. 2018).

Reid et al. (2018) identified four regional genetic groups of alewife and five regional genetic groups of blueback herring on the Atlantic coast, based on sampling from the Bay of Fundy through Florida. The genetic groups identified in Reid et al. (2018) were very similar to the genetic groups identified by Palkovacs et al. (2014); the major difference was that Reid et al. (2018) found that the Hudson River population of alewife grouped with the Mid-Atlantic genetic group instead of the Southern New England genetic group.

Within these regional genetic groups, Reid et al. (2018) found much weaker genetic differentiation between rivers. In addition, while they were able to assign individuals back to a regional genetic group with high accuracy, the accuracy of assigning individuals to specific rivers was low in most cases. This indicated that there is gene flow among rivers within a stock-region, likely due to straying, recolonization after an extirpation event, and/or anthropogenic intervention like stocking. McBride et al. (2015) found that genetic isolation by distance was non-significant among alewife populations that had undergone stocking, but significant among non-stocked populations.

This assessment used the genetic groups identified by Reid et al. (2018) to define the stock structure of alewife (Figure 5) and blueback herring (Figure 6) managed by ASMFC. Reid et al. (2018) sampled more rivers along the Atlantic coast and used single nucleotide polymorphisms (SNPs) to identify the genetic groups, which are easier to share across labs to facilitate the analysis and monitoring of mixed stock sampling (e.g., of bycatch data) than the microsatellite data that Palkovacs et al. (2014) used.

1.1.3 Habitat

River herring utilize a variety of habitat throughout their lifecycle. As adults, river herring reside in marine waters most of the year and move to freshwater rivers to spawn. Nursery areas primarily include freshwater portions of rivers and their associated bays and estuaries. Both alewives and blueback herring can tolerate a wide range of salinities. Alewives may prefer cooler water and northern populations may be more cold-tolerant than other migratory anadromous fish (Stone and Jessop 1992).

Alewives spawn over a range of substrates such as sand, gravel, organic detritus, and submerged aquatic vegetation in a diversity of physical habitats that includes rivers, small streams, lakes, and ponds. Blueback herring usually spawn over sand or gravel in swift-flowing areas of freshwater tributaries, channel sections of fresh and brackish tidal rivers, and Atlantic coastal ponds over gravel and clean sand substrates, especially in northeastern rivers where alewives and blueback herring coexist. In southeastern rivers where alewives are few, blueback herring exhibit more of a variety in their spawning sites including shallow areas covered with vegetation, rice fields, swampy areas, and small tributaries upstream of the tidal zone. Substrates with 75% silt or other soft material containing detritus and vegetation are suggested as optimal for spawning, egg, and larval habitat for river herring.

Nursery habitats for alewives and blueback herring occur in non-tidal and tidal freshwater and semi-brackish areas during spring and early summer, moving upstream during periods of decreased flows and encroachment of saline waters. In the lower Chesapeake Bay, juvenile river herring can be found among submerged aquatic vegetation beds.

Along the U.S. continental shelf, Neves (1981) found that catches of river herring were most common at depths less than 92 meters. The National Marine Fisheries Service (NMFS) observed alewives in water depths from 56 to 110 meters in offshore areas. Blueback herring were found at depths of 27 to 55 meters throughout their offshore range. Stone and Jessop (1992) looked at the seasonal distribution and relative abundance of river herring offshore of Nova Scotia. They found that catches shifted from mid-depths in the spring (101–183 meters) to shallower, near shore waters (46–82 meters) in the summer and finally to deeper offshore waters (119–192 meters) in the fall.

1.1.4 Age

River herring have historically been aged using scales, with protocols first developed by Cating (1953) for American shad and Marcy (1969) for river herring. Although used extensively, these protocols have not been validated with known-age river herring. More recent work (e.g., Duffy et al. 2012; Upton et al. 2012; Elzey et al. 2015) has indicated that American shad scale ages are biased compared to otolith ages and inaccurate compared to known-age fish. ASMFC conducted a river herring ageing workshop in 2014 to investigate the precision and bias of age determinations made between labs and structures, and to make recommendations to improve river herring ageing practices. Systematic bias was commonly detected for inter-lab comparisons and paired sample (i.e., otolith and scales from the same fish) comparisons, where otoliths were generally aged younger than scales for younger fish and otoliths were generally aged older than scales for older fish (ASMFC 2014). CVs were generally greater than 5%, which Campana (2001) suggests as a generic ageing precision reference point. However, these results were likely affected by the difference in experience across readers, as well as differences in samples from different rivers. Workshop participants noted that reading samples from unfamiliar river systems and regions likely reduced precision and increased bias compared to reading samples within a familiar river system (ASMFC 2014). ASMFC (2014) recommended collecting paired samples of otoliths and scales, further standardizing protocols across states, and developing reference collections by river system. Collection of otoliths has increased since the last benchmark, and several thousand otolith ages were available across multiple stock-regions for both species.

Scales also have spawning marks, scar-like rings extending around the scale, much like an annuli, but caused by absorption, or erosion, of the scale during the spawning migration into fresh water where little or no food is eaten by adult fish (Cating 1953). Spawning marks are counted as annuli as they erode back from each year’s outer most annulus. They usually occur annually after fish are mature and begin to spawn each year. Spawning marks are not apparent on otoliths, so comparisons of bias and precision cannot be made across structures for this metric. While spawning marks have generally been considered to be easier to read and therefore more precise or reliable than scale ages (ASMFC 2012), some of the bias that affects scale ages likely affects this metric as well.

1.1.5 Climate Impacts

As diadromous fish, alewife and blueback herring are subject not only to a changing marine environment, such as warming surface and bottom temperatures, increasing salinity, lower dissolved oxygen, increasing ocean acidification, and changes to ocean circulation patterns, but also to changes in precipitation patterns and freshwater flow as well as increasing inland water temperatures.

Staudinger et al. (2024) reviewed existing literature on climate change impacts on alewife and blueback herring as part of a larger Northeast Climate Science Center report, and their results are summarized here.

They noted that climate impacts on alewife have been studied more extensively than impacts on blueback herring, with a total of 48 studies on alewife published from 2013-2023, compared to only 8 for blueback herring.

Alewife and blueback herring have been ranked as “Very High Risk” to climate change by Hare et al. (2016) and as “Vulnerable” by Galbraith and Morelli (2017) (the highest and second highest rankings of risk/vulnerability in their respective studies). These rankings were due to their exposure to multiple factors of climate change impacts and their life history (i.e., temperature-driven spawning runs to their natal freshwater spawning grounds) that make it more difficult for them to adapt to these changes.

Staudinger et al. (2024) highlighted the potential for range shifts with these species, including the finding by Nye et al. 2009 that alewife’s center of biomass has been shifting further north in the NEFSC trawl survey. However, without genetic composition data, it is difficult to determine whether the biomass of the total coastwide population is shifting north, or whether the change in the center of biomass is driven by different patterns in abundance trends in northern vs. southern populations of alewife.

Staudinger et al. (2024) found that evidence of changes in the timing (initiation and peak) of spawning runs was mixed, with some populations shifting earlier in recent years, some shifting later, and some not changing.

Studies on climate change impacts on juvenile river herring are also more limited than studies on adults, but in a laboratory study, Guo et al. (2022) found that increased temperatures and reduced food availability resulted in less growth for juvenile alewife and blueback herring and increased mortality for juvenile blueback herring.

1.2 History of the Fisheries

Anadromous species have been fished in the U.S. since human civilizations were present. Their observed spawning runs signaled the end of winter and the beginning of spring and it not only allowed sustenance for early settlers but a source of income as it was commercialized. Characteristics of these early fisheries are difficult to quantify because of the lack of quantifiable data.

The earliest commercial river herring data were generally reported in state and town reports or local newspapers. In 1871, the U.S. Fish Commission was founded, and its name has evolved through the years including the “U.S. Fish and Fisheries Commission” in 1881. This organization collected fisheries statistics to characterize the biological and economic aspects of commercial fisheries. Data describing historical river herring fisheries were available from two of this organization’s publications: the Bulletin of the U.S. Fish Commission (renamed Fishery Bulletin in 1971; Collins and Smith 1890; Smith 1891) and the U.S. Fish Commission Annual Report (USFC 1888–1940). River herring data were transcribed from digitized versions of these reports and entered into Microsoft Excel.

There are several caveats to using the historical fisheries data. There is an apparent bias in the area sampled. In most cases there was no systematic sampling of all fisheries; instead, sampling appeared to be opportunistic, concentrating on the mid-Atlantic states. It is also difficult to assess the accuracy and precision of these data. In some instances, the pounds were reported at a fine level of detail (e.g., at the state/county/gear level), but details regarding the specific source of the data were often not described. The level of detail provided in the reports varied among states and years. Additionally, not all states and fisheries were canvassed in all years so absence of landings data does not necessarily indicate the fishery was not active; it is very possible that a canvass was not conducted. For these reasons, these historical river herring landings should not be considered even minimum values because of the variation in detail and coverage over the time series. No attempt was made to estimate missing river herring data since no benchmark or data characteristics could be found, we also did not attempt to estimate missing data in a time series at a particular location because of the biases associated with these estimates.

From 1880 to 1938, reported commercial landings of river herring along the Atlantic Coast averaged approximately 30.5 million pounds per year (Figure 9). The majority of river herring landed by commercial fisheries in these early years are attributed to the mid-Atlantic region (NY–VA). The dominance of the mid-Atlantic region is, in part, due to the apparent bias in the spatial coverage of the canvass (see previous section describing methods). From 1920 to 1938, the average weight of reported commercial river herring landings was about 22.8 million pounds.

Pound nets and seines were the dominant reported gear types used to harvest river herring throughout the 1887–2021 time period (Figure 10). Seines were more prevalent prior to the 1960s, but by the 1980s, they were rarely used. Purse seines were only used for herring landed in Massachusetts, but made up a large proportion of the landings in the 1950s and 1960s.

Offshore exploitation of river herring and shad (generally <190 mm in length) by foreign fleets began in the late 1960s and landings peaked at about 80 million pounds in 1969. Total U.S. and foreign fleet harvest of river herring from the waters off the coast of the US peaked at about 140 million pounds during 1969. Landings declined dramatically thereafter. After 1977 and the formation of the Fishery Conservation Zone, foreign allocation of river herring (to both foreign vessels and joint venture vessels) between 1977 and 1980 was 1.1 million pounds. The foreign allocation was reduced to 220,000 pounds in 1981 due to the condition of the river herring resource. In 1985, a bycatch cap of no more than 0.25% by catch was enacted. The cap was exceeded once in 1987 and this shut down the foreign mackerel fishery. In 1991, area restrictions were passed to exclude foreign vessels from within 20 miles of shore for two reasons: 1) in response to the increased occurrence of river herring bycatch closer to shore and 2) to promote increased fishing opportunities for the domestic mackerel fleet.

Recreational catches of these species remain largely unknown for the historical (pre-1980s) period. Anecdotally, recreational fishing for American shad and to a lesser extent river herring is popular coastwide during the spring spawning run, but harvest information is unreliable.

Severe declines in landings began coastwide in the early 1970s and domestic landings are now a fraction of what they were at their peak, having remained at persistently low levels since the mid-1990s. Moratoria were enacted in Massachusetts (commercial and recreational in 2005), Rhode Island (commercial and recreational in 2006), Connecticut (commercial and recreational in 2002), Virginia (for waters flowing into North Carolina in 2007), and North Carolina (commercial and recreational in 2007). As of January 1, 2012, river herring fisheries in states or jurisdictions without an approved sustainable fisheries management plan, as required under ASMFC Amendment 2 to the Shad and River Herring FMP, were closed. As a result, prohibitions on harvest (commercial or recreational) were extended to the following states: New Jersey, Delaware, Pennsylvania, Maryland, D.C., Virginia (for all waters), Georgia and Florida.

1.3 Regulatory History

River herring are managed under Amendment 2 (2009) to the FMP for Shad and River Herring, which addresses concerns regarding declining river herring populations. The Amendment requires that states and jurisdictions develop sustainable fishery management plans (SFMPs), which are reviewed by the Technical Committee and approved by the Board, in order to maintain a commercial and/or recreational river herring fishery beyond January 2012. For 2023, approved River Herring SFMPs remain in effect for Maine, New Hampshire, Massachusetts, New York, and South Carolina. Under Amendment 2 to the FMP, states may also implement, with Board approval, alternative management programs for river herring that differ from those required by the FMP. States and jurisdictions must demonstrate that the proposed management program will not contribute to overfishing of the resource or inhibit restoration of the resource. The Management Board can approve a proposed alternative management program if the state or jurisdiction can show to the Management Board's satisfaction that the alternative proposal will have the same conservation value as the measures contained in the FMP. For 2023, approved alternative management plans for recreational fishery regulations remain in effect for in South Carolina, Georgia, and Florida. The remaining states and jurisdictions are required to prohibit commercial and recreational harvest.

1.3.1 Maine

Municipal boundaries are the units used to manage Maine's river herring resources in inland waters. Exclusive harvest rights to river herring resources that migrate inland, beyond the immediate coastal waters of the state, may be granted to a municipality by the Commissioner of the Maine Department of Marine Resources. The Maine Department of Marine Resources (DMR) manages all river herring resources within the municipal management units. The coastal area outside municipal boundaries is closed to all commercial fishing for river herring by state law.

From 1960 through 1987, the State of Maine recommended a one day closed period per week to allow river herring escapement to spawning grounds. Most municipalities, though not all, instituted the one closed day per week. From 1988–1994 the state required that all municipalities have two closed days or a conservation equivalent to ensure spawning escapement. In 1995, the state required three closed days or a conservation equivalent.

The Department of Marine Resources, and the municipalities that were granted the exclusive rights to harvest river herring resources, monitor river herring returns to the municipal fisheries. Each town must submit an annual harvesting plan to DMR for approval that includes a three-day per week escapement period or biological equivalent to insure conservation of the resource. In some instances, an escapement number is calculated and the harvester passes a specific number upstream to meet escapement goals. River herring runs not harvested by a municipality and not approved as sustainable by the ASMFC River Herring and American Shad Management Board are closed to commercial harvest.

Each run and harvest location is unique, either in seasonality, fish composition, or harvesting limitations. Some run specific management plans require continuous escapement and are more restrictive than the three-day closed period. Others have closed periods shorter than the three-day requirement, but require an escapement number, irrespective of the number harvested during the season. Maine increased the weekly fishing closure from a 24-hour closure in the 1960s to a 48-hour closure beginning in 1988. The closed period increased to 72-hours beginning in 1995 to protect spawning fish. All towns are required to operate a harvest site at one location within the system and law prohibits fishing at any other location within the system for the harvest year. The state landings program compiles in-river landings of river herring from mandatory reports provided by the municipality under each municipal harvest plan or the municipality will lose exclusive fishing rights to the river herring resource for the following year.

The state will permit twenty-three municipalities to fish for river herring in 2024. The river specific management plans require the remaining municipalities to close their runs for conservation and not harvest. There are several reasons for the state/municipal restrictions imposed on these fisheries. Many municipalities voluntarily restrict harvest to increase the numbers of fish that return in subsequent years. Some of these runs are large, but have the potential to become even larger and some suffer from lack of good upstream or downstream fish passage. The commercial fishery does not exploit the estimated 1.5–2.0 million river herring that return to the East Machias River or the millions of fish in the main stem of Maine's nine largest rivers.

Recreational fishermen are allowed to fish for river herring year-round but are restricted to four fishing days a week to allow river herring an opportunity to reach spawning habitats. Access to river herring populations for recreational anglers is poor and as a result, landings are low. The three-day closed period required for commercial fishermen is also required for recreational anglers. The limit is 25 fish per day and gear is restricted to dip net and hook-and-line. Recreational fishermen may not fish in waters, or in waters upstream, of a municipality that is granted exclusive river herring harvest rights by the Commissioner of the Maine Department of Marine Resources. Recreational anglers are not required to report their catch. The MRIP program does sample some of these fishermen based on results queried from the database.

1.3.2 New Hampshire

NHFGD manages the river herring populations within state waters. Primarily river herring are intercepted for biological sampling and enumerated at Department owned fish ladders at the head-of-tide dams for management purposes.

The regulatory history of river herring in New Hampshire state waters (inland and 0–3 miles) began in 1967. With the establishment of a permit and reporting requirement for residents or nonresidents utilizing a seine, net, or weir for the taking of river herring. In 1987, the taking of river herring in state waters on Wednesdays by any method was prohibited. New regulations were instituted in 2005 closing a large section of tidal waters in the Taylor River and restricting harvest days in the Squamscott River in Exeter. In 2012, the Oyster River and its tributaries were closed to the taking of river herring from the head-of-tide dam downstream to its mouth at Great Bay. The new regulations were intended to allow more river herring returns to the Exeter, Taylor, and Oyster River fishways.

Currently, the harvest of river herring in New Hampshire is prohibited. New Hampshire did not meet its ASMFC River Herring Sustainable Fishery Management Plan's fishery-independent target in 2020 resulting in a 5-year fishery closure beginning in 2021.

1.3.3 Massachusetts

The Massachusetts Division of Marine Fisheries (MA DMF) has management authority over river herring throughout the Commonwealth of Massachusetts. Under Chapter 130 of Massachusetts

General Laws MA DMF can transfer the authority to manage local harvest of river herring to Towns. In practice, MA DMF works closely with towns to maintain migratory, spawning and nursery habitats for river herring. MA DMF enacted a state-wide closure of river herring harvest in 2006. Prior to the closure, Towns managed harvest with MA DMF-approved plans that included closed days and bag limits. Since the closure, Sustainable Fishery Management Plans were drafted by MA DMF and approved by ASMFC for the Nemasket River, Middleborough/Lakeville (2016) and Herring River, Harwich (2022), although the towns have not yet elected to hold a harvest.

1.3.4 Rhode Island

The Rhode Island Department of Environmental Management (RIDEM) has management authority over river herring (alewives and bluebacks) occurring in the state's fresh and marine waters. Currently there is a moratorium on harvest of river herring (alewives and bluebacks) in Rhode Island's fresh and marine waters. Due to drastic declines in spawning stock size beginning in 2001, Rhode Island passed regulations in March 2006 for the complete closure. Prior to 1998, the freshwater daily river herring limit was 12 fish per day and closed Sunday, Monday, and Tuesday. There were no regulations for marine waters. In 1998, the daily freshwater limit was increased to 24 fish per day with the same closed days, and then decreased to 12 fish per day in 2005. The 2006 closure marked the first time there were reciprocal regulations for Rhode Island marine and fresh waters. The marine and freshwater closure has continued through 2023.

1.3.5 Connecticut

The Connecticut Department of Energy and Environmental Protection manages river herring populations located within Connecticut state waters. The demarcation line between the marine and inland districts typically occurs at the first bridge upstream from the river mouth or cove unless otherwise specified. The moratorium for river herring is in effect for all state waters. Long Island Sound is jointly managed by Connecticut and New York.

From 2002 to present there has been a statewide moratorium on commercial and recreational take of anadromous blueback herring and alewife. Under emergency declaration authority of section 26-102 of the Connecticut General Statutes, the commercial or recreation taking of migratory alewives and blueback herring is prohibited from all marine waters and most inland waters. This prohibition is determined on an annual basis.

Historically, Connecticut's river herring commercial fisheries were not heavily regulated. Regulations placed on the commercial river herring fishery, such as restrictions in coves and tributaries, were typically put into place to protect other species. Most of the focus of alosine regulations were for the American shad fishery, which at one time was one of the most important commercial species in the state (Blake and Smith 1984). Connecticut has three major rivers (Connecticut, Housatonic and Thames) and several smaller rivers and coastal streams. While river herring fisheries likely occurred in all of these systems, the bulk of Connecticut's river herring fisheries occurred in the Connecticut River (Blake and Smith 1984). Regulatory jurisdictions of the fisheries were divided into marine and freshwater districts.

During the early 19th century, Connecticut regulations applied penalties for preventing fish migration. Laws were enacted prohibiting constructing dams unless there was a proper opening for fish to pass from April through June. Any obstructions created to catch fish near a dam in the river during spring migration would result in a fine. Rest days prohibited seining and scoop netting in the Shetucket River below the junction with the Quinebaug (Thames River Watershed) during designated nights in the spring. Seining was prohibited at the mouth of Housatonic River during the spring (Goodrick et al. 1821). No weirs or other obstructions, were allowed across Bride Brook outlet in East Lyme, between sunset on Saturday and sunrise on the following Friday from late March early May (Connecticut General Assembly, 1900). In the mid-20th century, Connecticut state statutes identified specific coves within the Connecticut River prohibiting the use of seines and fyke nets during spring anadromous spawning runs.

Haul seine was the primary gear for commercial river herring fisheries in the Connecticut River. Use of haul seines eventually phased out in the 1980s. Since the 1990s, there were landings reported using gill nets and trawls.

Prior to the statewide fishery moratorium in 2002, the recreational limit for both inland and marine waters was 25 blueback herring or alewife, in aggregate, per person per day, for personal use purposes. Land locked alewives from specific lakes were allowed to be taken recreationally by angling and scoop net. There is no historical data on catch and effort in the river herring recreational fishery. Catches were most likely used for bait purposes, but no attempt has been made to determine the magnitude of these fisheries in Connecticut.

1.3.6 New York

The management unit for river herring stocks in New York State comprises three sub-units. All units extend throughout the stock's range on the Atlantic coast. The largest consists of the Hudson River Estuary from the Verrazano Narrows at New York City to the Federal Dam at Troy including numerous tributary streams. The second is made up of all Long Island streams that flow into waters surrounding Long Island and streams on the New York mainland (Bronx and Westchester Counties) that flow into the East River and/or Long Island Sound. The third subunit consists of the non-tidal Delaware River and tributaries upriver of Port Jervis.

During the 19th century, regulating fisheries within New York waters was the sole responsibility of the state. In 1868, in response to an apparent decline in American shad, the New York State legislature implemented fishing net restrictions, an escapement (net free) period and a season to control fishing on the Hudson. It is likely that these restrictions (season and net use) also affected the take of river herring, as all three alosines (American shad, alewife and blueback herring) occurred in the river at the same time. Prior to 2013, take of river herring in New York remained relatively unregulated. Most restrictions concerned the use of gear to take fish, with no limits on take for either recreational or commercial use.

In response to Amendment 2, New York State proposed, and ASMFC approved, the 2012 Sustainable Fishery Management Plan (SFMP) for New York River Herring Stocks (Hattala et al. 2011). This SFMP included an experimental five-year restricted fishery in the Hudson River, a partial fishery closure in tributaries, a 10 fish per day recreational creel limit, a moratorium for all non-Hudson waters, and annual stock monitoring in the Hudson River. Monitoring included young-of-year indices, and for adults: age and length characteristics, mortality estimators, and commercial fishing catch per unit effort (CPUE). The sustainability target for both species was set using the young-of-year indices. The sustainability target value was defined as the 25th percentile of the time series, such that three consecutive years with index values below this target would trigger management action. From 2012–2022, the indices did not fall below the target for three consecutive years for either species.

In 2022, New York State submitted a mandatory five-year SFMP update, which proposed a continuation of the moratorium in non-Hudson waters, a restricted fishery in the Hudson River, annual stock monitoring, and sustainability targets described in the original SFMP with an additional sustainability target for total mortality. This update was approved by the ASMFC Management Board in February 2022 (Eakin et al. 2022).

Current regulations can be viewed at https://www.dec.ny.gov/nature/animals-fish-plants/hudson-delaware-marine-fisheries/river-herring

1.3.7 New Jersey

New Jersey Division of Fish and Wildlife manages river herring populations occurring within New Jersey's sections of the Basin and the coastal waters from Cape May Point to Sandy Hook including Raritan Bay and River.

As of January 1, 2012, commercial and recreational landings of river herring in New Jersey have been prohibited. These regulations are in compliance with the Atlantic States Marine Fisheries Commission Amendment 2 to the Fisheries Management Plan for Shad and River herring.

Historically, no specific regulations have been adopted to reduce or restrict commercial landings of river herring in New Jersey; however, there have been regulations which limited commercial fishing effort and had a direct impact on catch. New Jersey adopted general regulations that apply to the commercial fishery such as limited entry, limitations on the amount of gear, and gear restrictions in defined areas.

Historically, the recreational fishery for river herring was very small with few participants and low retention rates. Those herring that were landed were typically frozen for bait, pickled, harvested for their roe, or kept for other traditional uses. Recreational gears included hook and line, dip net, bait seine, cast net, and umbrella net.

Harvest of landlocked freshwater populations of river herring is permitted year-round on lakes in select counties in New Jersey for bait purposes. Anglers are restricted to 35 fish per day with a six-inch maximum size limit. Any unused herring must be returned to the water upon conclusion of the angler's fishing trip. Herring may not be transported away from the shoreline of these lakes by any mechanism. They may not be sold.

1.3.8 Pennsylvania

A robust commercial river herring fishery existed near Philadelphia on the Delaware River in the late 1800s and early 1900s. This fishery was eliminated by the "DO block" in the mid-1900s.

Historically, the sport fishery for river herring in Pennsylvania was almost exclusively a bait fishery which was limited to hook and line fishing, open year-round, with no minimum length limit. Since the mid-1980's, the daily creel limit for river herring in the Delaware River and Estuary was a total of 35 fish. Beginning in 2010, the Pennsylvania Fish and Boat Commission adopted regulations in coordination with New Jersey and later coordinated with New York reducing the daily creel limit from the historic limit to a limit of 10 river herring from the confluence of the East and West Branches downriver to the Commodore Barry Bridge. The remaining 2.9 river miles below the Commodore Barry Bridge remained at the historic daily limit of 35 herring, in cooperation with New Jersey's Marine Council.

As of January 1, 2012, the commercial and recreational fisheries in Pennsylvania waters have been closed. No harvest of river herring is permitted.

1.3.9 Delaware

Prior to January 1, 2012, no specific regulations were ever adopted to reduce or restrict commercial landings of river herring, however there are regulations that applied to the commercial fishery that limited commercial fishing effort and have a direct impact on catch and effort. In Delaware, these restrictions include a limited entry license system, limitations on the amount of gear allowed to be fished, and season and area closures.

Additionally, since 1985, every fisherman holding a commercial food-fishing license was required to submit a monthly report specifying where they fished, the type and amount of fishing gear deployed, and the pounds landed of each species taken for each day fished. Those herring that were landed were typically frozen for bait, pickled, harvested for their roe, or kept for other traditional uses. As of January 1, 2012, possession of river herring is prohibited in Delaware.

1.3.10 Maryland

Historically, Maryland’s commercial river herring fishery was seasonally restricted, closed from June 5th to Jan 1st of the next year. Since migrations occur in the spring, this law had little, if any, management consequences. Up until 2005, it was primarily a directed fishery using drift gill nets with meshes ranging from 3 ⅛ to 3 ¼ inches. A limited pound and fyke net bycatch fishery also existed. After 2005, the directed fishery reported few fish and little effort, and many commercial gill netters no longer targeted river herring. A directed commercial river herring fishery developed in 2006 in a select Chesapeake Bay tributary (based on landing records) and was the result of new spring regulations allowing river herring as live bait to target striped bass in the upper Chesapeake Bay. There were no state limits on total river herring catch or the amount of gear utilized. Individual rivers may have had distinct gill net area restrictions.

Like the commercial fishery, Maryland’s recreational river herring fishery was seasonally restricted, closed from June 5th to Jan 1st of the next year. There were no size or creel limits on river herring. Maryland has no recreational landings data. Limited data indicated that catches were minimal but there may have been small incidental catches of river herring used for striped bass bait that were not documented. Historically, anglers used dip nets to catch river herring and very few herring were caught by hook and line, usually when fishing for other species. Dip nets were not to be used within 50 yards of the mouth of any river or tributary or the base of a dam and were not to be used in any waters of the state stocked with trout. In non-tidal waters an individual could only use hook and line to take herring. Dip nets were not to be used in the Susquehanna River upstream of Deer Creek. Nets, other than a landing net, were not to be used in Deer Creek.

As of January 1, 2012, the commercial and recreational fishery were closed, and possession of river herring is prohibited in Maryland.

1.3.11 Virginia

Virginia’s Department of Wildlife Resources (VDWR) is responsible for the management of fishery resources in the state’s inland waters. The Virginia Marine Resources Commission (VMRC) oversees the management of resources in the state’s marine waters.

The conservation and management of Virginia's river herring stocks dates back to colonial times. Loesch and Atran (1994) provide a brief historical overview of *Alosa* fisheries management in Virginia.

As of January 1, 2008, possession of alewives and blueback herring is prohibited on rivers draining into North Carolina (VMRC Regulation 4 VAC 15-320-25). Those rivers include the Meherrin River, Nottoway River, Blackwater River (Chowan Drainage), North Landing and Northwest rivers, and their tributaries plus Back Bay. On June 28, 2011, the VMRC voted to implement a ban on the possession of alewives and blueback herring in state waters; this ban became effective January 1, 2012 (VMRC Regulation 4 VAC-20-1260-30). The ban was enacted due to the collapse of the fishery over the last four decades and in order to comply with Amendment 2 to the Interstate Fishery Management Plan for Shad and River Herring (ASMFC 2009).

1.3.12 Potomac River Fisheries Commission

During colonial times, the fisheries were essentially unregulated. In 1785, Maryland and Virginia adopted a compact to regulate the fisheries by requiring all fishery laws for the Potomac River to be enacted jointly by the legislatures of both states. In 1963, the Potomac River Fisheries Commission (PRFC) was created and charged with the establishment and maintenance of a program to conserve and improve fishery resources. While PRFC has never had any specific regulations regarding river herring, there have been prohibitions against certain gears such as purse nets, trawls, trammel nets, troll nets, or drag nets have been in place which has limited commercial harvest of river herring such that river herring harvest in the Potomac is almost exclusively taken by pound nets.

The pound net fishery shifted from a shad and herring fishery in the 1960s and early 1970s, when those species began declining, to primarily a menhaden fishery in the late 1970s and early 1980s. The deep water in-line pound nets were replaced by shallow water singly-set pound nets, and as a result shad and river herring became by-catch species in pound nets. The PRFC adopted a commercial fishery moratorium for river herring in 2010, with a minimal by-catch provision of 50 pounds per licensee per day for pound nets. A pound net by-catch provision was put in place to enable monitoring of river herring runs. In 2012, all fisheries were closed to the taking and/or possession of river herring. The PRFC now has no commercial or recreational fisheries for river herring.

The PRFC adopted the mandatory use of fish cull panels in all pound nets in the Potomac River, effective January 1, 2011. Fish cull panels are specially designed and manufactured by-catch reduction devices that have been tested and used (prior to 2011) voluntarily in Potomac River pound nets. They were effective in the safe release of sublegal flounder, weakfish, spot, croaker and bluefish when installed in the bottom corners of the sides of the pound nets. The regulation requires that four panels be installed in the bottom corners of the upriver and downriver sides of the net, and two additional panels be installed closer to the surface for the purpose of releasing river herring. It is expected that this conservation measure will greatly reduce the by-catch of small fish in pound nets.

The Potomac River recreational fishery for river herring under the jurisdiction of PRFC was closed in 2010 in the main stem of the river below the District of Columbia.

Note that the PRFC regulates and records harvest for only the main stem of the river, while the tributaries on either side are under Maryland or Virginia jurisdiction. Harvest records for alewife and blueback herring in the Potomac River have been historically combined as river herring.

1.3.13 District of Columbia

Recreational anglers have historically been permitted to harvest river herring within the District of Columbia's portion of the Potomac River by way of hook and line fishing, dip netting, and snagging, with no size or creel limit. As of January 1, 2012, recreational and commercial harvest of river herring was prohibited within the District's waters.

1.3.14 North Carolina

The management of river herring in North Carolina is conducted in joint and coastal waters by the NCDMF and in inland waters by the NCWRC. The management units established in the 2000 NCRHFMP include the two species of river herring (blueback and alewife) and their fisheries throughout coastal North Carolina.

From 1915–1965 various regulations including season and area closures as well as gear restrictions were implemented in the NC river herring fisheries. Beginning in 1995, various restrictions including season closures and total allowable catch limits were implemented.

The two management areas, the Albemarle Sound River Herring Management Area (ASRHMA) and the Chowan River Herring Management Area (CRHMA), were established in the 2000 NCRHFMP and defined in North Carolina Fisheries Rules for coastal waters 2003 rule 15A NCAC 3J. 0209. An annual quota, or total allowable catch (TAC) of 300,000 pounds was established in 2000 for the ASRHMA and was allocated as follows: 200,000 pounds to the pound net fishery for the CRHMA; 67,000 pounds to the ASRHMA gill net fishery; 33,000 pounds to be allocated at the discretion of the NCDMF Director (15A NCAC 3M.0513). The same rule also granted the Director proclamation authority as it applies to blueback herring, alewife, American and hickory shad fisheries, and also established a 25 fish per person per day (blueback herring and alewife combined) recreational creel limit.

The commercial TAC was further reduced in 2006 for the ASRHMA with 65,000 pounds allocated to CRHMA pound net fishery; 35,000 pounds to the ASRHMA gill net fishery; 5,000 pounds to be allocated at the NCDMF Director discretion.

Rule 15A NCAC 3O.0503 outlines the requirements for the Albemarle Sound Management Area River Herring Dealer Permit. To purchase river herring a dealer must obtain an Albemarle Sound Management Area River Herring Dealer Permit. The permit conditions require the dealer to report landings daily to the NCDMF, and allow biological sampling of catches by NCDMF personnel.

The NCMFC through the development and approval of Amendment 1 to the NCRH FMP approved a no harvest provision for river herring, commercial and recreational, in waters under their jurisdiction in 2007. The NCMFC approved a 7,500-pound limited research set aside to be allocated at the NCDMF Director's discretion to collect data necessary for stock analysis, and to provide availability of local product for local festivals. To implement the harvest of this discretionary amount, a Discretionary Herring Fishing Permit (DHFP) was created. Individuals interested in participating had to meet the following requirements: (1) obtain a DHFP, (2) harvest only from the Joint Fishing Waters of Chowan River during the harvest period, (3) must hold a valid North Carolina Standard Commercial Fishing License (SCFL) or a Retired SCFL, and (4) participate in statistical information and data collection programs. If harvested river herring were sold, they had to be sold to a licensed and permitted River Herring Dealer. The Director allocated a maximum of 4,000 pounds of the 7,500 pounds set aside for harvest in the limited fishery. Each permit holder was allocated 125–250 pounds for the four-day season during Easter weekend from 2007–2010. This limited fishery has also met the requirements of Amendment 2 to the ASMFC Shad & River Herring Fisheries Management Plan and was approved by the ASMFC Shad & River Herring Management Board in 2011. In 2015, through the development and approval of Amendment 2 to the NCRHFMP the NCMFC eliminated the discretionary harvest season for river herring; prohibited the possession of river herring greater than six inches aboard a vessel or while engaged in fishing from the shore or a pier in all coastal waters (NC rule 15A NCAC 03M.0513); and removed river herring from exceptions in the NC rule 15A NCAC 03M.0101 for mutilated finfish.

Anadromous Fish Spawning Areas (AFSA) have been adopted by NCWRC and NCMFC into NC rule 15A NCAC 03R.0115 through the implementation of Amendment 1 of the NCRHFMP. These areas are designated using spawning area surveys conducted in North Carolina as well as current and future surveys that will continue to re-evaluate spawning habitat.

The NCWRC has authority over the Inland Waters of the state. Since July 1, 2006 harvest of river herring, greater than 6 inches has been prohibited in the inland waters of North Carolina’s coastal systems.

1.3.15 South Carolina

Management of blueback herring in South Carolina is shared between the Marine Resources and Freshwater Divisions of the Department of Natural Resources (SCDNR). Management units are defined by stock and the complex of river(s) utilized. Management units include all rivers and tributaries within each area complex: Winyah Bay (Sampit, Lynches, Pee Dee, Bull Creek, Black, and Waccamaw Rivers), the Santee-Cooper Rivers complex, the Savannah River and the ACE Basin (Ashepoo-Combahee-Edisto Rivers).

The SCDNR manages commercial herring fisheries using a combination of seasons, gear restrictions, and catch limits. In 1964, commercial blueback herring fishing in Cooper River was restricted to daylight hours with a dip net not more than three feet in diameter and a limit of 100 lb (45.4 kg) per man per day. By 1969, regulations had been liberalized to allow nets with six-foot diameters, fishing until ten o'clock p.m., and no limit on the harvest. Between 1966 and 1969, herring were abundant and the fishery expanded. Fishing success declined in the early 1970s and a limit of 45.4 kg of herring per man day was reimposed in 1975. Today, the commercial fishery for blueback herring has a 10-bushel daily limit (227 kg) per boat in the Cooper and Santee Rivers and the Santee-Cooper Rediversion Canal and a 250 lb (113.4 kg) per boat limit in the Santee-Cooper lakes. Seasons generally span the spawning season. All licensed fishermen have been required to report their daily catch and effort to the SCDNR since 1998, and regular creel surveys occur on the Rediversion Canal to ground truth reported landings.

The recreational fishery has a one bushel (22.7 kg) fish aggregate daily creel for blueback herring in all rivers, however very few recreational anglers target blueback herring. The majority of recreational landings have been observed on the Rediversion Canal in recent years.

1.3.16 Georgia

Georgia does not have a commercial fishery for river herring, and there are no laws regarding the recreational take of river herring in Georgia’s rivers. A creel survey aimed at identifying potential river herring angler effort on the Altamaha River was conducted from January–April 2022 by GADNR staff. No river herring were observed and no angling effort for river herring was reported. Cast nets can be utilized to capture landlocked blueback herring for bait within Georgia reservoirs.

1.3.17 Florida

Blueback Herring have not been specifically regulated in the St. Johns River, Florida. Gear restrictions in other fisheries have affected Blueback Herring catch. New pound net licenses were no longer issued for the St. Johns River after 1982. Existing pound net licenses were non-transferable (FAC 68A-23.003) and no pound nets are operating on the St. Johns River, Florida. The Florida Constitution was amended by voter referendum to prohibit entanglement nets larger than 500 ft^2 in state waters. This net ban became effective on July 1, 1995 (Art. X, Sec. 16).

As of January 1, 1997, hook and line is the only permissible gear for all *Alosa* spp. in Florida (FAC 68B-52.001). Recreational anglers must possess a valid saltwater fishing license in order to retain anadromous species in fresh water.

1.3.18 Federal Management

Although NOAA Fisheries does not manage river herring directly, they have taken actions that directly and indirectly affect river herring bycatch in the Atlantic herring and Atlantic mackerel fleets.

Federal Bycatch Caps

In 2014, after the last benchmark assessment for river herring (ASMFC 2012), NMFS implemented catch caps for shad and river herring in the Atlantic mackerel and Atlantic herring fisheries, where incidental catch rates were highest. The Atlantic herring fishery has four area- and gear-specific catch caps (Figure 7): Gulf of Maine (GOM) midwater trawl, Cape Cod (CC) midwater trawl, Southern New England/Mid-Atlantic (SNE/MA) midwater trawl, and SNE/MA bottom trawl. The cap applies to all trips that land more than 6,600 lbs of herring. When 95% of the catch cap for a gear and area is projected to be reached, all vessels fishing with that gear type in that area will be subject to a reduced herring possession limit of 2,000 lb per trip, per calendar day in that area for the remainder of the fishing year. There is only one catch cap for the Atlantic mackerel fishery, but it operates similarly: the cap applies to vessels landing more than 20,000 lbs of Atlantic mackerel, and when 95% of the cap is predicted to be reached, the Atlantic mackerel fishery will be closed for the rest of the year.

These caps are based on historical bycatch levels for each fishery. Bycatch of all alosine species (alewife, blueback herring, American shad, and hickory shad) is counted towards the cap. Initially, the cap was based on the median river herring and shad bycatch rates for 2008-2012 for Atlantic herring and 2005-2012 for Atlantic mackerel. In 2016, the caps were revised, but remain based on historical estimates rather than biological metrics. The Atlantic mackerel cap was decreased from 89mt to 82mt and the GOM midwater trawl cap was decreased from 85.5 mt to 76.7 mt, while the other caps increased, going from 13.3mt to 32.4mt for CC midwater trawls, from 123.7mt to 129.6mt for SNE/MA midwater trawls, and from 88.9mt to 122.3mt for SNE/MA bottom trawls (Table 1). The revised caps remain in place for the Atlantic herring fishery, but in 2020, the Atlantic mackerel cap was increased from 82mt to 129 mt. In 2022, the total bycatch permitted annually under the Atlantic herring caps was 361 mt, approximately 70% of which was allocated to the SNE/MA management areas, with an additional 129mt permitted under the Atlantic mackerel cap.

Estimates of bycatch have rarely exceeded the catch caps (Figure 8). Estimates of bycatch for 2020-2022 were low in these fisheries, but in 2023 and 2024, the Cape Cod midwater trawl catch cap was reached and the reduced trip limit provisions were implemented in that area for that gear.

While recent reductions in the quotas for Atlantic herring and mackerel have resulted in lower effort in these fisheries, observer and port sampling coverage was also lower in those years. From 2020 to 2022, observer coverage of Atlantic herring trips qualifying for RH/S catch caps in the SNE catch cap area was either zero or confidential (NEFMC 2023). When zero trips for a catch cap gear and area are observed in a fishing year, the RH/S bycatch rate from the previous year is used as a proxy for in-season monitoring of bycatch against the cap. If there were no observed trips in that strata in the previous year, the overall mean RH/S bycatch rate across all of the catch cap gears/areas is applied. As a result, estimates of bycatch may be biased low if coverage in the fisheries with historically higher bycatch rates have low or no observer coverage.

Between 2014 and 2022, a total of 1,117.2mt of alosine bycatch was reported against the Atlantic herring and Atlantic mackerel catch caps, an average of 130.1mt per year. In the Atlantic herring fishery during this time, 663.9mt (77%) were reported from the SNE catch cap area, 128.1mt (15%) from the Cape Cod catch cap area, and 73.8mt (9%) from the Gulf of Maine catch cap area.

Atlantic Herring Spawning Closures

In addition to the bycatch cap, the GOM management area for Atlantic herring utilizes effort control measures that are not implemented in other management areas. Since 1999, Area 1A (Inshore GOM) has had annual spawning closures, as well as varying forms of a “days out” provision that restricts fishing days to manage when landings occur during the June-September period to better align with peak demand for bait. The “days out” provision was complemented in 2002 with the introduction of a seasonal division of the GOM quota to further manage effort in this time of year. Additionally, the NEFMC prohibits midwater trawling from June 1-September 30 in Area 1A.

In response to the 2018 Atlantic herring research track assessment (NEFSC 2018), which showed reduced levels of recruitment and spawning stock biomass, spawning closures were extended from four to six weeks, and the trigger threshold of spawning population was reduced from 25% to 20%. The three inshore GOM spawning areas of eastern Maine, western Maine, and Massachusetts-New Hampshire have independent closures during the fall that may begin on the default dates of August 28, September 23 and September 23, respectively. If sufficient samples are available, actual closure effective dates are determined using a Gonadal-Somatic Index-based forecast system, which tracks reproductive maturity to align the timing of spawning area closures with the onset of spawning.

1.4 Restoration Efforts

1.4.1 Maine

The goal of Maine’s river herring restoration activities is to provide access to all habitats that supported river herring historically. Many of these habitats are well inland of the coastal rivers that currently support river herring runs. Access to much of this habitat is still blocked by dams without upstream fish passage and other impediments. The resource agencies have made significant progress by installing upstream and downstream fish passage facilities, especially in the Penobscot, Kennebec, St. Croix and Sebasticook river watersheds and several smaller coastal watersheds. In 2021, a significant restoration project on Outlet Stream in the town of Vassalboro restored a run of more than two-million returns. Fish passage or dam removals at five sites on Outlet Stream now provides passage into China Lake, a 3,845-acre lake that now adds to the growing number of river herring in the Sebasticook watershed.

Starting in 2010 the DMR began restoring river herring to the Penobscot River, Maine's largest river. The trap and transfer program introduced 21,556 pre-spawn river herring from the Kennebec River into three habitats (Chemo, Perch, and Mattamiscontis Ponds) in the Penobscot drainage. This trap and transfer program will continue until sufficient returns to the Penobscot permit transfers of fish from sources within the Penobscot basin. Since 2010, the Department has made significant progress in recolonizing 13 lakes and ponds with river herring. Starting in 2022, five additional lakes are in the process of a four-year stocking program to recolonize river herring. These lakes include Wytopitlock, Pleasant River, Gristmill, and Silver lakes. By 2025 a total of 18 lakes and ponds, in addition to the main stem river, will be fully contributing river herring to the Penobscot River watershed. Pushaw Lake and several additional waters have potential to create significant commercial fisheries for river herring. Pushaw Lake currently returns 1.5-million fish to this single waterbody.

In 2013, the Maine Legislature ordered that the fishways on the St. Croix River be operated to allow river herring to pass into a larger portion of the St. Croix watershed beginning in 2014. The remnant populations of river herring in the lower river have responded and recolonized a larger portion of the watershed. River herring returns to the St. Croix River exceeded 840,000 fish in 2023, with expectations that this number will continue to increase in future years. In 2023, the Milltown Dam, the first dam on the river, was decommissioned and removed, leaving only two main stem dams on the St. Croix River. The Grand Falls dam fishway, now the second dam on the main stem river, is in the process of receiving two new fishways to pass river herring upstream.

In the same general geographic area, a fishway will be constructed at Baskahegan starting in 2024. Baskahegan Lake contains 6,944 surface acres and annual river herring production is expected to produce 2.75 million returns to the towns of Brookton and Topsfield in Washington county.

Several smaller restoration projects and passage improvements are being implemented on the Medomak, Cobbosee, Sabattus, and Eastern rivers. Although these smaller projects, when compared to Maine's larger rivers, will return fewer than 10-million fish total, they will make significant contributions to the recovery of river herring throughout Maine.

Maine operates a well-established trap and truck program that maintains historic runs that currently do not have upstream passage until resource agencies can achieve permanent passage. The number of alewife stocked varies based on available habitat and access to broodstock. The annual stocking goal of these restoration projects range from a few hundred fish to 200,000 fish, with most stocked in the Androscoggin, Kennebec, and Penobscot watersheds. These watersheds still have some locations that do not have upstream passage and require transport of spawning fish around existing barriers. Once passage is achieved the stocking programs to these waterbodies will be discontinued to allow natural river herring migration and reproduction.

The interim restoration-stocking target for inland spawning habitats is six fish per surface acre for inland lakes and ponds locations stocked by truck. The State of Maine established this stocking rate during a 10-year study conducted by MDMR, Maine Department of Environmental Protection and Maine Inland Fisheries and Wildlife (Kircheis 2002). The goal of the study was to quantify the effects of a spawning population of alewife on the resident fish species and zooplankton community within inland waters. A stocking rate of six fish per surface acre of lake or pond habitat showed no negative effects for growth rates of resident freshwater fish species. The DMR observes this stocking rate for all truck-stocked locations. It is important to note that the initial stocking rate for this study was arbitrary and the stocking density could be higher and still not demonstrate significant negative impacts to resident fish species.

The state manages coastal runs for free passage and does not restrict these waters to the six fish per acre limit. All fishways that provide upstream passage for alewives are free passage, even those that provide access to habitats once stocked by truck. The management threshold for these locations is a return rate of 235 fish per acre with minimum 35 fish per acre escapement into spawning habitat.

1.4.2 New Hampshire

The restoration target for New Hampshire’s river herring is to restore spawning populations to levels of abundance that will enable the full utilization of available and/or historical spawning habitat.

Restoration efforts for river herring in New Hampshire’s river systems have included constructing and improving upstream passage facilities at dams; stocking of adult fish into historic and viable spawning reaches; removing dams; and improving water quality in spawning and rearing reaches. From 1984 to 2023, approximately 78,400 adult river herring have been stocked in coastal rivers of New Hampshire. The transfers that occurred were either in-basin transfers to increase spawning habitat or out-of-basin transfers to help supplement spawning runs in rivers with lower return numbers.

Restoration of diadromous fish populations began with construction of fishways from the late 1950s to the early 1970s by the NHFGD in the Cocheco, Exeter, Oyster, Lamprey, Taylor, and Winnicut Rivers. These fishways re-opened acres of freshwater spawning and nursery habitat for river herring, American shad, and other diadromous fish. Construction of a Denil fish ladder was completed in early 2012 on Wiswall Dam, the second dam from the head of tide on the Lamprey River.

In addition, NHFGD is actively involved in improving riverine processes, connectivity, and habitat for diadromous fish through collaborative efforts between federal and state agencies, local municipalities, and dam owners. Collaborative efforts include; removal of the last remaining dam on the main stem of the Winnicut River in 2009. The Great Dam and associated fish ladder on the Exeter River was removed in the fall of 2016. Most recently, the Upper and Lower Sawyer Mill Dams on the Bellamy River in Dover were removed in 2019 and 2020.

1.4.3 Massachusetts

Massachusetts’ statutes direct MA DMF to work with Towns to sustain river herring runs, manage fisheries and provide fish passage. MA DMF has maintained a fishway crew since 1934. The crew operates within the Diadromous Fish Project as part of an ongoing effort to sustain and restoring passageways for adult river herring migration and juvenile herring emigration. The present project continues this tradition with additional efforts aimed at collaborative projects, spawning and nursery habitat restoration and the monitoring, restoration and management of other diadromous fish species.

The present MA DMF crew typically completes 4-6 fishway structural repairs or reconstructions every year during summer and fall. In the spring, the Fishway Crew responds to identified issues and requests to make numerous adjustments and minor fishway repairs each year. The crew maintains a mini-excavator, fabrication shop and stocking truck to assist restoration efforts. In recent years, river herring stocking from suitable donor run has occurred at 5-6 sites following restoration actions. In addition, the project leads contracts annually for larger fishway projects and participates in large cooperative restoration projects including dam removals and channel improvements.

Recent initiatives with the MA DMF Diadromous Fish Project include a large effort to improve river herring habitats through stream maintenance, spawning and nursery habitat assessments, and a GIS-based diadromous fish restoration priority list. Stream maintenance involves manual removal of debris jams caused by tree falls and accumulation of trash and natural debris and the encroachment of natural and invasive wetland plant in stream channels. The periodic impedance of stream channels for diadromous fish passage is not a new problem but may be exacerbated in some watersheds where surface flows are altered for water supplies. This condition led to the preparation of a Wetlands Protection Act policy in 2022 to clarify the process for conducting stream maintenance (https://www.mass.gov/doc/dep-dmf-stream-maintenance-policy-april-2022/download). River herring spawning and nursery habitat assessments are conducted to identify impairments that could reduce river herring reproductive success and identify restoration opportunities (*link provided at MA DMF website*: https://www.mass.gov/info-details/diadromous-fisheries-project). A Mass-GIS datalayer was published in 2023 that provides information on nearly 500 locations in Massachusetts where diadromous fish passage can be impeded and relates these locations to a coast-wise MA DMF Diadromous Fish Restoration Priority List (https://www.mass.gov/info-details/massgis-data-diadromous-fish).

1.4.4 Rhode Island

The Rhode Island Division of Fish and Wildlife is partnering with many government agencies, NGOs, and private entities on a wide variety of anadromous habitat restoration projects throughout the state. Projects include constructing new fishways, culvert modifications, and dam removals to enhance spawning and nursery habitat. Since the last assessment fish passage projects have been completed on the Pawcatuck, Pawtuxet, Ten Mile and Woonasquatucket Rivers. Currently several fish passage projects are proposed or currently being implemented on the Blackstone River, Pawcatuck River, and Factory Brook (Edwards 2015; Erkan 2002).

The state of Rhode Island has informally adopted a recovery target of greater than 50% of the spawning stock size estimated by Gibson (1984). The estimates are calculated based on habitat size and are used as indicators to predict the spawning stock size potential of restored habitat or strength of existing runs.

Stocking has been important to Rhode Island’s river herring restoration efforts. Each year trap-and-transport is conducted utilizing out-of-state and in-state broodstock sources to supplement existing runs or restore extirpated systems that have been restored. Gilbert Stuart was Rhode Island’s only broodstock source for river herring between 1966 and 1972, and today is still an important source. Nonquit has not been utilized as a broodstock source, but was considered in 2001, prior to the drastic decrease in spawning stock size. Between 1990 and 1993, both Gilbert Stuart and Nonquit received supplemental stockings from the Agwam and Bourne rivers located in Massachusetts. Since 2001, it has become increasingly difficult to obtain available out-of state and in-state broodstock sources, due to the declines in river herring run sizes.

1.4.5 Connecticut

The CT DEEP Diadromous Fish Restoration program is responsible for the enhancement and restoration of diadromous fish in Connecticut. The program was largely limited in its interactions and efforts with river herring through much of the twentieth century, however, large reductions in run sizes across the state in the mid to late 1990’s sparked harvest moratoriums on the Connecticut River in the mid 1990’s and a statewide moratorium in 2002, that remains in place today. These documented large reductions in river herring numbers lead CT DEEP to focus resources and staff towards identifying, enumerating, and protecting remaining runs, while working to address those that were extirpated by the twenty-first century.

To accomplish these tasks, staff first worked to identify, prioritize, and remove barriers to passage at historic spawning habitats. Historically, this barrier removal work focused largely on the construction of fish passages over or around barriers, but efforts have more recently swayed towards full-scale barrier removal projects. This move was largely due to the maintenance requirements and passage limitations associated with engineered fishways but was also supported by successful barrier removal projects across New England. Several engineered fishways are still planned for construction across CT in the coming years, as the barriers blocking river herring passage at these sites cannot be removed due to a number of infrastructure concerns.

As passage improvements are completed, CT DEEP staff have worked to install and maintain a network of electronic fish counters and video monitoring sites to enumerate the run response to these efforts. Enumeration efforts are ever growing, with the planned installation of two more electronic counters in 2024. Currently, river herring numbers are enumerated at twenty-one of the sixty-five state and privately owned fish passage facilities operated and maintained by CT DEEP Diadromous Fish staff and private owners. Additionally, CT DEEP staff work with the public and NGO groups to identify and maintain a network of visual inspection sites at historic runs to help guide future needs and restoration goals.

When a run has been extirpated or the response to a barrier removal projects does not result in run size growth, CT DEEP staff transplant pre-spawn river herring from donor streams with healthy runs to “re-seed” the run in need. This effort began in earnest in 2002, with a total of 61,000 pre-spawn river herring stocked across CT by 2018. Most of the pre-spawn river herring stocked in CT have been Alewives, due to poor returns of Blueback Herring that are too low to support such efforts (CT DEEP staff have been unable to locate numbers of Blueback Herring large enough to stock since 2014).

Since 2019, CT DEEP staff have worked to increase pre-spawn Alewife trucking efforts and stocking rates in response to a successful pilot project at Rogers Lake in Old Lyme CT that resulted in large returns, suggesting the number of individuals stocked per site had historically been too low. This evidence, coupled with communications with Maine DMR staff, lead CT DEEP staff to increase stocking numbers to an average of 23,000 a year, spread across twenty-one stocking locations, between 2019 and 2022. In addition to increasing stocking efforts, CT DEEP staff have worked with Yale University researchers to identify the best available rearing habitat for young-of-the-year Alewives, utilizing oxygen and zooplankton monitoring coupled with nighttime purse seine JAI surveys. Unfortunately, accelerated run reductions across southern New England in 2022 and 2023 ended trucking efforts until donor runs return to escapement goals.

The Connecticut River watershed spans across 4 states which includes Connecticut, Massachusetts, New Hampshire and Vermont. The Connecticut River Anadromous Fish Restoration Program is a cooperative interjurisdictional management effort that began in 1967. In 1983, an interstate compact relating to the restoration of Atlantic salmon and diadromous fish was created including the four states located in the Connecticut River watershed, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service (Public Law 98-138). While the initial focus of the compact was Atlantic salmon, the Connecticut River Atlantic Salmon Commission (CRASC) also worked on diadromous fish recovery and restoration. Goals outlined in the CRASC River herring management plan include increasing passage through upstream barriers, maximizing out-migrating juvenile survival, and enhancing and restoring habitat in the Connecticut River Basin (CRASC 2004). That plan includes an annual adult passage escapement target of 300,000 to 500,000 Blueback Herring at the Holyoke Fish Lift, located at river kilometer 139. In October of 2023, the CRASC concluded without federal re-authorization. The Connecticut River Migratory Fish Restoration Cooperative was developed by the same member agencies and has assumed that role, seamlessly, with updated, contemporary purposes and goals.

The US Fish and Wildlife Service Connecticut River Fish and Wildlife Conservation Office (CRFWCO) works with CT DEEP and the other CRASC and now Cooperative members to coordinate and participate in population research, assessments and restoration activities in the Connecticut River Basin. Ongoing river herring data assessments conducted by CRFWCO, include an adult spring river herring, electrofishing based, population monitoring program and has included truck-and-transport of blueback herring (Sprankle and Desmarais, 2018).

1.4.6 New York

Hudson River Estuary

The Hudson River Estuary Habitat Restoration Plan (Miller 2013) has identified several river and tributary restoration activities that will benefit river herring, including barrier mitigation and side channel restoration. Recent research has highlighted important barrier removal opportunities for river herring habitat in the Hudson River Estuary (Alderson and Rosman, 2014). Mitigation of these barriers is an important priority for many researchers, non-profits, and local governments in the estuary, and features prominently in the Hudson River Estuary Program's Action Agenda 2015–2020.

In May 2016, the first dam upstream of the confluence with the Hudson River was removed from the Wynants Kill, a relatively small tributary in Troy, NY, downstream of the Federal Dam. Within days of the May 2016 removal, hundreds of herring moved past the former dam location into upstream habitat. Subsequent sampling efforts yielded river herring eggs, providing evidence that river herring were actively spawning in the newly available habitat. This dam removal will provide an additional half kilometer of spawning habitat for river herring that has not been available for 85 years.

There are also several side-channel restoration projects under development that will improve habitat for river herring in the estuary. Side channels within the riverbed provide important shallow water and intertidal habitats that are isolated from the higher energy regime of the main channel. These side channels historically occurred in the northern third of the estuary as part of a braided river-channel system dominated by vegetated shallows and intertidal wetlands. These habitats were destroyed on a large scale in the early twentieth century, particularly in the upper estuary, as a result of dredge and fill activities associated with construction of the federal navigation channel.

Gay's Point (rkm 196) has been identified as a potentially suitable location for side channel creation. The site consists of an artificially created tidal embayment that is separated from the main river channel by dredge spoils. Contiguous backwaters, such as those at Gay's Point, typically have lower current velocities, greater sediment deposition resulting in finer substrates, higher water temperatures, and lower dissolved oxygen levels than side channels with relatively unimpeded flow. Increasing tidal flow through the embayment at Gay's Point is anticipated to improve water quality, provide coarser-grained bed materials, and ultimately create more productive spawning, nursery, and foraging habitat for river herring. This project is currently under way and is being overseen by the New York State Department of Environmental Conservation.

Long Island, Bronx, and Westchester County

Initial barrier mitigation to benefit river herring included restoration of herring runs on the Carmans and Peconic Rivers (Eakin et al. 2022), and rudimentary fish passage at Beaver Lake, Oyster Bay. Since 2011, additional completed barrier mitigation projects that benefit alewife include the installation of passage devices at 14 locations (Canaan Lake, Brookhaven; Twin Ponds, Centerport; Argyle Lake, Babylon; Udall's Mill Pond, Saddle Rock; and Massapequa Creek, Massapequa; Penataquit Creek, Bay Shore; Grangebel Park (Peconic River) and Woodhull Dam (Little River), Riverhead; 182nd St Dam, Bronx River, Bronx; Upper Lake, Carmans River; Beaver Lake, Oyster Bay; Yaphank Creek, Wertheim National Wildlife Reserve; Mill Creek, Hubbard County Park; Edwards Avenue Dam, Riverhead); a box culvert modification at Alewife creek, Southampton; and dam removals at Harrison Pond in Smithtown; and at Sunken Meadow State Park.

Barrier mitigation remains a priority for several environmental groups and local, state, and federal agencies. NY DEC are aware of at least six additional projects that are likely to occur in the next five years.

1.4.7 New Jersey

Restoration programs for river herring in New Jersey have been limited to the installation of fish ladders and occasional minor trap- and-transport programs or dam removal. The total amount of freshwater habitat opened up through these efforts has not been calculated.

1.4.8 Pennsylvania

Within Pennsylvania, restoration efforts have focused on dam removal and installation of fish passage. Fishways have been constructed in the Schuylkill River at Fairmount Dam (rebuilt in 2008), Flat Rock Dam (2007), Norristown Dam (2007), and Black Rock Dam (2009), which, along with dam removals have opened up 100 river miles to migratory fish. Fishways have been built on the Lehigh River at Easton Dam (rebuilt in 2001), Chain Dam (rebuilt in 2001), and Hamilton Street Dam (1983), opening up 24 river miles to migratory fish. Dam removals have occurred in Ridley Creek (2 dams), Chester Creek (2 dams), Neshaminy Creek (2 dams), Darby Creek (4 dams, 10.5 miles opened), and Pennypack Creek (7 dams, 22 miles opened).

1.4.9 Delaware

Efforts in Delaware have been undertaken to restore river herring runs in some systems by installing fish ladders. Twelve tidal streams located within the Delaware River/Bay watershed have fish ladders installed (eight in Delaware and four in New Jersey) at the first upstream dam to allow for river herring passage into the non-tidal impoundments above the dams. The fish ladders are all of Alaskan Steeppass design and are operated to allow for increased spawning activity and nursery habitat. All of the ladders have been monitored at some level to determine passage rates and develop species use following construction. All fish using the ladder were trapped in a fish ladder exit trap, identified, counted and released. Only target species were released into the impoundment. A target passage rate of 5 adults per surface acre was established for all ladders as a threshold for successful river herring passage. Once the target rate was achieved, annual monitoring was suspended. Annual monitoring has continued at those ladders that have not met the 5 fish per surface acre target. Some engineering modifications to the entrance to the ladders have been done to enhance passage.

Monitoring at the ladders was discontinued at those sites that achieved their target for two consecutive years to avoid potentially impacting spawning behavior. Monitoring resumes at these sites every third year to determine trends in abundance and continued use. A supplemental stocking program for river herring was initiated in some impoundments as part of their restoration efforts. This stocking element was dependent on the availability of adult river herring in hopes of increasing spawning run size in subsequent years. No stocking has occurred since 2004 due to the limited availability of adult herring for trap-and-transfer.

1.4.10 Maryland

The MD DNR Fish Passage Program was established as part of the Chesapeake Bay Agreement in 1987. Initial efforts were focused on reopening over 1,300 miles for anadromous species like shad and river herring, so they could reach upstream spawning habitat. After surpassing the original goal by opening 1,838 miles by 2005, the group decided to expand the goal to 3,500 miles by 2025. This new goal now includes opening habitat for all fish species and favors dam removals over fish ladders. Since 1989, MD DNR's Fish Passage Program has completed 88 total projects, 39 of which were removal projects, reopening a total of 3,227 miles of upstream spawning habitat. In 2019, Bloede Dam, which is on the Patapsco River, was successfully removed and river herring have since been detected upstream of the dam removal site.

1.4.11 Virginia

Since 2019, Virginia Commonwealth University (VCU) and USFWS's Harrison Lake National Fish Hatchery have conducted a river herring propagation program focused on Alewife stocked in Harrison Lake. VCU collected broodstock from several locations, including the Chickahominy River and the James River. To date, 2.3 million Alewife larvae have been stocked in Harrison Lake. Starting in 2021, genetic samples were collected from the broodfish and larvae. This project hopes to use Parental Based Tagging (PBT) to identify hatchery produced fish in subsequent years. Adult Alewife were collected this year at the base of the Harrison Lake dam to be analyzed for PBT. VCU began a collaboration with the Upper Mattaponi Tribe in 2023 to implement stocking techniques in Herring Creek (King William County), a tributary of the Mattaponi River. A small batch of Alewife (80,000) and Blueback Herring (50,000) larvae were stocked in Herring Creek in 2023. These efforts are continuing in 2024.

The Virginia Department of Wildlife Resources (VDWR) has been working to restore access to two major river systems (the James and Rappahannock rivers), and their tributaries as part of a restoration effort for all anadromous species. Recently, the Harvell Dam was removed from the Appomattox River in 2014. DWR has documented Alewife and Blueback Herring upstream of the removal. In 2015, a new double Denil fishway was installed at Walkers Dam on the Chickahominy River. DWR has been conducting an electronic counting survey during the spring migration period at this fishway since 2017.

1.4.12 Potomac River Fisheries Commission

PRFC currently has no restoration programs for river herring.

1.4.13 District of Columbia

DC DOEE currently has no restoration programs for river herring.

1.4.14 North Carolina

In 2007, Amendment 1 to the NCRHFMP identified various restoration targets for the river herring stocks. Amendment 1 used the Chowan River blueback herring stock as the indicator species to establish stock recovery indicators. The plan identified stock recovery indicators that would be used to evaluate and determine recovery status of the river herring stock. The stock recovery indicators for the NCRHFMP are as follows:

- Juvenile abundance—The restoration target for juvenile abundance of blueback herring is to achieve a three-year moving average catch per unit of effort of at least 60.
- Percent Repeat Spawners—The Chowan River blueback herring spawning stock should contain at least 10% repeat spawners (percent of the spawning stock that have spawned more than once).
- Spawning Stock Biomass (SSB)—The restoration target to restore Chowan River blueback herring SSB to a minimum stock size threshold (MMST) of 4 million pounds.
- Recruitment—Recruitment of age three blueback herring should be restored to a three-year moving average of at least 8 million fish.

In 2015, under Amendment 2 to the NCRHFMP, it was determined that only three of the stock recovery indicators were necessary and the recruitment indicator was dropped from the NCRHFMP. Additionally, the term stock recovery indicator was changed to stock status indicator, this term was deemed more appropriate for the restoration targets.

In addition to the above stock recovery indicators, Amendment 2 to the NCRHFMP recommended a variety of research needs and management options that address various issues such as habitat availability and degradation, predation, bycatch, critical habitat and water quality and that would contribute to the recovery of river herring stocks in North Carolina. A full description of these recommendations can be found in Amendment 2 to the NCRHFMP.

1.4.15 South Carolina

The U.S. Fish and Wildlife Service, the National Marine Fisheries Service (NMFS) and SCDNR developed a fish restoration plan for the Santee-Cooper River basin with proposed restoration targets (USFWS 2001). River-specific goals were not established for other systems in South Carolina.

Pinopolis Dam (Cooper River)

Pinopolis Lock and Dam is located at river kilometer 77 on the Cooper River, confining the southern shoreline of Lake Moultrie. Upriver passage at the Pinopolis Dam occurs through a tailrace canal and navigation lock. Fish passage through the lock is measured by hydro-acoustic methods that estimate annual passage of fish biomass. Original counting methods involved a simple side-scan sonar array, mounted to the bottom adjacent to the lock opening. New counting methods have been evolving since 2018 (e.g., replacement of the older system with ARIS units) but a SOP has not been determined. Future passage estimates are expected to be required as a necessary condition for the updated FERC license, and these estimates are likely to be more representative of blueback herring abundance in this system than those produced from former methods. Downriver passage may occur through the navigation lock.

St. Stephen Dam (Rediversion Canal)

The St. Stephen fish lock is located approximately mid-way on the Santee-Cooper Rediversion Canal at river kilometer 92. Migratory fish are attracted into the entrance of the fish lock by an attraction flow. Fish are forced into the lock chamber and the chamber is then flooded to head level. A brail basket prompts the fish to swim 15–20 m up in the water column and releases the fish into the exit channel. There they pass viewing windows before continuing on to the upper Rediversion Canal and Santee-Cooper system. Generally, fish lock operations occur on the hour during daylight periods. Operations occur every 30 minutes when warranted by increased fish densities.

Passage efficiency at the St. Stephen Dam is unknown and likely varies among years. Poor passage efficiency was demonstrated by Cooke and Coale (1997), Cooke and Leach (2000), and Cooke and Leach (2002). Initially, high or intermittent discharges from the St. Stephen Dam on the Rediversion Canal prevented fish from entering the lock. In the 1990s, the SCPSA implemented a flow agreement to improve the fish-lock function, and a series of modifications were completed from 1995 through 2000 that may have increased the efficiency of the fish-lock. Annual variation in attraction flow, turbine discharge and water temperature in addition to fish abundance in the Rediversion Canal alter annual passage numbers of blueback herring at this facility.

The number of blueback herring that enter the Rediversion Canal from the Santee River varies among years depending on the relative flows in the Rediversion Canal and the Santee River above the canal. In moderate to high flow years, discharge of water from the St. Stephen Dam attracts fish into the Rediversion Canal. However, in low flow years when limited water is released from the St Stephen Dam, fish may bypass the Rediversion Canal and use the Santee River proper.

Fish moving downriver through the Rediversion Canal go through the turbines at the St. Stephen Dam. There have been no directed studies to determine turbine mortality on blueback herring at this facility, but it is believed that turbine strike mortality is minimal, with anecdotal information indicating that passage is more problematic for larger fish. Blueback herring appear to be more affected by pressure differential than by turbine strikes during their downstream migration at this facility (William McCord, SCDNR, pers. comm.). Above Lake Marion, several impediments to migration exist on Santee River tributaries.

Wilson Dam

There are no fish passage facilities on the Wilson Dam on the Santee River, though this will likely be a requirement to the recently issued FERC license. Downriver passage may occur over the spillway.

Savannah River

New Savannah Bluff Lock and Dam are located at rkm 301 of the Savannah River. The dam was constructed in the 1930s as a commercial navigation lock. Currently, fish passage is possible only at flows greater than 453 m^3/s when water levels above and below the dam are roughly equal. A navigation lock was used prior to 2015 for passage, however the lock is currently inoperable. When river flows do not reach 453 m^3/s there is no passage above the dam.

1.4.16 Georgia

There are no restoration programs in Georgia.

1.4.17 Florida

There are no restoration programs in Florida.

1.5 Assessment History

The first coast-wide ASMFC assessment of Atlantic coastal river herring stocks was conducted by Crecco and Gibson (1990). This assessment evaluated the status of six blueback herring stocks and nine alewife stocks between New Brunswick, Canada and North Carolina, USA using long term commercial catch and effort, age composition, and relative abundance data for juveniles and adults. The assessment developed benchmark estimates of maximum sustained yield (MSY) and of fishing rates (u) at MSY (u_{MSY}) and at stock collapse (u_{coll}). Benchmark fishing rates were then compared to recent estimates of u. Stocks were considered overfished if the observed u exceeded u_{MSY} and severely overfished if u exceeded u_{coll}. Stocks were considered fully exploited if u was within 75% of u_{MSY} and partially exploited if u was less than 75% of u_{MSY}. Models were modified to include both in-river and ocean fishing to allow predictions of effects of change in ocean fishing on benchmark estimates for in-river fisheries in two blueback herring stocks.

The 1990 assessment concluded that the St. John River alewives and blueback herring and the Damariscotta, Potomac, and Chowan River alewife stocks were or had been overfished to the point that recruitment failure was apparent. The authors recommended that restrictions should be placed on these stocks to bring fishing mortality rates below u_{MSY} levels. When ocean fishing mortality was added to the S-R models for blueback herring of the Chowan and Connecticut Rivers, MSY, u_{MSY}, and u_{coll} decreased for in-river fisheries. Since ocean losses to a given stock are often not known, the authors recommended that in-river fishing rates should be kept 20 - 30% below u_{MSY} levels for all stocks.

In 2012, first benchmark stock assessment for river herring was completed (ASMFC 2012), which assessed Atlantic coastal river herring stocks on an individual river basis where the data were available and also using a coastwide population approach. This included trend analysis of run counts and fishery-independent indices, trend analysis of life history characteristics like maximum age and length-at-age, estimates of total mortality compared to total mortality SPR reference points, as well as exploration of modeling approaches like statistical catch-at-age models where data were available and a coastwide Depletion-Based Stock Reduction Analysis (DBSRA) model.

The 2012 assessment evaluated trend data for alewife and/or blueback herring from 37 rivers from Maine to South Carolina and evaluated total mortality for 14 of those rivers from Maine to North Carolina. The majority of the rivers were assessed as depleted relative to historic levels; trend in the previous ten years were variable, with some rivers showing increasing trends, some showing decreasing trends, and some showing no trend, with some assessed as “Unknown” where the data were not sufficient to make a determination. Three-year average Z values were above these benchmarks for all 18 of the stocks with available data.

The 2012 assessment was update in 2017 with data through 2015. Of the 54 stocks of river herring for which data were available, 16 experienced increasing trends over the ten most recent years of the update assessment data time series, 2 experienced decreasing trends, 8 were stable, 10 showed no discernible trend due to high variability, and 18 did not have enough data to assess recent trends, including one that had no returning fish. Three-year averages of observed Z values were above Z benchmarks recommended by the benchmark assessment for 12 of the 14 stocks with available data.

This assessment updated and refined the trend analyses and the *Z* estimates from the 2012 benchmark analysis and brought in new fishery-independent data sources. In addition, this assessment re-estimated life history parameters such as maturity, natural mortality, and size-at-age at the stock-region level, including the development of a hierarchical growth model for each species. These life history estimates were used to develop *Z* reference points for each stock-region using a stochastic approach to better incorporate uncertainty. Finally, a habitat model was developed to assess the impacts of habitat loss on productivity at the river and stock-region level for each species.

2 FISHERY-DEPENDENT DATA

2.1 Commercial

Commercial landings data for years prior to 1950 came from the US Fish Commission reports as described in Section 1.2. Data for 1950-2022 came from the Atlantic Coastal Cooperative Statistics Program (ACCSP), which compiles fisheries data from state and federal databases along the Atlantic coast. The state commercial data collection programs for river herring are described below. The ACCSP database was queried for landings records of alewife, blueback herring, and river herring, and ACCSP staff validated the data with the states.

Species identification in reported landings remains problematic, with the majority of landings being reported as “alewife” even in states where landings should be exclusively blueback herring. As a result, commercial landings are discussed in terms of river herring, rather than separated to species.

2.1.1 Maine

2.1.1.1 Landings

Landings of river herring are reported through the requirements of the Commercial Pelagic License (required for all directed fisheries) and through VTR reports (recorded as bycatch in commercial fisheries targeting other species). Directed harvest reports for the approved directed municipal river herring fisheries are obtained through the municipalities. All municipalities must report to the DMR the amount harvested and value landed before August 1st of each calendar year. However, harvesters are not required to report through their Pelagic License until they renew their license, typically spring of the following year. This may explain the disparity between harvester and dealer reported landings. The DMR will continue to pursue harvesters in non-compliance with reporting to correct this disparity. As such, the reported landings numbers should be considered preliminary.

2.1.1.2 Biosampling

Funding and personnel limitations do not allow state resource management agencies an opportunity to collect biological information at all locations containing river herring. Beginning in 2008, Maine DMR asked all commercial fishermen to voluntarily collect scale samples from the commercial catches to determine the age structure and repeat spawning of fish returning to natal streams. The majority of commercial fishermen did collect samples, but there were some fishermen and/or municipalities that did not participate. Since 2010, the collection of biological samples (scales, length, sex) is now a requirement for those harvesting river herring. Failure to collect biological samples, in conjunction with those that Maine DMR is able to collect, may lead to the municipality’s loss of exclusive river herring harvest rights the following year. In addition, there is mandatory reporting of annual landings for each commercial fishery operated by a municipality.

The majority of Maine's rivers have only one harvester providing catch information and biological samples, and so data and results from those rivers are considered confidential. The river names have been anonymized to protect that confidentiality.

2.1.2 New Hampshire

2.1.2.1 Total Landings

Direct river herring harvest information is collected through the Coastal Harvester Program for 1989–2020; harvest was closed in 2021 because the fishery independent target was not met. The program collects catch and effort information from coastal harvesters fishing strictly in NH waters by methods other than angling. Individuals who take marine species in NH are required to obtain a free Harvest Permit and submit trip-level logbooks monthly, which provides location of harvest, harvest pounds, effort, and catch per unit effort (CPUE). Landings of river herring from federal waters (bycatch in other commercial fisheries) are reported through federal VTR reports or the Coastal Harvester Program if no federal reporting requirements.

2.1.2.2 Biosampling

The catch composition of harvested river herring in state waters is not directly evaluated. Most of the river herring harvest by coastal harvesters and anglers occurs in rivers with monitored fishways. The harvested fish can be characterized by those that are sampled in the fishways located upstream of these fisheries.

2.1.3 Massachusetts

2.1.3.1 Total Landings

No commercial fisheries exist for river herring in Massachusetts. The recreational harvest of river herring has been prohibited statewide since 2006. Spawning runs can be opened to harvest when authorized by the Director, provided the run has a SFMP approved by the ASMFC. Two SFMPs were approved in 2022 for Massachusetts river herring runs but to date no harvest has occurred. Occasional minor reports are received from commercial or recreational harvest that are either in violation of commercial and recreational harvest bans or misidentified species. River herring harvest does occur as bycatch in offshore fisheries targeting sea herring and mackerel. Massachusetts allows landings of a 5% bycatch by weight per trip for river herring in these fisheries. These activities are conducted in Federal waters and reported in Section 2.2. Prior portside sampling of landing in this fishery by MA DMF were discontinued in 2020. The remaining source of river herring harvest is native American sustenance harvest. Two federally recognized tribes made an agreement with Massachusetts in 2010 to allow aboriginal harvest of river herring in exemption of the state's river herring harvest moratorium. No information is available on the amount of harvest occurring under aboriginal rights.

2.1.3.2 Biosampling

No fishery-dependent biosampling presently occurs in Massachusetts.

2.1.4 Connecticut

2.1.4.1 Total Landings

Although commercial fishermen on the Connecticut River have reported their annual catches to the State of Connecticut since 1890, this information may not be reliable to determine fluctuations in abundance. In early years, license data did not include catch effort (Smith et al. 1989). Better documentation of landings started in 1975 when all lobster pot and otter trawl fishermen licensed by the State of Connecticut were required to report their monthly catch by species in monthly logbooks.

From 1981 to 1995, all haul seine and gillnet commercial fishermen licensed in Connecticut were also required to report their annual landings and fishing effort to the State by September of following year. After 1995, all gillnet and haul seine fishermen were required to report their landings in the monthly logbook system. Because of the difficulty of differentiating blueback herring from alewife, commercial landings reported for most years were not separated by species.

2.1.4.2 Biosampling

2.1.5 New York

2.1.5.1 Total Landings

Recorded landings of river herring in New York State began in the early 1900s. Anecdotal reports indicate that herring only played a small part in the historic commercial fishing industry in the Hudson River. Total New York commercial landings for river herring include all herring caught in all gears and for both marine and inland waters. NMFS data do not specify river or ocean source(s) and landings are often reported as either alewife or blueback herring, but not both in a given year. It is unlikely that only one species was caught. From 1995 to the present, the Department has summarized landings and fishing effort information from mandatory state catch reports required for Hudson River marine permits. Full compliance for this reporting started in 2000. All Hudson River data are sent to NMFS and ACCSP for incorporation into the national databases.

Since 1995, landings are separated between the Hudson and other waters. However due to optional participation and minimal enforcement of commercial reporting, any in-river reporting from 1995–1999 is unreliable. It is likely that additional effort was shifted to river herring catches during this time-period than is reported. Moving forward, analyses on in-river landings begin in 2000.

2.1.5.2 Biosampling

Up until the mid-1990s, the Department's commercial fishery monitoring program was directed at the American shad gill net fishery, a culturally historic and economically important fishery. We expanded monitoring to the river herring fishery in 1996 but remain limited by available manpower and the ability to connect with the fishers. Monitoring focuses on the lower river fixed gill net fishery since we considered it to be a better measure of annual abundance trends as described in the above section.

Data are obtained by observers onboard commercial fishing vessels. Staff record numbers of fish caught, gear type and size, fishing time, and location. Scale samples, lengths and weights are taken from a subsample of the fisher's catch.

All commercial fishers fill out monthly mandatory reports. Reports include catch, discards, gear, effort, and fishing location for each trip. CPUEs are calculated as total catch divided by total effort (square yards of net * hours fished), separately by gear type (fixed gill nets, drift gill nets, and scap nets).

2.1.6 New Jersey

2.1.6.1 Total Landings

New Jersey river herring landing estimates were obtained from two sources. The NMFS estimates (1950 to 2009) are for the entire state, while mandatory logbooks of the GNSMEP (2000 to 2015) are from Delaware Bay. The average reported NMFS landings for the time period is estimated at 8,180 pounds. There are no estimates of underreporting, however it is assumed that the current data for river herring is underreported since some landings may be categorized as bait.

2.1.7 Delaware

2.1.7.1 Total Landings

Delaware’s commercial landings were determined annually from mandatory commercial catch reports under the provisions enacted by the Delaware General Assembly in 1984. Every fisherman holding a commercial food-fishing license was required to submit a monthly report specifying what general area gear was deployed at within the estuary, the type and amount of fishing gear deployed, and the pounds landed of each species taken for each day fished. The effort data reflects days that fishermen actually landed river herring and does not account for days when the species was not landed.

2.1.7.2 Biosampling

Adult river herring in Delaware have not been sampled for any biological characteristics such as size, sex, and age structure or species composition. In the past there has been concern over the misidentification of river herring by commercial watermen in the Delaware Estuary. Analysis of past data has resulted in a cutoff date of June 1 for reported herring landings. Landings were reported monthly until 1989, after which they were reported on a daily basis.

2.1.8 Maryland

2.1.8.1 Total Landings

Maryland DNR has a mandatory reporting system for commercial fishermen that began in 1980. Catch in pounds by species, days fished, area fished and amount and type of gear used were reported by month prior to 2006. A daily trip log was phased in from 2002 to 2005 with all fishermen using the daily log for the entire year beginning in 2006. Effort data is only available for 1980–1984, 1990 and 1992–2022. Maryland relied on the NMFS for collecting commercial landing data prior to 1980. Landings of alewife and blueback herring are collectively reported as river herring.

2.1.8.2 Biosampling

Alewife and blueback herring in Maryland’s portion of the Nanticoke River were collected from commercial pound nets and fyke nets, and the number of nets and locations were fished at the discretion of the commercial watermen. These nets were generally sampled at least one to two times per week from early March to late April. Fish were sorted according to species and transferred to the survey boat for processing. Monitoring began in 1989, when it was still legal for commercial fishermen to harvest river herring, but continued even after the fishery was closed as bycatch monitoring. In 2015, there was extensive ice coverage late into the spring on the Nanticoke River that prohibited commercial fishermen from setting their gear. In 2020, no sampling was completed due to COVID restrictions. No sampling was completed in 2022, therefore analyses using data from this monitoring have a terminal year of 2021.

A minimum of ten alewife and ten blueback herring, selected at random from unculled commercial catches, were counted, sexed, measured (FL), and scaled for age analysis. The total number of herring harvested was estimated by multiplying the number of bushels harvested by the number of fish per bushel from sampled nets on that particular day or by direct counts. Beginning in 2014, if random scale samples taken during the sampling season exceeded 300 samples per species, then a randomly chosen subset of 300 scales were aged. Ages were then assigned to the total catch using an age length key. This was a necessary change to accommodate large catches and limited available staff time for processing.

2.1.9 Virginia

2.1.9.1 Total Landings

The VMRC's commercial fisheries records include information on both commercial harvest (fish caught and kept from an area) and landings (fish offloaded at a dock) of marine species in Virginia. The VMRC began collecting voluntary reports (monthly) of commercial landings from seafood buyers in 1973. A mandatory harvester reporting system was initiated in 1993 and collects trip-level data on harvest and landings within Virginia waters. Data collected from the mandatory reporting program are considered reliable starting in 1994, the year after the pilot year of program. The Potomac River Fisheries Commission (PRFC) has provided information on fish caught in their jurisdiction and landed in Virginia since 1973. Records of fish harvested from federal waters and landed in Virginia have been provided by the NMFS and its predecessors since 1929 (NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.).

Estimates of commercial landings for river herring prior to the start of the mandatory harvester reporting program should be interpreted with care. A significant portion of the river herring catch has been used for oil, meal, and crab bait (Joseph and Davis 1965). Prior to 1993, most of that catch was not recorded since data collection programs primarily considered food fish. The mandatory harvester program does, however, allow the reporting of landings as "bait" with no identification to species. As such, some true river landings may be reported as bait and therefore not classified as river herring in the data (VMRC, Fisheries Management Division, pers. comm.). Another issue is that the river herring species were not differentiated in the landings records prior to VMRC's mandatory harvester reporting program—historic landings recorded as alewives include both alewives and river herring (e.g., U.S. Bureau of Fisheries 1941). Data obtained from the VMRC's mandatory reporting program suggest alewives continue to make up the majority (~98%) of Virginia's commercial river herring landings. However, available biological samples from the commercial fisheries suggest the proportion of alewives in the commercial landings is not that excessive or, at least, did not dominate the landings to that degree in the past. It is likely that at least a portion of the blueback herring landings continue to be reported as alewives. There is also concern that some commercial landings reported as alewives are, in fact, Atlantic menhaden (VMRC, Fisheries Management Division, pers. comm.). This may be reflected in river herring landings being reported in all months of the year and in gill nets that are harvesting larger fish, like striped bass, which has an eighteen inch minimum size.

2.1.9.2 Biosampling

The VMRC Biological Sampling Program was initiated in 1989 to collect fisheries-dependent biological information to support assessment and management activity within the state and coast-wide. There are currently twenty-one species targeted for sampling in the program; non-target species, such as alewives and blueback herring, are sampled based on availability and staff time. When river herring are available for sampling, samples are identified to species, measured for total length (TL), and individual weights are taken for most samples. The fork length and sex of most samples is also recorded. River herring have been available for sampling from Virginia's commercial fishery in all years since the program's inception, except for 2009 and 2010. The samples were considered insufficient for characterizing the species composition of the commercial landings (J. Cimino, VMRC, pers. comm.).

The VIMS collected biological samples from Virginia's commercial fishery from 1966 to 1988 as part of their annual assessment of the structure of adult alosine populations in Virginia's inshore alosine fishery. Adult alosines were randomly sampled from the commercial fishery—primarily pound nets—over the duration of the spring spawning run. The majority of samples were collected from the James, York, Rappahannock, and Potomac rivers. The Potomac River samples are not included in this report. Individual samples were identified to species, measured for fork length (FL), weighed, and sexed. Structures were also removed and processed for ageing. Scales were collected during 1966 through 1978, and otoliths were collected during 1975 through 1988. In this assessment, data from the following reports were used: Davis et al. 1970, 1971, 1972; Hoagman et al. 1973, 1974; Hoagman and Kriete 1975; Loesch and Kriete 1976, 1980–1984; Johnson et al. 1978; Loesch et al. 1977, 1981, 1985, 1986; Blumberg and Loesch 1988, 1989. Refer to one of the cited reports for a more detailed description of this monitoring program. Also note that most of those data were not available in raw form. The numbers of each species sampled were summarized by year to evaluate the species composition of Virginia's commercial river herring landings.

2.1.10 North Carolina

2.1.10.1 Total Landings

NCDMF has monitored commercial landings of river herring since 1972. Prior to 1994, commercial landings in North Carolina were acquired via a NCDMF and National Marine Fisheries Service (NMFS) Cooperative statistics program on a monthly basis from licensed seafood dealers; however, reporting at the time was not mandatory. In 1994 NCDMF implemented a mandatory commercial harvest data collection system known as the Trip Ticket Program (TTP). The Trip Ticket Program is a dealer-based reporting program that obtains a trip-level census of commercial landings in North Carolina.

2.1.10.2 Biosampling

Age samples of the blueback herring and alewife catch from the Chowan River commercial pound net fishery are available from fish house sampling conducted from 1972-2006. The target sampling frequency is to collect unculled samples of at least 30 fish per week, from at least 3 area commercial fishhouses during the fishing season.

Following the closure of the commercial river herring fisheries in North Carolina a commercial pound net survey was implemented to collect aging samples of river herring from the Chowan River. Depending on the year 3-4 commercial fishermen were contracted to fish commercial pound net sets in the Chowan River, NC during the traditional river herring commercial harvest season. All fishermen were required to obtain a weekly unculled adult sub-sample of approximately 20 pounds of river herring from their contracted pound nets. In 2009 sampling was expanded to include a visual estimate of the total daily catch of river herring in pounds from all of the pound nets set regardless of whether it was a designated contracted net or not.

Adult samples are sorted to species and all individuals of each alosine species present were measured in millimeters (mm) fork length (FL) and total length (TL), weighed (kg), sexed, spawning maturity was determined, and an ageing sample was taken. Scale samples collected for ageing were mounted between two microscope slides and read under an Eyecom 3000 microfiche reader and aged by methods similar to that in Street et al. (1975). Stratified sub-sampling, based on techniques developed by Ketchen (1950), was used to compile individuals for ageing. Samples were sorted by species, and sex, then placed in 10 mm size groups. If 15 or less samples were present in a size group, all of the samples were aged. If more than 15 samples were present in a size group, half of the fish in the group were aged. Proportions within each sex and size group were calculated and expanded to the remaining sample.

2.1.11 South Carolina

2.1.11.1 Total Landings

Annual estimates of catch in kg, effort in man days, and kg catch/man day (CPUE) are available since 1969 from daily surveys of the Santee-Cooper fishery. Much of this fishery has moved from the Cooper River to the Rediversion Canal, as the majority of flows have been produced from the St. Stephen Dam since 1990.

2.1.11.2 Biosampling

Biological samples have been collected from creel survey efforts in the Santee-Cooper system since 2011. Paired sampling (scales and otoliths) began in 2021, from random selections of ten fish per day through the length of the commercial fishing season.

2.1.12 NAFO Landings

Foreign fleet landings of river herring (reported as alewife and blueback shad) are available through the Northwest Atlantic Fisheries Organization (NAFO) for 1960-2022. Landings from areas off of the US coast (NAFO areas 5 and 6; Figure 11) were included; US landings reported to NAFO were excluded as they would be part of the reported US landings through ACCSP.

2.1.13 Commercial Landings in Numbers

To facilitate comparisons with run counts (see Section 3.1 below), estimates of commercial landings in weight were converted to landings in numbers. For the ACCSP and US Fish Commission data, state biosampling was used to develop the annual average weight of a river herring (pooled across species) for each state. Where fish were measured but not weighed individually, total lengths were converted to weights. If the sample size of fishery-dependent weights was less than 30 for a state in a year, the average weight of fishery-independent adult sampling (e.g., from run count or spawning stock surveys) from that year was used as the average weight. When there was no annual adult weight from either fishery dependent or fishery independent sources in a state, the overall average weight for that state was used. For states that had historical landings but no adult sampling data, the average weight from nearby states was used (e.g., South Carolina was used for Florida and Georgia, and Maryland and Virginia were used for Delaware and PRFC).

For NAFO landings, the average weight of river herring in the Northeast Fishery Observer Program's bycatch sampling (see Section 2.2 below) was used as a proxy for the average weight of this fleet.

2.2 Bycatch/Incidental Catch

2.2.1 Total Incidental Catch Estimates

In this assessment, we use the terms "bycatch" and "incidental catch" interchangeably to refer to the total catch of river herring, regardless of final disposition, that is taken in fishery operations that target other species. We use the term "discards" to refer to the portion of the incidental catch that is discarded at sea.

The total (retained + discarded) incidental catch of river herring (alewives and blueback herring) was quantified by fleet. Fleets included in the analyses were those sampled by the Northeast Fishery Observer Program (NEFOP) and were stratified by region fished (Mid-Atlantic versus New England), time (year and quarter), gear group, and mesh size. Gear groups included in the analyses were: bottom trawls, paired midwater trawls, single midwater trawls, gillnets, dredges, handlines, haul seines, longlines, pots/traps, purse seines, scallop trawl/dredge, seines and shrimp trawls. Bottom trawls and gillnets were further stratified into three mesh-size categories (see ASMFC 2012 Appendix 3).

The combined ratio method (Wigley et al. 2007) was the standard discard estimation method implemented in Northeast Fisheries Science Center (NEFSC) stock assessments. We used this method to quantify the magnitude and precision (CV) of river herring total incidental catch for 1989 -2019 across all fleets. In 2023, the NEFSC transitioned to the Catch Accounting and Monitoring System (CAMS), a shared data system between the Greater Atlantic Regional Fisheries Office (GARFO) and the NEFSC that provides a single, comprehensive source for all catch in the Greater Atlantic region. CAMS was used to estimate incidental catch for 2020 – 2022 across all fleets. Incidental catch estimates for the midwater trawl (MWT) fleets are only provided for 2005-2022 because marked improvements to NEFOP sampling methodologies occurred in the high-volume MWT fisheries beginning in 2005, limiting the interpretability of estimates from these fleets in prior years.

For each trip, NEFOP data were used to calculate a total catch to kept (t/k) ratio, where t represents the total (retained + discarded) catch of an individual species (e.g., alewife) and k is the kept weight of all species. Annual estimates of total incidental catch were derived by quarter. Imputations were used for quarters with one or zero observed trips; if no trips with river herring bycatch were observed within a quarter or a year, trips from the next closest time period for that gear-region strata were used to impute bycatch rates.

The t/k ratios were expanded using a raising factor to quantify total incidental catch. With the exception of the midwater trawl fleets, total landed weight of all species (from the dealer database) was used as the raising factor. Total landings from the dealer database are considered to be more accurate than those of the VTR database because VTR landings represent a captain's hail estimate. However, for the MWT fleets, we were unable to use the dealer data to estimate the kept weight of all species when stratifying by fishing area. When the area allocation (AA) tables were developed, MWT was not included in effort calculations because of difficulties determining effort for paired MWTs. Only those gears with effort information could be assigned to a statistical area. Consequently, VTR data were used as the expansion factor for the MWT fleets.

From 2005-2022, the total annual incidental catch of alewife ranged from 22.7-537.8 mt in New England and 6.5-295 mt in the Mid-Atlantic. The dominant gear varied across years between paired midwater trawls and bottom trawls (Figure 13). Corresponding estimates of precision (coefficients of variation, CVs) exhibited substantial interannual variation and ranged from 0.01-10.61 across gears and regions.

Total annual blueback herring incidental catch from 2005-2022 ranged from 8.2–186.6 mt in New England and 1.4-388.3 mt in the Mid-Atlantic. Across years bottom trawl, paired and single midwater trawls exhibited the greatest blueback herring catches (Figure 14). Corresponding CVs ranged from 0.01 – 3.56.

The NEFSC's Standardized Bycatch Reporting Methodology (SBRM) Amendment selected a CV of 30% as the standard level of precision based on the recommendation from the National Working Group on Bycatch (NEFMC et al. 2015). However, as river herring are not covered under the SBRM Amendment, observer coverage is not allocated to achieve that level of precision for those species, and CVs are frequently higher than 30% (Figure 13 - Figure 14).

The temporal distribution of incidental catches was summarized by quarter and fishing region for 2005-2022 (Table 5 and Table 6). Differences in gear stratification with the CAMS system required separation of tables for 2005-2019 (Table 5) and 2020-2022 (Table 6). From 2005-2019, river herring catches occurred primarily in midwater trawls (57%, of which 42% were from paired midwater trawls and the rest from single midwater trawls), followed by small mesh bottom trawls (42%). Catches of river herring in gillnets were negligible. Across gear types, catches of river herring were greater in New England (59%) than in the Mid-Atlantic (41%). The percentages of midwater trawl catches of river herring were similar between New England (28%) and the Mid-Atlantic (29%). However, catches in New England small mesh bottom trawls were three times higher (31%) than those from the Mid-Atlantic (11%). Overall, the highest quarterly catches of river herring occurred in midwater trawls during Q1 in the Mid-Atlantic (27%), followed by catches in New England during Q4 (17%) and Q3 (16%). Quarterly catches in small mesh bottom trawls were highest in New England during Q3 (10%) and totaled 6-9% during each of the other three quarters.

Observer coverage was substantially reduced in 2020 due to the COVID-19 pandemic, and 2021-2022 levels have not recovered to pre-2020 levels (Table 7 and Table 8), which reduces the reliability of the estimates, especially at the region and gear level. From 2020-2022, river herring catches occurred primarily in gillnets not in the defined mesh categories (47%), followed by large mesh bottom trawls (22%) and small mesh bottom trawls (10%). Catches of river herring in the other gillnet mesh categories ranged from 1-6.5%. Across gear types, catches of river herring were greater in the Mid-Atlantic (68%) than in New England (32%). The percentages of midwater trawl catches of river herring were low in both New England (0.25%) and the Mid-Atlantic (0.18%), a significant difference from 2005-2019 estimates. While recent quota reductions for Atlantic herring and mackerel resulted in reduced effort in these fisheries, there was also little to no observer coverage during this time in the southern New England areas where river herring bycatch has historically been highest in this fishery. Overall, the quarterly catches of river herring were similar in the Mid-Atlantic (16%-18%), while catches in New England ranged from a low of 4% in Q1 to a high of 12% in Q3.

Species-specific annual incidental catch estimates and the associated coefficients of variation are presented in (Table 9). Estimates of total river herring bycatch from 2020-2022 were among the lowest in the time series, averaging 55mt per year for alewife and 36.3mt per year for blueback herring, compared to 187.8mt for alewife and 155mt for blueback herring per year from 2005-2019. CVs were higher for 2020-2022 as well, particularly for blueback herring, with alewife averaging 0.37 and blueback herring averaging 1.13 for 2020-2022 compared to average CVs of 0.34 for alewife and 0.41 for blueback herring for 2005-2019 (Table 9).

Estimates of species-specific bycatch (Table 9) are calculated slightly differently than the estimates of bycatch calculated for comparison with the bycatch caps in the Atlantic herring and Atlantic mackerel fisheries (Section 1.3.18). The estimates for comparison with the catch caps are calculated for a subset of observed trips and total catch expansion factors that align with the definitions of the fleets and areas that the caps apply to, but they also include the catch of American shad and hickory shad, not just river herring. In addition, the catch cap method only looks at the previous year for imputing data for gears and areas with less than five observed trips and will use an overall mean bycatch rate across gears and areas if the previous year also had insufficient observer coverage, while the annual estimates only impute across years, not gears and regions, and may go back further in time to obtain sufficient sample sizes. From 2014-2022, the period covered by the catch caps, a total of 1,171.2mt of alosine bycatch was counted against the catch caps (averaging 130.1mt per year), while the coastwide estimates of total alosine bycatch over that time period was 2,267.9mt (averaging 252mt per year). Over that time period, at the coastwide level, 70.1% of the total alosine bycatch (1,588.9mt) was alewife and blueback herring. The CVs on the estimates of bycatch counted towards the catch caps was also generally higher than the species-specific CVs at the coastwide level, but was also confidential in several years, making direct comparisons more difficult.

2.2.2 Incidental Catch Biosampling

In addition to counts of species, observers will collect information on the length composition of sampled fish (Figure 15 and Figure 16). Sample size is small to non-existent in some years, but has increased in recent years, and provides valuable insight into the biological characteristics of the river herring caught in these fisheries.

The Kolmogorov-Smirnov goodness-of-fit test was used to compare the length frequencies from the bottom-trawls and the mid-water trawls for each species and found a significant difference for both alewife and blueback herring ($p<0.001$). Fish caught by mid-water trawls had a slightly smaller mean length and a lower variance than fish caught by bottom trawls. The mean fork length of alewife from bottom trawls was 210mm with a standard deviation of 44mm, while the mean fork length of alewife from midwater trawls was 205 ± 38mm. The mean length of blueback herring from bottom trawls was 212mm with a standard deviation of 50mm, while the mean fork length of blueback herring from midwater trawls was 207 ± 26mm.

Similarly, the Kolmogorov-Smirnov goodness-of-fit test found a significant difference in the length frequencies of samples from the New England and Mid-Atlantic regions for both alewife and blueback herring ($p<0.001$). Alewife caught in New England were slightly smaller than fish caught in the Mid-Atlantic region, although the variance was similar; blueback herring caught in the New England region were also slightly smaller than fish caught in the Mid-Atlantic region, but the variance was higher in the New England region. Alewife caught in New England had an average fork length of 207mm, while alewife caught in the Mid-Atlantic region averaged 216mm; both had a standard deviation of 44m. Blueback herring caught in New England had an average fork length of 201mm with a standard deviation of 50mm, while blueback herring caught in the Mid-Atlantic region averaged 228 ± 35mm.

The distributions of fish caught in bottom trawls and mid-water trawls overlapped with the distributions of fish caught in in-river fisheries (Figure 15Figure 17 - Figure 18). However, both the mid-water and bottom trawls caught size classes of small fish that were not observed in the river samples. Although no histological data were collected, these small fish were most likely immature, since they were not represented in the spawning adults returning to the rivers.

Overall, weighted by gear and region, the average fork length of alewife in the bycatch samples was 210mm with a standard deviation of 8mm, while the average fork length of alewife in the in-river fishery dependent sampling was 238 ± 16mm. The average fork length of blueback herring in the bycatch samples was 220mm with a standard deviation of 16mm, while the average fork length of blueback herring in the in-river fishery dependent sampling was 235mm ± 16mm. This translates into an average weight of 126g per fish for alewife and 133g per fish for blueback herring in the bycatch, compared to 201g per fish for alewife and 175g per fish for blueback herring in the in-river fishery dependent sampling. The average weight of alewife and blueback herring in the bycatch was used to convert bycatch estimates by species in weight to estimates in numbers of fish.

2.2.3 Stock Composition of Incidental Catch

The NEFOP program does not monitor the genetic composition of incidental catch. However, some individual studies have been done that provide a snapshot of genetic composition. Reid et al. (2022) sampled bycatch during the winter months (December – March) from 2012-2015 in the Atlantic herring and mackerel fisheries around southern New England. They found that the highest proportion of the bycatch of alewife came from the Block Island (34%) and Long Island Sound (22%) reporting groups in the SNE stock-region, and the highest proportions for blueback herring were from the MAT (47%) and CAN-NNE (24%) stock-regions. These results were similar to Hasselman et al. (2016) who found that alewife from the SNE stock-region made up approximately 70% of genetic assignments and blueback herring from the MAT stock-region made up approximately 78% of genetic assignments from bycatch in the Atlantic herring fishery.

These studies sampled bycatch in areas, gears, and times of year when observer data has the highest catch rates of river herring, so these studies are broadly representative of the majority of the incidental catch. However, the genetic composition of the total bycatch will vary from year to year depending on the relative abundance of the runs in each stock-region as well as the timing and location of fishery effort.

2.3 Recreational

2.3.1 Marine Recreational Information Program (MRIP)

Estimates of recreational harvest and live releases for river herring on the Atlantic coast come from the NOAA Fisheries Marine Recreational Information Program (MRIP), which uses a combination of effort surveys and angler-intercept surveys to develop those estimates (Papacostas and Foster 2018). However, the MRIP program has limitations that result in higher uncertainty for river herring and likely an underestimate of the recreational catch of this species complex. In particular, the MRIP angler-intercept survey that estimates catch per trip of each species does not occur above the head-of-tide, so in-river catches, where the directed fishery is most commonly prosecuted, are not captured by MRIP. In addition, MRIP relies on the anglers to report the numbers of each species they caught that are not available for the interviewer to measure and identify (e.g., fish that are released alive, used for bait, already filleted, etc.), so a portion of the recreational catch of river herring may be misidentified as other herrings or similar bait species. River herring catch may also be underreported if anglers do not report fish they caught to use as bait.

MRIP estimates of river herring recreational catch are highly variable from year to year, ranging from a minimum of less than 1,000 fish for alewife and zero for blueback herring in several years to maximums of 1.3 million alewife and 3.4 million blueback herring (Table 10 and 0; Figure 19 and Figure 20). The percent standard error (PSE) of the estimates are also high, with most years having a PSE of greater than 50%, and several years having a PSE of greater than 100%, even at the coastwide level. In most years, the confidence intervals of the estimates include zero. The majority of reported river herring recreational catch was harvested; only about 14% of alewife and 6% of blueback herring were reported released alive.

Over the full MRIP time series (1982-2022), about 380 alewife and 329 blueback herring were measured (Figure 21), meaning the annual size frequency of the harvest is not well-described; there are no measurements of river herring released alive. The time-series average length of each species was converted to an average weight to convert total catch in numbers into total recreational removals in weight; this calculation assumed that 100% of river herring released alive died as a result of being caught.

In addition to MRIP, several states have conducted creel surveys that provide more insight into the in-river recreational fisheries for river herring.

2.3.2 New York

NYSDEC contracted with Normandeau Associates, Inc. (NAI) to conduct creel surveys on the Hudson River in 2001 and 2005 (NAI 2003 and 2007). Estimated catch of river herring in 2001 was 34,777 fish with a 35.2% retention rate. When the 2001 data were analyzed, NAI found that the total catch and harvest of herring was underestimated due to the angler interview methods. In the 2001 survey, herring caught by fishers targeting striped bass were only considered incidental catch, and not always included in herring total catch and harvest data. Fishers were actually targeting herring and striped bass simultaneously. Corrections were made to the interview process for the 2005 survey and estimated catch increased substantially to 152,117 herring. Catch rates from 2001 survey were also adjusted using the 2005 survey data. The adjusted 2001 catch increased to 93,157 fish.

River herring use by striped bass anglers can also be evaluated using data obtained from the Cooperative Angler Program (CAP). The CAP was designed to gather data from recreational striped bass anglers through voluntary trip reports. Volunteer anglers log information for each striped bass fishing trip including fishing time, location, bait use, fish caught, length, weight, and bycatch. From 2006 to present, volunteer anglers have been asked to provide specific information about river herring bait use. Due to the difficulties associated with differentiating between alewife and blueback herring, anglers are only asked to report the catch as river herring. The annual proportion of angler trips where river herring was used for bait ranged from 27% to 58 % with a mean of 48%. River herring caught per trip varied from 3.80 to 11.30 with a mean of 7.61.

The most recent creel information and the CAP trips were combined in an attempt to estimate recreational river herring harvest. Annual numbers of striped bass trips taking place after 2007 were calculated as the 2007 creel estimate (Connelly and Brown 2009) multiplied by the annual percent change in CAP trips (proxy for change in annual effort). This value was then multiplied by the annual proportion of angler trips using herring as bait, and multiplied again by the number of herring caught per trip in the CAP. From 2006-2022, estimates of river herring harvest by striped bass anglers ranged from 92,638 to 565,634 fish with a mean of 348,906. To put potential recreational herring harvest in context, the average estimated annual recreational harvest from 2013–2021 was 362,364 river herring. During the same time period, electronic run counts from Black Creek, a small tributary to the Hudson with approximately 1.8 km of available spawning habitat, averaged 309,766 alewives annually. Black Creek is only one of the 68 primary tributaries to the Hudson River.

This analysis should be interpreted with caution and viewed only as potential recreational river herring harvest scenarios. It should also be noted that these estimates are derived from a group of dedicated striped bass anglers who presumably exert more effort than a typical angler and thus we view these estimates as the maximum potential recreational herring harvest. Until a creel survey can be conducted, this is the Department’s best estimate of recreational herring harvest.

The number of river herring taken from the Hudson River and tributaries for personal use as food by recreational anglers is unknown but expected to be minimal.

2.3.3 New Jersey

An access point survey of the recreational fishery for river herring within the Delaware Basin was conducted in conjunction with an aerial effort survey conducted by Versar, Inc. during 2002 (Volstad et al 2003). The study area included all tidal and non-tidal waters from the Delaware Memorial Bridge to Downsville, NY.

A total of 7,553 river herring were estimated to be caught and 4,916 were harvested by recreational anglers in the Delaware River for 2002. Angler catch rate was estimated 0.0189 per angler hour and the harvest rate was estimated at 0.0123 per angler hour.

2.3.4 Delaware

There are over 500 'recreational' gill net permits issued to Delaware fishermen. The permit stipulates that a fisherman is entitled to set up to 200 feet of anchored or fixed gill net with a minimum mesh size of 3.25 inches. Many commercial crabbers hold these permits which allow them to catch bait, primarily Atlantic menhaden. River herring were also reported as discards from this fishery but were highly variable ranging from 6 fish per year to over 1,000. All recreational gill net fishermen abided by the same seasons, size and creel limits for foodfish that applied to recreational anglers except the harvest of certain species (such as striped bass) was not allowed. From 1996 through 2003 annual total harvest estimates ranged from 4,400 fish in 1996 to 297 in 2002. The number of river herring harvested per trip declined steadily from 1998 through 2004.

2.3.5 Maryland

MD DNR has conducted a roving creel survey below Conowingo Dam on the Susquehanna River since 2001. In general, few anglers (less than one percent) target river herring in the spring, with most anglers targeting American or hickory shad or other sport fish. In most river systems, river herring are not targeted and are caught as bycatch.

2.3.6 North Carolina

Historically, river herring have been taken for personal consumption in every major North Carolina coastal river system. An analysis of river herring harvest by Baker (1968) indicated the majority of herring harvested by special device licensees in 1967–1968 occurred in the Chowan and Roanoke River basins. River herring were also harvested in other river basins, but American shad and hickory shad were of more importance to fishermen in those areas. Coastwide, Baker (1968) estimated that special device licensees harvested 2.9 million pounds of river herring, some of which were sold. The recreational component of this total, however, is unknown. Although these fish were taken by fishermen licensed by NCWRC at that time, changes in designations of coastal/joint/inland waters, changes in jurisdictional responsibilities between NCDMF and NCWRC, and the unknown proportion of these fish which were harvested with the intent of sale precludes an estimate of the historical level of river herring harvest for personal consumption.

A recreational drift net river herring fishery existed on the Roanoke River for many years. This fishery has never been fully assessed by NCDMF or NCWRC. The NCDMF initiated a pilot drift net creel survey in 1999 to characterize this fishery for development of future monitoring strategies and to provide managers with weekly reports of recreational drift net activity (participation, catch rates, species composition, net sizes, etc.). Sampling was conducted in the lower river area including Williamston, Jamesville, and Plymouth. Interviews were conducted three days per week, for a total of 21 sampling days in 1999. Catches of river herring ranged from 20 to 300 fish per vessel with a mean of 106. Drift duration ranged from 1 to 5 hours with a mean of 2.2 hours. A total of 2,764 river herring were observed in the survey. Because there was no estimate of total effort, total catch cannot be estimated.

2.3.7 South Carolina

Recreational creel survey efforts occur in the Santee-Cooper system and have historically focused on American shad targeted efforts. Surveys also gauge the amount of blueback herring efforts, but landings and catch per unit effort of blueback herring in the recreational fishery continues to vary without trend through the time series. Blueback herring are not typically targeted in the recreational fishery and are most often not harvested. Often, CPUE has been based on the number of blueback herring the angler remembered catching and releasing and this number was often guessed by the angler. Anecdotal reports seem to indicate a growing number of blueback herring fishermen arriving to the system from northern states, but total landings remain a fraction of commercial harvest. Nearly all recreational blueback herring harvest has occurred from the Rediversion Canal in recent years.

2.3.8 Georgia

A 1999 creel survey conducted by the South Carolina Department of Natural Resources at the New Savannah Bluff Lock and Dam documented the only known recreational harvest of blueback herring in Georgia’s rivers. This survey was conducted from February 1, 1999 through June 30, 1999 and anglers harvested an estimated total of 95 blueback herring. During this same time period anglers harvested an estimated 3,828 American shad. The extremely low blueback herring harvest numbers seem to indicate that anglers targeting American shad incidentally harvested these fish.

2.4 Total Removals

Total removals in the last ten years from all available sources (directed landings, bycatch, recreational catch) are a fraction of what they were at the height of the directed fishery in the 1950s and 1960s (Figure 1, 0-Table 4). Reported commercial landings averaged 1,016 mt (2.24 million lbs) from 2013-2022, compared to 27,923 mt (61.6 million lbs) from 1950-1969. From 2013-2022, incidental catch estimates averaged 189 mt (0.42 million lbs), and recreational removals averaged 7.7 mt (0.02 million lbs). From 2013-2022, estimates of total river herring removals on the US Atlantic coast from all sources averaged 1,213 mt (2.67 million lbs) or approximately 4% of the average reported landings at the peak of the directed fishery.

In terms of numbers of fish, reported commercial landings averaged 5.22 million fish from 2013-2022, compared to 154 million fish from 1950-1969. From 2013-2022, incidental catch estimates averaged 1.57 million fish, and recreational removals averaged 0.04 million fish. From 2013-2022, estimates of total river herring removals on the US Atlantic coast from all sources averaged 6.83 million fish per year, approximately 4% of the average reported landings at the peak of the directed fishery.

From 2005-2019, when the estimates of bycatch were most comprehensive, bycatch ranged from 13% to 65% of annual removals by weight and 18%-75% of removals by numbers (Figure 23). Overall, from 2005-2019, bycatch made up 27% of total removals in weight and 37% of total removals in numbers. From 2020-2022, the estimates of bycatch were much lower, due to a combination of reduced effort in the Atlantic herring and mackerel fisheries and reduced observer coverage in fleets and areas with the historically highest rates of river herring bycatch. As a result, from 2020-2022, bycatch was 7.5% of total removals in weight and 11% of total removals in numbers. Bycatch accounts for a higher proportion of removals in numbers of fish because the average size of river herring in the bycatch is smaller than the size of river herring in the directed in-river fisheries (Figure 17- Figure 18).

3 FISHERY-INDEPENDENT DATA

3.1 Run Counts

3.1.1 Maine

Run counts, trap and transfer numbers, and biological data including weight, length, species composition, scale samples, and intermittent gonad weights are collected at three state-operated fishways on the Androscoggin, Kennebec and Sebasticook rivers (Figure 24-Figure 25). In addition, an increasing number of volunteer and conservation groups are collecting count data on several non-commercial river herring runs. These data are collected at noncommercial locations to assess changes made to upstream passage facilities, collect biological data to start a commercial fishery, and monitor run size. Counts occur at the first fishway or accessible passage location that leads to upstream spawning and nursery habitats. Data collection and counts occur annually at most locations and several locations now have an increasing time series of data available for assessment purposes. Counts of river herring runs in Maine fall under two categories, total counts, and subsample counts. Total counts occur at locations where the state maintains electronic tube counters or trapping facilities that make counting the total population possible. Most volunteer or community counts use the VisuCount software and count protocol to determine total run counts and associated confidence intervals. The VisuCount system works well for volunteer groups and is adaptable to staffing and funding constraints. Some locations use a standardized 10-minute counts at the beginning of each hour from 7:00a.m. to 7:00p.m throughout the duration of the river herring run. The methods used to collect volunteer run count data have not changed since 2010.

3.1.2 New Hampshire

Seven fish ladders on six coastal New Hampshire rivers (Cocheco, Exeter, Lamprey, Oyster, Winnicut, and Taylor rivers; Figure 26-Figure 27) are operated from early April to mid-July, to allow for the passage of American shad, river herring, and other diadromous fish to historical spawning and nursery areas. The number of fish passing through the fishways are either enumerated by hand or estimated by the use of Smith-Root Model 1101 electronic fish counters. Counts recorded by the electronic fish counters are adjusted by daily calibration counts consisting of a minimum of ten one-minute counts. During daily visits, fish ladders and electronic counting devices are examined to assure of proper operation.

Fish ladder counts in some rivers should be classified as minimum estimates of spawning river herring. For example, large numbers of blueback herring are often observed below the ladders in the Lamprey and Cocheco Rivers in late May but do not ascend the ladders. Several factors may be contributing to this. The passage inefficiency of fish ladders created by construction/design or unusually high river flow levels, reduces the annual return rates through fish ladders. An example of influential environmental conditions is when New Hampshire coastal rivers experienced “100-year flood” levels in 2006 and 2007. Many river herring were unable to reach or successfully ascend the fish ladders during high water periods of the spawning run. Other factors affecting returns include; poor water quality affecting survival of young-of-the-year, low DO during summer months, lack of downstream passage, water withdrawals by the local municipalities, and drought conditions in some years.

Modifications made to the Cocheco River fishway in 2016 coupled with equipment failure led to decreased river herring passage. Many more river herring were observed in the fishway but could not be accurately counted due to poor attraction flow within the modified fishway and inaccurate electronic fish counting equipment. Starting in 2022, the fish ladder was converted back to operate as it had done prior to the modifications.

The Great Dam and associated fish ladder on the Exeter River was removed in the fall of 2016. The Pickpocket Dam fishway 13.4 river kilometers up on the Exeter River was modified in 2017 to allow monitoring and enumerate fish passage. With only minimal river herring passing through the Pickpocket fishway in 2020, it was determined that numbers of river herring reaching the Pickpocket fishway was not providing an accurate reflection of fish migrating past the former Great Dam location. New monitoring methods were adopted to estimate fish passage at the former dam site. Beginning in 2021, quantitative monitoring of river herring occurs at the former Great Dam site, by conducting three 10-minute time counts daily throughout the fish migration period. The daily average of the time counts is expanded over the course of a twelve-hour migration period, taking into account passage over the falls and ledges generally only occurs during a high tide. Daily totals are summed to estimate annual river herring passage. Biological samples (length, sex, species differentiation, and scale samples) are collected at the beginning, middle, and end of the spawning runs at five monitored rivers each year. Each river’s sample consists of up to 150 random total length measurements (mm), species identifications, and sex determinations. Scale samples from five fish are taken from each centimeter increment, or “BIN”, from each sex and species from each river (e.g., scale samples from five male Blueback Herring in the Oyster River between 25.0 cm and 25.9 cm, etc.).

NHFGD and the U.S. Fish and Wildlife Service conduct a cooperative trap and transport program to enhance river herring runs in NH rivers. Most years during the spawning run, river herring are collected from coastal fishways and transported to impoundments or lakes in NH coastal and Merrimack River watersheds. Out-of-basin transfers of river herring are limited to 10% of the previous year’s spawning run from the source river.

3.1.3 Massachusetts

Run counts are available from a number of Massachusetts rivers, some of which are conducted by state personnel and some of which are conducted by towns or private volunteers (Figure 28-Figure 29). MA DMF set monitoring goals in 2012 to have a continuous counting station (video or electronic) with biological sampling of river herring in each of the state’s major coastal drainage areas. This was accomplished in 2016 with eight such stations maintained by MA DMF or in partnership with local NGOs or Towns. Additionally, there is substantial interest in Massachusetts to engage volunteer teams for visual spawning run counts. The total number of visual count stations changes each year with some stations not reoccurring due to low numbers of fish or changes in the volunteer pool. These eight MA DMF “sentinel” stations are listed below along with sites that include volunteer visual monitoring and local management of video or electronic counts.

Acushnet River (New Bedford)

Since 2005, DMF has conducted a census of river herring entering the spawning ground using a fish trap. Simultaneous estimation of passage by using an electronic counter began in 2008, and video counting was attempted in 2008. DMF has also collected biological samples from dead fish, but samples were non-random and sample sizes were too small to use in this assessment. This location monitors the herring run response to fish passage restoration.

Agawam River (Wareham)

The Buzzard Bay Coalition and MA DMF have been estimating spawning run counts using an electronic counter since 2006. Biological data are available from only 1991.

Back River (Weymouth)

The town of Weymouth's herring warden has provided a "relative" passage estimate from his daily observations of run activity since 1986. No statistically-valid design is used. In 2007, DMF characterized the alewife population under a NOAA Anadromous Fish Conservation Act grant. DMF collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River below). DMF resumed collecting biological data and installed a SR-1601 Electronic Resistivity Counter in 2015.

Charles River (Boston)

The University of Massachusetts with assistance of DMF conducted video counts in 2008 and 2009. DMF conducted video counts in 2013 and 2014. Biological data are available from 1985, 1993, 2013, and 2014.

Connecticut River (Holyoke)

Fishlift counts have been made at the Holyoke Dam since 1967 for blueback herring by the US Fish and Wildlife Service. The numbers are used by the State of Connecticut in their river herring assessment; therefore, the information is not discussed herein to avoid duplication of effort.

Coonamessett River (Falmouth)

Falmouth Department of Natural Resources has been estimating passage using visual estimation since 2005. There are no biological data available.

Essex River (Essex)

MA DMF and installed a SR-1601 Electronic Resistivity Counter in 2014 to provide spawning run count estimates. There are no biological data available.

Herring Brook, Third (Norwell/Hanover)

The North and South Rivers Watershed Association conducted passage counts using visual estimation in 2003, and 2005–2006, with renewed counting efforts in 2022. Low counts to date have prevented a statistical estimate. There are no biological data available.

Herring River (Wellfleet)

The Association to Preserve Cape Cod has been estimating passage numbers using visual counting since 2007. There are no biological data available.

Herring River (Harwich)

The Harwich Conservation Trust and Association to Preserve Cape Cod has been estimating passage numbers using visual counting since 2007. DMF began collecting biological data and installed a SR-1601 Electronic Resistivity Counter in 2016.

Ipswich River (Ipswich)

The Ipswich Watershed Association has been estimating passage using visual counting since 2000. They've attempted to use the statistical design of Rideout et al. (1979) but prior to 2005, effort was not sufficient to provide reliable estimates. In 2006–2008, DMF also made census counts by using a fish trap. There are no biological data available.

Jones River (Kingston)

The Jones River Watershed Association has been conducting passage counts using visual estimation since 2005. There are no biological data available. A suitable sample for a statistically-valid estimate has not collected in all years.

Little River (Gloucester)

Massachusetts Audubon made passage counts using visual estimation during 2000–2002, 2005, and 2009. There are no biological data available. A suitable sample for a statistically-valid estimate has not collected in all years.

Marston-Mills River (Marston-Mills)

Starting in 2007, a local watershed group provides visual counts of combined herring passage at Mill Pond dam in the Marston-Mills River. They use a stratified random design. There are no historical or current data on population characteristics.

Mattapoisett River (Mattapoisett)

Since 1988, Alewives Anonymous has provided passage counts of alewife using an electronic fish counter. Harvest data are also provided. In 1995, 2006 and 2007, DMF collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River below).

Merrimack River (Lawrence)

The number of herring lifted at the Essex and Pawtucket Dam fishlifts since 1983 are provided by the US Fish and Wildlife Service. In 2014, DMF began collecting 100 herring a week from the Essex Dam fish lift to biologically characterize this population.

Monument River (Bournedale)

DMF has been scientifically monitoring the abundance, sex composition, length structure, age composition and removals of alewife and blueback herring in the Monument River since the early 1980s (Churchill, 1981; O’Hara, 1980; Brady, 1987a, b). Prior to 1985, abundance was estimated by using visual counts following the statistical design of Rideout et al. (1979). Since 1985, escapement has been estimated by using a Smith-Root electronic fish counter that is calibrated daily. Fish entering the system are sampled weekly by using a dipnet. Ages are determined from otoliths and scales are used to identify repeat spawners and are also aged using the criteria of Rothschild (1963), Marcy (1969) and Kornegay (1977). Fish samples are used to apportion abundance into species- and sex-specific estimates (Brady, 1987). In the past, DMF often used herring from this river as donor stock to other river systems. All numbers transported are added to harvest recorded by the Bournedale fish warden to get total number of removals. Scale ages are only available for 1984–1987, 1993, and 1995–present. Since the counting location is not far above the catchment basin where herring are removed, and both are close to the river mouth, the total run size is estimated by adding escapement counts to removal numbers.

Mystic River (Boston)

DMF has collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations since 2004 (see Monument River above). Beginning in 2012, the Mystic River Watershed Association began a visual count estimate using the statistical method of Nelson (2006). In 2018, the water association started a video monitoring system at the same location with technical assistance from MA DMF.

Nemasket River (Middleboro)

Since 1996, the town of Middleboro has provided visual counts of alewife passage at the fishway off Wareham Street (river mile 7.5). Since 2004, DMF has characterized the alewife and blueback populations under a NOAA Anadromous Fish Conservation Act grant. DMF has collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River above).

Parker River (Newbury)

Students and researchers at the University of Massachusetts, Amherst conducted several studies during the 1970s that provide information on juvenile and adult population characteristics, abundance and migration of alewives (Beltz, 1975; Cohen, 1976; Cole et al., 1976; Cole et al., 1978; Huber, 1974; Jimenez, 1978; Libey, 1976; Mayo, 1974; Rideout et al., 1979). Since 1997, the Parker River Clean Water Association has been estimating passage numbers at the first dam using visual counting and the statistical design of Nelson (2006). In 2014, DMF installed a video system to better estimate passage at the first dam. Due to high flood waters of 2005 and 2006, a weir failed, making it difficult for alewives to pass. The weirs were repaired in the summer of 2013 and additional modifications were made to the fishway in 2014. Passage counts between 2005 and 2014 may have been biased. Since 2012, DMF has collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River above).

Pilgrim Lake (Orleans)

The Association to Preserve Cape Cod has provided abundance estimates of alewife passage using visual counting and a stratified random design since 2008. MA DMF installed a SR-1601 Electronic Resistivity Counter at Pilgrim Lake during 2019-2021 with unsuccessful results given low flow. MA DMF installed a video monitoring system at Pilgrim Lake in 2022 in partnership with the Town of Orleans. There are no biological data available.

Quashnet River (Falmouth/Mashpee)

In 2004, DMF characterized the alewife population under a NOAA Anadromous Fish Conservation Act grant. DMF collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River above). There are no estimates of passage numbers available.

Sippican River (Wareham)

Alewives Anonymous made electronic census counts of alewife passage in 1995–2002 and 2006. There are no biological data available.

South River (Marshfield)

The North and South Rivers Watershed Association conducted passage counts using visual estimation in 2006, 2008 and 2010. No statistical design was used. There are no biological data available. More recent attempts at video monitoring have not produced run size estimates.

Stony Brook (Brewster)

The Association to Preserve Cape Cod has provided estimates of alewife passage numbers at the lower Mill Pond dam using visual counting and a stratified random design since 2007. In 2004, DMF characterized the alewife population under a NOAA Anadromous Fish Conservation Act grant. DMF collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations (see Monument River above). MA DMF installed a SR-1601 Electronic Resistivity Counter at Stony Brook in 2018 in partnership with the Town of Brewster.

Town Brook (Plymouth)

DMF has collected biological data on size structure, sex composition, age structure, length-weight relationships and length-at-age relationships of spawning populations since 2004 (see Monument River above). The town of Plymouth, University of Massachusetts, and DMF have made visual counts since 2008 and video counts were made in 2008 and 2009. In 2019, a video monitoring system was deployed at Town Brook in partnership with the Town of Plymouth, NOAA and MA DMF.

Town River (Bridgewater)

The town of Bridgewater has made electronic passage counts of river herring (species combined) since 2000. There are no biological data available.

Trunk River (Falmouth)

Falmouth Department of Natural Resources has been estimating passage since 2008. No statistical design is used. There are no biological data available.

Wankinco River (Wareham)

The Buzzards Bay Coalition and the Town of Wareham have made electronic passage counts since 2007. There are no biological data available.

3.1.4 Rhode Island

Each spring river herring spawning stock size is estimated using electronic fish counters or direct count methods on several Rhode Island river systems (Figure 30-Figure 31). In addition to estimating run sizes, a representative sample of river herring from Gilbert Stuart and Nonquit were sampled for biological data. River herring were sampled and measured for length, weight, and scale samples taken for age analysis. Approximately 50 alewives were sampled three times throughout each spring migration. Gilbert Stuart has a break in the biological data time series between 1993 and 2000; however spawning stock size was estimated during those years.

Gilbert Stuart

The Division has estimated spawning stock size since 1981 using electronic fish counters or direct count methods. River herring were sampled for biological data during two time periods. The first sampling period was between 1980 and 1992, and the second from 2000 to present. The break in the biological data time series between 1993 and 1999 was due to changes in staff, but spawning stock size estimates were continued during this time period. Due to low run size, data could not be collected in 2015 following numerous attempts to sample fish.

Nonquit

The Division has estimated spawning stock size at Nonquit since 1999 using a solar operated electronic fish counter. The only known data, which included run size estimates, were collected in 1976 and reported as 80,000 fish (Lynch 1976). River herring were sampled for biological data since 2000, except for in 2010 when river herring were unable to be captured after numerous attempts.

Buckeye Brook

The Buckeye Brook Coalition and Division partnered in 2003 to initiate a direct count program utilizing volunteers (Puriton 2000; Stevenson 1997). River herring have not been sampled for biological data, nor have JAI's been performed at Buckeye Brook.

Pawcatuck River

A fishway trap is installed and operated each spring to monitor American shad returns. The increased number of river herring compared to American shad and high water volume make utilizing the fishway trap unfeasible for estimating river herring run size. Direct count techniques have failed, due to visibility and electronic counters are not efficient at the site. Since 2006, in addition to observations (presence/absence) the Division has initiated a four-factor ranking system in which personnel estimate the number of herring in the trap and fishway each day the trap is checked for American shad. In addition, video techniques should assist in estimating the Pawcatuck River run size in the future.

Annaquatucket River and remaining RI herring runs

At other Rhode Island river herring systems, the Division conducts periodic qualitative analysis which consists of determining the presence and absence of adult and juvenile river herring. Methods include random net surveys, visual observations and electrofishing to determine spawning success.

3.1.5 Connecticut

Fishway counts are monitored by the CT DEEP Diadromous Fish Restoration Program utilizing Smith-root 1601 electronic fish counters and video monitoring equipment (Figure 32-Figure 33). Although river herring runs are monitored at twenty-one sites across Connecticut, only nine fishways have long-term counts of river herring at this time. Additionally, Bride Brook (East Lyme, CT), which lacks a fishway, has a long-term dataset enumerated at a counting weir which allows Alewives to be counted as the fish enter the lake. Observational data is not utilized for run enumeration in CT at this time.

Mianus River (Greenwich)

The town of Greenwich Conservation Commission, with the assistance of CT DEEP staff, has been enumerating passage of Blueback Herring and Alewife through this Alaskan Steep-pass fishway with a Smith-root 1601 electronic fish counter since 2005. A video count system has recently been added to this site, in addition to the electronic counter, but CT DEEP staff has not evaluated this system yet. To date, only the electronic counter data is being utilized. Passage efficiency has likely improved in recent years, as a large school of Striped Bass that was present at this fishway each spring has largely disappeared over the last five to ten years. Because this fishway entrance is at the head-of-tide, it is assumed that this fishway is below 100% of the freshwater spawning habitat. No supplemental stocking of river herring has occurred at this location. CT DEEP believes this run data is an accurate assessment of abundance and utilizes this location as an index site.

Pequonnock River (Bridgeport)

CT DEEP staff have been enumerating passage of Alewife through this Alaskan Steep-pass fishway with a video counter since 2014. Passage efficiency at this site is assumed to be high in all but extreme flows based on visual observations. It is assumed that 100% of the spawning in this system happens in the habitat above the dam, as the river from the head of tide to the dam is only a few hundred meters in length. No supplemental stocking of Alewives has occurred at this site. CT DEEP believes this run data is an accurate assessment of abundance and utilizes this location as an index site.

Quinnipiac River (Wallingford)

CT DEEP staff have been enumerating passage of Alewife and Blueback Herring through this Denil fishway with a video counter since 2013. Passage efficiency at this site is unknown due to low numbers of returning adults. Prior to fishway construction, there was a large and well-known run of both Alewives and Blueback herring to the base of this dam, however, by the time fishway construction completed, river herring runs on the Quinnipiac River had already collapsed. Until runs recover, it will be difficult to know if fish are missing the fishway entrance and pilling up below the dam. In recent years, no fish have been sampled in the pool below the dam where “tens of thousands” were present each spring. It is assumed that there is spawning occurring in the river below the dam as the large run was present prior to fishway construction, but the population size below this fishway is not known. Supplemental stocking of Alewives has occurred at this site since 2002. Based on prior observations of run strength at this site, CT DEEP believes this run data is an accurate assessment of abundance in the Quinnipiac River for both species and utilizes this location as an index site.

Queach Brook (Branford)

CT DEEP staff have been enumerating passage of Alewife through this Alaskan Steep-pass fishway with a Smith-root 1601 electronic fish counter since 2006. Passage efficiency at this site is assumed to be high in all flows based on visual observations. It is assumed that 100% of the spawning in this system happens in the habitat above the dam, as the river from the head of tide to the dam is only a few hundred meters in length. Supplemental stocking of Alewives has occurred at this site periodically since 2019. CT DEEP believes this run data is an accurate assessment of abundance and utilizes this location as an index site.

East River (Guilford)

CT DEEP staff have been enumerating passage of Alewife through this Alaskan Steep-pass and nature-like fishway with a Smith-root 1601 electronic fish counter since 2015. Passage efficiency at this site is assumed to be high in all but extreme flows based on visual observations. It is assumed that some spawning does occur in the habitat below the dam, as there is a ponded area, but the amount is unknown. Limited supplemental stocking of Alewives occurred at this site in 2005. CT DEEP believes this run data is an accurate assessment of abundance and utilizes this location as an index site.

Eightmile River (Lyme)

CT DEEP and Eightmile Wild and Scenic staff have been enumerating passage of Alewife and Blueback Herring through this Alaskan Steep-pass fishway with a video monitoring system since 2014. Passage efficiency at this site, relies highly on stream flows in the Eightmile river. Years with low flows create better attraction flow at the fishway entrance. Flow improvements to the fishway were completed by CT DEEP staff in 2022 and 2023 to encourage increased passage, but the river below the fishway had very few river herring during these years to test the improvements. It is assumed that some spawning takes place in the tidal freshwater habitat of Hamburg Cove on the Connecticut River, but what percentage of the Eightmile River run utilized this area historically is not known. Supplemental stocking of Alewives from Bride Lake began at this location in 2020. CT DEEP believes this run data is an accurate assessment of abundance during most flows and utilizes this location as an index site.

Mill Brook (Old Lyme)

CT DEEP staff have been enumerating passage of Alewife through this Alaskan Steep-pass fishway with a Smith-root 1601 electronic fish counter since 2003. Passage efficiency at this site is believed to be high in all flows based on visual observations. It is assumed that 100% of the spawning in this system happens in the habitat above the dam, as the stream from the head of tide to the dam is limited to just a few hundred meters of free-flowing stream. Supplemental stocking of Alewives from Bride Lake has occurred in Rogers Lake since 2015. In 2017, stocking numbers into Rogers Lake were greatly increased, and passage numbers at this fishway quickly increased as a result before dropping off in 2022, as seen across Southern New England. CT DEEP continue stocking between 2,500 and 5,000 Alewives a year into Rogers Lake to support run reestablishment. CT DEEP believes this run data is an accurate assessment of abundance and utilizes this location as an index site.

Bride Brook (East Lyme)

CT DEEP staff has been enumerating passage of Alewife through this weir into Bride Lake with a Smith-root 1601 electronic fish counter since 2003. Passage efficiency was greatly improved at the mouth of Bride Brook in 2009 when a failing tidal culvert at the Rocky Neck State Park was replaced. This replacement allowed adult Alewives to successfully navigate at all tidal phases and in much larger numbers. In response to this restoration project, passage numbers at Bride Lake quickly grew to 300,000-400,000 before dropping off again in 2022 and 2023. It is assumed that this fish counter is below 100% of the freshwater spawning habitat (Bride Lake and Beaver Swamp Pond). No supplemental stocking of river herring has occurred at this location. CT DEEP believes this run data is an accurate assessment of abundance and utilizes this location as an index site.

Latimer Brook (East Lyme)

CT DEEP staff have been enumerating passage of Alewife through this Alaskan Steep-pass fishway with a hand count starting in 2006 and with a Smith-root 1601 electronic fish counter since 2012. Passage efficiency at this site is believed to be high in all flows based on visual observations. It is assumed that 100% of the spawning in this system happens in the habitat above the dam, as the stream from the head of tide to the dam is limited and of a very steep gradient with few pools. Supplemental stocking of Alewives from Bride Lake occurred here in the early 1990's. CT DEEP believes this run data is an accurate assessment of abundance and utilizes this location as an index site.

Shetucket River (Norwich)

CT DEEP staff have been enumerating passage of Alewife and Blueback Herring through this fish elevator with a video counter since 1996. This is the second largest river in CT and historically supported large runs of Alewife and Blueback Herring. Passage efficiency at this site is unknown for river herring as numbers of returning fish have been low since the mid to late 1990's when the passage project was complete. Most of the river herring spawning habitat is above the dam, as there is only a few thousand meters of habitat from the head of tide to the dam. Supplemental stocking of Alewives has occurred in this drainage since 2002. CT DEEP believes this run data is an accurate assessment of abundance in the Shetucket River and utilizes this location as an index site.

3.1.6 New York

In 2013, a pilot study was initiated using an in-stream fish counter in Black Creek. Black Creek is a small tributary located at rkm 135, just south of Kingston, NY and has a known river herring spawning run. The primary objective was to determine if a fish counting device was an appropriate method to collect absolute abundance data for river herring in small tributaries. The secondary objectives were to compare run counts in Black Creek to relative abundance estimates derived from main-stem fisheries independent sampling to assess whether main-stem sampling was capturing similar trends in population abundance. Additionally, we sought to identify when river herring migrate into tributaries and identify parameters that may influence those migrations (e.g., moon phase, water level, water temperatures).

The study design consisted of a stream wide weir to guide river herring through a Smith Root SR-1601® multichannel fish counter. NYSDEC staff built the counting head using four-inch PVC tubes stacked in two rows of four, forcing fish through one of eight individual counting tubes. The counter was installed at the end of March each year and remained in place until the end of May. The location of the counter is close to the head of tide. Staff attempted to visit the counter on a daily basis. During site visits, technicians recorded fish counts on the counter system, along with any applicable environmental observations, such as weather conditions, temperature, and water level. Once the daily count was recorded, the counter was reset to zero.

From 2013-2023, monitoring of Black Creek occurred on an annual basis with run counts ranging from 87,764 to 590,680 with a mean of 309,766. Historic evidence shows the spawning run in Black Creek to be exclusively made up of alewife (Schmidt and Lake 2000). This has been verified in all years of monitoring, as all mortalities and all live captured river herring at or near the weir were identified as alewife.

Unfortunately, due to increased occurrence of high flow events over the past several years that led to severe equipment damage and unreliable run counts, monitoring at Black Creek has been suspended indefinitely. However, correlation analysis indicates that run counts from Black Creek and annual relative abundance estimates derived from main-stem fisheries independent sampling are significantly correlated (Pearson R-value=0.63, $p<0.05$) and capturing similar trends in population abundance. Therefore, the suspension of monitoring in Black Creek will not preclude our ability to assess trends in alewife abundance in the Hudson River.

3.1.7 New Jersey

The Raritan River, which empties into Raritan/Sandy Hook Bay, historically supported a spawning run of river herring. A dam constructed at the confluence of the Millstone and Raritan rivers was equipped with a fish ladder that included an underwater viewing room. Data is available for 1996 to 2005 (except for 2000 and 2004) and 2011 to 2012. Catch per unit effort was calculated as the number of fish counted per day. Confidence that all herring are counted is low.

3.1.8 Maryland

Conowingo Dam, constructed in 1928, is the first of the four large hydroelectric dams (rkm 16) located within the first 89 kilometers of the Susquehanna River. There is functionally no suitable in-river spawning habitat for alewife or blueback herring downstream of Conowingo Dam or in the reservoir above the dam (there is a lack of suitable spawning habitat below the first three dams). Conowingo

Dam had its first fish lift, the west fish lift, installed in 1972 and then its second in 1991. Prior to 1997, fish collected in the fish lifts were manually sorted and target species were trucked to upstream spawning habitat. Beginning in 1997, all fish collected in the east fish lift were passed through a viewing window where a trained biologist counted all fish species as they exited the fishway and entered the upstream reservoir. Beginning in 2002, river herring that entered the west fish lift were enumerated and then either retained for samples or released back into the Conowingo Dam tailrace. From 1990 to 2001, 89,226 river herring collected in the fish lifts were trucked to upstream spawning habitat (no river herring were trap and transported prior to 1990). From 1997 to 2019, 708,956 river herring were passed to the upstream reservoir. In 2020, fish lift operations were interrupted due to both the COVID-19 pandemic and northern snakehead (*Channa argus*) being passed upstream. Since 2021, fish collected in both fish lifts have been manually sorted (the east fish lift did not operate in 2021) and the majority of river herring have been trucked upstream.

Overall, river herring passage efficiency at both fish lifts is low, with high interannual variability, making them poor measures of relative abundance. Furthermore, attraction flows were increased in the 1990's to maximize American shad catches in the east lift, which may have led to decreases in river herring catches.

From 2013 to 2019, the Smithsonian Environmental Research Center collected hourly run counts in four systems: the Choptank River (2014–2017), Deer Creek (a tributary of the Susquehanna River, 2015), Marshyhope Creek (a tributary of the Nanticoke River, 2013–2014), and the Patapsco River (2016–2019, 2021–2022). Fish were counted for the duration of the spawning runs, from March to late May or early June, using a dual-frequency identification sonar unit (DIDSON V5.25.52, Sound Metrics Corp, Bellevue, WA). Imaging sonar video recordings were collected and processed following protocols described in Ogburn et al. 2017. Sonar recordings were collected for 10 min segments every hour, with a randomized hourly start time. These counting methods were consistent for the Choptank River, Deer Creek, and the Patapsco River. In Marshyhope Creek, sonar recordings were collected every other hour each day from 6:00 to 18:00 GMT/UTC-5, as opposed to every hour, for a portion of the season in 2013 and for the entire season in 2014.

To measure the relative abundance of each species and estimate species specific counts, weekly biological samples were collected using boat electrofishing (Choptank River, Marshyhope Creek, and Patapsco River) or fyke nets (Deer Creek) in each river within 500 m of the sonar sites. All fish within the 200–350 mm TL size range were counted and identified to species. The proportion of alewife and blueback herring was calculated for each biological sample, and daily proportions for each species was calculated using linear interpolation (described in Hughes and Hightower 2015, Ogburn et al. 2017). These daily proportions were then applied to the 10 min sonar counts for each date to generate species specific counts. Hourly estimates were generated by multiplying the 10 min species-specific counts by a factor of six.

3.1.9 Virginia

Electronic count data was collected annually during the spring migration season at the Walkers Dam double Denil fishway on the Chickahominy River (river mile 22) near Lanexa, VA. Fishway evaluation via electronic counts has occurred annually since 2017 (pilot season) and the same method is still in use. Each tunnel array consists of two rows of four, 20" long PVC pipes (five-inch ID) outfitted with three equally spaced stainless electrode rings wired (shielded data wire) to the Smith-Root 1601 (16 channel) counter (located in a dry container on the decking of the fishway). All fish that cannot fit through the ¾” mesh surrounding the tunnel frame must swim through the tunnels. Daytime periodic box trapping (¾” mesh) in the fishway exit channels inserted immediately upstream of the tunnel arrays is conducted to determine species composition estimates of the total count. A unique video system records the counting data on the equipment display to track hourly and daily patterns of passage through the fishway, and to aid in counter accuracy evaluation during trapping events.

River herring passage efficiency of the double Denil fishway has not been directly evaluated. However, very high rates of herring passage have been recorded at the double Denil fishway by both electronic counts and trapping efforts indicating high efficiency of passing river herring during peak migration periods. Counter accuracy has been demonstrated to be very high. For example, regression analysis of time synchronized trap and electronic count sessions in 2021 showed very high automated count accuracy (r^2=0.99, p=2.2e-16) for all species combined. In 2021 confidence in count accuracy was the highest for the two most numerous species: 1) Gizzard Shad (r^2= 0.82, p= 2.2e-16) and 2) Blueback Herring (r^2=0.95, p=2.2e-16). Alewife was only the most numerous in six of the 247 trap sessions and thus the confidence in count accuracy was reduced (r^2 =0.64, p=0.11).

The run count does not represent 100% of the run. Spawning of Alewife and Blueback Herring occur below the dam (RM 23.2) in the Chickahominy River and during periods of extreme high tides and higher flow fish can swim over the low head dam, bypassing the fish counter. The percentage of fish that swim directly over the dam versus through the fishway during these periods is unknown at this point but the majority of conditions require the fish to use the fishway on a daily basis. There is no history of stocking or trap-and-transport during the years this fishway was operational. The run count indexes relative abundance well, and although it can be environmentally influenced after large rain events coupled with extreme high tides, it is an accurate representation of spawning abundance.

3.1.10 South Carolina

St. Stephen Fish Lift Counts- Santee-Cooper Rediversion Canal

Fish released upriver of St. Stephen Dam are counted as they pass through the exit channel of the fish lift (Figure 34). Numbers were interpreted from hydro-acoustic sampling in 1986 and 1987, real-time observer counts in 1988–1994, and from time-lapse video recording from 1994 through the present. Passage counts varied widely among years and did not appear to be affected by changes in counting methodology. Cooke and Leach (2000) suggested that these peaks reflected the cycling of strong year classes through the population. The hypothesis continues to be unproven as passage numbers continue to vary widely, and counts are likely influenced by other variables specific to this system (e.g., discharge magnitudes and duration, mechanical efficiency of the fish lift over time).

Since efficiency of the lift operation is poorly known and probably varied among years with changes in operational characteristics and river flow, passage numbers are not considered to be good indices of numbers of blueback herring in the Santee-Cooper system. Estimates of population size as harvest plus passage counts were a small fraction of estimated annual population size from mark-recapture population estimates of blueback herring conducted in the Santee River from 1977 through 1990 for the overlapping years of 1986–1990, suggesting that a very small fraction of blueback herring in the Santee River are caught or are lifted over the St. Stephen Dam.

3.2 Fishery-Independent Surveys

3.2.1 Maine-New Hampshire Inshore Trawl Survey

The Maine-New Hampshire inshore trawl survey takes place during spring and fall in five regions and four depth strata along the coast of Maine and New Hampshire (Figure 35). The survey was initiated in the fall of 2000, with the fourth depth strata added in 2003. Regions are based on geologic, oceanographic, geographic and biologic factors and divided into four depth strata: 5–20, 21–35, 36–55, and 55+ fathoms. Stations are selected randomly to reflect representative conditions within each of the strata, with a target level of 115 stations per season. Gear consists of a modified shrimp net with a 2-inch mesh in wings and 1-inch mesh liner in the cod end. Foot rope and head ropes are 57' and 70' respectively, with 6-inch rubber cookies. Indices were developed separately for each season for each species (Figure 36).

3.2.2 Merrymeeting Bay Juvenile Alosine Survey

Maine conducts an annual juvenile alosine survey for six Maine rivers including Merrymeeting Bay (Figure 37). This survey samples for all juvenile alosines managed by the state resource agencies. The survey began in 1979, covering 17 fixed stations as well as data from a separate juvenile striped bass survey designed to assess the numbers of juvenile striped bass in the lower Kennebec River. The Juvenile Alosine Survey for the Kennebec/Androscoggin estuary monitors the abundance of juvenile alosines at 14 permanent sampling sites. Four sites are on the upper Kennebec River, three on the Androscoggin River, four on Merrymeeting Bay, one each on the Cathance, Abadagasset, and Eastern Rivers. These sites are in the tidal freshwater portion of the estuary. Since 1994, MDMR added six additional sites in the lower salinity-stratified portion of the Kennebec River.

The sampling protocol for all stations is similar to that used in the juvenile shad-sampling program on the Connecticut River. Field staff samples each site once every other week from July to the end of September. The goal is to sample each site six times during the season. Field staff collects samples with a beach seine within three hours of high slack water. The seine is made of 6.35 mm stretch mesh nylon, measures 17 m long and 1.8 m deep with a 1.8 m x 1.8 m bag at its center. One person holds an end of the seine stationary at the land/water interface, and the boat operator tows the opposite end perpendicular to shore. After the net fully extends, the boat operator tows the seine in an upriver arc and pulls the net ashore. The net samples an area of approximately 220 m^2. Staff sort and process the catch in the field. Indices were developed for alewife and blueback herring (Figure 38).

3.2.3 NH Juvenile Finfish Seine Survey

A beach seine survey is conducted annually on a monthly basis from June to November at 15 fixed stations in New Hampshire’s estuaries. Four of these stations are located in the Hampton-Seabrook Estuary and 11 are located in the Great Bay Estuary. Within the Great Bay Estuary, three stations are located in Little Harbor, three stations are located in the middle to upper Piscataqua River, and five stations are located in Little Bay/Great Bay area.

Beach seine hauls are conducted by boat using a 30.5 m long by 1.8 m high bag seine with 6.4 mm mesh deployed 10–15 m from the beach. A single seine haul is made at each station during the months of June through November. Seine hauls are conducted during daylight hours and constrained to the period of approximately two hours before to two hours after low tide. Seines are set into the current and, at most stations, in water depths less than six feet to prevent the foot rope of the net from coming off the bottom. With each seine haul, surface salinity (ppt) and temperature (°C) are measured and substrate type at the station is recorded.

All fish captured are identified to the lowest possible taxon (species level is the target) and enumerated. All finfish captured are measured, total length to the nearest millimeter up to a maximum of 25 individuals per species per seine haul sample. The primary species of interest are winter flounder, rainbow smelt, river herring, American shad, and Atlantic silverside. Indices were developed for alewife and blueback herring (Figure 39).

3.2.4 MA DMF Coastal Trawl Survey

The Massachusetts Division of Marine Fisheries runs a synoptic coastal trawl survey performed in the spring and autumn. The bottom trawl surveys of Massachusetts territorial waters have been conducted by the Resource Assessment Project of the Massachusetts Division of Marine Fisheries since 1978. The objective of this survey is to obtain fishery-independent data on the distribution, relative abundance and size composition of finfish and select invertebrates.

The study utilizes a stratified random sampling design and six depth zones (Figure 40). Trawl sites are allocated in proportion to stratum area and randomly chosen in advance within each sampling stratum. Randomly chosen stations in locations known to be untowable due to hard bottom are reassigned. Sampling intensity is approximately 1 station per 19 square nautical miles. A minimum of two stations are assigned to each stratum.

A standard tow of 20-minute duration at 2.5 knots is attempted at each station during daylight hours with a 3/4 size North Atlantic type two seam otter trawl (11.9 m headrope/15.5 m footrope) rigged with a 7.6 cm rubber disc sweep; 19.2 m, 9.5 mm chain bottom legs; 18.3 m, 9.5 mm wire top legs; and 1.8 X 1.0 m, 147 kg wooden trawl doors. The codend contains a 6.4 mm knotless liner to retain small fish.

Environmental variables taken at each station include depth and bottom temperature. Standard bottom trawl survey techniques are used when processing the catch. Bottom temperatures were continuously recorded with an Onset Computer Tidbit TM attached to the net's headrope.

MA DMF collects biological samples with the trawl survey using standard bottom trawl techniques when processing the catch. The total weight and length-frequency of each species were recorded directly into Fisheries Scientific Computer System (FSCS) data tables. Fish collected in each tow were sorted, identified, counted and measured to the nearest mm (fork or total length). Large catches were subsampled, with length measurement taken on a minimum of 30 randomly selected individual fish of each species. Some samples were stratified by length group such that all large individuals were measured and only a subsample of small (YOY or yearlings) specimens were measured. Subsampled counts could then be expanded by length group for each tow. An index of abundance was developed for alewife, but not blueback herring, as the proportion positive tows and overall catch rates of blueback herring were too low (Figure 41).

3.2.5 RI DEM Trawl Survey

The Rhode Island Department of Environmental Management Division of Fish and Wildlife (RI DEM) research trawl survey is conducted using a 2-seam otter trawl with a 210 x 4.5" mesh fishing circle. The trawl has a 40' headrope and 55' footrope. The trawl uses a chain sweep consisting of 5/16" chain hung at 12 inch spacing with 13 links per space. There is a double sweep that consists of 16 loops of 3/8" chain shackled to the center of the main sweep. There are seven 8-inch floats spaced evenly along the headrope. The codend of the trawl is fitted with a ¼ "mesh liner to help retain juvenile and adult finfish and crustaceans. The bridles on the trawl are constructed of 48’ 3/8” wire attached to 44” Type 4 Thyboron trawl doors. The trawl doors are fitted with Notus doors sensors to monitor how the gear is fishing in real-time. The trawl is currently towed off the western-rigged RV John H. Chafee for 20 minutes at 2.5 knots. The RV John H. Chafee was built in 2002 using a 50’ Wesmac hull and powered by a 700 hp 3406 Caterpillar engine. Sampled areas include Narragansett Bay and Rhode and Block Island Sounds. Data include a mixture of fixed and random sampling stations. Data collection has been consistent across seasons from 1990 to the present. Data elements include numbers caught by species and suite of environmental information including bottom and sea surface water temperature, depth, sea conditions, and wind speed/direction. The survey has two components, a seasonal survey with a random stratified design which began in 1979, and a monthly fixed station survey which began in 1990 that is conducted monthly throughout the year. Indices were developed for alewife and blueback herring (Figure 42).

3.2.6 RI DEM Narragansett Bay Juvenile Finfish Seine Survey

The RI DEM Narragansett Bay juvenile finfish survey began in 1988 to monitor the relative abundance and distribution of the juvenile life history stage of commercial and recreationally important species in Narragansett Bay. These are used to evaluate short- and long-term annual changes in juvenile population dynamics, to provide data for stock assessments, and to develop Fishery Management Plans. Additionally, the fish community data collected by this survey is used to continue to identify, characterize, and map essential juvenile finfish habitat in Narragansett Bay.

The survey encompasses 18 fixed stations throughout Rhode Island’s Narragansett Bay (). The survey began in 1986 with fifteen stations. The data represented begins in 1988 as the period of time when the survey began using consistent methodology with 15 stations, and then station 16 (Dyer Is.) was added in June 1990, station 17 (Warren R.) was added in July of 1993, and station 18 (Wickford) was added in July of 1995.

Finfish are collected using a 61-meter (200') x 3.05-meter (10'), 6.4 mm stretched (¼”) mesh beach seine. The seine has a bag at its midpoint and a weighted footrope. The beach seine is set in a semi-circle, away from the shoreline and back again using an outboard powered 22' (7 m) boat. The net is then hauled toward the beach by hand and the bag is emptied into large water-filled totes. Area swept was calculated, to determine the area covered by an average set (5,837 sq ft; 542.3 sq m).

Physical parameters such as weather conditions, water temperature, dissolved oxygen, salinity, are taken at each station. Fish are sorted by species, measured and counted. If over 50 individuals of one species are collected a sub-sample is taken. Fish collected in the sub-sample are measured and counted. The fish are released immediately after measurements are taken. Relative abundances of invertebrates and aquatic vegetation are also noted. Finfish are sampled monthly, from June through October of each year.

3.2.7 RI DEM Coastal Ponds Seine Survey

The RI DEM Coastal Ponds Beach Seine Survey has been conducted weekly from May-October since 1996. A single haul is conducted at 24 fixed stations with a 39.62 m x 1.67 m beach seine and 16’ boat (Figure 43). Number and length are collected for each species, and bottom temperature, salinity, and dissolved oxygen are collected at each station. An index was developed for alewife in the Narrow River (Figure 44), as the proportion positive hauls and overall catch rates of alewife at the other sites and blueback herring for all rivers were too low.

3.2.8 RI Trap Net Juvenile Surveys

Gilbert Stuart

Between 1988 and 1996 a trapnet was installed during the fall to capture juveniles exiting the freshwater impoundment. The trapnet was connected to the exit of the Alaskan steeppass fishway, therefore trapped fish endured high velocities of water. Due to high juvenile mortality the JAI was discontinued in 1996. During the 2007 season a different style trapnet, which prevents juvenile mortality was utilized. This weir-based trap located 200 yards below the fishway allows trapped out-migrating juveniles a safe holding pen. The trap is set for one hour and juveniles are enumerated and length measurements are collected.

Nonquit

Since 2001 a trapnet was installed weekly each fall in the Denil fishway. The trap is placed in slots located at the front of the turning pool, and juveniles are captured as they exit the freshwater impoundment and held in the turning pool.

3.2.9 CT DEEP Long Island Sound Trawl Survey (LISTS)

The LISTS has been conducted annually throughout Long Island Sound since 1984. The trawl survey employs a Sound-wide stratified random design with four depth strata and three bottom substrate types (Figure 45). Forty stations are usually sampled monthly during spring (April-June) and fall (September-October) for a total of 200 samples each year. Most (90%) of the trawl strata from the CT DEEP trawl survey are located in the central (west of the Connecticut River) and western basins of LIS. Length frequencies (cm, FL) of all finfishes including blueback herring and alewife have been monitored by LISTS annually from 1989 to 2010. Indices were developed for alewife and blueback herring (Figure 46).

3.2.10 Connecticut River Juvenile Beach Seine Survey

A long (1979–2016) time series of juvenile blueback herring relative abundance has been established in the Connecticut River at 7 stations located between Essex, CT (river km 10) and Holyoke, MA (river km 139) (Figure 47). Each year this beach seine survey has been conducted weekly during the months of July through October. One seine haul is made at each station using a 30.5 m bag seine (Crecco et al. 1981; Marcy 1976). Although some juvenile alewife remain in the lower river throughout summer and fall when the survey is conducted (Crecco et al. 1981), few are taken in the seine. Loesch (1987) reported juvenile alewife are distributed mainly in deeper (> 5 m) water and are less susceptible than juvenile blueback herring and shad to the beach seine. Therefore, an index was developed only for blueback herring (Figure 48).

3.2.11 USFWS Connecticut River River Herring Spawning Stock Assessment

Initiated in 2013, this program uses boat electrofishing to sample the following basin tributary and cove areas annually south (rkm 52) to north (rkm 129) for the following; Mattabesset River, Wethersfield Cove, Farmington River, Westfield River and Chicopee River from April through mid-June, weekly. A minimum of five standard timed sample runs are completed at all sites, except Chicopee River due to its accessibility. All tributaries are sampled in lower reaches, close the main stem river. Study objectives include: 1) obtain a minimum whole fish sample of 80 Blueback Herring and Alewife for age structure, per target sample location, event; 2) obtain baseline demographic data on all sampled river herring (species, length, weight, sex, spawning condition); 3) derive relative abundance, reported as fish per minute 4) conduct surveys across a broad geographic range of spawning aggregations and over the duration of the runs, representing spatial and temporal variations for both species; 5) determine fish ages from otoliths and spawning history from scale examinations; and 6) utilize standard stock assessment procedures and statistics to describe status and trends, including catch-at-age abundances. An index of abundance for blueback herring was developed for this survey (Figure 49).

3.2.12 NY DEC River Herring Spawning Stock Survey

To meet the requirements outlined in Amendment 2 (ASMFC 2009) for the mandatory fishery-independent monitoring programs, in 2012 New York established the river herring spawning stock survey. The objectives of the survey were to evaluate species, size, and sex composition of spawning river herring; and then develop the methodology to use the gear to perform an annual assessment of the Hudson River's river herring spawning stock. The sampling target was four sample days per week (March 15 to June 15). A minimum of five beaches were sampled each day, and results were used to evaluate sample sites for future sampling use as well as collect spawning adult river herring in the area.

In 2012, sampling sites ranged from Tappan Zee (rkm 45) to Albany (rkm 232). Despite much effort in 2012, no river herring were caught in the southern part of the river from Poughkeepsie south to the Tappan Zee. These areas were dropped in 2013, and the sampling area was pared to the mid and upper river sections where river herring were most readily caught. Currently, each sampling day of the week focuses on one river reach from Kingston (rkm 136) to Albany (rkm 232). Reaches are broken down as follows: Kingston (rkm 136–169), Catskill (rkm 170–190), Coxsackie (rkm 191–213), and Albany (rkm 214–232). Initially, sites were randomly selected from a map of all known beaches within the Hudson River Estuary. After scouting, sites were removed if they no longer had beaches or had major sampling obstructions. Current sampling focuses on 15 fixed sites spread throughout the four reaches (Figure 50).

After each haul, technicians examine each fish for species, sex, and spawning condition. A subsample of ten fish is sampled for each sex and species for total length, weight and scale samples are removed. When possible, 30 extra fish are measured from each sex and species for each sampling event. All other incidental catch is tallied by species. Indices were developed for adult alewife and blueback herring (Figure 50).

3.2.13 NY DEC Juvenile Beach Seine Survey

Since 1980, the Department has produced an annual measure of relative abundance of YOY alewife and blueback herring in the Hudson River Estuary. Although the program was designed to sample YOY American shad, it also provides data on the two river herring species. Blueback herring appear more commonly than alewife throughout the time series. In the first four years of the program, sampling occurred river-wide (rkm 0-252), bi-weekly from August through October, beginning after the peak in YOY abundance occurred. The sampling program was altered in 1984 to concentrate in the freshwater middle and upper portions of the estuary (rkm 88-225), the major nursery area for young American shad and river herring (Figure 52). Timing of sampling was changed to begin in late June or early July and continue biweekly through late October each year. Gear is a 30.5 m by 3.1 m beach seine of 6.4 mm stretch mesh. Collections are made during the day at 28 fixed sites in nearshore habitats spanning four reaches of the freshwater portion of the river. Indices of young-of-year alewife and blueback herring were developed (Figure 53).

3.2.14 New Jersey Ocean Trawl Survey

The New Jersey Ocean Trawl Survey is a multispecies survey that started in August 1988 and samples the near shore waters from the entrance of New York Harbor south, to the entrance of the Delaware Bay five times a year (January, April, June, August and October). There are 15 strata with five strata assigned to three different depth regimes; inshore (3 to 5 fathoms), mid-shore (5 to 10 fathoms), and off-shore (10 to 15 fathoms). Station allocation and location is random and stratified by strata size.

The survey net is a two-seam trawl with forward netting of 4.7 inch stretch mesh and rear netting of 3.1 inches stretch mesh. The codend is 3.0 inches stretch mesh and is lined with a 0.25 inch bar mesh liner. Each trawl is 20 minutes long and at the end of each tow, the total weight of each species is measured in kg and the length of all individuals, or a representative sample by weight for large catches, is measured to the nearest cm. A series of water quality parameters, such as surface and bottom salinity, temperature and dissolved oxygen, are also recorded at the start of each tow. New Jersey began collecting otoliths and other biological data in 2009 to develop age at length keys for both species. Processing and aging of these samples will be completed as funding becomes available. Indices were developed for alewife and blueback herring (Figure 54).

3.2.15 New Jersey River Herring Adult and Juvenile Abundance Survey

In 2015 the state of New Jersey began a river herring adult and juvenile abundance survey on the Great Egg Harbor River which has been known to have historical river herring populations. Gillnetting is performed once a week at two locations on the river representing brackish and freshwater environments. Adult river herring moving into spawning areas are collected by use of anchored sinking gill nets that measure 141’ x 6’ x 3” and 171’ x 6’ x 3” stretch mesh set for 90 minutes. River herring collected are measured by fork and total length and are inspected for sex and ripeness. Water chemistry data (water temperature, salinity, dissolved oxygen, and pH) as well as atmospheric conditions (tidal stage, weather, wind directions and speed, cloud cover, moon phase, and air temperature) were recorded.

In the summer and fall juvenile river herring are collected at 7 sites along the river representing freshwater and estuarine environments utilizing a 100’ x 6’ x ¼ mesh bagged beach seine bi-weekly. Water chemistry data (water temperature, salinity, dissolved oxygen, and pH) as well as atmospheric conditions (air temperature, cloud cover and moon phase) were recorded. A total of 30 alewife and 30 blueback herring were subsampled from each haul and measured to fork length. All remaining alewife and blueback were counted and released.

This project is anticipated to continue as long as funding is available. As a longer time series is established, indices of abundance will be calculated to track adult returns and spawning success within the Great Egg Harbor River.

3.2.16 New Jersey Juvenile Striped Bass Seine Survey

Since 1980, the NJDFW Bureau has conducted a striped bass young-of-year (YOY) seine survey in the Delaware River. The Delaware River is divided into three regions based on habitat; region 1 includes brackish, tidal water extending from the springtime saltwater/freshwater interface to the Delaware Memorial Bridge; region 2 includes brackish to tidal fresh water extending from the Delaware memorial Bridge to the Schuylkill River at the Philadelphia Naval Yard; region 3 includes tidal freshwater from Philadelphia to the fall line at Trenton. The region 1 shoreline is dominated by saltmarsh vegetation while region 2 is primarily urban with a shoreline heavily developed for commerce and industry. The sampling scheme has been modified over the years but the core survey area and station locations have remained consistent. In 2002, the second two weeks of June and first two weeks of July were added to the sampling protocol.

Field sampling employed a bagged, 30.5 m (100-feet) long, by 2 m (6-feet) deep, with a 6 mm (1/4-inch) mesh beach seine. The seine is deployed as follows: one end of the seine is held fixed at the waterline while a vessel backs off the beach in a half-circle or elliptical pattern before returning to the beach with the other end of the seine. The two ends of the seine are drawn together and hauled on shore at which point all fish are identified to species level, quantified and a sub-sample of up to 30 lengths (cm, FL) are recorded for each species from each seine haul; the total size range is also recorded. Basic water quality parameters, including water temperature, salinity and dissolved oxygen, were also recorded at each station. Indices were developed for young-of-year alewife and blueback herring (Figure 55).

3.2.17 Delaware DFW 30' Trawl Survey

The Delaware Estuary is monitored annually by DFW to document the relative abundance and distribution of a number of important finfish species. A 30-foot bottom trawl was used to sample nine fixed stations in the Delaware Bay from March through December (Greco 2015). Tow duration was 20 minutes with a minimum tow time of 10 minutes required for the data to be considered valid. A global positioning system (GPS) was used to determine exact vessel position at the start and conclusion of each tow. Odometer readings from the GPS unit were used to determine distance towed (nautical miles).

Length frequencies have been determined for blueback herring and alewife resulting from collections during the adult finfish surveys conducted on the Delaware Bay. Species represented by less than 50 individuals were measured for fork length to the nearest half-centimeter. Species with more than fifty individuals were randomly sub-sampled (50 measurements) for length with the remainder being enumerated for each tow. Indices of age-1 abundance for alewife and blueback herring were developed (Figure 56).

3.2.18 Delaware DFW 16' Trawl Survey

DE DFW monitors the relative abundance and distribution of a number of important juvenile finfish species encountered in the Delaware River estuary from April through October at 38 fixed stations using a 16' trawl seine. Tow duration was 10 minutes for the 16-foot trawl survey. A global positioning system (GPS) was used to determine exact vessel position at the start and conclusion of each tow. Odometer readings from the GPS unit were used to determine distance towed (nautical miles). A representative subsample of 30 juvenile specimens per species was measured for fork length to the nearest millimeter; the remainder were enumerated. An index of young-of-year alewife was developed (Figure 57), as the proportion positive tows and overall catch rates of blueback herring were too low.

3.2.19 Maryland DNR North East River Gillnet Survey

MD DNR has conducted a gill net survey targeting river herring in the North East River since 2013 (Figure 60). A multi-panel sinking monofilament gill net is set perpendicular to the channel at four randomly chosen sites once a week for 10 weeks from mid-March to mid-May. For the 2013 and 2014 sampling years, the gill net had three separate panels each 100 ft x 6 ft with mesh sizes of 2 ½, 2 ¾, and 3”. In 2015, the 3” mesh panel was replaced with a 2 ¼” mesh panel, as there was evidence the current mesh size selection was not successful in capturing smaller sized blueback herring. The sites are randomly selected from a grid of 1000 ft x 1000 ft squares overlaid on a map of the North East River. Determination of whether to set the net shallow or deep is also randomized. The net is soaked for 30 min prior to retrieval. All fish are identified and enumerated to species per gill net mesh size. All alewife and blueback herring are sexed and measured to the nearest mm FL and TL. Scales are taken from the first 20 alewife and blueback herring encountered of per panel to determine age and spawning history. Since 2016, otoliths have been taken from the first 10 alewife and blueback herring encountered per day; however, these otoliths have only been archived and have not been examined for age determination. Additional data collected at each site include: set time, surface water temperature, surface salinity, specific conductivity, surface dissolved oxygen, tidal stage, depth, and secchi depth. Indices were developed for adult alewife and blueback herring (Figure 61).

3.2.20 Maryland DNR Estuarine Juvenile Finfish Survey

The MD DNR Juvenile Striped Bass Seine Survey has documented annual year-class success and relative abundance of many fish species in the Chesapeake Bay since 1954. Fixed sample sites are located in four areas of Maryland’s Chesapeake Bay: the Nanticoke, Choptank, and Potomac Rivers and the Upper Chesapeake Bay region north of the Chesapeake Bay Bridge (Figure 62). Sites have occasionally been lost due to erosion, bulkheading, or proliferation of submerged grasses. When necessary, replacement sites are located as close as possible to the original site. Each site is visited monthly, from July to September, and up to two samples are collected at each visit. Effort was slightly variable prior to 1998, with sample sizes ranging from 72 to 80 seine hauls per year. From 1998 to present, effort was standardized and sample size has been constant at n=75. Samples are collected with a 30.5 m x 1.24 m bagless beach seine of untreated 6.4 mm bar mesh set by hand. One end of the net is held on shore, while a biologist pulls the other end of the net perpendicular from shore to the 1.2 m depth contour or the net’s full extension, whichever comes first. The net is then pulled parallel to shore to sweep the largest area possible and returned to the beach. All fish captured are sorted and counted by species.

A random subsample of up to 30 individuals is measured for species of interest. Select species are separated into age 0 and age 1+ groups. Ages are assigned from length frequencies and verified by direct examination of scales. Additional data collected at each site include: time of first haul, maximum distance from shore, surface water temperature, surface salinity, primary and secondary substrates types, percent submerged aquatic vegetation, dissolved oxygen, pH, and turbidity. Indices of young-of-year alewife and blueback herring were developed for each river (Figure 63).

3.2.21 VA DWR Electrofishing Surveys

Since 1994, the VDGIF has conducted electrofishing surveys for American shad, hickory shad, alewife, and blueback herring in the Rappahannock River near Route 1 and in the James River near the Manchester Bridge in downtown Richmond. Sampling is conducted weekly at both locations. The total number of each species collected and the sex of each individual in a sample is recorded. Individual weights and total lengths are collected from a subsample per sampling date at each station.

The Route 1 sampling station starts at the very head of tide (the tidal/non-tidal interface) approximately 1.5 miles downstream of the Embrey Dam (removed in 2004) and extends downstream several hundred meters (900 seconds of boat electrofishing effort). This area was essentially unchanged by the dam removal in 2004 and represents the most consistently sampled site by the VDGIF on the river. Alewives are observed at the Rappahannock stations in March and April of each year. Blueback herring can be found in April through early June; the two species usually co-occur in April only.

Three of the four stations (Manchester 1, 2, and 4) in the James River start at the very head of tide just downstream of the last riffle/rapids and extend downstream to the 14th Street Bridge (300–500 seconds of electrofishing effort each). The Manchester 5 sampling station starts at Interstate 95 and extends downstream along the bank (500 seconds of electrofishing effort). Alewives appear in March and April at the Manchester Bridge sampling sites on the James River. Blueback herring occur at this site in April, May, and early June. Indices of adult alewife and blueback herring were developed for each river (Figure 64).

3.2.22 VA DWR Pushnet Survey

Push net sampling is conducted at night when the fish exhibit negative-phototropic behavior that orients them closer to the surface and thus makes them more vulnerable to the gear. The push net gear is mounted on a 5.2 m jon boat with a 50 hp motor. Originally, we used a custom made push net that has a rectangular shaped open collection end (0.87 m^2). The nylon net has a 6.4 mm mesh size. The 2.1 m long net tapers down from the open collection end to a small opening that is used to empty the net (tied off during sampling). The net frame is mounted to the boat so that the net can be deployed in front of the bow. Several years ago, we swiched to circular nets with an open collection end of 0.456m^2 and a depth of approximately 1 m. Circular net mesh sizes vary from 1.59 mm up to 6.35 mm. The circular nets are also mounted to the push net frame on the boat.

Generally, six push net sites are randomly selected (Excel) from a larger number of sites per river reach (e.g. Boshers Dam pool). A sample starts when the push net is lowered into the water and the boat is driven forward in the center of the river channel. The "passenger" keeps track of the time and operates the power winch to raise and lower the net. Pushes range from 2.5 to 10 minutes in length and the boat is operated to maintain a range of 2500 to 3000 RPM.

A flow meter is mounted to the push net frame to determine the volume of water sampled during a push. A flow meter reading is taken before and after each push to determine the total number of rotations during the sample. The rotation data is entered into an Excel spreadsheet that employs a manufacturer's formula to calculate the linear distance that the meter traveled (Distance = Pitch factor * No. turns). The distance is then multiplied by the net mouth area to calculate the volume of water sampled in cubic meters. The number of target species are entered into the Excel spreadsheet to calculate juvenile fish density that is expressed as the number of fish per 100 cubic meters. One way to think of it is that with a net mouth area of approximately 0.5 m^2, 100 m^3 is sampled over a distance of about 200 m. So, a result of 16 Blueback Herring juveniles per 100 m3, for example, means that there were 16 Blueback Herring near the surface in a 200 m long path roughly one meter wide and one meter deep.

Inter-annual trends of abundance, densities related to spawning success and/or stocking survival, and densities related to spatial, temporal and flow conditions can be analyzed in part using push net data. This project's long-term push net data set begins in 1997. The data set provided here starts with 2005. An index of young-of-year blueback herring was developed (Figure 65), as the proportion positive and overall catch rates of alewife were too low.

3.2.23 VIMS Juvenile Striped Bass Seine Survey

The VIMS Juvenile Striped Bass Seine Survey tracks trends in the annual year-class strength of striped bass in the spawning and nursery areas of the lower Chesapeake Bay. JAIs for alewives and blueback herring were calculated as the geometric average number of fish per seine set for the James, York, and

Rappahannock rivers separately. The indices series start in 1989 because the number of sites sampled (~109) became consistent in that year. The JAIs for both species were calculated based on data collected in July through September using only data from sites where each species can be expected to be captured. All sampling sites are fixed in location. An index of young-of-year blueback herring was developed (Figure 67), as the proportion positive and overall catch rates of alewife were too low.

3.2.24 VIMS River Herring Adult Relative Abundance Monitoring Program

In response to the moratorium for river herring enacted in 2012, an annual adult spawning stock monitoring program gill net was established in 2015 on the Chickahominy River, a major tributary of the James River and the location of a historical fishery for river herring; in 2018 this survey was expanded to include sampling on the Rappahannock River. Each week, generally from February to May, nets are fished for approximately 24 hours. All herring are counted and returned to the lab for collection of length, weight, and sex data; otoliths are removed to age the fishes; scales are removed to count spawning marks; mortality is calculated. Indices of adult abundance for alewife and blueback herring were developed (Figure 66).

3.2.25 VIMS River Herring Juvenile Surface Trawl Survey

In 2014, a nighttime surface trawl survey was established to target juvenile alewife and blueback herring in the Chickahominy River. This survey employs a mamou trawl, which is a 6.7 m x 1.8 m floating surface trawl constructed of 35 mm high density polyethylene netting. Sampling occurs weekly during July and August. During each cruise, three stations are randomly chosen within each of four adjacent 9.3 river km long blocks. Stations are designated at every 1.9 river km, beginning approximately 1.2 km (c. 2 miles) below Walker's Dam and ending at the river mouth. Night time sampling is conducted when juvenile *Alosa* spp. are most susceptible to surface trawling (Loesch et al. 1982). Each tow lasts 5 minutes and is conducted along the central axis of the river channel. Alewife and blueback herring caught at each station are identified and counted. Ten randomly selected individuals of each species from each station are measured and weighed.

3.2.26 VIMS NEAMAP Trawl Survey

The NEAMAP Mid-Atlantic/Southern New England Nearshore Trawl Survey uses a stratified random design to sample the coastal ocean from Martha's Vineyard, MA to Cape Hatteras, NC since the fall of 2007. NEAMAP conducts two cruises per year, one in the spring and one in the fall, and samples inshore areas that were lost from the NEFSC Bottom Trawl Survey with the vessel change in 2009 (Figure 69). Lengths, otoliths, and maturity data are collected, but the otolith samples have not been aged in the absence of an accepted coastwide protocol. Length an maturity data indicate the river herring sampled by this survey are a mix of immature and mature fish. Indices were developed for alewife and blueback herring (Figure 70).

3.2.27 NC DMF Juvenile Seine Survey

The NCDMF began nursery area sampling for juvenile blueback herring and alewife in the Albemarle Sound area in 1972, with eleven core stations being established and sampled throughout the time period (Figure 71). This survey was designed to index annual relative abundance of juvenile blueback herring and alewife. Thirty-four stations were established in the western Albemarle Sound area and sampled with trawls and seines. Due to a further reduction in federal aid funds, trawl sampling was dropped at the end of June 1984.

Seine stations were sampled with a 60-foot bag seine with ¼ inch mesh bag, with a single haul considered one catch-per-unit-of-effort (CPUE). Samples were sorted to species, and up to 30 individuals of each alosine species present were measured to the nearest millimeter fork length (mm, FL), and all others were counted.

Sampling with seines at the 11 core stations has continued during June-October each year from 1972–present. During September, an additional 13 seine stations are sampled throughout the Albemarle Sound area to determine distribution and migration. Indices of young-of-year abundance were developed for alewife and blueback herring by gear (Figure 72)

3.2.28 NC DMF Independent Gillnet Survey

Since 1990, NCDMF has been conducting an independent gill net survey (IGNS) throughout the Albemarle Sound area (Figure 73). Since 1990, NCDMF has conducted an independent gill net survey (IGNS) throughout the Albemarle Sound area. The survey was designed for striped bass data collection; however, river herring are captured during the survey and size, age, and sex data are collected. Gill net mesh sizes from 2.5 through 7.0 ISM in half-inch increments and 8.0 and 10.0 ISM in whole mesh increments are utilized. The Albemarle Sound IGNS is conducted from November through May but results for river herring are only reported for January through May because catches of these fish at other times are rare. Areas fished, sampling effort and sampling frequency vary seasonally. The Albemarle Sound is divided into six zones. From November-February each zone is sampled twice monthly. From March-May all effort is focused in “Zone 2”, in the western Albemarle Sound, and sampled seven days a week (weather permitting). Each unit of effort is one 40-yard net, fished for 24-hours. Gill nets are fished in 40-yard shots totaling 960 yards per set (24 units of effort). This survey was suspended February 2020 and resumed November 2021. Indices of adult abundance were developed for alewife and blueback herring (Figure 74).

3.2.29 NC WRC Electrofishing Survey

The N.C. Wildlife Resources Commission conducts electrofishing sampling on four major coastal rivers each spring from March through early June. Indices of adult abundance was developed by alewife and blueback herring in the Chowan River and blueback herring in the Neuse and Cape Fear River systems (Figure 75). The NC Wildlife Resources Commission conducts electrofishing sampling on four major coastal rivers each spring from March through early June. Within the Chowan River basin, annual monitoring sites are completed in Dillard’s (Indian) Creek, Catherine’s Creek, and sites added in Vaughan’s Creek in 2018 were sampled again in 2019, 2020, 2021, and 2022. Sites added in Catherine’s creek in 2006 were sampled again in 2020, 2021, and 2022. Sampling in Bennett’s Creek was discontinued due to low catches and access limitations. River herring are opportunistically collected in the mainstem Tar River sample sites during American Shad and Striped Bass survey activities, but Tar River basin annual monitoring sites in Bear and Chicod creeks were stopped because of historically low catches and the need to focus effort in other areas. In the Neuse River basin, annual monitoring sites are sampled in Core and Village creeks and exploratory sites throughout the basin are sampled each year to further evaluate the extent of river herring distribution in the Neuse River basin. River herring are collected in annual monitoring sites in Town and Rice’s creeks in the lower Cape Fear River basin as well as in the mainstem Cape Fear River at Lock & Dam 1. Additional exploratory herring sampling is often conducted in small tributaries of the Cape Fear River. Daily and overall CPUE, sex, and length frequency (TL mm) information for both species are collected for each stream sampled. Because the herring sampling season was abbreviated due to limitations from the Covid-19 pandemic, relative abundance indices should not be calculated in 2020 or compared to other years.

3.2.30 FL FWRI St. Johns River Electrofishing Survey

Adult *Alosa* species were collected on the spawning grounds in the St. Johns River by electrofishing beginning in 2001. In 2001 and 2002 sampling was haphazard 10 minute transects. The sampling protocol was standardized beginning in 2003. Standard sampling occurred from January to April in each year. Ten random transects were sampled in two representative river sections lying between rkm 278 and 357. One section is referred to as the “Creel Area”. The other section is referred to as “Upstream” and combines two sub-areas. The Creel Area lies between river kilometers 274 and 297 as measured from the river mouth and falls between Lake Monroe and Lake Harney. “Upstream” includes four transects in a six-kilometer reach between Lake Harney and Puzzle Lake (rkm 314–320) and six transects in 12 km of river bracketing State Road (SR) 50 near Christmas, Florida (rkm 345–357). In 2009 and 2010, peak-season trips were made to various tributaries in search for spawning locations of Alosa species outside the mainstem of the St. Johns River. These locations included spring fed streams, blackwater creeks, and back channels in the braided section of the St. Johns River.

Sampling was conducted using an 18-foot aluminum boat outfitted with a Smith-Root GPP 9.0 electrofisher using two four-dropper Wisconsin rings. Pulsed direct current (60 Hz) was used at 340 or 680 volts depending on water conductivity. Amperage was standardized for effective power transfer and the electricity was cycled 25 seconds on by 5 seconds off. Sampling lasted for 10 minutes of “on pedal” in each transect and targeted open water. The boat path meandered between the center of the channel and the two-foot depth contour or outer edge of vegetation where channel width exceeded 50 meters. The entire navigable channel was covered where channel width was less than 50 m. Electrofishing direction was downstream with boat speed about 1–2 mph faster than ambient current. Two netters were used for all samples in the St. Johns River for catch per unit effort (CPUE) samples.

Fish collected were held live, processed between transects, and then released except when retained for biological sampling. Sex, total length (mm, TL), and weight (g) were recorded for all *Alosa* spp. collected. From 2003 to 2005 scales and otoliths were retained but aging has not been attempted. River herring are present primarily in February and March so CPUE for the adult index is calculated from sampling conducted in these months.

3.2.31 FL FWRI St. Johns River Juvenile Pushnet Survey

A bow mounted pushnet was constructed in 2006 to begin developing a juvenile abundance index for *Alosa* species in the St. Johns River, Florida. The sample gear consisted of a 5.3 m aluminum boat used to push a modified four panel Cobb trawl mounted on a rigid frame. The net opening was 1.2 m high X 1.5 m wide. The body was 3 m deep and constructed of 19 mm stretched mesh knotless nylon. The cod end was 2 m deep and constructed of 12.7 mm stretched mesh knotless nylon.

Pushnet sampling was haphazard in 2006 while the gear was being tested for efficacy in the river. Sampling was expanded to cover the entire nursery zone during the spring, summer, and early fall of 2007 through 2009. The nursery zone was sampled monthly from March to September. Sampling consisted of 48 five-minute tows at randomly selected stations between Warner Point and Lake Harney which corresponds to river kilometers 125 and 305, respectively. The river was stratified into 10 km blocks with 3 samples selected in each block to ensure sample coverage throughout the nursery zone in a sampling month. Sampling occurred on four consecutive nights starting 45 minutes after sunset with 12 stations visited each night along a 40 km river reach. Juveniles appear to be most vulnerable to the gear for the longest period of time between Lake George and Lake Monroe. Therefore, a 40 km reach was selected from rkm 210 to 250 for annual monitoring (Figure 76). In 2010 this stretch was sampled biweekly from the end of March until September. Twelve stations were visited each night with three randomly selected in each 10 km block. The index is calculated as the geometric mean of April through July catches. A second sampling reach in tidal freshwater between rkm 125 and 165 was added in 2011 and bi-weekly sampling has occurred in this reach from April through July in each year since.

Distance pushed through the water was measured using a General Oceanics 2030R mechanical flowmeter mounted between the inner and outer vertical bars of the frame. Tow speed was standardized with the motor at 2000 rpm corresponding to a speed of approximately 2.6 statute miles per hour in still water. An index of young-of-year blueback herring abundance was developed (Figure 77).

3.2.32 NEFSC Summer Shrimp Survey

The NEFSC Summer Shrimp Survey has been conducted offshore (depths > 50 m) each summer (July-August) in the Gulf of Maine since 1984 aboard the RV Gloria Michelle. It employs a stratified random sampling design and gear specifically designed for Gulf of Maine conditions. Although it targets northern shrimp (*Pandalus borealis*), it also encounters other species, including alewife, in high enough numbers to develop an index. An index of abundance was developed for alewife, but not blueback herring, as the proportion positive tows and overall catch rates of blueback herring were too low (Figure 78).

3.2.33 NEFSC Bottom Trawl Survey

The Northeast Fisheries Science Center (NEFSC) bottom trawl surveys are conducted in both the spring and fall and sample from Maine through North Carolina (Azarovitz et al 1997). The surveys follow a stratified random sampling design with strata defined primarily by depth and stations allocated approximately in proportion to stratum area (Azarovitz 1981). Inshore (8-27 m) and offshore strata (27-366 m) have been most consistently sampled by the research vessels Albatross IV and Delaware II since the fall of 1975 and spring of 1976.

In 2009, the survey changed primary research vessels from the Albatross IV to the Henry B. Bigelow. Due to the deeper draft of the Bigelow, the two shallowest series of inshore strata (8-18m depths) are no longer sampled. Concurrent with the change in fishing vessel, substantial changes to the characteristics of the sampling protocol and trawl gear were made, including tow speed, net type and tow duration (NEFSC 2007). Although calibration experiments were done, sample size of river herring in the calibration tows was limited, and the time-series was split at 2008 rather than calibrating from one survey methodology to the other. Indices of abundance for alewife and blueback herring were developed for each season and each vessel time-series (Figure 79 - Figure 80).

4 METHODS

4.1 Life History Inputs

4.1.1 Growth Modeling

4.1.1.1 Age and Length Data

Alewife age-length data included 89,382 ages assigned from scales and 29,547 ages assigned from otoliths (0), with 297 fish having ages assigned from both scales and otoliths and an additional 20,313 known YOY without associated aging structures. Estimated ages ranged from 1 to 11 years for alewife. A total of 92 systems were represented in the data set from North Carolina in the southern extent of the anadromous alewife range through Maine in the northern extent of the US range (Figure 81). Years of data collection ranged from the late 1960s for several rivers through 2023, with length of time series varying among systems. Scale data were generally more common in historical data for most states, with increasing use of otoliths for age assignment in more recent years within those systems for which otoliths were collected. However, data sets in some rivers included both scales and otoliths or one structure or the other across the available timeseries.

Blueback herring age-length data included 48,426 ages assigned from scales and 20,733 ages assigned from otoliths (0), with 505 fish having ages assigned from both scales and otoliths. Assigned ages ranged from 1 to 12 years. An additional 87,165 known-age YOY were included for blueback herring. A total of 67 systems from South Carolina to Maine were represented in the blueback herring data set used for analysis (Figure 82). The variation in frequency of otolith and scale use for age assignment within and among years and rivers, as well as the longevity of most data sets, was similar to alewife.

For both species, we assigned known YOY an age of zero for both otoliths and scales. If a system lacked data from YOY, we randomly sampled a subset of 30 YOY from the appropriate stock-region to help calibrate the lower end of the growth curve and avoid fitting unrealistic values of size at age zero, which can bias growth parameter estimates (Gilligan et al. 2021). Because sex of YOY was unknown, we randomly sampled sex of individual YOY assuming that the sex ratio was even (i.e., 50% probability of being female). Several biologically unrealistic values were removed from the data set prior to analysis. These included only pairs of exceedingly large sizes at young ages or small sizes at old ages. Fish of mixed stock origin and unsexed adult fish were incorporated into the analysis to use all available information. Parameters for these groups were intermediate to target groups and are not presented in the results for clarity.

4.1.1.2 Analysis

Individual fish growth was estimated using the three-parameter von Bertalanffy growth function (VBGF; von Bertalanffy 1938) as parameterized by Beverton and Holt (1957) using a Bayesian hierarchical modeling approach. Total length (mm) of individual fish *i* at age *t* was modeled as:

$$L_{i,t} = L_{\infty}\left(1 - e^{-K(t - t_0)}\right),$$

where L_{∞} is the mean asymptotic length, K is the Brody growth coefficient governing the rate of approach to L_{∞}, and t_0 is the theoretical age at which fish length is zero.

Growth parameters were estimated separately using (1) a sex-aggregated and (2) a sex-specific parameterization of the VBGF to fulfill multiple stock assessment needs. In both cases, we estimated system-specific growth parameters (L_{∞_j}, K_j, and t_{0_j}) informed by shared, coastwide hyper-parameters

(μ_{L_∞}, μ_K, and μ_{t_0}) and incorporated a fixed offset for aging structure (otolith or scale) that was shared across all rivers. System-specific growth parameters of the VBGF were specified as the outcome of linear predictors that incorporated system-specific offsets (Υ_j) to the coastwide hyperprior, and additive effects (β) of aging structure and/or sex (X):

$$L_\infty = \mu_{L_\infty} + \beta_{L_\infty}X + \gamma_{L_\infty j},$$
$$K = \mu_K + \beta_K X + \gamma_{K_j},$$
$$t_0 = \mu_{t_0} + \beta_{t_0}X + \gamma_{t_{0j}}.$$

We used weakly informative priors for hyper-parameters with means based on parameter estimates from a naïve non-linear fit to the coastwide data for each species ($\bar{x}_{L_\infty}$, $\bar{x}_K$, and $\bar{x}_{t_0}$). Variances for all hyper-parameters were specified using half student-t priors with 3 degrees of freedom, a mean of zero, and a scale parameter (*v*) derived from the data for each species (Bürkner 2017). Priors for μ_{L_∞} and μ_K were specified on the log*ₑ* scale because they are zero-constrained:

$$\log(\mu_{L_\infty}) \sim \mathrm{Normal}(\bar{x}_{L_\infty}, \sigma^2_{L\infty}),$$
$$\sigma^2_{L\infty} \sim \mathrm{Half\ student}\ t(3, 0, \nu_{L_\infty}),$$

and

$$\log(\mu_K) \sim \mathrm{Normal}(\bar{x}_K, \sigma^2_K),$$
$$\sigma^2_K \sim \mathrm{Half\ student}\ t(3, 0, \nu_K).$$

The hyperprior for t_0 was specified on the real scale because t_0 can be negative and generally remains on a close scale to log$_e$ values of L_∞ and *K*, which is computationally efficient. The mean of the hyperprior (μ_{t_0}) was drawn from a weakly informative normal distribution on the log$_e$-scale with a mean based on the naïve NLS fit for each species, and the variance was drawn from a half student-t distribution as described for L_∞ and *K:*

$$\log(\mu_{t_0}) \sim \mathrm{Normal}(\bar{x}_{t_0}, \sigma^2_{t_0}),$$
$$\sigma^2_{t_0} \sim \mathrm{Half\ student}\ t(3, 0, \nu_{t_0}).$$

All models were estimated in Stan (Carpenter et al. 2017) with the *brms* package (Bürkner 2017) for R (R Core Team 2023) using Hamiltonian Monte Carlo (HMC) methods for the Markov Chain Monte Carlo (MCMC) algorithm in the No U-Turn Sampler (NUTS; Hoffman and Gelman 2014). For each model, we ran three separate chains for 7,000 iterations each and discarded the first 5,000 iterations as warmup. This resulted in 6,000 posterior estimates for each parameter within the growth models. Convergence of estimates was confirmed using the Gelman-Rubin convergence diagnostic ($\hat{r} \leq 1.01$ for all parameters, Gelman and Rubin 1992) and both the bulk and tail effective sample sizes (ESS) indicated that the posterior distributions were sufficiently sampled (all ESS ≥ 300 for each chain). We did not thin posterior distributions because ESS were sufficiently large and computing memory was not limiting (Link and Eaton 2012; Annis et al. 2017).

We used system-specific VBGF parameter estimates to derive estimates at the stock-region level for alewife (MAT, SNE, and NNE) and blueback herring (SAT, MAT, SNE, MNE, and CAN-NNE) from both the sex-aggregated and sex-specific models. We summarized stock-region parameters across all systems within a region across all MCMC iterations to incorporate biological and computational uncertainty in the posterior estimates of regional VBGF parameters. Unless otherwise specified, all estimates are presented as posterior medians with corresponding 95% credible intervals. For the sake of clarity, only the results of the sex-specific VBGFs are presented in text, but full parameter estimates from both models are provided at the end of the tables in Appendix 3 for future use.

4.1.2 Maturity Curves

As nearly all biological sampling is completed in-river and few fish utilize natal rivers outside of spawning runs, information on immature fish was extremely limited, and maturity schedules derived solely from these collections would likely be biased. Thus, maturity schedules were estimated following Maki et al. (2001) to better reflect all possible age classes. This method was developed to estimate the probability of American shad reaching maturity at each age class, with the following model assumptions: similar maturation cycles exist for all years within a collection, no collected fish were mature before age 3 and no immature fish were greater than age 7, no difference in mortality exists between mature and immature fish, mature fish do not skip spawning years, and equal catchability of same-age fish exists, regardless of maturation. Examination of spawning marks and annuli on scales has not shown evidence of skip spawning (i.e., annuli with no spawning marks between them). The assumption that mortality is equal between mature and immature fish is likely violated to some degree; however, Maki et al. (2001) found from simulation work that when the difference between mature and immature survival was less than 25%, the estimated probability of maturing was very similar to the true probability of maturing. Methods utilized capture ages and spawning marks, both taken from scales, as model inputs.

Similar proportions at each age were apparent for virgin collections from all regions, and for both alewife and blueback herring. Few age 2 examples were observed throughout, ages 3, 4, and 5 were common, and age 6 virgin examples were generally rare. These observations informed the decision to cut off the age 2 class as immature examples, and to assume full maturity by age 6.

Analyses were completed in the *fishmethods* package, with the following model inputs: capture age, mature age, and ages where all fish were to be treated as mature and immature. All fish were assumed immature below age 3 and mature by age 6, and age at maturity was taken as the difference between capture age and the number of repeat spawning marks. Biological collections were pooled by stock-region (Reid et al. 2018), separated by sex, and each model produced estimates of the proportion mature at each age class. Standard errors were derived through one thousand randomizations of each model. Cumulative proportions were used to develop male, female, and pooled-sex maturity-at-age ogives for each stock-region.

4.2 Abundance Trends

4.2.1 Index Selection and Standardization

Fishery-independent data sets that caught river herring were evaluated and accepted or rejected for assessment use based on established criteria. Criteria for inclusion were:

- Consistent data collection methods over the time series, or a way to calibrate between gear or vessel changes, or other method changes

- 10 consecutive years of data; surveys with 7-9 years of data were accepted for use in future updates but not included in the trend analysis results for this assessment
- 10% of tows/hauls/sampling events were positive for alewife or blueback herring, when subset to the most representative strata, stations, months, etc.

The methods that the data providers used to calculate the indices varied from survey to survey (e.g., stratified random mean, geometric mean, GLM-standardized mean), so the SAS elected to standardize the methods used to calculate the indices across datasets for this assessment. The SAS explored using GLMs and GAMs to incorporate environmental information into the calculation of the abundance indices. If the model-based standardization reduced interannual variability or the CVs of a dataset or could account for changes in sampling methods that would otherwise require dropping years of data, the standardized index was used. Otherwise, the nominal index was used. For surveys with a stratified random design, the stratified arithmetic mean was used as the nominal index. For surveys without a stratified random design, the delta mean was used as the nominal index. The SAS explored using the geometric mean in those cases, but found the bootstrapped CVs of the geometric mean were generally higher than those of the delta mean and felt the delta distribution was a better representation of the distribution of river herring catch rates than the lognormal distribution, as the data frequently had a high proportion of zeros. Additional details on the standardization process and the comparisons of nominal and standardized means are presented in Appendix 1 for example surveys.

4.2.2 Index Correlation Analysis

Graphing the normalized indices by region gives some indication of the trends and the similarity of trends across indices within each region. The vast majority of the indices are in the MAT region while the more northerly and southerly regions have only a small number of surveys to represent them. Because the MAT region has so many indices, after showing them on one graph, the MAT indices are subset to river system in order to be able to see the lines more clearly.

Indices have been shown by cohort year. Comparing by cohort year has the advantage of being able to analyze different age-range surveys together and illustrate them on the same graph. Surveys are slotted into cohorts by setting YOY surveys to cohort year = survey year; Age-1 surveys to cohort year = (survey year - 1); Adult surveys to cohort year = (survey year - 4); Adult/Juvenile surveys to cohort year = (survey year - 4); and all other surveys with cohort year = (survey year - 3).

As part of the analysis of the indices, the SAS sought to measure the strength of association between the indices using correlation analysis. Correlation is a bivariate analysis to measure the strength and direction of association between two indices. The correlation coefficient ranges between -1 and +1 with highest strength (perfect degree of association) at the ends of the range weakening as the correlation coefficient value goes towards zero, which is no correlation. A positive correlation coefficient indicates that the indices move in similar directions.

Pearson's correlation, Kendall rank correlation, and Spearman's rank correlation were all considered as methods of measurement, but Spearman's rank analysis (Spearman, 1904) was chosen as the final approach. Spearman's rank analysis is a non-parametric test for a monotonic relationship between two variables. Each index value is ranked relative to the other values and the rankings are compared to the ordered rankings of another index. Spearman's rho, the association statistic, is more robust to outliers than Pearson's correlation coefficient due to a conversion of each index value to an ordered rank (Croux and Dehon 2010). Spearman's rho requires the less restrictive assumption of a monotonic relationship, as opposed to the assumed linear relationship for the Pearson's correlation coefficient, does not assume normal distribution of the variables, and does not assume continuity. Because the populations may not be normally distributed, Spearman's Rank Correlation is more appropriate than the other methods considered. The strength of the association is determined by the Spearman's rho with a value of -1 indicating a perfect negative association, +1 indicating a perfect positive association, and zero indicating no association. Statistical significance of the Spearman correlation is determined by the p-value relative to a selected alpha level. An alpha level of 0.05 was selected for these tests.

The correlations by cohort have been tested for each species for each region with multiple surveys.

4.2.3 Power Analysis

Power analysis was used to calculate the probability of detecting trends in the abundance indices developed from fishery-independent data using the methods of Gerrodette (1987). Using this approach, changes in abundance can take place due to constant increments (linear model) or at a constant rate (exponential model). Linear trends were modeled as $A_i=A_1[1+r(i-1)]$ where A_i represents the abundance as a function of an index of time (i) and r is a constant increment of changes as a fraction of the starting abundance index (A_1). Exponential trends were modeled as $A_i=A_1(1+r)^{i-1}$. For a linear change, r=R/(n-1) where R is the overall fraction change in abundance. For an exponential change, $r=(R+1)^{1/(n-1)} – 1$. For each survey, the median CV can be calculated as the median proportional standard error or ($SE(A_i)/A_i$). The SAS established a reference point of a power of 0.80 for surveys to detect an increasing trend.

All fishery-independent surveys that were developed into abundance indices were tested in the power analysis including any species/season/life stage variants. Variability in abundance as a function of both linear and exponential change was tested using a one-tailed test. Power was calculated for a change (R) of ±50% over a 10-year time period for both a linear and exponential trend. Power analyses were not conducted for run count surveys because there was generally no CV or SE associated with annual run count values.

It should be noted that this is not a retrospective power analysis (e.g., one done after a statistical test for a trend is conducted). It is an indication of the probability of detecting a trend if it should actually occur. A fishery-independent survey could have high power, but still not show any increasing or decreasing trend if it does not occur. Likewise, a survey with low power could show a statistically significant trend if that trend is large enough in magnitude or the time series is long enough. This is power analysis is a means to qualify the data from a given survey.

4.2.4 Mann-Kendall Test

Indices and run counts were analyzed with Mann-Kendall trend analysis (Mann 1945, Kendall 1975) to determine if a monotonic trend was present in each series. Monotonic trends were detected with the Mann-Kendall test statistic (Tau) which falls between -1 to 1, indicating the time series follows a consistently downward, upward, or no defined trend (negative value, positive value, or value approximates zero, respectively). Mann-Kendall testing is non-parametric, and test assumptions include: observations taken over time are independent and identically distributed (not correlated), and are representative of the true population throughout the series and for each season where observations occurred. Mann-Kendall tests were performed in R, and p-values were generated to assign statistical significance to the prescribed trend using the *trend* package.

4.2.5 Autoregressive Integrative Moving Average (ARIMA)

Fishery independent surveys for river herring can be quite variable, making inferences about population trends uncertain. Observed time series of abundance indices represent true changes in abundance, within survey sampling error, and varying catchability over time. One approach to minimize measurement error in the survey estimates is by using autoregressive integrated moving average models (ARIMA, Box and Jenkins 1976). The ARIMA approach derives fitted estimates of abundance over the entire time series whose variance is less than the variance of the observed series (Pennington 1986). This approach is commonly used to gain insight in stock assessments where enough data for size or age-structured assessments (e.g., yield per recruit, catch at age) are not yet available.

Helser and Hayes (1995) extended Pennington's (1986) application of ARIMA models to fisheries survey data to infer population status relative to an index-based reference point. This methodology yields a probability of the fitted index value of a particular year being less than (or greater than) the reference point [P(index_t<reference) or P(index_t>reference)]. Helser et al. (2002) suggested using a two-tiered approach when evaluating reference points whereby not only is the probability of being below (or above) the reference point is estimated, the statistical level of confidence is also specified. The confidence level can be viewed as a one-tailed α-probability from typical statistical hypothesis testing. For example, if the P(index_t>reference) = 0.90 at an 80% confidence level, there is strong evidence that the index of the year in question is greater than the reference point. This methodology characterizes both the uncertainty in the index of abundance and in the chosen reference point. Helser and Hayes (1995) suggested the lower quartile (25th percentile) of the fitted abundance index as the reference point in an analysis of Atlantic wolfish (*Anarhichas lupus*) data. The use of the lower quartile as a reference point is arbitrary but does provide a reasonable reference point for comparison for data with relatively high and low abundance over a range of years. Alternatively, some other value of the fitted abundance index may be used as a reference point (e.g., a year in which management changed).

The purpose of this analysis was to fit ARIMA models to time series of river herring abundance indices to infer the status of the population(s) and make general regional conclusions. Both fishery-independent and run count time series of data were analyzed with ARIMA models. Run count data were treated similarly to typical fishery-independent surveys (e.g., trawl or seine surveys) because run counts are generally not a true census of the migrating population as efficiency of fish passage facilities and counting methods are not 100% accurate and this efficiency can also change with environmental conditions.

The ARIMA model fitting procedure of Pennington (1986) and bootstrapped estimates of the probability of being greater than an index-based reference point (Helser and Hayes 1995) and corresponding levels of confidence (Helser et al. 2002) were coded in R and used the "surveyfit" and "surveyref" functions of the *fishmethods* package (Nelson 2021). ARIMA models were fit to natural-log transformed index values in the majority of surveys and years. In the case of a survey having a 0 index value in a particular year, that 0 value was converted to 10% of the next lowest positive index value instead of being treated as a missing value, to recognize that a 0 value is most likely not a complete absence of the species, but rather low abundance coupled with low catchability. An 80% confidence level was chosen for evaluating the probability of the fitted index value in the terminal year (i_f) being greater than an index-based reference point [i.e., P(i_f>reference point)]. Two index-based reference points were considered: 1) the bootstrapped lower quartile of the fitted abundance index (Q_{25}) as proposed by Helser and Hayes (1995); and 2) the bootstrapped fitted abundance index from 2009 (i_{2009}) representing a change in management corresponding to the initiation of Amendment 2 to the

Shad and River Herring FMP. Neither reference point should be viewed as a biological reference point for determining overfished status. They allow qualitative evaluation of status with respect to historic levels and when a change in management occurred.

The residuals of ARIMA model fits were tested for normality using a Shapiro-Wilk test for normality and if residuals were found to be non-normal, caution should be used interpreting the probability of the terminal year being greater than an index-based reference point.

ARIMA model fit results were summarized within a region with respect to the Q_{25} and 2009 reference points. The fraction of surveys whose $P(i_f > Q_{25})$ and $P(i_f > i_{2009})$ values were greater than 0.50 was enumerated for each region/species/life stage combination and the mean $P(i_f > Q_{25})$ and mean $P(i_f > i_{2009})$ calculated in an attempt to make general conclusions about the status of alewife and blueback herring in a region.

4.2.6 Multivariate Auto-Regressive State-Space (MARSS) Model

A Multivariate Auto-Regressive State-Space (MARSS) model was explored for each stock-region which analyzed river-level surveys and run counts in an attempt to identify underlying trends across rivers within each stock-region. However, the overall performance of this model was poor, indicating an inability to isolate a single consistent trend in abundance across rivers within stock-regions.

4.3 Age, Length, and Repeat Spawner Trends

4.3.1 Trends in Maximum Age

Age data comes from commercial and fisheries-independent sampling programs, although lengths of the time series differ greatly (see state reports for more details). In general, female alewife and blueback herring are larger and heavier, and grow slightly faster than males of the same species and age, although blueback herring are smaller than alewife. For the purpose of the assessment, we did not separate surveys by fishery type as states with commercial fisheries did not believe that survey type biased age or length data. Analyses were separated by sex given the differences observed in growth rate, length, and weight between the sexes in both species. The times series for some rivers also switched ageing structures from scales to otoliths. In these instances, the time series were separated. If paired samples were available at the year of transition the ages for that year were included for the structure dependent data set that was longer. Time series analyses are based upon scale derived ages unless otherwise noted.

4.3.2 Trends in Mean Length and Mean Length-at-Age

Length data from all 3 alewife and 5 blueback herring genetic reporting groups were submitted for analysis. Although surveys were not analyzed by type, length data were collected in fisheries dependent and independent surveys and were typically collected randomly. Detailed information on the individual surveys of state water bodies can be found in the individual state summary reports. In cases where only fork lengths were recorded, fork length data were converted to total length prior to analysis. Fork length to mean length conversions were made for each species using all available data, including age-0 and sub-adult fish collected in ocean trawl surveys. Mean total lengths were then calculated by spawning population for each sex in every available year where at least 30 samples were collected.

For data series that had at least five continuous years of data and ten years of data overall, the Mann-Kendall test for trend in data collected over time was performed. The test was performed on complete time series as well as from 2010 to the terminal year to examine potential effects from the implementation of Amendment 2 to the ASMFC Management Plan. A significance level of 0.05 (α= 0.05) was used to determine whether a statistically significant trend was present. The Mann-Kendall test, while most appropriate for these data sets, can only test for monotonic trends, meaning trends within timeseries will not yield significant results. Like analyses of maximum age and repeat spawning proportion, mean length is sensitive to year-class effects, making shorter time series (10 to 15 years) less informative.

For alewife, mean lengths from 86 rivers were calculated from the data submitted for the assessment. However, many time series were of shorter durations and 25 populations had time series that were eligible for Mann-Kendall analysis. Of these, 16 were in the NNE region, 5 in the SNE region, and the remaining 4 in the MAT region. These 25 populations yielded a total of 46 combinations of river and sex to perform Mann-Kendall trend analysis on.

For blueback herring, mean lengths from 45 rivers were calculated from the data submitted for the assessment. However, many time series were incomplete or of shorter durations and only 11 populations had time series that were eligible for Mann-Kendall analysis. Of these, none were in the CAN – NNE region, two were in the MNE region, two in the SNE region, 5 in the MAT region, and the remaining two in the MAT region. These 11 populations yielded a total of 20 combinations of river and sex to perform Mann-Kendall trend analysis on.

Mean lengths-at-age of alewife and blueback herring from all stock-regions were examined to determine if changes have occurred over time. Samples were collected in fisheries dependent and independent surveys. Detailed information on the individual surveys of state water bodies can be found in the individual state summary reports. In cases where only fork lengths were recorded, fork length data were converted to total length prior to analysis. Fork length to mean length conversions were made for each species using all available data, including age-0 and sub-adult fish collected in ocean trawl surveys. Mean total lengths were then calculated by spawning population for each age class and each sex in every available year where at least 30 samples were collected. Many combinations of river-sex-age-year had no or very low sample sizes and only combinations with three or more samples were included in analyses.

For data series that had at least five continuous years of data and ten years of data overall, the Mann-Kendall test for trend in data collected over time was performed. The test was performed on complete time series as well as from 2010 to the terminal year to examine potential effects from the implementation of Amendment 2 to the ASMFC Management Plan. A significance level of 0.05 (α= 0.05) was used to determine whether a statistically significant trend was present. The Mann-Kendall test, while most appropriate for these data sets, can only test for monotonic trends, meaning trends within timeseries will not yield significant results. A total of 143 combinations across the two species were analyzed.

For alewife, mean lengths at age from 25 rivers were calculated from the data submitted for the assessment. However, small samples sizes or no samples existed for many combinations of river, sex, age, and year and some time series were shorter than the minimum requirements. As a result, 19 rivers had time series that were eligible for Mann-Kendall analysis. Of these, 12 were in the NNE region, five in the SNE region, and the remaining two in the MAT region. These 19 populations yielded a total of 102 combinations of river and sex to perform Mann-Kendall trend analysis on.

For blueback herring, mean lengths at age from 15 rivers were calculated from the data submitted for the assessment. However, small samples sizes or no samples existed for many combinations of river, sex, age, and year and some time series were shorter than the minimum requirements. As a result, seven rivers had time series that were eligible for Mann-Kendall analysis. Of these, none were in the CAN-NNE region, two were in the MNE region, two in the SNE region, two in the MAT region, and one in the SAT region. These seven populations yielded a total of 41 combinations of river and sex to perform Mann-Kendall trend analysis on.

4.3.3 Trends in Repeat Spawner Percentages

Rates characterizing the percentage of repeat spawners were calculated and evaluated for alewife and blueback herring populations along the U.S. East Coast where data were available. Repeat spawner data for these species have been collected from various fisheries-independent and fisheries-dependent monitoring programs. Surveys were not separated by fishery type as states with commercial fisheries did not believe that survey type biased age or length data. Detailed information on the individual surveys of state water bodies can be found in the individual state summary reports.

Repeat spawner rates were calculated by dividing the number of sampled fish with one or more spawning marks by the total number of fish sampled and multiplying the resulting quotient by 100. When possible, rates were calculated by species, sex, year, and water body for each region. To be retained, a rate needed to be based on a minimum of 10 fish.

Comparisons among the repeat spawner rates from different states were not made due to the large variability in sampling gears and time series available. For data series that had at least five continuous years of data and ten years of data overall, the Mann-Kendall test for trend in data collected over time was performed. The test was performed on complete time series as well as from 2010 to the terminal year to examine potential effects from the implementation of Amendment 2 to the ASMFC Management Plan. A significance level of 0.05 ($\alpha = 0.05$) was used to determine whether a statistically significant trend was present. The Mann-Kendall test, while most appropriate for these data sets, can only test for monotonic trends, meaning trends within timeseries will not yield significant results.

For alewife, datasets from 48 rivers were considered, with 31 rivers in Northern New England, 9 in Southern New England, and 8 in the Mid-Atlantic. For blueback herring, datasets from 26 rivers were considered with 6 rivers in Northern New England, 4 in Middle New England, two in Southern New England, 12 in the Mid-Atlantic, and two in the Southern Atlantic Region.

4.4 Per-Recruit Analysis

Biological reference points (BRPs) provide a metric to assess stock status from a biological perspective (Gabriel and Mace 1999), integrating several components of stock dynamics (growth, recruitment and mortality, usually including fishing mortality (*F*)) into a single index (Gabriel and Mace 1999) that can inform fisheries management objectives. In turn, they provide a gauge as to whether specific management objectives are being achieved; as such, they provide both the link between mortality and biomass estimates available from stock assessments and management objectives (Caddy and Mahon 1995), and a basis for risk analysis of management actions (Punt and Hilborn 1997).

Three common modeling approaches for developing BRPs are spawner-recruit, dynamic pool and production models. The choice of model selection is predicated on life history and availability of catch, relative abundance, stock-recruitment and age-specific mortality, growth and maturity data (Gabriel and Mace 1999). The SAS believes a spawning stock biomass per recruit model (SPR) is most appropriate for the development of BRPs for river herring stocks based on the following rationale: SPRs do not require constant recruitment, they do not require a defined stock-recruit relationship, and they require limited data inputs.

River herring are subject to many different sources of mortality, some anthropogenic (e.g., directed and incidental fishing mortality, habitat loss, dam and passage mortality), and some natural (e.g., predation); however, it is difficult to partition this total mortality into its various fishing and non-fishing components. Therefore, a benchmark rate for Z was developed in lieu of F. This does not eliminate the issue of partitioning mortality into F and M in the SPR model, but it does avoid the emphasis on F when comparing the results to observed estimates of Z.

SPR based reference points are defined based on the level of additional mortality beyond natural mortality (M) the stock can experience without reducing the spawning stock biomass per recruit below a certain percent, say X, of the unexploited spawning stock biomass per recruit. Historically, values in the range of $F_{20\%}$ to $F_{30\%}$ (i.e., in terms of total mortality (Z): $Z_{20\%}$ to $Z_{30\%}$) have frequently been used to characterize recruitment overfishing thresholds (Rosenberg et al. 1994). However, several more contemporary lines of evidence suggest the need to maintain higher levels of spawning stock biomass per recruit for species such as alewife and blueback herring. First, simulations by Clark (1993) suggests that fishing at a level between 35-45% ($F_{35\%}$-$F_{45\%}$; or in terms of Z: $Z_{35\%}$-$Z_{45\%}$) provides a high percentage of maximum sustainable yield, especially if there is uncertainty in the stock-recruitment relationship, which is the case for many river herring stocks. Second, Clark (2002) went on to suggest that SPR would need to be even higher for less resilient and/or data-poor stocks but could be lower for resilient and/or data-rich stocks. River herring possess many of the qualities of species traditionally considered to be less resilient and many of the individual stocks found in individual river systems remain data poor. Third, as temporal correlation amongst annual recruitment increases (and a temporal correlation in river herring recruitment is expected given their life history (Section 1.1)) simulations suggest the SPR required to achieve MSY increases to greater than 40% and that there is a high probability that spawning stock biomass will fall below 20% of unfished levels if SPR is reduced to 35-45% of unfished levels; only if recruitment variation is uncorrelated (i.e., truly random) does fishing at $Z_{40\%}$ prevent spawning stock biomass from falling below 20% unfished levels (Clark 1993). Fourth, Clark (2002) suggests that if one is unsure of the stock's resilience (i.e., could be very low), even fishing at $Z_{40\%}$ could lead to trouble. Finally, Mace (1994) suggests that the choice of an appropriate SPR based reference point is highly dependent on the degree of resilience exhibited by individual species, with his simulations suggesting even stocks of average or above-average resilience, of which river herring are not, should have SPRs maintained in excess of $Z_{35\%}$, with $Z_{40\%}$ being more appropriate.

Consistent with the above contemporary views on appropriate SPRs, the data-poor characterization for most, if not all, river herring stocks, and the uncertainty related to stock resiliency, the SAS selected $Z_{40\%}$ as the threshold BRP. $Z_{40\%}$ is the total mortality rate that will preserve 40% of the unexploited spawning stock biomass per recruit.

Deterministic SPR models (modified Thompson-Bell SPR) and stochastic SPR models were explored to develop instantaneous total mortality (Z) reference points. However, due to deterministic SPRs inability to incorporate uncertainty of life history parameters (e.g., weight-at-age, maturity schedule, natural mortality, and selectivity-at-age), the SAS determined the use of a stochastic SPR, which incorporates parameter uncertainty, was more appropriate. A stochastic SPR model was developed in R following similar methods described in the most recent ASMFC Atlantic Sturgeon Benchmark Assessment (ASMFC 2017). The underlying population model was the same as used in the deterministic SPR. Results of the deterministic SPR are provided for comparison. It should be noted that in addition to the lack of inclusion of parameter uncertainty, selectivity was fixed at one in the deterministic SPR models

4.4.1 Deterministic SPR Model Configuration

Deterministic SPR models were implemented using the *fishmethods* package in R (Nelson 2023; RCT 2023) and follow methods described in Gabriel et al. (1989). The SPR models start with recruits at age one. The abundance of age 1 recruits (N_1) is set to a constant value (say 1000) to obtain a per-recruit value. Recruits are decremented annually by M until they reach harvestable ages. Then they are decremented by M and F through the maximum age observed. The spawning stock biomass per recruit for a given level of F, SPR_F, is given by:

$$SPR_F = \sum_a N_a m_a w_a$$

where N_a is the number at age a, m_a, is the age-specific maturity probability and w_a is the mean weight at age a. Values of F ranged from 0 to 2.0. The number of fish at age a is given by:

$$N_a = N_{a-1} e^{-(cp_{a-1}F + dM)},$$

where c is the fraction of fishing mortality within a year before spawning, p is the fraction recruited to the gear at age a and d is the fraction of natural mortality within a year before spawning.

4.4.2 Stochastic SPR Model Configuration

To carry through the uncertainty in model inputs, distributions of the parameters were developed (Section 4.43 below) and 5,000 sets of parameters were drawn for each species and stock-region. The $Z_{40\%SPR}$ reference point was calculated for each set of parameters, resulting in a distribution of $Z_{40\%SPR}$ values for each species and stock-region. Life history parameters were drawn independently, without regards to potential correlations between parameters (e.g., maximum age and L_∞).

In order to make the results more compatible with the observed values estimated using the Poisson GLM method (Section 4.5), the estimated full $Z_{40\%SPR}$ values were converted to number-weighted mean values, using the numbers-at-age-per-recruit values of a population with that level of Z. Estimates of number-weighted $Z_{40\%SPR}$ were calculated over the age range used in the total mortality estimators for each stock-region.

Z estimates derived from the Poisson GLM total mortality estimator were then compared to the median number-weighted $Z_{40\%SPR}$ (hereafter referred to as "median $Z_{40\%SPR}$") using the *pgen()* function in the *fishmethods* package in R (Nelson 2023; RCT 2023) to determine the probability that Z was above the median $Z_{40\%SPR}$. The *pgen()* function uses randomization methods as approximations to the equations in Shertzer et al. (2008) to calculate the probability that a management value (e.g., river-specific Z estimates) exceeds a reference point (e.g., median $Z_{40\%SPR}$). A probability threshold of 50% was used to determine if Z estimates were credibly above or below the median $Z_{40\%SPR}$ (i.e., $p(Z) > Z_{40\%SPR}$ was greater or less than 50%) to summarize results across a stock-region.

4.4.3 SPR Data Inputs

Distributions of growth and maturity parameters were developed for each stock-region, and used to develop the weight, maturity, natural mortality, and selectivity at age to parameterize the SPR models (Figure 83 -Figure 98). The maximum age was sampled from a uniform distribution of integers from 10 to 15. The von Bertalanffy growth parameters were drawn from the lognormal posterior distributions of the hierarchical growth models developed for this assessment (Section 4.1). Length-at-age was converted to weight-at-age using length-weight parameters which were drawn from lognormal distributions with the mean and standard deviation estimated as part of this assessment (Section 4.1). Lorenzen's (1996) parameters were used to calculate natural mortality at age as a function of weight-at-age where:

$$M_a = M_u W_a^b$$

The 90% confidence intervals reported in Lorenzen (1996) for M_u and b were used to derive the standard deviation for each parameter; M_u was drawn from a lognormal distribution and b was drawn from a normal distribution.

The probability of maturing at a given age was drawn from the Maki estimates developed for this assessment (Section 4.1.2). For each run, the cumulative probability of maturing at age was used as the maturity ogive, scaled to the maximum to asymptote at one.

Once the maturity ogive was set for a run, selectivity on ages that were not fully mature was set by randomly drawing a value from a uniform distribution between the probability of being mature at that age and 1, and a logistic curve was fit to those values. This was intended to capture uncertainty around the selectivity of the bycatch fishery and other sources of mortality on immature fish.

Note that while the central tendencies of the life history parameters are the same across the deterministic and stochastic SPR methods, the difference in how selectivity is handled means that the deterministic results are not directly comparable to the stochastic results. The deterministic approach assumes selectivity is 100% for all ages, as was done in the 2012 benchmark assessment, while the median selectivity of the stochastic SPR model is lower on younger ages.

4.5 Total Mortality Estimates

A Poisson log-linear model was used to estimate total instantaneous mortality (Z) rates (Millar, 2015) for each species and year combination for two different spatial scales: at the river level and at the regional level. The Poisson log-linear model was selected over other methods because Nelson (2019) demonstrated that it was one of the least biased methods under multi-stage cluster sampling. Most age samples for river herring are not collected randomly throughout the run; many programs intentionally sample equally at set points at the beginning, middle, and end of the run and take a subsample if catch rates are high during a sampling trip. Initial comparisons of Z estimates from the Poisson log-linear model and the Chapman-Robson bias-corrected estimator, the other estimator recommended by Nelson (2019), indicated that they produced very similar results, so the Poisson estimator was used going forward. The SAS considered the Billard (2020) method that incorporates repeat spawner marks into the estimation process, but did not pursue it because it could not be used with otolith ages, and because the SAS had concerns about the potential for compounding error with ageing error and error in repeat spawner readings, which was not considered in the Billard (2020) simulation study.

The age of full recruitment was assumed to be equal to the age of full (> 99%) maturity, which was age 5 for all regions. Estimates were only calculated for years and locations when there were at least 3 ages equal to or older than the age of full recruitment and when there were at least 30 individuals among those ages. Individuals with unknown sex were excluded except for estimates in New Hampshire. This was due to the fact that in 2004, New Hampshire changed from random sampling for ages to random sampling for length and an equal subsample of ages across length bins, meaning the age samples alone were no longer representative of the age distribution of the run. Annual age-length keys were used to convert the length distribution to an age distribution for the Z estimates; sex information for the length samples was not retained with this process. Locally estimated scatterplot smoothers (LOESS) were used to visualize trends in Z estimates over time. Approximate ninety-five percent confidence intervals for mortality estimates were calculated as $Z \pm (2 \times SE)$ where SE is the asymptotic standard error from the poisson log-linear model. Code for data preparation and analyses is online at https://github.com/mmace3/RiverHerring.

4.6 Statistical Catch-at-Age (SCA) Models

4.6.1 Monument River

A forward-projecting age-structured statistical escapement-at-age (SCA) model for the Monument River alewife stock was constructed in 2011 and was used to estimate age-3 abundance and natural mortality rates during 1980-2022 from total in-river catches, escapement counts, and escapement age composition. The model likelihoods and method for deriving effective samples sizes were changed to reflect current best practices. In addition, instead of estimating "M" values, an M multiplier which is applied to user-specified natural mortality rates is estimated. No other changes to the model structure were made.

The annual proportions of fish mature at each age and sex were estimated from age and repeat-spawner frequency data collected in the Monument River by using the Maki et al. (2001) method.

Two sets of data are used in the estimation of total population abundance and "natural" mortality rates. The first set of data is total removals (numbers per year) of alewife which includes harvested fish and fish taken for transplant to other rivers. For this update, the number of fish taken for determination of sex and species from 1993-2022 were added to the total removals. The second set of data is escapement counts and age structure. Count data were available from 1980-1981, 1984-1987, and 1990-2022. Escapement age data were available only from years 1985-1987, 1993, and 1995-2022. A multiple regression model that predicts well total abundance in the Monument River from lagged autumn monthly cumulative rainfall data was used to fill-in missing escapement data for 1982, 1983, 1988 and 1989 after subtracting removal estimates from the prediction.

Estimates of age-specific, base natural mortality rates were calculated by using the Lorenzen (1996) equation and average weights-at-age for males and females.

See Appendix 4 for more details on model structure.

4.6.2 Nanticoke River

A forward-projecting age-structured statistical catch-at-age model for the Nanticoke River alewife and blueback herring stocks was updated for this assessment. The model structure was based on the cohort dynamics described in Gibson and Myers (2003). The model tracks abundance at year (y), age (a), and repeat spawner class (r) and fits against observed proportion at age and repeat spawner class, total catch, and a fishery-dependent CPUE index. With the closure of the fishery, the only removals were research samples.

See Appendix 4 for more details on model structure.

4.6.3 Chowan River

A forward-projecting age-structured statistical catch-at-age model for the Chowan River blueback herring stock was applied to total in-river catches, catch age compositions, and the fisheries-independent young-of-year (YOY) index and gillnet adult index to estimate age-3 abundance and mortality rates.

Total catch for 2007 to 2015 was estimated by using pound net catch proportions provided in 2008, average blueback landings to alewife landings ratio from years prior to 2007, and annual mean weight by species. After the start of the moratorium in 2015, the weight of research samples was used as the total catch.

See Appendix 4 for more details on model structure.

4.7 Habitat Model

4.7.1 Model Overview

We modeled population abundance of diadromous river herring as a function of freshwater habitat availability throughout their native ranges. This modeling framework (hereafter “habitat model”) relies on a combination of biological parameters and habitat distribution in freshwater spawning and rearing environments for diadromous fishes to project populations through time. Functionally, it is a stochastic per-recruit framework with a freshwater migration and spawning routine that allows for investigation of habitat access limitations to population productivity due to dams, in addition to typical harvest regimes. This approach was identical to that used by Zydlewski et al. (2021) as implemented in ASMFC (2020) for American shad. We made species-specific changes to biological and habitat parameters within the habitat model for American shad to allow for extension of this stock assessment tool to river herring.

The habitat model is initialized by drawing an age-structured ocean population from a random number of starting individuals, with the total number of individuals in each age class determined by age-specific natural mortality rates. We used a relatively large average number of starting fish (1 million fish) to ensure rapid stabilization of populations for shorter model run times. The numbers of males and females in each age class (years) were assigned based on a sex ratio that was randomly drawn from a distribution: p[female] ~ Beta(1, 1). A spawning population was selected from the age- and sex-structured ocean population using age- and sex-specific probabilities of recruitment to spawn. Spawning fish were distributed into discrete reaches of individual watersheds according to the proportion of habitat available in each reach. The probability that fish reached that habitat was governed by upstream passage rates at dams delineating reaches. Once adults were allocated to spawning reaches, they were allowed to spawn eggs. A Beverton-Holt (1957) recruitment function was used to govern the relationship between number of spawning adults and the number of larval recruits (i.e., carrying capacity). Within this framework, the ratio of recruits per spawner (a) was the mean number of simulated eggs per female. The density-independent parameter, S, was the number of adults in each reach of the watershed. For alewife and blueback herring, the density-dependent parameter (b) of the Beverton-Holt function was set to 0.05 to approximate a larval carrying capacity that equivalated to an adult density of 500 fish per acre. A discrete, spawning survival rate for adults was applied based on an assumed duration of 2 months and the age- and sex-specific natural annual mortality rate *M*. A 30-d larval-to-outmigrant survival rate was applied to juvenile fish in each habitat reach to account for time-based mortality risk in freshwater habitats (e.g., predation). A downstream mortality rate through dams was applied separately for juvenile and age-structured adult cohorts for downstream migration. Following return to the marine environment, the freshwater emigrants were re-combined with the ocean population, annual instantaneous mortality rates were applied, and the population was projected to the next year.

4.7.2 Biological Inputs

Biological inputs for river herring models were driven primarily by estimates from this stock assessment and were sampled in the same fashion as for the stochastic SPR model. All biological parameters were incorporated as regional, sex-specific estimates. Unless indicated, this is the case for all biological parameters described in the model overview, although application of population vital rates and processes was otherwise identical to Zydlewski et al. (2021) using the *anadrofish* package (Stich et al. 2020) for R (R Core Team 2023). Biological parameters that were included in the habitat model that were not included in the present stock assessment were daily, larval-to-out-migrant mortality (Z_d), potential annual fecundity (*PAF*), and rate of iteroparity (*I*). For lack of empirical information, we assumed that the rate of iteroparity (probability of returning to spawn again) was 100% given survival throughout the rest of the year.

We used separate Z_d estimates for alewife and blueback herring to simulate 30-d mortality of juvenile fish prior to outmigration. The value of Z_d was simulated from a truncated normal distribution for each species with a lower limit of zero and an unbounded upper limit (∞). For alewife, we used a mean daily mortality rate of 0.205 and a standard error (S.E.) of 0.048 to approximate the range of daily rates reported by Hook et al. (2007) and Overton et al. (2012). Similarly, we used a daily rate $Z_d = 0.21$ (± 0.038) of for blueback herring from the temporal middle of the spawning run in the Tar-Pamlico stock where sample size was largest (Table 4 in Overton et al. 2012). For both species, we used $\sqrt{\text{S.E.}}$ to simulate new observations and limit generation of biologically less-realistic daily mortality rates (e.g., values of Z_d near zero or > 0.30) based on derived 30-day rates.

We simulated potential annual fecundity from length-fecundity relationships reported in the literature. For alewife, we randomly sampled coefficients reported by Jessop (1993) and simulated potential annual fecundity as the mean prediction across all four regression equations reported. For blueback herring, we used the length-fecundity relationship reported by Sullivan et al. (2019).

4.7.3 Characterization of River Herring Habitat

We estimated the extent and area of river herring habitat based on information collected from best available science and local knowledge. We consulted with local experts in each state to determine the extent of historical habitat for both Blueback Herring and Alewife that helped us to identify known HUC8 watersheds that the species historically have been detected within (Figure 99). Within the historical range of both species, we used the United States National Hydrography Plus Dataset (NHDPlus) to determine freshwater networks (flowlines) potentially used for migration, spawning, and rearing. The freshwater network was a series of river reach segments of varying lengths and each with its own unique ID that allowed us to estimate habitat within each unique reach segment for all rivers across the range.

To estimate the area and accessibility of habitat for each reach segment, we followed a similar approach to Zydlewski et al. (2021) by using determined stream discharge-width relationships to calculate the horizontal surface area of each reach segment. Mean annual discharge (Q) was estimated within the NHDPlus dataset by using the enhanced runoff method (EROM) which allowed us to estimate mean reach segment width (w) using the power law equation:

$$w = kQ^b$$

where Q was mean annual discharge, k was a derived width coefficient, and b was a derived exponent. We used k and b values that have been commonly used in regions throughout the geographic range of river herring (Zydlewski et al. 2021). We then used our mean reach segment width estimates to calculate horizontal surface area as:

$$A = w * l$$

where l was reach length. For any lacustrine habitat that overlapped the flowline network we used the calculated lake surface area attribute within the NHDPlus dataset as the horizontal surface area estimate to reflect the actual size of the waterbody along those river reach segments. Any lacustrine habitat that did not have a connection to the flowline network was assumed to be inaccessible during migration. Lacustrine habitat was included for Alewife due to the species using this habitat during spawning and rearing (Greene et al. 2009). Blueback herring will avoid lentic environments (Greene et al. 2009) and thus we removed lacustrine habitat from their flowline network. We assumed all stream/river area as habitat for both species.

To assess accessibility of river reach segments during migration we used the National Dam Inventory database (https://nid.sec.usace.army.mil/#/) to determine the amount of habitat above and below dams or impoundments. We used an upstream trace analysis to assign every river reach segment a dam order position that reflected how many dams a migrating river herring would have to pass to access that river reaches habitat (Figure 100). For each dam order position, we summed habitat area for all river reach segments to compare the proportions of accessible habitat (e.g., dam order = 0) to potentially inaccessible habitat (e.g., dam order ≥ 1). We then grouped river reach segments by HUC 4, 6, and 8 watersheds. We additionally grouped river reach segments by genetic stock-regions identified by Reid et al. (2018) (Figure 101).

4.7.4 Population Modeling Scenarios

We simulated regional and coastwide abundance under multiple fish passage scenarios at dams for each species. We considered upstream passage and downstream survival rates through dams of 0, 0.50, and 1.00 to explore population responses to a range of dam passage rates. We used a fully crossed design to sample all combinations of values for adult upstream passage through dams, adult downstream survival through dams, and juvenile downstream survival through dams, for a total of 27 possible scenarios. Simulations with upstream passage and downstream survival rates of 1.00 were used to represent a “no-dam” scenario, whereas all simulations with upstream passage of 0 were representative of a “no-passage” scenario.

We ran all simulations for 50 years each after confirming that populations stabilized prior to this. All biological parameters were sampled stochastically in each year and simulation using a Monte Carlo approach. To provide adequate coverage of stochastic inputs, we ran a total of 50,000 simulations for each species. This resulted in a minimum of 60-116 simulations per scenario, per stock for alewife and 45-100 for blueback herring using HUC-4 watershed units. Unless otherwise specified, results are presented as mean and 95% confidence intervals.

4.8 Bycatch Caps/Bycatch Mitigation Approaches

Ocean bycatch of river herring is a significant component of overall removals of river herring along the Atlantic coast, in some years exceeding the directed commercial fishery (Figure 23). Genetic work suggests that much of this bycatch is coming from runs in southern New England that are already at low levels (Palkovacs et al. 2014; Reid et al. 2022), adding to concerns that ocean bycatch is hindering the rebuilding of these species.

NOAA Fisheries implemented a set of bycatch caps in the Atlantic herring and Atlantic mackerel fisheries in 2014 (Section 1.3.18), but the caps are based on historical levels of alosine bycatch in those fisheries, not biological metrics.

4.8.1 Data-Limited Catch Caps

The SAS developed a proof-of-concept example for a bycatch cap based on the data-limited index-based methods simulation-tested as part of the 2020 SAW/SARC Research Track “Topics” Assessment, specifically the Plan B Smooth (aka iSmooth) and iSlope approaches (NEFSC 2020). In the simulations, these approaches were able to rebuild stocks above SSB_{MSY} on average in the long term, and also had the highest median catch among the methods that achieved rebuilding more than 50% of the time (NEFSC 2020).

These methods are conceptually simple and intuitive: if the index of abundance for a species is trending down, total allowable catch should be reduced. If the index is trending up, catch can be increased. iSmooth uses the slope of the loess-smoothed index in the last three years to develop the catch multiplier, while iSlope uses the log-linear regression on the last five years of the index, unsmoothed to develop the multiplier, which is applied in conjunction with additional multipliers on the slope and the average catch depending on how conservative managers want to be.

While the concept is simple, the application is challenging for river herring. The bycatch fishery is operating on the mixed stock population, and the proportion of each run or genetic stock-region that is present in the bycatch is a function of the abundance of each run as well as the time and area where the fishery is operating. The available indices for river herring (predominately the NEFSC, NEAMAP, and state trawl surveys in the ocean, and run counts and YOY indices in the rivers) do not overlap well spatially and temporally with the majority of the bycatch fishery. For this example, the NEFSC and NEAMAP surveys were used as ocean/mixed-stock indices, and an index from run counts from stock-regions identified as significant contributors to bycatch in the midwater trawl fishery by Reid et al. (2022) was used as a sensitivity run (SNE for alewife, MAT for blueback herring). The index value for 2020 was missing, as the surveys were not completed due to the COVID-19 pandemic. For the iSmooth approach, which uses only a 3-year average, the 2019 index and catch values were used as a proxy for the 2020 values, to avoid using only two years of data in the analysis. For iSlope, which uses a 5-year average, 2020 was treated as missing.

These approaches were applied to the coastwide estimates of bycatch to develop a coastwide cap, but they could also be applied to the existing caps that are stratified by fishery, gear, and region to produce caps that align with the current management framework for the Atlantic herring and mackerel fisheries. The current caps are not species-specific; for iSlope, which uses the recent quotas to provide catch advice, the observed proportion of alewife and blueback herring in estimates of river herring and shad bycatch were used to derive recent species-specific quotas. These methods can also be used in conjunction with a constraint to prevent next year's catch advice from deviating too far from the current advice, to prevent large swings in the cap.

The iSmooth and iSlope approaches utilize available information on river herring abundance to adjust the bycatch caps instead of using a fixed, historical level. This allows the caps to decrease when river herring abundance is decreasing and increase as river herring abundance increases, making them more responsive to trends in the river herring population. However, there is no mechanistic population model underlying these methods to provide an estimate of what a sustainable level of removals for these populations are. In addition, declines in river herring are only partially driven by ocean bycatch, so reducing incidental catch may not lead to increases in abundance and the TAC would continue to be reduced if the population continued to decline.

This is presented as a proof-of-concept; additional consultation with management would be needed to evaluate risk tolerance to select an appropriate method as well as deal with the question of whether caps would be species-specific and if so, how to deal with the shad and unknown herring component of the current bycatch monitoring.

While improved biological data and population models for river herring would improve the estimates of sustainable bycatch caps, the bycatch cap approach is still very resource intensive to implement appropriately. Increased observer coverage is needed to provide more precise, species-specific estimates of bycatch, and in order to avoid depleting individual runs or even stock-regions, the genetic composition of the catch would have to be monitored.

4.8.2 Spatial Distribution Models

The SAS was in favor of the time-area closure model as an alternative or complement to the catch cap approach to reduce river bycatch. Turner et al. (2016, 2017) explored using habitat associations to predict incidental catch hotspots for river herring and Roberts et al. (2023) extended this method to use sub-seasonal forecasts of ocean conditions to identify these hotspots in-season in a changing environment. By identifying these areas of overlap between river herring, commercially targeted species, and the fisheries, time-area closures could be implemented to mitigate fisheries interactions with river herring and reduce bycatch.

The benefit of this approach is that it relies on widely, rapidly available environmental data and subseasonal forecasts instead of the intensive levels of observer coverage necessary to estimate bycatch reliably against a cap. These models have been based on the NEFSC trawl survey data, but incorporating additional surveys, especially more inshore state surveys, and fishery dependent data could significantly improve their predictive power. For example, Roberts et al. (2023) were only able to develop estimates of bycatch risk for the spring and fall, due to the lack of summer survey data. There is a summer spawning closure for the Atlantic herring fishery in the Gulf of Maine (Section 1.3.18), but Roberts et al. (2023) did not evaluate the risk of bycatch for that season. More comprehensive models could evaluate the effects of closures like this on river herring bycatch, as well as providing more fine-scale hotspot identification with higher confidence to make time-area closures feasible on a management scale.

However, the development of that kind of model was beyond the scope of this assessment.

5 ALEWIFE STOCK-REGIONS RESULTS

5.1 Northern New England (NNE)

The NNE stock-region for alewife includes river from the St. Croix River at the Maine-New Brunswick border though the Merrimack River in Massachusetts.

5.1.1 Growth Curves

Alewife growth parameters varied among regions. The lowest *K* and t_0, and highest L_∞ occurred in the NNE region (Table 13, Figure 102), resulting in the largest length at a given age in the NNE region (Figure 103). Individual rivers within the northern New England (NNE) region displayed the largest L_∞ and t_0, and lowest *K* compared to the rest of the coast (Appendix 3 Tables S1-S4). These systems also tended to display the largest size at age for alewife. The NNE region was also the most variable with respect to estimated VBGF parameters. The river displaying the largest L_∞ was ME-C9, with an estimated L_∞ of 345 mm (337-353 mm) for females (Appendix 3 Table S1) and 329 mm (322-337 mm) for males (Appendix 3 Table S2) based on ages assigned with otoliths. Despite that the NNE region included the largest lengths at age for fish on average, the river displaying the smallest L_∞ and t_0, and highest *K* was also from the NNE region. In the ME-N23 river, where L_∞ was smallest, the L_∞ was predicted to be 275 mm (271-280 mm) for females (Appendix 3 Table S1) and 262 mm (258-267 mm) for males (Appendix 3 Table S2) based on ages assigned using otoliths.

5.1.2 SPR Reference Points

The median $Z_{40\%SPR}$ was 0.96 with 95% confidence interval of 0.75to 1.62 (Table 14, Figure 104).

5.1.3 NNE Summary Results

5.1.3.1 Trends in Maximum Age

The data from commercially harvested runs in Maine (ME C1 – ME C19) all run from 2008 to 2021 (Figure 105 - Figure 106). The maximum age for most rivers fluctuated between 5 and 7 with a range of 4 to 9 years old. None of these rivers showed notable visual trends in maximum age over the complete time series. Fisheries independent samples collected from Maine largely corresponded in length and general trends with those from fisheries dependent surveys (Figure 106). Males in ME N8 did show a slight upward trend in maximum age over the 11-year time series.

In 2010, New Hampshire Fish and Game switched from random sampling to bin sampling, which may have altered biases in the data over the time series. For alewife, visual observation of sampled rivers in New Hampshire largely showed a slight upward trend over the course of the mostly 20+ yearlong time series (Figure 107). The Exeter River appeared to have a stable range of 5 to 7 years of maximum age across the time series, although the data were interrupted by a dam removal in Exeter that made sample collection more difficult. Since 2016, samples were able to be collected in 2021 only. Likewise, river restoration work on the Winnicut River caused the time series for both species to be mostly discontinued after 2009, although data are available for 2018 and 2019. In the Cocheco, Lamprey, and Oyster rivers the maximum age increased from age 6 to ages 7 – 8 in the early 2000s and have remained in that range through 2021 (Figure 107).

5.1.3.2 Trends in Mean Length

The NNE region was composed of 20 sex and river specific datasets from Maine and 8 datasets from New Hampshire. Of these, four datasets had positive trends (females and males in ME N8 and ME N13) while the rest had no detectable trend (Table 15). Most Maine datasets began between 2008 and 2010, so trend analysis of the recent time period results were identical across rivers with the exception of female alewife in the Cocheco River in NH, where no trend was observed in the full 28 year time series but a positive trend existed for 2010 through 2021. Many populations in the NNE region showed what appeared to be year class driven trends with dips in mean length around 2014 – 2015 and 2017 and increase in between those year (e.g., ME C3, ME C5, ME C7, ME N13, ME N14, ME N8, Lamprey River, Oyster River; Figure 108 and Figure 109).

5.1.3.3 Trends in Mean Length-at-Age

The 12 rivers in the NNE, ten from Maine and two from New Hampshire, yielded 54 potential combinations of river, sex, age, and year for Mann-Kendall trend analysis. For full time series, there were a total of five positive trends among the 54 combinations, with four of the five occurring in Maine rivers and only one of them positive trends being for females (Figure 110–Figure 112; Table 16). Conversely, 10 of the 17 combinations in the two New Hampshire rivers were negative. The New Hampshire time series were 25 years longer than the Maine series and the negative trends appeared to occur gradually over the entire time series (Figure 112). Negative trends were also confined to ages 3 - 5 of both sex; age-6 and age-7 alewife in both the Cocheco and Lamprey Rivers have maintained a neutral trend or, in the case of age-7 males in the Lamprey, shown a positive trend. In the recent period, there were three positive and three negative trends (Table 16). The positive trends were all consistent with full time series positive trends in Maine rivers. Two of the three negative trends were also consistent but one negative trend, for age-6 females in the Cocheco River, was a change from a stable full trend.

5.1.3.4 Trends in Repeat Spawner Percentages

Repeat spawning frequency data from populations in Northern New England were numerous with datasets from Maine being of shorter duration compared to some of New Hampshire's. For complete time series, Mann-Kendall trend analysis of 43 combinations of sex and river across the region resulted in 8 series with positive trends and 35 with no trends (Table 17; Figure 113-Figure 115). Of the 8 positive trends, all occurred in Maine populations and three were female while five were male. Mann-Kendall results for the recent time period found 8 positive trends and 30 series without trend (Table 17). Females comprised three of the positive trends while males comprised the other 5. Although most time series in Maine began in 2008 at the earliest, the change of start date between full time series and recent led two time series to change from positive to no trend and two time series to change from no trend to positive trend.

5.1.3.5 Index Correlations

The two NNE indices (the ME Merrymeeting Bay Juvenile Alosine Survey and NH Juvenile Finfish Seine Survey) are significantly positively correlated with a Rho > 0.5 (Figure 116).

5.1.3.6 ARIMA

NNE alewife abundance indices included two juvenile abundance indices (Figure 117) and six run counts (Figure 118). Trends in ARIMA fits generally indicated increases in abundance for both adults and juveniles with a high probability of being greater than the Q_{25} and 2009 index based reference points (Table 18). The exception was run counts on the Cocheco River, which decreased after 2016 and have been at their lowest levels for the time series in the last three years (Figure 118).

There were 11 rivers in the NNE region where run counts did not separate river herring species. Four of these run counts have continued through 2021 or 2022 while others terminated in early years. Of those with data through 2021 or 2022 (Androscoggin River, Kennebec River, Saco River, and St. Croix River), river herring abundance has increased over the last two decades with high probabilities in the terminal year of being greater than the 2009 reference point (Figure 119-Figure 120, Table 18).

5.1.3.7 Total Mortality

Mortality estimates for mature fish were only available from scale data for the NNE region. There was a decreasing trend from the early 1990s until the mid-2000s, then there was an increase until around 2015 followed by a decrease in the final years of the time series (Table 19, Figure 122). For the entire time series, average Z was 1.1/yr and ranged from 0.56/yr to 1.7/yr.

For the 29 rivers that had Z estimates since the last assessment, 21 (or 72.4%) of them had a greater than 50% probability of exceeding the $Z_{40\%SPR}$ reference point (Table 20, Figure 123).

5.1.4 Habitat Model

About 35% (2,684 km^2) of alewife habitat was in the NNE region (Table 29). The NNE region had the greatest proportional reduction of habitat due to dams out of all three stock-regions, with a loss of 90% (2,409 km^2). Predicted changes in spawner abundance due to changes in fish passage mirrored trends in habitat across regions (Figure 124). In the NNE region, we predicted 119 (80-160) million spawners under the no dam scenario, which was reduced to 12 (8-16) million fish under the no passage scenario and 17 (12-23) million spawners under current conditions (Figure 124).

5.1.5 River-Specific Results

5.1.5.1 St. Croix River

Abundance Trends

Run counts for river herring (not separated by species) were available for the St. Croix River for 1981-2022. Run counts peaked in 1987 and 1988 at 2.6 million fish but declined precipitously over the next decade, averaging less than 15,000 fish per year from 1998-2013 (Figure 24-Figure 25). In 2014, fish passage on the St. Croix was reopened, resulting in a significant increasing trend in run counts in recent years, according to the Mann-Kendall test. The run count in 2022 was 712,760 fish. There was a 100% probability that the river herring run count in 2022 was above both the 25th percentile of the time series and the 2009 value (Figure 119, Table 28).

5.1.5.2 Union River

Abundance Trends

Run counts for the Union River were available for alewife from 1982-2022. Run counts peaked in 1986 at 1.24 million alewives, then declined to 119,476 alewives by 1996 (Figure 24-Figure 25). Run counts were variable but increasing after that. The 2022 run count was 1.19 million alewives. There was an increasing trend in run counts over the time series, according to the Mann-Kendall test. There was a 98% probability that the alewife run count in 2022 was above the 25th percentile of the time series, and a 95% probability that it was above the 2009 value (Figure 118, Table 28).

5.1.5.3 Penobscot River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Penobscot River for 2015-2022. There was a marginally significant increasing trend over the time series (p=0.06), according to the Mann-Kendall test, with run counts increasing from 782,521 fish in 2015 to a time-series high of 2.85 million fish in 2022 (Figure 24-Figure 25, Table 28).

5.1.5.4 Damariscotta River

Abundance Trends

Run counts for alewife from the Damariscotta River were available from 1977-2021. Run counts declined from an initial high of 1.31 million alewives to a low of approximately 50,000 alewives in 1994 before increasing again (Figure 24-Figure 25). The run count in 2022 was 1.38 million fish. There was an increasing trend over the full time series, and over the 2009-2021 time period, according to the Mann-Kendall test. There was a 96% probability that the alewife run count in 2021 was above the 25th percentile of the time series, and a 97% probability that it was above the 2009 value (Figure 118, Table 28).

5.1.5.5 Sebasticook River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Sebasticook River for 2000-2021. There was a significant increasing trend over the full time series and over the more recent period (2009-2021), according to the Mann-Kendall test. Run counts increased from 1.41 million fish in 2000 to a peak of 6.28 million fish in 2018, although they have declined somewhat since then to 3.88 million fish (Figure 24-Figure 25). There was a 100% probability that the river herring run count in 2021 was above both the 25th percentile of the time series and the 2009 value (Figure 119, Table 28).

5.1.5.6 Kennebec River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Kennebec River for 2006-2022. There was a significant increasing trend over the time series, according to the Mann-Kendall test, with run counts increasing from 4,094 fish in 2006 to a high of 307,035 fish in 2018, although they have declined somewhat since then to 83,978 fish in 2022 (Figure 24-Figure 25). There was a 95% probability that the river herring run count in 2022 was above both the 25th percentile of the time series and the 2009 value (Figure 119, Table 28).

5.1.5.7 Androscoggin River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Androscoggin River for 1983-2022. There was a significant increasing trend over the full time series, according to the Mann-Kendall test. Run counts increased to an early peak of 100,895 fish in 1989 before declining through the early 1990s, averaging 17,870 fish from 1992-2000. From 2001 onwards, run counts have been variable but increasing, with 139,326 fish counted in 2022 (Figure 24-Figure 25). There was a 97% probability that the river herring run count in 2022 was above the 25th percentile of the time series, and a 94% probability that it was above the 2009 value (Figure 119, Table 28).

5.1.5.8 Saco River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Saco River for 1993-2021. There was a significant increasing trend over the time series, according to the Mann-Kendall test, with run counts increasing from a low of 831 fish in 1993 to a time-series high of 134,654 fish in 2021 (Figure 24-Figure 25). There was a 99% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and a 98% probability that it was above the 2009 value (Figure 119, Table 28).

5.1.5.9 Maine ME C1-N33

The majority of Maine's rivers have only one harvester providing catch information and biological samples, and so data and results from those rivers are considered confidential. The river names have been anonymized to protect that confidentiality.

Trends in Size and Age

The data from commercially harvested runs in Maine (ME C1 – ME C19) all run from 2008 to 2021 and are characterized by many samples being of unknown sex (Figure 105). The maximum age for most rivers fluctuated between 5 and 7 with a range of 4 to 9 years old. None of these rivers showed notable visual trends in maximum age over the complete time series. Fisheries independent samples collected from Maine largely corresponded in length and general trends with those from fisheries dependent surveys (Figure 106). Males and unknown sex herring in ME N8 did show a slight upward trend in maximum age over the 11-year time series

Total Mortality

Mortality estimates from scale data were available for 30 rivers. For 15 rivers there was only one or two estimates and among all these rivers mortality estimates ranged from 0.36/yr to 2.3/yr with a mean of 1.3/yr (Figure 125-Figure 127). For the ME C11, ME C20, ME N13, and ME N2 rivers there were only 3 estimates available from each river and these ranged from 1.1/yr to 2.2/yr with a mean of 1.6/yr. There was a decreasing trend in the ME C10, ME C14, ME C4, ME C6, and ME C8 rivers and across all rivers, mortality estimates ranged from 0.1/yr to 2.6/yr with a mean of 1.3/yr. In the remaining rivers there was variation over time with no strong trends and across all of these rivers, mortality estimates ranged from 0.12/yr to 2.3/yr with a mean of 1.3/yr.

The probability of being above the $Z_{40\%SPR}$ reference point ranged from 12.1% in ME N23 to 99.1% in ME N2. Overall, 18 of the 23 confidential rivers in Maine had a greater than 50% chance of exceeding the $Z_{40\%SPR}$ reference point for the NNE stock-region in the terminal year of the dataset (since 2017) (Table 19).

5.1.5.10 Merrymeeting Bay

Abundance Trends

A young-of-year index from the Maine Merrymeeting Bay Juvenile Alosine survey was available for 1982-2021 (Figure 38). Although the index was variable from year to year, there was an increasing trend in the alewife YOY index over the time series and over the 2009-2021 time period, according to the Mann-Kendall test. The alewife YOY index in 2021 had a 97% probability of being above the 25th percentile of the time series, and an 83% probability of being above the 2009 value (Figure 117, Table 28).

5.1.5.11 Cocheco River

Maximum Age and Repeat Spawner Percentages

In the Cocheco River, the maximum age increased from age 6 to ages 7 – 8 in the early 2000s and has remained in that range through 2021. (Figure 107). There was no significant trend in the percent of repeat spawners for either sex (Figure 115).

Abundance Trends

Run counts for alewife for the Cocheco River were available from 2004-2021 (Figure 118; Figure 26-Figure 27); from 1976-2003, run counts were not separated to the species level. Run counts were variable over the time series, increasing to a high of 90,335 alewives in 2016 before declining to near time-series lows of 1,366 alewives in 2021 (Figure 26-Figure 27). There was no significant trend over the time series, or from 2009-2021, according to the Mann-Kendall test. There was a 0% probability that the alewife run count in 2021 was above either the 25th percentile of the time series or the 2009 value (Table 28).

Total Mortality

Average mortality for the Cocheco River was 1.0/yr during 1996-2004 and declined to 0.32/yr in 2021 (Table 19, Figure 127).

5.1.5.12 Oyster River

Maximum Age and Mean Repeat Spawner Percentages

In the Oyster River, the maximum age of alewife increased from age 6 to ages 7 – 8 in the early 2000s and has remained in that range through 2021 (Figure 107). There was no significant trend in the percent of repeat spawners for either sex (Figure 115).

Abundance Trends

Run counts for the Oyster River were available from 2004-2021 (Figure 26-Figure 27); from 1976-2003, run counts were not separated to the species level. Combined run counts peaked from 1990-1992, averaging 155,000 fish, followed by a steady decline. From 2004-2010, blueback herring run counts exceeded alewife, but in recent years, the scale has been similar. Over the species-specific time series, there was a significant increasing trend in alewife run counts, according to the Mann-Kendall test, with counts increasing from 1,217 alewives in 2004 to 5,612 alewives in 2021, although there has been year-to-year variability in the counts, with peaks followed by drops. There was a 95% probability that the alewife run count in 2021 was above the 25th percentile of the time series, and an 89% probability that it was above the 2009 value (Table 28, Figure 118).

Total Mortality

In the Oyster River, there was a decreasing trend over time with a Z estimate of 1.6/yr in 2011 that declined to 1.1/yr in 2021 (Table 19, Figure 127).

5.1.5.13 Lamprey River

Maximum Age and Mean Repeat Spawner Percentages

In the Lamprey River, the maximum age of alewife increased from age 6 to ages 7 – 8 in the early 2000s and has remained in that range through 2021. (Figure 107). There was no significant trend in the percent of repeat spawners for either sex (Figure 115).

Abundance Trends

Run counts for the Lamprey River were available from 2004-2021 (Figure 26-Figure 27); from 1975-2003, run counts were not separated to the species level. Combined species and alewife run counts have shown a somewhat cyclical pattern with increases and decreases over the years. There was no significant trend over the alewife time series; run counts declined during the mid-2000s to 29,328 alewives in 2010, increased to a peak of 92,364 alewives in 2016 then dropped to 35,920 in 2017. The run count in 2021 was 79,478 alewives. There was a 92% probability that the alewife run count in 2021 was above the 25th percentile of the alewife time series, and a 91% probability that it was above the 2009 value (Table 28, Figure 118).

Total Mortality

In the Lamprey River the Z estimate in 1992 was 1.3/yr and decreased over time with an estimate of 0.62/yr in 2021 (Table 19, Figure 127).

5.1.5.14 Exeter River

The time series for the Exeter River was interrupted by a dam removal that made sampling and run counts more difficult. Samples were not collected between 2017 and 2020, but were available in 2021.

Maximum Age and Mean Repeat Spawner Percentages

The Exeter River appeared to have a stable range of 5 to 7 years of maximum age across the time series, although the data were interrupted by a dam removal in Exeter that made sample collection more difficult (Figure 107). There was no significant trend in the percent of repeat spawners for males or females over the time series (Figure 115).

Abundance Trends

Run counts for alewife for the Exeter River were available from 2004-2016 (Figure 26-Figure 27); from 1975-2003, run counts were not separated to the species level. Combined species run counts peaked at over 15,000 fish in 1981, which was an unusually high value as most years before and after had counts of less than 3,000 fish. There was a significant increasing trend in alewife run counts in recent years, according to the Mann-Kendall test; counts increased from less than a hundred alewives in the mid-2000s to 4,050 in 2016. There was a 100% probability that the run count in 2016 was higher than both the 25th percentile and the 2009 run count (Table 28, Figure 118).

Total Mortality

In the Exeter River, the Z estimate in 1993 was 1.0/yr, increased to 1.4/yr in 2009, and then decreased to 1.0/yr in 2021 (Table 19, Figure 127).

5.1.5.15 Hampton-Seabrook/Great Bay Estuaries

Abundance Trends

A young-of-year index from the New Hampshire Juvenile Finfish survey for the Hampton-Seabrook and Great Bay Estuaries was available for 1997-2021. There was no significant trend over the time series, according to the Mann-Kendall test. The alewife YOY index in 2021 had a 100% probability of being above the 25th percentile of the time series, and a 93% probability of being above the 2009 value (Table 28, Figure 117).

5.2 Southern New England (SNE)

The SNE stock-region for alewife includes rivers from the Parker River in Massachusetts to the Carlls River on Long Island in New York.

5.2.1 Growth Curves

The SNE stock-region had the highest *K* and t_0, and lowest L_∞ (Table 13, Figure 102), resulting in the smallest length at a given age (Figure 103). Fish from the southern New England (SNE) region displayed the least variability in estimated VBGF parameters (Appendix 3 Tables S1-S4) and were the smallest on average at a given age. Estimated L_∞ of females ranged from 288 mm (287-289 mm) in the Monument River to 320 mm (301-342 mm) in the Chicopee River based on ages assigned using otoliths (Appendix 3 Table S1). Estimated L_∞ of males ranged from 275 mm (274-276 mm) to 305 (287-326 mm) in these same rivers (Appendix 3 Table S2). Likewise, *K* was highest for females in the Monument River (0.77, 0.75-0.82) and lowest for females in the Chicopee River (0.49, 0.40-0.61) when using ages assigned from otoliths (Appendix 3 Table S1). Estimated *K* for males ranged from a high of 0.82 (0.80-0.84) in the Monument River to a low of 0.52 (0.43-0.65) in the Chicopee River (Table S2).

5.2.2 SPR Reference Points

The median $Z_{40\%SPR}$ was 0.97 with 95% confidence interval of 0.78 to 1.59 (Table 14, Figure 104).

5.2.3 SNE Summary Results

5.2.3.1 Trends in Maximum Age

In 2013, Massachusetts Division of Marine Fisheries switched ageing structures from scales to otoliths. Analyses suggest that otoliths increased the precision of age estimates but did not alter accuracy biases. Scale based maximum ages of male and female alewife are available for the Gilbert Stuart River from 1984 to 1990 and 2000 to 2018 (Figure 129). Maximum age of males fluctuated between 5 and 6 while maximum age of females was 7 to 8 prior to 1990 and predominantly 6 after 2000.

Otolith based times series for 5 rivers in Massachusetts are available for either 2012 or 2013 to 2022, depending on the river. Most rivers showed largely consistent maximum ages for both sexes fluctuating between 6 and 7 years old with a range of 5 to 8 (Figure 129). The Mystic showed a potentially different pattern, with maximum age of males fluctuating between 6 and 8 years old and female between 7 and 8. Females in Town Brook also appeared to fluctuate between 7 and 8.

5.2.3.2 Trends in Mean Length

Plots of the mean total length from fisheries-independent monitoring versus year for the Parker River, Town Brook, Monument River, and Nemasket River did not show any apparent trends in mean length for females or males while the Mystic showed a slight increase from the start of the time series in 2004 to the present (Figure 130). Trend analyses for full and recent time series also indicated that no trend was apparent for either sex in any of the rivers in the SNE region except the Mystic, where both sexes have a positive trend for mean length in the full time series but no trend in the recent period (Table 23). Like many rivers in the NNE region, Town Brook, the Monument River, and the Nemasket River had more variable mean length in recent years with low points in 2014-2015 and 2017 – 2018 (Figure 130).

5.2.3.3 Trends in Mean Length-at-Age

The populations available for analysis in Southern New England came exclusively from Massachusetts and are all 10 to 11 years old. Although scale-based ages for the Monument River exist for many samples back to 1984, the decision was made to split scale and otolith-based time series, leading to the Monument time series for scales being discarded from analyses. The 5 rivers in the SNE region produce 29 combinations for analysis and since all time-series were begun after 2010 results for full and recent time series were identical. Visual inspection of mean length at age against year suggested few apparent trends (Figure 131). In Town Brook, 3-year-old fish of both sexes showed some evidence of a declining trend and as did 5-year-old females in the Nemasket River. Of the 29, only 5-year-old females in the Nemasket River had a significant Mann-Kendall trend in mean length and it was declining (Table 24).

5.2.3.4 Trends in Repeat Spawner Percentages

In 2013, the Massachusetts Division of Marine Fisheries discontinued processing scale samples from all site-species combinations except alewife in the Monument River. Additionally, Rhode Island Department of Environmental Management only provided repeat spawning data through 2018, making the data available for the Southern New England Region more sparse than past assessments. There was a total of eight data sets available across four rivers, with the two from the Nemasket River concluding in 2013 and showing no trend (Figure 132). The Nonquit Pond time series, which ran from 2000 to 2018, showed positive trends for both sexes due to a large surge in repeat spawners at the end of the time series. The Gilbert-Stuart stream saw a similar rise but this was balanced by higher rates at the beginning of this longer time series. These are all changes from the 2017 Assessment update which indicated that Monument and Gilbert Stuart had negative trends for both sexes and Nonquit Pond had no discernable trend. Repeat spawning frequency was comparable between sexes across most rivers and years with females occasionally having greater frequency in the Rhode Island Rivers. The Monument River and Gilbert-Stuart Stream, both time series over 20 years, also showed no trend for either sex. The Monument was the only river that could be examined for the recent period and both sexes had no detectable trend.

5.2.3.5 ARIMA

SNE alewife abundance indices included a single juvenile abundance index from the Rhode Island Coastal Pond Survey specific to the Narrow River (Figure 133) and 11 run counts (Figure 134). The Rhode Island Coastal Pond Survey for juveniles has fluctuated through time without a consistent trend, but in 2020 and 2022, the fitted ARIMA estimates were below both the Q_{25} and 2009 reference points. ARIMA fits to Southern New England count time series showed mixed results with some rivers showing a general increase through time with terminal years greater than the Q_{25} and 2009 reference points (e.g., Mill Brook), while others showing general declines (e.g., Queach Brook; Table 28, Figure 134).

There were 10 rivers in the SNE region where run counts did not separate river herring species (Figure 121). All of these run counts extended until at least 2019 and their trends were quite variable with probabilities of their terminal year's value being greater than 2009 widely ranging from 0.04 to 1.00 (Table 28).

5.2.3.6 Total Mortality

Mortality estimates for mature fish were available for scale data from 1993 to 2018 and from 2012 to 2022 for otolith data. For scale data there was a slight increase from 1993 until 2005 and then a slight decreasing trend until 2018 (Figure 137). During this time period average Z was 1.6/yr and ranged from 0.69/yr to 2.1/yr. For otolith data, Z estimates varied and there was no strong trend from 2012 to 2020, which was followed by a decreasing trend until 2022. During this time period average Z was 1.5/yr and ranged from 0.98/yr to 2.1/yr.

In the SNE region, Z estimates are available for nine rivers since the previous assessment (Table 22). Seven of nine rivers (77.8%) had a probability of Z being above the median $Z_{40\%SPR}$ (Table 20, Figure 123).

5.2.4 Habitat Model

About 12% (924 km^2) of alewife habitat was located in the SNE region (Table 29). The SNE stock-region had the second greatest proportional reduction of habitat due to dams with a loss of 83% (766 km^2) in the region. Abundance was reduced from 39 (33-73) million to 7 (5-10) million spawners in the SNE region, with 8 (5-11) million fish expected under current conditions (Figure 124).

5.2.5 River-Specific Results

5.2.5.1 Parker River

Maximum Age and Repeat Spawner Percentages

Maximum ages for both sexes in the Parker River fluctuating between 6 and 7 years old with a range of 5 to 8, similar to other rivers in the region (Figure 129).

Abundance Trends

Run counts have historically been available for the Parker River, but MA DMF does not recommend using them to assess stock status, due to concerns about data quality.

Total Mortality

There were only otolith estimates available from the Parker River, which had a decreasing trend over time (Figure 139). The mortality estimate in 2013 was 2.3/yr and decreased to 0.88/yr in 2022. There was a 26.8% probability of Z in 2022 being above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 22, Figure 139).

5.2.5.2 Mystic River

Maximum Age and Repeat Spawner Percent

In the Mystic River, the maximum age of males fluctuating between 6 and 8 years old and female between 7 and 8 (Figure 129). Scales are no longer collected in the Mystic River, so there were no metrics of RSP available.

Abundance Trends

Run counts were available for river herring (not separated by species) in the Mystic River for 2012-2021. There was a significant increasing trend in the river herring run counts for the time series, according to the Mann-Kendall test, going from 198,932 fish in 2012 to 552,903 in 2021 (Figure 28-Figure 29).

Total Mortality

Only one estimate from scale data was available from the Mystic River and was 0.72/yr in 2011 (Figure 138). In the Mystic River for otolith data, there was a slight decreasing trend from 1.5/yr in 2012 to 1.04/yr in 2021. There was a 61.2% probability that the estimate of Z for 2021 was above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 22, Figure 139).

5.2.5.3 Back River

Abundance Trends

Run counts were available for river herring (not separated by species) in the Back River for 1986-2021. There was no significant trend in the river herring run counts for the time series, according to the

Mann-Kendall test. Run counts averaged approximately 292,000 fish over the time series, with a count of 231,106 fish in 2021 (Figure 28-Figure 29). There was an 85% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and an 83% probability that it was above the 2009 value (Figure 135, Table 28).

Total Mortality

Mortality estimates from otolith data were available for alewife from 2015 to 2022 in the Back River. These estimates varied over time but showed no substantial trend (Figure 139) and the average was 1.4/yr. There was a 92.4% probability that the estimate of Z in 2022 was above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 22).

5.2.5.4 Town Brook

Maximum Age and Repeat Spawner Percentages

Maximum ages for males in Town Brook fluctuating between 6 and 7 years old with a range of 5 to 8, while females appeared to fluctuate between 7 and 8.

Abundance Trends

Run counts were available for river herring (not separated by species) in Town Brook for 2011-2021. There was no significant trend in the river herring run counts for the time series, with counts averaging approximately 157,000 fish per year over the time series, and the run count in 2021 being 132,194 fish (Figure 28-Figure 29). There was a 79% probability that the river herring run count in 2021 was above the 25th percentile of the time series (Table 28, Figure 136).

Total Mortality

In Town Brook, mortality estimated from scale data was 2.4/yr in 2004, decreased to 1.2/yr in 2009 and then increased to 1.9/yr in 2012. Mortality estimates from otolith data varied and had a slightly decreasing trend over time and was 0.89/yr in 2022. There was a 27.1% probability of Z in 2022 being above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 22).

5.2.5.5 Monument River

Maximum Age and Repeat Spawner Percentage

In 2013, Massachusetts Division of Marine Fisheries switched ageing structures from scales to otoliths. Analyses suggest that otoliths increased the precision of age estimates but did not alter accuracy biases. Scale based maximum ages of male and female alewife are available for the Monument River for most years from 1993 to 2012. In the Monument, maximum ages for both sexes fluctuated between 5 and 7 throughout the time series (Figure 129). There was no significant trend in the repeat spawner percentage for males or females (Figure 132).

Abundance Trends

Run counts were available for river herring (not separated by species) in the Monument River for 1980-2021. There was no significant trend in the river herring run counts for the time series or for the 2009-2021 period. Run counts were variable with periods of increases followed by periods of declines (Figure 28-Figure 29). Run counts averaged approximately 240,000 fish per year, reaching a recent high of 526,929 fish in 2019 followed by a decline to 117,075 fish in 2021. There was a 64% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and an 70% probability that it was above the 2009 value (Table 28, Figure 135).

The statistical catch-at-age model estimated that prior to 1989, alewife total abundance (3+) was low and average about 585,000 fish. Although variable, total abundance increased to 3.7 million fish by 2000. Total abundance declined steadily to 307,000 fish by 2005. During 2006-2011, total abundance averaged only 532,000 fish. Total abundance increased through 2014 to 2.2 million fish, declined to 327,000 fish through 2016, and increased to 3 million fish in 2018. Since 2020, total abundance has averaged about 596 million fish. The abundance estimates of the Monument River alewife by sex, maturity state, year and age are given in Appendix 4 Table 1.

Recruitment, represented as age-3 abundance, followed similar patterns as total abundance (Figure 157). Age-3 numbers were low prior to 1989 (average = 412 thousand fish), increased and peaked at about 2 million fish in 1995 (1992 year-class), declined to 478 thousand fish in 1998, increased to over 2.9 million fish in 2000, and declined to 210 thousand fish by 2005 (2002 year-class). From 2006-2011, age-3 numbers varied around an average of 451 thousand fish. Age-3 numbers increased to 2.0 million fish in 2014, but it declined to 186 thousand fish in 2016. Age-3 numbers increased to 2.9 million fish by 2018 and has since declined to average 634,000 fish.

Prior to 1989, female SSB (3+) was low and averaged about 7,996 kilograms (Figure 158). Although variable, female SSB increased steadily to 38 thousand kilograms by 1996 and remained high but variable through 2001. Female SSB declined steadily from about 16 thousand kilograms in 2002 to its lowest value of about 4,524 kilograms in 2006. (Figure 158). Since 2013, female SSB fluctuated widely but has increased through 2019. In 2020-2022, SSB has averaged about 11 thousand kilograms. Estimates of female spawning stock biomass (SSB) for alewife by age are provided in Appendix 4 Table 3.

The SSB target and threshold at $F_{40\%SPR}$ and $F_{20\%SPR}$ were estimated to be 24,531 and 11,607 kilograms, respectively. Compared to the SSB threshold and target, Monument River Alewife SSB exceeded SSB20% frequently, but SSB rarely exceed the SSB40% target (Figure 158), and was below the SSB20% threshold in 2021 and 2022.

Total Mortality

In the Monument River, mortality estimates from catch curves based on scales varied but had no substantial trend during 1993 to 2008 and the average was 1.6/yr (Figure 138). Mortality estimates from catch curve estimates based on otolith data in the Monument River decreased from 2.8/yr in 2020 to 1.03/yr in 2022 (Figure 139). There was a 56.4% probability that the catch curve estimate of Z in 2022 was above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 22).

The statistical catch-at-age model estimated M multipliers were 1.67 for 1980-1999 and 2.68 for 2000-2020. The magnitude of “other” mortality in the most recent years can be calculated by multiplying the multiplier value by average natural mortality for ages 3-8+ (0.66).

The $F_{40\%SPR}$ was estimated to be 0.22 and $F_{20\%SPR}$ was 0.41. Due to the 2005 moratorium, which is still in effect, there was no harvest taken from the Monument River, so µ and F were effectively zero in recent years, with a small amount of removals in the form of fish killed for sampling purposes resulting in negligible exploitation rates.

5.2.5.6 Stony Brook

Abundance Trends

Run counts were available for river herring (not separated by species) in Stony Brook for 2007-2019. There was a marginally significant increasing trend in the river herring run counts over the time series, according to the Mann-Kendall test (p=0.059). Run counts increased to a time-series high of approximately 247,000 fish per year in 2014 and 2015 before declining to 102,527 fish in 2019 (Figure 28-Figure 29). There was a 95% probability that the river herring run count in 2019 was above both the 25th percentile of the time series and the 2009 value (Table 28, Figure 136).

5.2.5.7 Herring River (Wellfleet)

Abundance Trends

Run counts were available for river herring (not separated by species) in the Herring River for 2012-2021. There was no significant trend in the river herring run counts for the time series, according to the Mann-Kendall test. Run counts averaged approximately 25,000 fish per year over the time series, with a count of 27,895 fish in 2021 (Figure 28-Figure 29). There was a 100% probability that the river herring run count in 2021 was above the 25th percentile of the time series (Table 28, Figure 136).

5.2.5.8 Agawam River

Abundance Trends

Run counts were available for river herring (not separated by species) in the Agawam River for 2006-2021. There was no significant trend in the river herring run counts for the time series, according to the Mann-Kendall test. Run counts averaged approximately 50,000 fish over the time series, with a count of 53,381 fish in 2021, a decline from a time-series high of 102,105 fish in 2019 (Figure 28-Figure 29).There was a 97% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and a 94% probability that it was above the 2009 value (Table 28, Figure 135).

5.2.5.9 Wankinko River

Abundance Trends

Run counts were available for river herring (not separated by species) in the Wankinko River for 2007-2021. There was a significant increasing trend in the river herring run counts over the time series, according to the Mann-Kendall test, with run counts going from 2,788 fish in 2007 to highs near 25,000 fish in 2012, 2017, and 2020, although the run count in 2021 declined to 11,095 fish (Figure 28-Figure 29). There was a 100% probability that the river herring run count in 2021 was above both the 25th percentile of the time series and the 2009 value (Table 28, Figure 136).

5.2.5.10 Mattapoisett River

Abundance Trends

Run counts were available for river herring (not separated by species) in the Mattapoisett River for 1988-2021. There was a significant decreasing trend in the river herring run counts for the time series, according to the Mann-Kendall test. Run counts increased from 22,000 fish in 1988 to a time-series high of 130,000 fish in 2000, then declined to 5,300 fish per year by 2004 (Figure 28-Figure 29). Counts recovered to 55,429 fish in 2014, but have declined again since then. The run count in 2021 was 1,886 fish, a time-series low. There was a 4% probability that the river herring run count in 2021 was above the 25th percentile of the time series or above the 2009 value.

5.2.5.11 Nemasket River

Maximum Age and Repeat Spawner Percentage

Maximum ages for both sexes in the Nemasket River fluctuating between 6 and 7 years old with a range of 5 to 8, similar to other rivers in the region (Figure 129). From 2004-20013, there was no significant trend in the repeat spawner percentages for either sex (Figure 132); collection of scale samples was discontinued after 2013, so no recent estimates of RSP are available.

Abundance Trends

Run counts were available for river herring (not separated by species) in the Nemasket River for 2005-2021. There was a significant increasing trend in the river herring run counts over the time series, according to the Mann-Kendall test, with run counts going from 163,722 fish in 2005 to 534,699 fish in 2021 (Figure 28-Figure 29). There was a 95% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and an 94% probability that it was above the 2009 value (Table 28, Figure 135).

Total Mortality

In the Nemasket River, alewife mortality estimates from scale data had an increasing trend during 2004 to 2011 and went from 0.94/yr to 2.1/yr (Figure 139). Mortality estimates from otolith data also had an increasing trend and went from 2.4/yr in 2015 to 3.3/yr in 2020 (Figure 139). There was a 100% probability of Z in 2020 being above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 22).

5.2.5.12 Nonquit River

Maximum Age and Repeat Spawner Percentages

There was a significant increasing trend in the repeat spawner percentages for both male and female alewife in the Nonquit River from 2000-2018 (Figure 132).

Abundance Trends

Run counts for the Nonquit River were available from 1999-2022. There was a significant negative trend over the time series, according to the Mann-Kendall test, with run counts declining from a high of 230,853 alewives in 1999 to 23,753 alewives in 2021 (Figure 30-Figure 31). There was an 18% probability that the alewife run count in 2022 was above the 25th percentile of the time series, and a 16% probability that it was above the 2009 value (Table 28, Figure 134).

Total Mortality

For the Nonquit River, mortality varied over time with no substantial trend and was 1.9/yr in 2018 (Figure 140). There was a 98.8% probability of Z in 2018 being above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 22).

5.2.5.13 Ten Mile River

Abundance Trends

Run counts for the Ten Mile River were available from 2015-2021. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts were highly variable, ranging from a low of 3,054 alewives in 2020 to a high of 21,644 alewives in 2019; the run count in 2021 was 6,423 alewives (Figure 30-Figure 31).

5.2.5.14 Woonasquatucket River

Abundance Trends

Run counts for the Woonasquatucket River were available from 2010-2021. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts averaged approximately 16,000 alewives over the time series, with the run count in 2021 being 9,744 alewives (Figure 30-Figure 31). There was an 87% probability that the alewife run count in 2021 was above the 25th percentile of the time series (Table 28, Figure 134).

5.2.5.15 Buckeye Brook

Abundance Trends

Run counts for Buckeye Brook were available from 2003-2021. There was no significant trend over the time series, according to the Mann-Kendall test. From 2003-2019, run counts averaged approximately 30,000 alewives per year, but increased to 153,933 alewives in 2020 and 122,190 alewives in 2021 (Figure 30-Figure 31). There was a 100% probability that the alewife run count in 2021 was above the 25th percentile of the time series, and a 99% probability that it was above the 2009 value (Table 28, Figure 134).

5.2.5.16 Hunt Forge

Abundance Trends

Run counts for the Hunt Forge were available from 2010-2021. There was no significant trend over the time series, according to the Mann-Kendall test. Most years averaged around 1,600 alewives, excluding the extremely high value of 40,032 alewives in 2013. The 2021 run count was 1,123 alewives (Figure 30-Figure 31). There was a 79% probability that the alewife run count in 2021 was above the 25th percentile of the time series (Table 28, Figure 134).

5.2.5.17 Narrow River

Abundance Trends

A young-of-year index from the RI Coastal Ponds survey for the Narrow River was available for 1994-2022 (Figure 133). There was no significant trend over the time series, according to the Mann-Kendall test (Figure 44). The alewife YOY index in 2022 had a 29% probability of being above the 25th percentile of the time series, and a 6% probability of being above the 2009 value (Table 28, Figure 133).

5.2.5.18 Gilbert-Stuart River

Maximum Age and Repeat Spawner Percentages

In the Gilbert-Stuart River, the maximum age of males fluctuated between 5 and 6 while maximum age of females was 7 to 8 prior to 1990 and predominantly 6 after 2000 (Figure 129). There was no significant trend in the repeat spawner percentage for males or females over the time series (Figure 132).

Abundance Trends

Run counts for the Gilbert-Stuart River were available from 1981-2021. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts peaked from 1998-2001, averaging approximately 264,000 alewives per year, but the rest of the time series varied around a mean of approximately 61,000 alewives per year, with the 2021 run count being 32,760 alewives (Figure 30-Figure 31). There was an 81% probability that the alewife run count in 2021 was above the 25th percentile of the time series, and a 63% probability that it was above the 2009 value (Table 28, Figure 134).

Total Mortality

Z was estimated at 1.01/yr in 2017 from the Gilbert Stuart River; there was a 54.7% probability of *Z* in 2017 being above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 22, Figure 140).

5.2.5.19 Shetucket River

Abundance Trends

Run counts for Shetucket River were available from 2007-2022. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts averaged less than 1,000 alewives per year over the time-series. Run counts peaked in 2021 at 3,753 alewives then dropped to 775 alewives in 2022 (Figure 32-Figure 33). There was an 85% probability that the alewife run count in 2022 was above the 25th percentile of the time series, and a 37% probability that it was above the 2009 value (Table 28, Figure 134).

5.2.5.20 Latimer Brook

Abundance Trends

Run counts for Latimer Brook were available from 2006-2022. Run counts were variable, showing increases followed by declines, but there was a significant increasing trend over the time series, according to the Mann-Kendall test. Run counts reached a near time-series high in 2019 at 26,390 alewives and have since declined to 3,744 alewives in 2022 (Figure 32-Figure 33). There was an 82% probability that the alewife run count in 2022 was above the 25th percentile of the time series, and an 84% probability that it was above the 2009 value (Table 28, Figure 134).

5.2.5.21 Bride Lake

Abundance Trends

Run counts for Bride Lake were available from 2011-2022. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts averaged approximately 280,000 alewives per year over the time-series, with the 2021 run count being 153,237 alewives (Figure 32-Figure 33). There was a 99% probability that the alewife run count in 2021 was above the 25th percentile of the time series (Table 28, Figure 134).

5.2.5.22 Mill Brook

Abundance Trends

Run counts for Mill Brook were available from 2003-2022. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts showed a pattern of increases followed by declines, reaching a time-series high in 2020 of 37,886 alewives before declining to 3,944 in 2022 (Figure 32-Figure 33). There was a 91% probability that the alewife run count in 2022 was above the 25th percentile of the time series, and an 89% probability that it was above the 2009 value (Table 28, Figure 134).

5.2.5.23 Eightmile River

Abundance Trends

Run counts for the East River were available from 2014-2022. There was no significant trend over the time series, according to the Mann-Kendall test. In most years, less than 100 alewives were counted, although 934 were counted in 2021; the run count in 2022 was 4 alewives (Figure 32-Figure 33).

5.2.5.24 East River

Abundance Trends

Run counts for the East River were available from 2015-2022. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts reached a high of 6,292 alewives in 2015, declined for several years before ticking up to 1,349 alewives in 2022 (Figure 32-Figure 33).

5.2.5.25 Queach Brook

Abundance Trends

Run counts for Queach Brook were available from 2006-2022. There was a significant decreasing trend over the time series, according to the Mann-Kendall test, with run counts declining from a high of 4,476 alewives in 2011 to 220 alewives in 2022 (Figure 32-Figure 33). There was a 29% probability that the alewife run count in 2022 was above the 25th percentile of the time series, and a 0% probability that it was above the 2009 value (Table 28, Figure 134).

5.2.5.26 Quinnipiac River

Abundance Trends

Run counts for the Quinnipiac River were available from 2013-2022. There was a significant decreasing trend over the time series, according to the Mann-Kendall test. From 2013-2019, although variable, run counts averaged approximately 3,000 alewives per year, while the three lowest values in the time-series occurred from 2020-2022, averaging less than 500 alewives per year (Figure 32-Figure 33). The 2022 run count was 373 alewives. There was a 25% probability that the alewife run count in 2022 was above the 25th percentile of the time series (Table 28, Figure 134).

5.2.5.27 Pequonnock River

Abundance Trends

Run counts for the Pequonnock River were available from 2014-2022. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts peaked in 2018 at 40,602 alewives before declining to 944 alewives in 2022 (Figure 32-Figure 33).

5.2.5.28 Mianus River

Abundance Trends

Run counts for the Mianus River were available from 2008-2021. There was a significant decreasing trend over the time series, according to the Mann-Kendall test, with run counts going from a time-series high in 2012 of 121,401 alewives to a time-series low of 3,148 alewives in 2021 (Figure 32-Figure 33).

5.3 Mid-Atlantic (MAT)

The MAT stock-region for alewife includes rivers from the Hudson River in New York to the Roanoke and Alligator Rivers in North Carolina.

5.3.1 Growth Curves

Alewife from the MAT stock-region were intermediate in VBGF parameter estimates (Table 13, Figure 102; Appendix 3 Tables S1-S4) and predicted length at age compared to fish in other stock-regions (Figure 103). Females from the Susquehanna River had the smallest estimated L_∞ of 291 mm (95% CRI = 273-283 mm) and the largest *K* of 0.69 (0.60-0.80), whereas females from the Pasquotank River had the largest L_∞ of 330 mm (322-339 mm) but the smallest *K* of 0.34 (0.33-0.36) was estimated for females from the Hudson River when based on ages assigned from otoliths (Appendix 3 Table S1). Males followed similar trends but with smaller L_∞ and larger K than females on average. The smallest L_∞ for males was 278 mm (273-283 mm) and the largest K was 0.73 (0.64-0.86), both in the Susquehanna River, when using ages assigned from otoliths (Appendix 3 Table S2). As with females, the largest L_∞ for males was 315 mm (308-324 mm) in the Pasquotank River, but the smallest K of 0.37 (0.35-0.38) was observed in the Hudson River (Appendix 3 Table S2).

5.3.2 SPR Reference Points

The median $Z_{40\%SPR}$ was 0.97 with 95% confidence interval of 0.76 to 1.56 (Table 14, Figure 104).

5.3.3 MAT Summary Results

5.3.3.1 Trends in Maximum Age

In the mid-2010s, Maryland officially adopted the MA DMF ageing protocol (see state report). Maryland also introduced new agers in 2011 and 2014, which may have created error or bias into recent age estimates. Maximum age of male and female alewife from the Nanticoke River has decreased slightly over the past 25 years. Male alewife were predominately age 7-8 until 2000 with a range of 6-7 since. Female alewife shifted from a range of 8-9 to a range of 7-8 in the late 2000s (Figure 141). In the Alligator River, maximum ages for males and females appear to have shifted downward 1 year as well, although lack of data between 1993 and 2000 make the timing difficult to determine. Data in the Chowan and Roanoke do not suggest an overall trend, although maximum ages for both sexes in the Chowan appear to have dipped by 1 year between the mid 1980’s and the early 2000s, then risen to previous levels.

5.3.3.2 Trends in Mean Length

Mean length datasets from the MAT were the longest of any region, with all sets spanning at least 20 years. Plots of mean total length against year showed variability from river to river (Figure 142). Some time series featured long gaps in collection or sparser collections among years at the beginning or end of the series. The Chowan River, despite a more than decade long interruption in the middle of the series, appeared to have a declining trend. The Hudson River, especially the females, appeared to have a slightly upward trend. Mann Kendall analysis indicated that 5 river-sex combinations had no trend but that both sexes in the Chowan had negative trends in mean length while females in the Hudson had a positive trend in mean length (Table 23). The Chowan, Hudson and Roanoke rivers all showed trends between 2013 and 2020 that were similar to those observed in the other two genetic reporting regions.

5.3.3.3 Trends in Mean Length-at-Age

Only two rivers in the MAT stock-region had enough length at age data available over a long enough time series: the Nanticoke River in Maryland and the Chowan River in North Carolina. Both rivers did feature long duration time series, with the Nanticoke running uninterrupted since the late 1980s and the Chowan starting in 1972 with a break from the mid- 1980s until 2000. These time series also had a broader range of ages (typically ages 3 – 7) than in many other rivers, producing a total of 19 combinations of year, sex, and age between them (0). Visual inspection of mean length for each age against year suggested that most ages in both rivers had declined from the start of the time series but that mean length at age had begun to rise in the past decade (Figure 143). Declines appeared larger in the Chowan than the Nanticoke. Mann-Kendall trend analysis indicated that a significant decline had occurred during the full time series for 7-year-old females and 5-year-old males in the Nanticoke and for ages 3 – 6 females and males in the Chowan. All other full time series trends were not significant.

Unfortunately, samples sizes from both rivers have been lower in recent years and fewer recent trends were available for analysis, especially in the Nanticoke, and all of these had no significant trends (0).

5.3.3.4 Trends in Repeat Spawner Percentages

The MAT region is the largest of the three stock-regions by area and suffers from a paucity of demographic information. Repeat spawning frequency rates were analyzed for both sexes of alewife in four rivers in the MAT: the Hudson River in New York; the Nanticoke River in Maryland; and the Chowan and Alligator Rivers in North Carolina (Table 23, Figure 144). Males and females in the Hudson and Chowan Rivers showed positive trends in repeat spawner frequency, alewife of either sex in the Alligator River had no trend, and both sexes displayed negative trends in the Nanticoke. The Nanticoke, Alligator and Chowan rivers have very long time-series when considered across the entire coast, although sampling in the Alligator has been sparse since 1990. The Chowan's positive trend seems to come from increasing repeat spawning frequency since 2010, which mirrors the positive trend in the shorter Hudson River time series (2009 – 2022). Paradoxically, the negative trend in the Nanticoke seems to result from declining repeat spawning frequency in males and females since 2010 in that river. In the recent time-period, Mann-Kendall analyses produced a significant positive trend for Hudson River males and a significant negative trend for Nanticoke River females.

5.3.3.5 Index Correlations

In comparing the 24 MAT indices (Figure 145), 300 pairwise comparisons, at a significance level of 0.05 only 36 pairwise correlations were significant with 28 of those being positive and 8 being negative (Figure 146). The Spearman's Rho values either met or exceeded 0.5 on 23 of the significant associations while being less than -0.5 on 7 of the significant associations.

The low number of significant correlations may stem from habitat and population differences at the river-level within stock-regions. The lack of significant positive correlations between indices even within stock-regions makes it difficult to draw coastwide or even regional conclusions from the available indices.

5.3.3.6 ARIMA

The MAT region had the most adult and juvenile alewife indices of abundance for which ARIMA models were fit: 12 adult indices and 11 juvenile indices. Trends in ARIMA fits varied among surveys but the majority of surveys generally showed no trend in recent years (Figure 147). An exception was the NC Albemarle Independent Gillnet Survey that showed an increasing trend from 1998 – 2019 and a high probability of being greater than the 2009 reference point.

5.3.3.7 Total Mortality

Mortality estimates were available for mature fish for scale data from 1972 to 2021 and for otolith data from 2015 to 2022. For scale data there was a decreasing trend across the entire time series (Figure 137). During this time period average Z was 1.1/yr and ranged from 0.4/yr to 2.3/yr. For otolith data, Z estimates varied and there was no strong trend from 2015 to 2020, which was followed by a decreasing trend until 2022. During this time period average Z was 1.1/yr and ranged from 0.35/yr to 1.4/yr.

In the MAT region, Z estimates are available for six rivers since the previous assessment (Table 27). 0 of 6 rivers had a probability of Z being above the median $Z_{40\%SPR}$ (Table 20, Figure 123).

5.3.4 Habitat Model

About 52% (3,921 km^2) of alewife habitat was in the MAT region (Table 29). Even at the lowest proportional loss of habitat, more than half (65% or 2,540 km^2) in the MAT region was located above first dams. In the MAT region, spawner abundance decreased from 194 (130-260) million fish under the no-dam scenario to 68 (46-92) million under the no-passage scenario, with about 75 (51-102) million spawners expected under current conditions (Figure 124).

5.3.5 River-Specific Results

5.3.5.1 Hudson River

Maximum Age and Repeat Spawner Percentages

Both male and female alewife in the Hudson River showed a significant positive trend in the proportion of repeat spawners from 2009-2022 (Table 23, Figure 144).

Abundance Trends

The NY DEC 300' Haul Seine survey provided an index of adult alewife abundance from 2012-2022, and the NY DEC Juvenile Beach Seine survey provided an index of YOY alewife abundance from 1980-2022. There was no significant trend in the adult index of abundance, but there was a significant increasing trend in the YOY index of abundance over the time series, according to the Mann-Kendall test. There was a 91% probability that the adult index in 2022 was above the 25th percentile of the time series. There was a 97% probability that the YOY index in 2022 was above the 25th percentile of the time series, and a 26% probability that it was above the 2009 value (Table 28, Figure 147).

Total Mortality

Mortality estimates from scale and otolith data were available from the Hudson River. For scale data, mortality estimates decreased from 1.14/yr in 2012 to 0.53/yr in 2018 (Figure 149). There were two estimates from otolith data of 0.62/yr in 2021 and 0.50/yr in 2022 (Figure 150). There was a 0% chance that Z in 2022 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 27).

5.3.5.2 Delaware River and Bay

Abundance Trends

There were several indices of young-of-year and age-1 abundance for alewife in the Delaware Bay and Delaware River, but no indices of adult abundance. The Delaware Bay 16' Trawl index of age-1 abundance (1991-2021) and the NJ Striped Bass Seine survey YOY index (1987-2021) both showed significant declining trends over their respective time series, but the DE Bay 30' Trawl index of age-1 abundance (1990-2021) did not show a significant trend, according to the Mann-Kendall test. All three indices had a greater than 50% chance of being above both the 25th percentile and the 2009 index value (Table 28, Figure 147).

5.3.5.3 Nanticoke River

Maximum Age and Repeat Spawner Percentages

Maximum age of male and female alewife from the Nanticoke River has decreased slightly over the past 25 years (Figure 141). Male alewife were predominately 7-8 until 2000 with a range of 6-7 since. Female alewife shifted from a range of 8-9 to a range of 7-8 in the late 2000s. There was a significant negative trend in the repeat spawner percentages for both males and females over the full time series (1989-2021), and for females over the recent time period (2009-2021); males did not show a trend over the recent time series (Figure 144).

Abundance Trends

The MD commercial fyke net CPUE provided a fishery dependent index of adult alewife abundance from 1991-2021. Seine surveys in the DE and MD portions of the Nanticoke provided young-of-year indices of abundance for 1999-2021 and 1959-2021, respectively.

The index of adult abundance showed a significant decreasing trend over the time series, according to the Mann-Kendall test. There was a 36% probability that the adult index in 2021 was above the 25th percentile of the time series, and a 20% probability that it was above the 2009 value (Table 28, Figure 147).

The MD YOY index, with its longer time series, showed a significant declining trend over the time series, while the DE YOY index did not show a significant trend, according to the Mann-Kendall test. Both YOY indices had a less than 50% chance of being above the 2009 index value. The DE index also had a less than 50% probability of being above the 25th percentile of its time series, while MD index had a 68% probability of being above the 25th percentile of its time series (Table 28, Figure 147).

Total Mortality

Mortality estimates in the Nanticoke River had no substantial trend over time and varied from 0.78/yr to 1.63/yr with a mean of 1.10/yr (Figure 151). There was a 39.8% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 27).

5.3.5.4 Choptank River

Abundance Trends

The MD DNR Juvenile Estuarine Finfish survey provided an index of young-of-year alewife abundance in the Choptank River from 1959-2021. There was no significant trend in the YOY index over the time series, according to the Mann-Kendall test. There was a 73% probability that the YOY index in 2021 was above the 25th percentile of the time series, and a 71% probability that it was above the 2009 value (Table 28, Figure 147).

5.3.5.5 North East River

Abundance Trends

The MD North East River Gillnet survey provided an index of adult abundance for 2015-2021. There was no significant trend in the index over the time series, according to the Mann-Kendall test. There was a 75% probability that the adult index in 2021 was above the 25th percentile of the time series (Table 28, Figure 147).

Total Mortality

Mortality estimates in the North East River had no substantial trend over time and varied from 0.73/yr to 1.93/yr with a mean of 1.22/yr (Figure 151). There was a 42.4% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 27).

5.3.5.6 Potomac River

Abundance Trends

The MD DNR Juvenile Estuarine Finfish survey provided an index of young-of-year alewife abundance in the Potomac River from 1959-2021. There was no significant trend in the YOY index over the time series, according to the Mann-Kendall test. There was an 82% probability that the YOY index in 2021 was above the 25th percentile of the time series, and an 85% probability that it was above the 2009 value (Table 28, Figure 147).

5.3.5.7 Rappahannock River

Abundance Trends

The VA DWR Electrofishing survey provided an index of adult alewife abundance for the Rappahannock River from 2001-2022. There was no significant trend over the time series, according to the Mann-Kendall test. There was a 90% probability that the index in 2022 was above the 25th percentile of the time series, and a 40% probability that it was above the 2009 value (Table 28, Figure 147).

Total Mortality

Mortality estimates from otolith data were available from the Rappahannock River. Total mortality was 0.86/yr in 2018, increased to 1.37/yr in 2020, and then decreased to 0.92/yr in 2021 (Figure 152). There was a 35.8% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 27).

5.3.5.8 Chickahominy River

Abundance Trends

The VA DWR Electrofishing survey provided an index of adult alewife abundance for the Chickahominy River from 2011-2022. The VIMS Surface Trawl survey provided an index of young-of-year abundance from 2014-2022. There was no significant trend for either index over their respective time series, according to the Mann-Kendall test. There was an 74% probability that the adult index in 2022 was above the 25th percentile of its time series, and a 65% probability that the YOY index was above the 25th percentile of its time series (Table 28, Figure 147).

5.3.5.9 Appomattox River

Abundance Trends

The VA DWR Electrofishing survey provided an index of adult alewife abundance for the Appomattox River from 2000-2018. There was an 11% probability that the adult index in 2018 was above the 25th percentile of the time series, and a 14% probability that it was above the 2009 value.

5.3.5.10 James River

Abundance Trends

The VA DWR Electrofishing survey (2002-2022) and the VIMS River Herring Gillnet survey (2015-2021) provided indices of adult alewife abundance in the James River. Neither index showed a significant trend over the time series, according to the Mann-Kendall test. The electrofishing index showed a large jump in the last three years of the survey, and there was a greater than 90% probability that the 2022 index value was above both the 25th percentile of the time series and the 2009 value. The gillnet index had an 80% chance of being above the 25th percentile of the time series.

Total Mortality

Mortality estimates from otolith data were available from the James River. Total mortality estimates varied over time with no substantial trend and varied from 0.84/yr to 1.76/yr with a mean of 1.29/yr (Table 27, Figure 152).

5.3.5.11 Albemarle Sound

Abundance Trends

The NC DMF P135 Independent Gillnet Survey provided an index of adult alewife abundance in Albemarle Sound for 1991-2019, and the NC DMF P100 Juvenile Seine Survey provided an index of young-of-year abundance for 1972-2021. The adult index showed a significant increasing trend over its time series, while the YOY index showed no significant trend, according to the Mann-Kendall test. There was a 100% probability that the adult index in 2019 was above the 25th percentile of the time series, and a 94% probability that it was above the 2009 value. There was an 89% probability that the YOY index in 2021 was above the 25th percentile of the time series, and an 83% probability that it was above the 2009 value (Table 28, Figure 147).

5.3.5.12 Chowan River

Maximum Age and Repeat Spawner Percentages

Data in the Chowan River do not show an overall trend, although maximum ages for both sexes in the Chowan appeared to have dipped by 1 year from the mid-1980s until the early 2000s, then risen to previous levels (Figure 141). There was a significant increasing trend in the percent of repeat spawners for both sexes over the full time series, although there was no trend over the most recent time period, 2009-2021 (Figure 144).

Abundance Trends

The NC WRC Electrofishing Survey provided an index of adult alewife abundance in the Chowan River for 2006-2022. There was a significant increasing trend over the time series, according to the Mann-Kendall test. There was a 100% probability that the adult index in 2022 was above both the 25th percentile of the time series and the 2009 value (Table 28, Figure 147).

Total Mortality

Mortality estimates were available from scale data from both fishery-dependent and fishery-independent sampling programs in the Chowan River. In the Chowan River, fishery-independent estimates of mortality varied over time with no strong trends and varied from 0.90/yr to 1.75/yr with a mean of 1.33/yr (Figure 153). For fishery dependent data, mortality was relatively high during 1973 to 2009 with an average of 1.38/yr, whereas average mortality was 1.07/yr during 2010 to 2021 (Figure 154). There was a 3.1% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 27).

5.4 Coastwide Meta Population/Mixed Stock Analysis Results

5.4.1 Growth Curves

At a coast-wide level, use of otoliths for age assignment generally resulted in larger median predicted total length at age than did use of scales for age assignment in alewife. Estimated slope coefficients (β) for aging structure within the linear predictors of VBGF parameters indicated a significant effect of aging structure on L_∞ and t_0 based on exclusion of zero from the credible interval for the coefficients, with weaker evidence for difference in estimated K (Figure 163). As a result, all estimated VBGF parameters (Table 18) and predicted length at a given age (Figure 164) were larger for growth curves estimated from otolith ages than those from scales. Likewise, VBGF parameters for females differed significantly from VBGF parameters of male alewife (Figure 163), and females were larger than males at a given age (Figure 164).

Alewife growth parameters varied among regions. No unidirectional trends in growth parameters or length at age were noted coincident with latitudinal changes.

5.4.2 Index Correlations

The Atlantic Ocean indices (Figure 165) had six significant correlations, of which five were positive with two having a Rho exceeding 0.5 and one was negative with Rho not less than -0.5 (Figure 166).

5.4.3 ARIMA

Mixed stock alewife indices came from trawl surveys conducted in the ocean that were capable of catching multiple river-specific stocks. Trends in ARMIA fits were variable across these surveys (Figure 167). It is interesting to note that the NEFSC Albatross trawl survey showed a general increase in alewife abundance in both spring and fall surveys from the 1980s through its termination in 2008, but this increasing trend did not continue when the vessel changed to the NEFSC Bigelow trawl survey after 2009. When increasing trends in alewife abundance occurred in recent times, they occurred in more northerly surveys such as the NEFSC Summer Shrimp survey and the ME-NH Inshore Trawl. Other surveys showed stable or decreasing trends. Probabilities of being greater than 2009 reference points varied greatly among mixed stock surveys (0.00 – 0.94), but all had a greater than 0.50 probability of being greater than their Q_{25} reference points.

5.4.4 Habitat Model

A total of 7,529 km^2 of alewife habitat was identified at the HUC-4 watershed level (Table 29). Of this total, 1,815 km^2 was located downstream of all dams. This represents a maximum potential reduction of 5,714 km^2 in available alewife habitat due to dams, a reduction of approximately 79% from historical baselines.

Historical abundance of spawning alewife was predicted to be 352 million (235-473 million) fish under the no-dam scenario (Figure 124). Abundance under the no-passage scenario was 87 million (58-118 million) spawning fish, a reduction of about 75% that corresponded directly to reductions in habitat. Current fish passage conditions provided little increase in abundance over the no passage scenario, with about 101 (68-136) million fish expected under current conditions (Figure 124).

5.4.5 Bycatch Caps

The iSmooth approach produced the highest coastwide catch cap for alewife, compared to the iSlope methods. The catch caps developed from the mixed stock indices (NEFSC Bottom Trawl and NEAMAP) was higher than the catch caps developed from the index of SNE alewife run counts, as that index has declined at a higher rate in recent years than the mixed stock index.

The estimates of the alewife catch cap for the coast ranged from a high of 85.2mt for the iSmooth approach with the mixed stock index to a low of 34.4mt for the iSlope approach with the run count index (Table 31). Coastwide bycatch of alewife has averaged 91.7 mt over the last three years, and the total cap for all river herring and shad was 490 mt per year.

From 2014 to 2022, the average change from one year to the next in the recommended iSmooth TAC for alewife was 22% when using the indices and 47% when using the run counts (Figure 170). The year-to-year change for the iSlope methods was lower, averaging 7% for the indices and 10% for the run counts (Figure 171).

6 BLUEBACK HERRING STOCK-REGIONS RESULTS

6.1 Canada-Northern New England (CAN-NNE)

The CAN-NNE stock-region for blueback herring includes rivers from the Margaree River in Canada to the Kennebec River in Maine, although only data for US rivers were included in this assessment.

6.1.1 Growth Curves

Blueback herring growth parameters and size at age within the CAN-NNE region were intermediate between the SNE region and the SAT, MAT, and MNE stock-regions (Table 32; Figure 173 and Figure 174). Within the CAN-NNE region, the river displaying the largest L_∞ was ME-C7, with an estimated L_∞ of 317 mm (298-339 mm) for females (Appendix 3 Table S5) and 298 mm (280-319 mm) for males (Table S6) based on ages assigned with otoliths although this system was also among the highest *K* within the region. The smallest L_∞ was predicted to be 263 mm (252-277 mm) for females (Appendix 3 Table S5) and 248 mm (238-261 mm) for males (Appendix 3 Table S6) in ME-N29 based on ages assigned using otoliths. Estimated *K* was smallest in ME-N29 at 0.44 (0.37-0.53) for females and 0.49 (0.41-0.59) for males, and largest in ME-C3 with a mean of 0.60 (0.54-0.68) for females and 0.68 (0.61-0.76) for males.

6.1.2 SPR Reference Points

The median $Z_{40\%SPR}$ was 1.15 with 95% confidence interval of 0.85 to 2.01 (Table 14, Figure 104).

6.1.3 CAN-NNE Summary Results

6.1.3.1 Trends in Maximum Age

Blueback herring were collected in far fewer rivers in Maine than alewife but had similar time series length of 11 to 12 years. The maximum age for most rivers fluctuated between 4 and 6 with a range of 3 to 8 years old (Figure 175). ME C3 and CE 8 showed potential upward trends in maximum age but the relatively short time frame and inability to differentiate sexes for many samples are complicating factors.

6.1.3.2 Trends in Mean Length

No rivers in the CAN-NNE stock-region met the criteria to be included in the mean length analysis.

6.1.3.3 Trends in Mean Length-at-age

No rivers in the CAN-NNE stock-region met the criteria to be included in the mean length-at-age analysis.

6.1.3.4 Trends in Repeat Spawner Percentages

Repeat spawning frequency was available from two fisheries dependent river surveys in Maine. Maine C10 was characterized by many samples of unknown sex and Maine C17 was comprised entirely of unknown sex samples. This feature of the data made between sex comparisons more difficult or impossible. For complete time series, Mann-Kendall trend analysis of 4 combinations of sex and river across the region resulted in no significant trends (Table 35, Figure 176) despite a range of values between 0 -55% for males and 15 – 80% for females. For recent time series, Mann-Kendall trend analysis of 3 combinations of sex and river for ME C10 also resulted in no significant trends.

6.1.3.5 ARIMA

An ARIMA model was fit to only one juvenile blueback herring survey in the CAN-NNE region (ME Merrymeeting Bay Juvenile Alosine Survey; Figure 177). This survey showed a general increasing trend in abundance from the 1980s through mid-2000s, followed by a decrease to 2010, but another increase back to levels observed in the mid-2000s.

There were 5 rivers in the CAN-NNE region where run counts did not separate river herring species. Of those with data through 2021 or 2022 (Androscoggin River, Kennebec River, Saco River, and St. Croix River), river herring abundance has increased over the last two decades with high probabilities in the terminal year of being greater than the 2009 reference point (Figure 119).

6.1.3.6 Total Mortality

None of the rivers in the CAN-NNE stock-region met the sample size requirements for the *Z* estimates.

6.1.4 Habitat Model

Only about 11% (320 km^2) of blueback herring habitat in the US was in the CAN-NNE region (Table 40), but that region had the second highest proportional reduction of habitat due to dams with a proportional loss of 89% (338 km^2). In the US watersheds of the CAN-NNE region, spawner abundance was 7.6 (4.7-10.9) million fish under the no dam scenario, 1.6 (0.92-2.23) million spawners under the no passage scenario, and 1.0 (0.58-1.47) million fish under the current conditions (Figure 234).

6.1.5 River-Specific Results

6.1.5.1 St. Croix River

Abundance Trends

Run counts for river herring (not separated by species) were available for the St. Croix River for 1981-2022. Run counts peaked in 1987 and 1988 at 2.6 million fish but declined precipitously over the next decade, averaging less than 15,000 fish per year from 1998-2013 (Figure 24-Figure 25). In 2014, fish passage on the St. Croix was reopened, resulting in a significant increasing trend in run counts in recent years, according to the Mann-Kendall test. The run count in 2022 was 712,760 fish. There was a 100% probability that the river herring run count in 2022 was above both the 25th percentile of the time series and the 2009 value (Table 39, Figure 119).

6.1.5.2 Penobscot River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Penobscot River for 2015-2022. There was a marginally significant increasing trend over the time series ($p=0.06$), according to the Mann-Kendall test, with run counts increasing from 782,521 fish in 2015 to a time-series high of 2.85 million fish in 2022 (Figure 24-Figure 25).

6.1.5.3 Sebasticook River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Sebasticook River for 2000-2021. There was a significant increasing trend over the full time series and over the more recent period (2009-2021), according to the Mann-Kendall test. Run counts increased from 1.41 million fish in 2000 to a peak of 6.28 million fish in 2018, although they have declined somewhat since then to 3.88 million fish (Figure 24-Figure 25). There was a 100% probability that the river herring run count in 2021 was above both the 25th percentile of the time series and the 2009 value (Table 39, Figure 119).

6.1.5.4 Kennebec River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Kennebec River for 2006-2022. There was a significant increasing trend over the time series, according to the Mann-Kendall test, with run counts increasing from 4,094 fish in 2006 to a high of 307,035 fish in 2018, although they have declined somewhat since then to 83,978 fish in 2022 (Figure 24-Figure 25). There was a 95% probability that the river herring run count in 2022 was above both the 25th percentile of the time series and the 2009 value (Table 39, Figure 119).

6.1.5.5 Merrymeeting Bay

Abundance Trends

A young-of-year index from the Maine Merrymeeting Bay Juvenile Alosine survey was available for blueback herring for 1982-2021. There was a significant increasing trend in the YOY index over the time series and over the 2009-2021 time period, according to the Mann-Kendall test (Figure 38). The YOY index in 2021 had a 100% probability of being above the 25th percentile of the time series, and an 98% probability of being above the 2009 value (Table 39, Figure 177).

6.1.5.6 Androscoggin River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Androscoggin River for 1983-2022. There was a significant increasing trend over the full time series, according to the Mann-Kendall test. Run counts increased to an early peak of 100,895 fish in 1989 before declining through the early 1990s, averaging 17,870 fish from 1992-2000. From 2001 onwards, run counts have been variable but increasing, with 139,326 fish counted in 2022 (Figure 24-Figure 25). There was a 97% probability that the river herring run count in 2022 was above the 25th percentile of the time series, and a 94% probability that it was above the 2009 value (Table 39, Figure 119).

6.1.5.7 Saco River

Abundance Trends

Run counts for river herring (not separated by species) were available for the Saco River for 1993-2021. There was a significant increasing trend over the time series, according to the Mann-Kendall test, with run counts increasing from a low of 831 fish in 1993 to a time-series high of 134,654 fish in 2021 (Figure 24-Figure 25). There was a 99% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and a 98% probability that it was above the 2009 value (Table 39, Figure 119).

6.1.5.8 Maine ME C1-N33

The majority of Maine's rivers have only one harvester providing catch information and biological samples, and so data and results from those rivers are considered confidential. The river names have been anonymized to protect that confidentiality.

Maximum Age and Repeat Spawner Percentages

Blueback herring were collected in far fewer rivers in Maine than alewife but had similar time series length of 11 to 12 years and many samples being of unknown sex (Figure 175). The maximum age for most rivers fluctuated between 4 and 6 with a range of 3 to 8 years old. ME C3 and CE 8 showed potential upward trends in maximum age but the relatively short time frame and inability to differentiate sexes for many samples are complicating factors. There was no significant trend in repeat spawner percentages in any of the rivers sampled (Figure 176).

Total Mortality

None of the rivers in the CAN-NNE stock-region met the sample size requirements for the *Z* estimates.

6.2 Mid-New England (MNE)

The MNE stock-region for blueback herring includes rivers from the Oyster River in New Hampshire to the Parker River in Massachusetts.

6.2.1 Growth Curves

Blueback herring from rivers within the MNE stock-region were comparable to those from the SAT and MAT stock-regions with respect to size at age and VBGF parameters (Table 32, Figure 173and Figure 174). The MNE region was also the least variable with respect to estimated VBGF parameters. Blueback herring displaying the largest L_∞were from the Taylor River, with an estimated $L_\infty$of 305 mm (301-308 mm) for females (Appendix 3 Table S5) and 287 mm (284-290 mm) for males (Appendix 3 Table S6) based on ages assigned with otoliths. Estimated *K* for blueback herring was also lowest in the Taylor with a mean of 0.51 (0.48-0.54) for females and 0.79 (0.76-0.81) for males. The river displaying the smallest L_∞ and t_0, and highest *K* within the NNE region was the Parker River, where the L_∞ was predicted to be 285 mm (284-286 mm) for females (Appendix 3 Table S5) and 268 mm (267-270 mm) for males (Appendix 3 Table S6) based on ages assigned using otoliths. These mean asymptotic sizes corresponded to estimated *K* of 0.79 (0.76-0.81) for males and 0.70 (0.68-0.72) for females in the Parker River.

6.2.2 SPR Reference Points

The median $Z_{40\%SPR}$ was 1.05 with 95% confidence interval of 0.79 to 1.66 (Table 14, Figure 104).

6.2.3 MNE Summary Results

6.2.3.1 Trends in Maximum Age

In 2010, New Hampshire Fish and Game switched from random sampling to bin sampling, which may have altered biases in the data over the time series. For blueback herring in Mid-New England, no real trends were apparent, and three of the four rivers suffered from sparser data availability from 2010 to 2021. For all rivers, the maximum age over the time series has fluctuated between 4 and 7 years old, with a range of 2 to 8 (Figure 179).

6.2.3.2 Trends in Mean Length

Data from the MNE region, which is the smallest of the blueback herring stock-regions, was relatively sparse. Only three surveys were eligible for Mann-Kendall analysis. In the Oyster River, both sexes appeared to have a declining trend which was confirmed by Mann-Kendall trend analysis (Figure 181 and Table 33). In the Parker River (MA), plots of mean length against year suggested both sexes had a variable but overall stable appearance (Figure 181). Only males had enough data for Mann-Kendall analysis and there was no significant trend detected. Since 2010, the Oyster River females showed no trend, a change from the full time series negative trend and the Parker River males showed no change as there is no difference in the scope of the data sets.

6.2.3.3 Trends in Mean Length-at-Age

This region, the smallest geographically, had sufficient mean length at age data from the Oyster River in New Hampshire and the Parker River in Massachusetts. The record from the Oyster River was much longer than that of the Parker, beginning in 1992 as opposed to 2012 for the Parker. Visual inspection of trends by plotting mean length at age against year suggested that all age classes for both sexes in the Oyster had experienced declines. Only male blueback herring had enough samples in the Parker and these reflected a stable trend in mean length at age (Figure 182). Mann-Kendall trend analysis indicated that the mean length of all combinations of sex, age, and year in the Oyster were declining, except for 6-year-old males (Table 34). Male blueback herring in the Parker did not experience a significant trend of any kind. Low sample availability in the Oyster since 2010 prevented the analysis of a recent trend in that river and the Parker time series began in 2012, making all full and recent trends the same.

6.2.3.4 Trends in Repeat Spawner Percentages

Repeat spawning frequency was available from two fisheries independent river surveys in New Hampshire, however only males retained enough samples to be considered in the Winnicut River. Mann-Kendall trend analysis of 3 combinations of sex and river across the Oyster and Winnicut rivers resulted in no significant trends (Table 33, Figure 180). Because sampling of the Winnicut has been sparse since 2010, Mann-Kendall trend analysis could only be performed for the Oyster River and yielded no significant trends regardless of sex. However, 3 of the 4 lowest female repeat spawning frequencies observed in the 22-year time series occurred since 2015.

6.2.3.5 ARIMA

The MNE region had one juvenile abundance survey and four run counts fit with ARIMA models. The NH Juvenile Finfish Seine Survey showed a declining trend in blueback herring abundance from 2000 – 2013, but then an increase through the end of the time series in 2021 (Figure 183). Blueback herring run counts in the MNE region were quite variable, both within and among rivers, with some very low counts in some years (Figure 184). However, the terminal year in three out of the four run counts had a high probability (≥ 0.85) of being greater than the 2009 reference point (Table 18).

6.2.3.6 Total Mortality

Mortality estimates were available for scale data from 1992 to 2021 and for otolith data from 2013 to 2016. Mortality estimates from scale data varied during 1992 to 2021 but overall, there was a decreasing trend (Figure 185). During this time period average Z was 1.1/yr and ranged from 0.54/yr to 1.9/yr. For otolith data, there were only two Z estimates of 2/yr in 2013 and 2.2/yr in 2016.

In the MNE region, Z estimates are available for the Oyster River since the previous assessment. That river had a greater than 50% probability of Z being above the median $Z_{40\%SPR}$ (Table 38, Figure 123).

6.2.4 Habitat Model

About 3% (147 km^2) of blueback herring habitat was in the MNE region, and the greatest proportional reduction of habitat due to dams was in this region, with a loss of 66% (57 km^2) (Table 40). Predicted changes in spawner abundance due to dams were similar to proportional trends in habitat across regions (Figure 178). Predicted spawner abundance decreased from 2.8 (1.5-4.2) under the no dam scenario to 0.44 (0.25-0.68) million under the no passage scenario in the MNE region, increasing to just 0.55 (0.29-0.84) million under current conditions (Figure 234).

6.2.5 River-Specific Results

6.2.5.1 Cocheco River

Maximum Age and Repeat Spawner Percentages

For the Cocheco River, the maximum age of blueback herring over the time series has fluctuated between 4 and 7 years old, with a range of 2 to 8 (Figure 179).

Abundance Trends

Run counts for alewife for the Cocheco River were available from 2004-2021 (Figure 26-Figure 27); from 1976-2003, run counts were not separated to the species level. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts averaged approximately 2,600 blueback herring over the time-series, with a high of 13,256 blueback herring in 2008 and several years of zero counts from 2010-2012; the run count in 2021 was 751 blueback herring. There was a 91% probability that the blueback herring run count in 2021 was above the 25th percentile of the time series and an 85% probability of being above the 2009 value (Table 39, Figure 184).

6.2.5.2 Oyster River

Maximum Age and Repeat Spawner Percentages

For blueback herring in the Oyster River, the maximum age over the time series has fluctuated between 4 and 7 years old, with a range of 2 to 8 (Figure 179). There was no significant trend in repeat spawner percentages for either sex over the time series (Figure 180).

Abundance Trends

Run counts for the Oyster River were available from 2004-2021 (Figure 26-Figure 27); from 1976-2003, run counts were not separated to the species level. Combined run counts peaked from 1990-1992, averaging 155,000 fish, followed by a steady decline. From 2004-2010, blueback herring run counts exceeded alewife, but in recent years, the scale has been similar. Over the species-specific time series, there was a significant decreasing trend in blueback herring run counts over the time series, according to the Mann-Kendall test. Blueback herring run counts declined from 51,717 blueback herring to a time-series low of 527 in 2016. Counts have increased somewhat since then, with the 2021 run count being 4,364 blueback herring. There was a 92% probability that the blueback herring run count in 2021 was above the 25th percentile of the species-specific time series time series, and a 16% probability that it was above the 2009 value (Table 39, Figure 184).

Total Mortality

In the Oyster River, average mortality was 1.39/yr during 1992-2014 and was slightly lower at 1.16/yr during 2016-2021 (Figure 186). There was an 79.4% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MNE stock-region (Table 37).

6.2.5.3 Lamprey River

Maximum Age and Repeat Spawner Percentages

For blueback herring in the Lamprey River, the maximum age over the time series has fluctuated between 4 and 7 years old, with a range of 2 to 8 (Figure 179).

Abundance Trends

Run counts for the Lamprey River were available from 2004-2021 (Figure 26-Figure 27); from 1972-2003, run counts were not separated to the species level. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts were highly variable for blueback herring, with

12 of the 18 years having a run count of zero, and the remaining six year averaging 2,046 blueback herring per year; the run count in 2021 was 1,089 blueback herring. There was a 100% probability that the blueback herring run count in 2021 was above the 25th percentile of the time series, and a 99% probability that it was above the 2009 value (Table 39, Figure 184).

6.2.5.4 Exeter River

The time series for the Exeter River was interrupted by a dam removal that made sampling and run counts more difficult. Samples were not collected between 2017 and 2020, but were available in 2021.

Maximum Age and Repeat Spawner Percentages

For blueback herring in the Exeter River, the maximum age over the time series has fluctuated between 4 and 7 years old, with a range of 2 to 8 (Figure 179).

Abundance Trends

Run counts for the Exeter River were available from 2004-2016 (Figure 26-Figure 27); from 1976-2003, run counts were not separated to the species level. There was no significant trend in blueback herring run counts over the time series, according to the Mann-Kendall test. A total of 59 blueback herring were counted from 2004-2013, but counts jumped in 2015 and 2016 to 2,193 and 2,572 blueback herring, respectively. There was a 100% probability that the run count in 2016 was higher than both the 25th percentile and the 2009 run count (Table 39, Figure 184).

6.2.5.5 Winnicut River

Maximum Age and Repeat Spawner Percentages

For blueback herring in the Winnicut River, the maximum age over the time series has fluctuated between 4 and 7 years old, with a range of 2 to 8 (Figure 179). There was no significant trend in repeat spawner percentages over the time series.

6.2.5.6 Hampton-Seabrook/Great Bay Estuaries

Abundance Trends

A young-of-year index from the New Hampshire Juvenile Finfish survey for the Hampton-Seabrook and Great Bay Estuaries was available for 1997-2021. There was a significant decreasing trend over the time series, according to the Mann-Kendall test. The blueback herring YOY index in 2021 had a 97% probability of being above the 25th percentile of the time series, and a 96% probability of being above the 2009 value (Table 39, Figure 183).

6.3 Southern New England (SNE)

The SNE stock-region for blueback herring includes rivers from the Mystic River in Massachusetts to the Gilbert-Stuart Pond in Rhode Island.

6.3.1 Growth Curves

Blueback herring from the SNE stock-region were the smallest on average among all regions (Table 32; Figure 173 and Figure 174), as was the case for alewife. Estimated L_∞ of females ranged from 270 mm (269-271 mm) in the Monument River to 289 mm (275-305 mm) in Town Brook based on ages assigned using otoliths (Appendix 3 Table S5). Estimated L_∞ of males ranged from 254 mm (253-255 mm) in the Monument River to 272 (259-287 mm) in Town Brook (Appendix 3 Table S6). Estimated *K* was highest for females in the Mystic River (0.73, 0.71-0.75) and lowest for females in Town Brook (0.50, 0.40-0.62) when using ages assigned from otoliths (Appendix 3 Table S5). Estimated *K* for males ranged from a high of 0.82 (0.80-0.84) in the Mystic River to a low of 0.56 (0.45-0.70) in Town Brook (Appendix 3 Table S6).

6.3.2 SPR Reference Points

The median $Z_{40\%SPR}$ was 1.04 with 95% confidence interval of 0.80 to 1.63 (Table 14, Figure 104).

6.3.3 SNE Summary Results

6.3.3.1 Trends in Maximum Age

In 2013, Massachusetts Division of Marine Fisheries switched ageing structures from scales to otoliths. Analyses suggest that otoliths increased the precision of age estimates but did not alter accuracy biases. Nonetheless, time-series were split by structure and Monument scale-based ages, which ended in 2012, were excluded from this analysis. Otolith based maximum ages for the Mystic fluctuated between 4 and 8 years old while the Monument ranged from 5 to 7 years (Figure 189). No rivers displayed an apparent trend over the shorter time period (10 -11 years) surveyed.

6.3.3.2 Trends in Mean Length

Like the MNE region, the SNE region only had two rivers with eligible data, the Mystic and the Monument, both in Massachusetts. The lack of data from Rhode Island and Connecticut is notable and makes any assessment of region-wide trends difficult. However, both sexes were analyzed in the two rivers. The trends for both sexes in each river appeared visually stable and Mann-Kendall trends detected no trend in all combinations except for males in the Mystic River, which had a positive trend. (Figure 190 and Table 33). All river and sex combinations, including males in the Mystic, showed no trend in the recent time period.

6.3.3.3 Trends in Mean Length-at-Age

In the SNE region, blueback herring mean length at age data was available for the Mystic and Monument Rivers, both of which are in Massachusetts. Although scale-based ages for the Monument River exist for many samples back to the late-1990s, the decision was made to split scale and otolith-based time series, leading to the Monument time series for scales being discarded from analyses. Visual inspection of plots of mean length at age against year suggested that trends for all combinations of river, sex, and age were without trend, although all combinations have been decreasing since 2019 (Figure 191). Mann-Kendall trend analysis confirmed these interpretations as no significant trends were returned for any combination in either river (Table 34). As all time-series began after 2012, the recent and full trends were identical.

6.3.3.4 Trends in Repeat Spawner Percentages

Repeat spawning frequency was only available from the Monument River in Massachusetts and only through 2013 as otoliths were used for aging bluebacks in the Monument River after that year. Mann-Kendall trend analysis of both sexes in the Monument resulted in no significant trends and repeat spawning frequency remained below 30% for the entire time-series (Table 33, Figure 192).

6.3.3.5 ARIMA

There were no SNE surveys or run counts for blueback herring available for analysis by ARIMA models. There were 8 mixed species run counts in this region (Figure 121). All of these run counts extended until at least 2019 and their trends were quite variable with probabilities of their terminal year's value being greater than 2009 widely ranging from 0.04 to 1.00 (Table 39).

6.3.3.6 Total Mortality

Mortality estimates for the SNE stock-region were available for scale data from 1985 to 2008 and for otolith data from 2012 to 2020. Mortality estimates from scale data varied during 1985 to 2008 but overall, there was an increasing trend (Figure 185). During this time period average Z was 1.4/yr and ranged from 0.84/yr to 2.4/yr.

For otolith data, Z estimates varied and there was a slightly increasing trend from 2012 to 2020. During this time period, average Z was 1.7/yr and ranged from 0.92/yr to 2.3/yr.

In the SNE region, Z estimates are available for two rivers since the previous assessment. 2 of 2 rivers had a greater than 50% probability of Z being above the median $Z_{40\%SPR}$ (Table 38, Figure 123).

6.3.4 Habitat Model

About 1% (47 km^2) of blueback herring habitat was in the SNE region (Table 40). Predicted changes in spawner abundance due to dams were similar to proportional trends in habitat across regions (Figure 178). In the SNE region, spawner abundance was reduced from 0.44 (0.18-0.75) to 0.24 (0.09-0.40) million fish, with 0.25 (0.09-0.45) million fish under current conditions (Figure 234).

6.3.5 River-Specific Results

6.3.5.1 Parker River

Maximum Age and Repeat Spawner Percentages

Otolith based maximum ages for blueback herring in the Parker River fluctuated between 4 and 8 years (Figure 180). Scales are no longer collected in the Parker River, so there were no metrics of RSP available.

Abundance Trends

Run counts have historically been available for river herring in the Parker River, but MA DMF does not recommend using them to assess stock status, due to concerns about data quality.

6.3.5.2 Mystic River

Maximum Age and Repeat Spawner Percent

Otolith based maximum ages for the Mystic River fluctuated between 4 and 8 years (Figure 189). Scales are no longer collected in the Mystic River, so there were no metrics of repeat spawning percentages available.

Abundance Trends

Run counts were available for river herring (not separated by species) in the Mystic River for 2012-2021. There was a significant increasing trend in the river herring run counts for the time series, according to the Mann-Kendall test, going from 198,932 fish in 2012 to 552,903 in 2021 (Figure 28-Figure 29).

Total Mortality

The only mortality estimate from otolith data from the Mystic River was 1.94/yr in 2020; there was a 98.3% probability that Z in 2020 was above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 37, Figure 185).

6.3.5.3 Back River

Abundance Trends

Run counts were available for river herring (not separated by species) in the Back River for 1986-2021. There was no significant trend in the river herring run counts for the time series, according to the Mann-Kendall test. Run counts averaged approximately 292,000 fish over the time series, with a count of 231,106 fish in 2021 (Figure 28-Figure 29). There was an 85% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and an 83% probability that it was above the 2009 value (Table 39, Figure 121).

6.3.5.4 Town Brook

Abundance Trends

Run counts were available for river herring (not separated by species) in Town Brook for 2011-2021. There was no significant trend in the river herring run counts for the time series, with counts averaging approximately 157,000 fish per year over the time series, and the run count in 2021 being 132,194 fish (Figure 28-Figure 29). There was a 79% probability that the river herring run count in 2021 was above the 25th percentile of the time series (Table 39, Figure 121).

6.3.5.5 Monument River

Maximum Age and Repeat Spawner Percentages

Scale based maximum ages of male and female blueback herring in the Monument River declined from ages 7 – 8 in the mid-1980s to ages 5 – 6 during the early 1990s and have remained relatively stable since that time (Figure 189). Otolith based maximum ages for the Monument ranged from 5 to 7 years. There was no trend for either sex in the percent of repeat spawners over the time series (Figure 192).

Abundance Trends

Run counts were available for river herring (not separated by species) in the Monument River for 1980-2021. There was no significant trend in the river herring run counts for the time series or for the 2009-2021 period. Run counts were variable with periods of increases followed by periods of declines (Figure 28-Figure 29). Run counts averaged approximately 240,000 fish per year, reaching a recent high of 526,929 fish in 2019 followed by a decline to 117,075 fish in 2021. There was a 64% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and an 70% probability that it was above the 2009 value (Table 39, Figure 121).

Total Mortality

In the Monument River, the only two estimates for blueback herring mortality available were 1.60/yr in 2017 and 1.44/yr in 2020 (Figure 193). There was a 93.3% probability that Z in 2020 was above the $Z_{40\%SPR}$ reference point for the SNE stock-region (Table 37).

6.3.5.6 Stony Brook

Abundance Trends

Run counts were available for river herring (not separated by species) in Stony Brook for 2007-2019. There was a marginally significant increasing trend in the river herring run counts over the time series, according to the Mann-Kendall test (p=0.059). Run counts increased to a time-series high of approximately 247,000 fish per year in 2014 and 2015 before declining to 102,527 fish in 2019 (Figure 28-Figure 29). There was a 95% probability that the river herring run count in 2019 was above both the 25th percentile of the time series and the 2009 value (Table 39, Figure 121).

6.3.5.7 Herring River (Wellfleet)

Abundance Trends

Run counts were available for river herring (not separated by species) in the Herring River for 2012-2021. There was no significant trend in the river herring run counts for the time series, according to the Mann-Kendall test. Run counts averaged approximately 25,000 fish per year over the time series, with a count of 27,895 fish in 2021 (Figure 28-Figure 29). There was a 100% probability that the river herring run count in 2021 was above the 25th percentile of the time series (Table 39, Figure 121).

6.3.5.8 Agawam River

Abundance Trends

Run counts were available for river herring (not separated by species) in the Agawam River for 2006-2021. There was no significant trend in the river herring run counts for the time series, according to the Mann-Kendall test. Run counts averaged approximately 50,000 fish over the time series, with a count of 53,381 fish in 2021, a decline from a time-series high of 102,105 fish in 2019 (Figure 28-Figure 29).There was a 97% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and a 94% probability that it was above the 2009 value (Table 39, Figure 121).

6.3.5.9 Wankinko River

Abundance Trends

Run counts were available for river herring (not separated by species) in the Wankinko River for 2007-2021. There was a significant increasing trend in the river herring run counts over the time series, according to the Mann-Kendall test, with run counts going from 2,788 fish in 2007 to highs near 25,000 fish in 2012, 2017, and 2020, although the run count in 2021 declined to 11,095 fish (Figure 28-Figure 29). There was a 100% probability that the river herring run count in 2021 was above both the 25th percentile of the time series and the 2009 value (Table 39, Figure 121).

6.3.5.10 Mattapoisett River

Abundance Trends

Run counts were available for river herring (not separated by species) in the Mattapoisett River for 1988-2021. There was a significant decreasing trend in the river herring run counts for the time series, according to the Mann-Kendall test. Run counts increased from 22,000 fish in 1988 to a time-series high of 130,000 fish in 2000, then declined to 5,300 fish per year by 2004 (Figure 28-Figure 29). Counts recovered to 55,429 fish in 2014, but have declined again since then. The run count in 2021 was 1,886 fish, a time-series low. There was a 4% probability that the river herring run count in 2021 was above the 25th percentile of the time series or above the 2009 value (Table 39, Figure 121).

6.3.5.11 Nemasket River

Maximum Age and Repeat Spawner Percentage

Maximum ages for both sexes in the Nemasket River were typically 6 - 7 years old with a total range of 5 to 8, similar to other rivers in the region (Figure 189). From 2004-2013, there was no significant trend in the repeat spawner percentages for either sex; collection of scale samples was discontinued after 2013, so no recent estimates of RSP are available (Figure 192).

Abundance Trends

Run counts were available for river herring (not separated by species) in the Nemasket River for 2005-2021. There was a significant increasing trend in the river herring run counts over the time series, according to the Mann-Kendall test, with run counts going from 163,722 fish in 2005 to 534,699 fish in

2021 (Figure 28-Figure 29). There was a 95% probability that the river herring run count in 2021 was above the 25th percentile of the time series, and an 94% probability that it was above the 2009 value (Table 39, Figure 121).

6.4 Mid-Atlantic (MAT)

The MAT stock-region for blueback herring includes rivers from the Connecticut River in Connecticut to the Neuse River in North Carolina.

6.4.1 Growth Curves

Blueback herring from the MAT stock-region were the largest on average among all regions (Figure 174), and VBGF parameters were also the most variable among rivers (Appendix 3 Table S5 and Table S6). Females from the Connecticut River had the smallest estimated L_∞ of 283 mm (281-285 mm) and largest *K* of0.85 (0.81-0.89), whereas females from the Neuse River had the largest $L_\infty$of 337 mm (332-342 mm) and the smallest *K* of 0.35 (0.33-0.37) when based on ages assigned from otoliths (Appendix 3 Table S5). The smallest L_∞ for males was 266 mm (264-268 mm) and the largest *K* was 0.95 (0.91-1.00), both in the Connecticut River, when using ages assigned from otoliths (Appendix 3 Table S6). As with females, the largest L_∞ for males was 318 mm (313-322 mm) in the Neuse River, which also had the smallest estimated *K* of 0.39 (0.37-0.42; Appendix 3 Table S6).

6.4.2 SPR Reference Points

The median $Z_{40\%SPR}$ was 1.02 with 95% confidence interval of 0.80 to 1.63 (Table 14, Figure 104).

6.4.3 MAT Summary Results

6.4.3.1 Trends in Maximum Age

In the mid-2010s, Maryland officially adopted the MA DMF ageing protocol (see state report). Maryland also introduced new agers in 2011 and 2014, which may have created error or bias into recent age estimates. Maximum age of male and female blueback herring from the Nanticoke River declined from ages >9 during the early 1990s to ages 5 – 6 and 6 – 7, respectively, during 2005 – 2021 (Figure 195). The maximum age observed for male and female alewife in North Carolina rivers ranged from ages 5 to 9 (Figure 195). Maximum age of male and female blueback herring from the Chowan River was generally $\geq$age 7 prior to 1984 but it declined thereafter to ages 6 – 7 through 2021. Incomplete time series for the Alligator and Roanoke made determinations difficult but downwards trends may have occurred between 1970 and the present in these systems.

6.4.3.2 Trends in Mean Length

The Mid-Atlantic region had data for 5 rivers and 10 combinations of river and sex. Visual examinations of mean length against year suggested that the four rivers with longer timer series (> 20 years) had declines in mean length over the course of decades. The Hudson River had a shorter time series (10 – 12 years depending on sex) and showed a potential increasing trend (Figure 196). Mann-Kendall analysis returned significant declines in mean length for males and females in the Nanticoke and Chowan Rivers, no trend for both sexes in the Roanoke and Neuse rivers as well as females in the Hudson River, and a positive trend for males in the Hudson (Table 33). Recent trends were available for a more limited pool of surveys and all were increasing over the time period, although the Hudson male timeframe was the same for both analyses as data was only available for 2010 - 2022. The positive recent trend in the Chowan was a reversal of the overall negative trend for the full time series and a change from no trend in the Neuse (Table 33).

6.4.3.3 Trends in Mean Length-at-Age

As with alewife, the Nanticoke and Chowan rivers contributed long term data series with broad age structure. Examination of plots of mean length at age by year suggested that some lengths in the Nanticoke may have declined slightly over the full time series but most had likely increased over the recent period. In the Chowan, which has a longer time series, declines appeared steady from 1972 until the late-1990s, after which the trend appeared stable. (Figure 197). Mann-Kendall trend results largely corroborated the visual evidence. For the Nanticoke River, full time series analysis was without trend except for 6-year-old females, which had experienced a decline in mean length. No combinations of age and sex had enough recent data points to analyze for a trend (Table 36). In the Chowan, all combinations of age and sex had significant declining trends in mean length, except for 7-year-old females, which had no significant trend. While the recent positive trend in the Chowan was less evident than the Nanticoke visually, 3-year-old males had a positive trend for mean length. Other combinations with enough available data had no significant trend (Table 36).

6.4.3.4 Trends in Repeat Spawner Percentages

Repeat spawning frequency rates were available from three rivers, the Hudson, Nanticoke and Chowan, yielding five sex dependent surveys for analysis. Hudson River male blueback herring had a statistically significant Mann-Kendall trend over the complete time series. Chowan River herring of either sex had no significant Mann-Kendall trends while both sexes had significantly negative trends over the complete Nanticoke time-series (Table 33, Figure 198). In the Nanticoke, female repeat spawning frequency dropped from being consistently above 50% to consistently below 50% around 2000 and male frequency made a similar decline after 2005. Both have appeared stable since. This visual observation was confirmed by Mann-Kendall trend analysis, which produced no significant trends for females in the Nanticoke (males were not collected in enough years to be included) or blueback herring of either sex in the Chowan. Hudson River blueback herring males, like alewives, produced a significantly positive trend.

6.4.3.5 Index Correlations

In comparing the 29 MAT indices (Figure 199), 406 pairwise comparisons, at a significance level of 0.05 only 43 pairwise correlations were significant with 33 of those being positive and 10 being negative (Figure 200). The Spearman’s Rho values either met or exceeded 0.5 on 23 of the significant associations while being less than -0.5 on 6 of the significant associations.

The low number of significant correlations may stem from habitat and population differences between locations in the regions. The lack of significant positive correlations between indices even within stock-regions makes it difficult to draw coastwide or even regional conclusions from the available indices.

6.4.3.6 ARIMA

The MAT region for blueback herring had many time series of data for blueback herring for which ARIMA models were fit: 14 adult surveys, 2 run counts, and 12 juvenile surveys. Overall, fisheries independent surveys for blueback herring in the MAT region showed declining or stable trends in recent years (Figure 201) with some above and some below the 2009 reference point in their terminal year. The run count with the longest time series (Connecticut River – Holyoke Dam) showed very low abundance compared to historic levels, but it has increased to above the 2009 reference point (Figure 202).

6.4.3.7 Total Mortality

Mortality estimates were available for the MAT stock-region for scale data from 1972 to 2021 and for otolith data from 2005 to 2022. Mortality estimates from scale data showed no strong trends over time Mortality estimates from scale data showed no strong trends over time (Figure 203). Average Z for scale data was 1.2/yr and ranged from 0.58/yr to 2/yr. For otolith data, Z estimates varied and there was an overall decreasing trend during 2005 to 2022. During this time period average Z was 0.92/yr and ranged from 0.33/yr to 1.4/yr.

In the MAT region, Z estimates are available for 10 rivers since the previous assessment. 3 of 10 rivers had a greater than 50% probability of Z being above the median $Z_{40\%SPR}$ (Table 38, Figure 123).

6.4.4 Habitat Model

About 43% (1,469 km^2) of blueback herring habitat was in the MAT region (Table 40). Habitat above first dams accounted for 28% (414 km^2) of habitat loss in the MAT region, one of the lowest proportional habitat losses (Table 40). Predicted changes in spawner abundance due to dams were similar to proportional trends in habitat across regions (Figure 178). Abundance was reduced from 27 (16-39) million spawners under the no dam scenario to 19 (11-29) million spawners under the no passage scenario in the MAT region with an expected 20 (12-29) million spawners under current conditions (Figure 234).

6.4.5 River-Specific Results

6.4.5.1 Eightmile River

Abundance Trends

Run counts for blueback herring in the Eightmile River were available from 2014-2022. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts were highly variable, ranging from a time-series high of 11,690 blueback herring in 2015 to a time-series low of two blueback herring in 2018; the run count in 2022 was 87 blueback herring (Figure 32-Figure 33).

6.4.5.2 Connecticut River

Abundance Trends

Run counts for blueback herring were available from the Holyoke Dam fish lift for 1976-2022 (Figure 32-Figure 33). An index of adult blueback herring abundance was available from the USFWS Connecticut River Electrofishing survey for 2013-2022. An index of young-of-year abundance was available from the Connecticut River Beach Seine survey for 1979-2021.

The run counts and the YOY index both showed a significant declining trend over the time series, according to the Mann-Kendall test. The adult survey index with its shorter time series had no significant trend.

Run counts increased from the start of the time-series to a peak of 632,255 blueback herring in 1985 before declining to less than 100 blueback herring per year from 2006-2010. Run counts have increased somewhat since then, reaching 5,052 blueback herring in 2019 before dropping to 283 blueback herring in 2022 (Table 39, Figure 202). The blueback herring run count in 2022 had a 75% probability of being above the 25th percentile of the time series, and a 100% probability of being above the 2009 value. The YOY index in 2021 had a 67% probability of being above the 25th percentile of the time series, and an 86% probability of being above the 2009 value. The adult survey index had an 87% probability of being above the 25th percentile of the time series (Table 39, Figure 201).

Total Mortality

Mortality estimates from otolith data were available from the Chicopee River, Farmington River, and Wethersfield Cove tributaries of the Connecticut River (Figure 204). In the Chicopee River, mortality estimates varied and there was no strong trend over time with estimates varying from 0.55/yr to 1.66/yr with a mean of 1.03/yr. In the Farmington River there was a slightly decreasing trend over time with a mean mortality of 1.14/yr during 2013 to 2016 and a slightly lower mean of 0.73/yr from 2017 to 2021. In Wethersfield Cove there was a slightly decreasing trend over time with a mean mortality of 1.20/yr during 2013 to 2016 and a slightly lower mean of 0.87/yr from 2017 to 2021. In all three sampling locations, the probability of Z in 2022 being greater than the $Z_{40\%SPR}$ reference point for the MAT stock-region was less than 50% (Table 37).

6.4.5.3 Quinnipiac River

Abundance Trends

Run counts for blueback herring in the Quinnipiac River were available from 2013-2022. There was a marginally significant decreasing trend over the time series, according to the Mann-Kendall test (p=0.06). Run counts averaged 373 blueback herring from 2013 to 2017, and 74 blueback herring per year from 2018-2022 (Figure 32-Figure 33). The run count in 2022 was 124 blueback herring. There was a 75% probability that the alewife run count in 2022 was above the 25th percentile of the time series (Table 39, Figure 202).

6.4.5.4 Mianus River

Abundance Trends

Run counts for blueback herring in the Mianus River were available from 2008-2021. There was no significant trend over the time series, according to the Mann-Kendall test. Run counts were quite variable, ranging from a time-series high of 28,122 blueback herring in 2013 to a time-series low of 1,235 blueback herring in 2021 (Figure 32-Figure 33).

6.4.5.5 Hudson River

Abundance Trends

The NY DEC 300’ Haul Seine survey provided an index of adult blueback herring abundance from 2012-2022, and the NY DEC Juvenile Beach Seine survey provided an index of YOY blueback herring abundance from 1980-2022. There was no significant trend in either index of abundance over the time series, according to the Mann-Kendall test. There was an 85% probability that the adult index in 2022 was above the 25th percentile of the time series. There was an 80% probability that the YOY index in 2022 was above the 25th percentile of the time series, and a 64% probability that it was above the 2009 value (Table 39, Figure 201).

Total Mortality

Mortality estimates from scales and otoliths were available from the Hudson River. There was a decreasing trend in mortality estimates from scale data. Mortality in 2012 was 2.0/yr and declined to 0.65/yr in 2018 (Figure 205). There was only estimate of 0.65/yr in 2022 for otolith data from the Hudson River (Figure 205). There was a 0.7% chance that Z in 2022 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 37).

6.4.5.6 Delaware River and Bay

Abundance Trends

There were two indices of young-of-year and age-1 abundance for blueback herring in the Delaware Bay and Delaware River, but no indices of adult abundance. The NJ Striped Bass Seine survey YOY index (1987-2021) showed a significant declining trend over its time series, but the DE Bay 30’ Trawl index of age-1 abundance (1990-2021) did not show a significant trend, according to the Mann-Kendall test. Both indices had a greater than 50% chance of being above the 25th percentile of their respective time series. The NJ index had a 39% probability of being above its 2009 index value, and the DE index had a 69% probability of being above its 2009 index value (Table 39, Figure 201).

6.4.5.7 Nanticoke River

Maximum Age and Repeat Spawner Percentages

Maximum age of male and female blueback herring from the Nanticoke River declined from ages >9 during the early 1990s to ages 5 – 6 and 6 – 7, respectively, during 2005 – 2021 (Figure 195). There was a significant negative trend in the repeat spawner percentages for both males and females over the full time series (1989-2021), but no significant trend over the recent time period (2009-2021) (Figure 198).

Abundance Trends

The MD commercial fyke net CPUE provided a fishery dependent index of adult blueback herring abundance from 1991-2021. Seine surveys in the DE and MD portions of the Nanticoke provided young-of-year indices of abundance for 1999-2021 and 1959-2021, respectively.

The index of adult abundance showed a significant decreasing trend over the time series, according to the Mann-Kendall test. There was a 26% probability that the adult index in 2021 was above the 25th percentile of the time series, and a 21% probability that it was above the 2009 value (Table 39, Figure 201).

The MD YOY index, with its longer time series, showed a significant declining trend over the time series, while the DE YOY index did not show a significant trend, according to the Mann-Kendall test. Both YOY indices had a greater than 50% chance of being above the 2009 index value. The DE index had a90% probability of being above the 25th percentile of its time series, while MD index had a 46% probability of being above the 25th percentile of its time series (Table 39, Figure 201).

Total Mortality

In the Nanticoke River, mean mortality estimated from scales for 1989 to 1995 was 0.72/yr and increased to 1.39/yr in 2006 to 2014 and then decreased to 1.21/yr in 2019 (Figure 206). There was a 78.9% probability that Z in 2019 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 37).

6.4.5.8 Choptank River

Abundance Trends

The MD DNR Juvenile Estuarine Finfish survey provided an index of young-of-year blueback herring abundance in the Choptank River from 1959-2021. There was a significant increasing trend in the YOY index over the time series, according to the Mann-Kendall test. There was a 99% probability that the YOY index in 2021 was above the 25th percentile of the time series, and an 81% probability that it was above the 2009 value (Table 39, Figure 201).

6.4.5.9 North East River

Abundance Trends

The MD North East River Gillnet survey provided an index of adult blueback herring abundance for 2015-2021. There was no significant trend in the index over the time series, according to the Mann-Kendall test. There was a 67% probability that the adult index in 2021 was above the 25th percentile of the time series (Table 39, Figure 201).

Total Mortality

In the North East River, there was a decreasing trend and mortality in 2014 was 2.17/yr and declined to 0.90/yr in 2021 (Figure 206). There was a 24.5% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 37).

6.4.5.10 Potomac River

Abundance Trends

The MD DNR Juvenile Estuarine Finfish survey provided an index of young-of-year blueback herring abundance in the Potomac River from 1959-2021. There was no significant trend in the YOY index over the time series, according to the Mann-Kendall test. There was an 84% probability that the YOY index in 2021 was above the 25th percentile of the time series, and an 87% probability that it was above the 2009 value (Table 39, Figure 201).

6.4.5.11 Rappahannock River

Abundance Trends

The VA DWR Electrofishing survey provided an index of adult blueback herring abundance for the Rappahannock River from 2001-2022. There was a significant increasing trend over the time series, according to the Mann-Kendall test. There was a 90% probability that the index in 2022 was above the 25th percentile of the time series, and a 74% probability that it was above the 2009 value (Table 39, Figure 201).

Total Mortality

Mortality estimates from otolith data were available from the Rappahannock River. There was no strong trend over time and mean mortality was 0.82/yr during 2018 to 2021 (Figure 207). There was an 16.1% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 37).

6.4.5.12 Chickahominy River

Abundance Trends

The VA DWR Electrofishing survey provided an index of adult blueback herring abundance for the Chickahominy River from 2011-2022. The VIMS Surface Trawl survey provided an index of young-of-year abundance from 2014-2022. There was no significant trend for either index over their respective time series, according to the Mann-Kendall test. There was a 76% probability that the adult index in 2022 was above the 25th percentile of its time series, and a 2% probability that the YOY index was above the 25th percentile of its time series (Table 39, Figure 201).

6.4.5.13 Appomattox River

Abundance Trends

The VA DWR Electrofishing survey provided an index of adult blueback herring abundance for the Appomattox River from 2000-2018. There was no significant trend over the time series, according to the Mann-Kendall test. There was a 58% probability that the adult index in 2018 was above the 25th percentile of the time series, and a 53% probability that it was above the 2009 value (Table 39, Figure 201).

6.4.5.14 James River

Abundance Trends

The VA DWR Electrofishing survey (2002-2022) and the VIMS River Herring Gillnet survey (2015-2021) provided indices of adult blueback herring abundance in the James River. The VIMS Striped Bass Seine survey provided an index of young-of-year blueback herring for 1967-2022. The VA DWR adult electrofishing index showed an increasing trend over the time series, and in the recent time period (2009-2022), according to the Mann-Kendall test. Neither the adult gillnet or the YOY index showed a significant trend over their time series.

The 2022 index value of the adult electrofishing survey had a 100% probability of being above both the 25th percentile of the time series and the 2009 value. The adult gillnet index had an 99% chance of being above the 25th percentile of the time series. There was an 87% probability that the YOY index in 2022 was above the 25th percentile of the time series, and an 86% probability that it was above the 2009 value (Table 39, Figure 201).

Total Mortality

Mortality estimates from otolith data were available for blueback herring from the James River. There was a decreasing trend over time, and mortality was 1.55/yr in 2015 and declined to 1.03/yr in 2021 (Figure 207). There was a 47.4% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 37).

6.4.5.15 Albemarle Sound

Abundance Trends

The NC DMF P135 Independent Gillnet Survey provided an index of adult blueback herring abundance in Albemarle Sound for 1991-2019, and the NC DMF P100 Juvenile Seine Survey provided an index of young-of-year abundance for 1972-2021. The adult index showed no trend over the full time series, but a significant increasing trend in the recent period (2009-2019), according to the Mann-Kendall test, while the YOY index showed a significant decreasing trend over its full time series. There was a 100% probability that the adult index in 2019 was above both the 25th percentile of the time series and the 2009 value. There was an 89% probability that the YOY index in 2021 was above the 25th percentile of the time series, and an 87% probability that it was above the 2009 value (Table 39, Figure 201).

6.4.5.16 Chowan River

Maximum Age and Repeat Spawner Percentages

Maximum age of male and female blueback herring from the Chowan River was generally $\geq$ age 7 prior to 1984 but it declined thereafter to ages 6 – 7 through 2021 (Figure 195). There was no significant trend in the percent of repeat spawners for either sex over the full time series (Figure 198).

Abundance Trends

The NC WRC Electrofishing Survey provided an index of adult blueback herring abundance in the Chowan River for 2006-2022. There was a marginally significant increasing trend over the time series, according to the Mann-Kendall test (p=0.053). There was a 100% probability that the adult index in 2022 was above both the 25th percentile of the time series and the 2009 value (Table 39, Figure 201).

The SCA model for the Chowan River estimated that blueback herring total abundance (age 3+) declined steadily from 173 million fish in 1976 to 75 million fish in 1980 (Figure 229). Total abundance increased through 1983 to 112 million fish but then declined precipitously to 5.6 million fish in 1995, reaching the lowest value of the time series (2.99 million fish) in 2010. Total abundance has been increasing slowly since 2011. The total population estimate for 2021 was 13.7 million fish. The abundance estimates of the Chowan River blueback herring stock by sex, maturity phase, year, and age are given in Appendix 4 Table 16.8.

Female SSB fluctuated but declined steadily from the peak of 6,600mt in 1972 to a low of 170mt in 1986 (Figure 229), reaching its lowest level of 93mt in 2012. The model estimated that female SSB, while still low, has been increasing since 2013 (Figure 229).

Based on the 2021 female spawning stock biomass estimates, the Chowan River blueback herring population is overfished (2021 SSB=720,142 versus SSB_{MSY}=1.86 million kilograms). Female SSB has been increasing since 2011, but still remains at approximately 38% of the target of 1.88 million kilograms.

Total Mortality

Mortality estimates were developed from catch curves from scale data from both fishery-dependent and fishery-independent sampling programs in the Chowan River. Estimates of mortality in the Chowan River fishery-independent data increased from 1.16/yr in 1983 to 1.95/yr in 2009 (Figure 208). For the fishery-dependent data, there was some variation over time but no strong trend and the mean mortality from 1972 to 2021 was 1.38/yr (Figure 209). There was an 84.9% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 37).

The SCA model estimated that exploitation rates for blueback herring in the Chowan River before the 2007 moratorium ranged as low as 0.098 in 1979 to as high as 0.84 in 1986 (Figure 229). Exploitation averaged about 0.22 prior to 1985, increased to an average of 0.67 during 1985–1988, and averaged 0.33 between 1989 and 2000. Since the moratorium (2015), exploitation rates have been close to zero. Fishing mortality averaged about 0.26 prior to 1985, increased to an average of 1.18 during 1985–1988, and averaged 0.45 between 1989 and 2000. Since the moratorium, fishing mortality has been close to zero.

Based on the 2021 fishing mortality estimates, over-fishing is not occurring (F=0.000 versus F_{MSY}=0.40) (Figure 229).

6.4.5.17 Neuse River

Abundance Trends

The NC WRC Electrofishing Survey provided an index of adult blueback herring abundance in the Neuse River for 2006-2022. There was a significant increasing trend over the time series, according to the Mann-Kendall test. There was a 100% probability that the adult index in 2022 was above both the 25th percentile of the time series and the 2009 value (Table 39, Figure 201).

Total Mortality

Total mortality estimates from the Neuse River were limited, with the most recent estimate from 2018 (Figure 208). There was a 50.2% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the MAT stock-region (Table 37).

6.5 South Atlantic (SAT)

The SAT stock-region for blueback herring includes rivers from the Cape Fear River in North Carolina to the St. Johns River in Florida.

6.5.1 Growth Curves

Blueback herring from the SAT stock-region reached the second largest mean maximum sizes (L_∞) and predicted length at age compared to fish in the remaining stock-regions (Table 32; Figure 173 and Figure 174). Females from the Great Pee Dee River had the smallest estimated L_∞ of 286 mm (95% CRI = 284-288 mm) and largest *K* of 0.75 (0.68-0.84). Females from the Cape Fear River had the largest L_∞ of 314 mm (309-319 mm) and the smallest *K* of 0.56 (0.54-0.57) was estimated for females from the Santee and Cooper rivers when based on ages assigned from otoliths (Appendix 3 Table S5). Males followed similar trends but with smaller L_∞ and larger *K* than females on average. The smallest L_∞ for males was 269 mm (268-271 mm) and the largest *K* was 0.85 (0.77-0.95), both in the Great Pee Dee River, when using ages assigned from otoliths (Appendix 3 Table S6). As with females, the largest L_∞ for males was 295 mm (291-300 mm) in the Cape Fear River, but the smallest *K* of 0.63 (0.61-0.65) was observed in the Santee and Cooper rivers (Appendix 3 Table S6).

6.5.2 SAT Summary Results

6.5.2.1 Trends in Maximum Age

In the Santee-Cooper system, a 10-year time series showed largely stable maximum ages of 7 for female blueback herring and 6 for males with no apparent trend (Figure 212).

6.5.2.2 Trends in Mean Length

Two rivers had data available for the South Atlantic region and contributed 3 combinations of sex and river for mean length analysis. All time-series were between 16 and 10 years. Plots of mean length against year suggested a slight increasing trend in mean length for males in the Cape Fear River as well males and females in the Santee-Cooper complex, although mean length for both sexes in the Santee-Cooper dropped in 2020 – 2021 (Figure 213). Mann-Kendall analysis indicated increasing trends for males in the Cape Fear River. The time series for the Santee-Cooper was 10 years for females and 11 years for males, so full and recent data sets were identical and both yielded increasing Mann-Kendall trends for mean length (Table 33).

6.5.2.3 Trends in Mean Length-at-Age

The Santee-Cooper, in South Carolina, was the only river in the South Atlantic region with data available. The time series is recent, beginning in 2011. For female blueback herring, sufficient data existed only for 5-year-old fish while data was available for 5 and 6-year-old males. Visual examination showed trends that increased for most of the time series but the most recent mean lengths were on par with the initial measures (Figure 214). Mann-Kendall trend analysis indicated a positive trend in length for male 5-year-olds but no significant trends for the remaining two combinations of sex and age (Table 36).

6.5.2.4 Trends in Repeat Spawner Percentages

Repeat spawner data for blueback herring in the Southern Atlantic Region was available from the Santee-Cooper system only. Samples available from 2011 through 2021 for both sexes. Repeat spawner rates were variable between 1980 and 1983, ranging from 14.1% to 84.3% for males and from 15.4% to 90.5% for females. Mann-Kendall analysis produced a significant positive trend for both sexes (Table 33, Figure 215).

6.5.2.5 Index Correlations
Of the six correlations of the SAT indices (Figure 216), two were significant at a significance level of 0.05, one positive and >0.5 and one negative <-0.5 (Figure 217).

6.5.2.6 ARIMA
The SAT region for blueback herring had two adult surveys, one run count, and one juvenile survey for which ARMIA models were fit. The adult surveys showed a stable over the past decade while the YOY survey showed an increasing trend since 2009 (Figure 218). The run count from the Santee-Cooper River system showed a slow decline since 2000 with the terminal year being less than both the Q_{25} and 2009 reference point (Figure 219).

6.5.2.7 Total Mortality
Mortality estimates were available for the SAT stock-region for scale data from 2012 to 2020; for otolith data, only one estimate was available from 2021. Besides the relatively high Z estimate in 2012, for the scale data there was an overall increasing trend from 2013 to 2020 (Figure 203). Average Z for scale data was 1.6/yr and ranged from 1.2/yr to 2.5/yr. For otolith data, there was only one Z estimate in 2021 of 1.9/yr.

In the SAT region, Z estimates are available for one river since the previous assessment. 1 of 1 river had a greater than 50% probability of Z being above the median $Z_{40\%SPR}$ (Table 380, Figure 123).

6.5.3 Habitat Model
About 41% (1,406 km^2) of blueback herring habitat was in the SAT region (Table 40). At the lowest proportional loss of habitat, more than half of habitat loss due to dams was in the SAT and MAT regions, where habitat above first dams accounted for 25% (358 km^2) loss in the SAT region (Table 40). Predicted changes in spawner abundance due to dams were similar to proportional trends in habitat across regions (Figure 178). In the SAT region, spawner abundance decreased from 25 (14-37) million fish under the no-dam scenario to 19 (11-28) million under the no-passage scenario, and 20 (11-30) million under the current condition scenario (Figure 234).

6.5.4 River-Specific Results
6.5.4.1 Cape Fear River
Abundance Trends

The NC WRC Electrofishing Survey provided an index of adult blueback herring abundance in the Town Creek and Rice's Creek tributaries of the Cape Fear River for 2006-2022. There was no significant trend over the time series, according to the Mann-Kendall test. There was an 88% probability that the adult index in 2022 was above both the 25th percentile of the time series and the 2009 value (Table 39, Figure 218).

6.5.4.2 Santee-Cooper River
Maximum Age and Repeat Spawner Percentages

In the Santee-Cooper system, a 10-year time series showed largely stable maximum ages of 7 for female blueback herring and 6 for males with no apparent trend (Figure 212). There was a significant increasing trend in the percent of repeat spawners for both sexed over the full time series (Figure 215).

Abundance Trends

Run counts for the Santee-Cooper River were available from 1986-2021. There was a significant decreasing trend in blueback herring run counts over the full time series and in the more recent period (2009-2021), according to the Mann-Kendall test. Run counts increased from 187,000 blueback herring in 1986 to a high of 1.86 million blueback herring in 2001 before declining to 17,377 blueback herring in 2021. There was a 16% probability that the blueback herring run count in 2021 was above the 25th percentile of the time series, and a 3% probability that it was above the 2009 value (Table 39, Figure 219).

Total Mortality

For the Santee-Cooper River there was no strong trend over time, and mortality estimates from scale data ranged from 1.1/yr to 1.89/yr with a mean of 1.48/yr (Figure 221-Figure 222). For otolith data there was only estimate of 1.8/yr in 2021. There was a 96.9% probability that Z in 2021 was above the $Z_{40\%SPR}$ reference point for the SAT stock-region (Table 37).

6.5.4.3 St. Johns River

Abundance Trends

The FL FWC Pushnet Survey provided an index for young-of-year index blueback herring in the St. Johns River from 2006-2021. There was a significant increasing trend over the time series, according to the Mann-Kendall test. The YOY index in 2021 had a 100% probability of being above the 25th percentile of the time series, and a 93% probability of being above the 2009 value (Table 39, Figure 218).

6.6 Coastwide Metapopulation/Mixed Stock Analysis Results

6.6.1 Growth Curves

Blueback herring exhibited variability in estimated length at VBGF parameters due to aging structure used and sex of fish. The Brody growth coefficient (K) and t_0 were significantly larger and L_∞ significantly smaller for fish aged with scales compared to those aged with otoliths (Table 42; Figure 230). In general, use of otoliths resulted in slightly larger median predicted sizes at age than did use of scales, and females tended to be larger at a given age than males (Figure 231). Blueback herring growth parameters varied among regions, with no obvious latitudinal clines in parameters from north to south.

6.6.2 SPR Reference Points

The median $Z_{40\%SPR}$ was 0.99 with 95% confidence interval of 0.74 to 1.57 (Table 14, Figure 104).

6.6.3 Index Correlations

The Atlantic Ocean indices had two significant correlations, both positive, one having a Rho exceeding 0.5.

6.6.4 ARIMA

Mixed stock blueback herring indices came from trawl surveys conducted in the ocean that were capable of catching multiple river-specific stocks. Trends in ARMIA fits were variable across these surveys with most not showing any clear trends over the last two decades (Figure 233). Of the few surveys that showed an increasing trend in recent times, the ME-NH Inshore Trawl survey showed an increasing trend in blueback herring abundance since 2009 for the spring survey, but the fall survey showed no trend. Probabilities of the terminal year of a mixed stock blueback herring survey being greater than the 2009 reference point varied from 0.00 to 0.96 (Table 18).

6.6.5 Habitat Model

A total of 3,389 km^2 of blueback herring habitat was identified at the HUC-4 watershed level (Table 40). Of this total, 2,199 km^2 was located downstream of all dams. This represents a maximum potential reduction of 1,190 km^2 in available blueback herring habitat due to dams, a reduction of approximately 35% from historical baselines.

Mean historical abundance of blueback herring was predicted to be 63 million (37-92 million) spawning fish under the no-dam scenario (Figure 178). Abundance under the no-passage scenario was 41 million (24-62 million) spawning fish, a reduction of about 35% that corresponded directly to reductions in habitat.

6.6.6 Bycatch Caps

The iSmooth approach produced the highest coastwide catch cap for blueback herring, compared to the iSlope methods. The catch caps developed from the mixed stock indices (NEFSC Bottom Trawl and NEAMAP) was higher than the catch caps developed from the index of MAT blueback herring run counts, as that index has declined at a higher rate in recent years than the mixed stock index.

The blueback herring catch cap for the coast ranged from a high of 41.4mt for the iSmooth approach with the mixed stock index to a low of 20.9mt for the iSlope approach with the run count index (Table 31). Coastwide bycatch of blueback herring has averaged 42.5 mt over the last three years, and the total cap for all river herring and shad was 490 mt per year.

From 2014 to 2022, the average change from one year to the next in the recommended TACs was higher for blueback herring than for alewife. The year-to-year change for the iSmooth TAC for blueback herring was 31% when using the indices and 65% when using the run counts (Figure 170). The year-to-year change for the iSlope methods was lower, averaging 20% for the indices and 32% for the run counts (Figure 171).

7 CONCLUSIONS

There was no clear trend signal for either species across the coast. Even within the genetic stock-regions, individual rivers often differed in recent and long-term trends for both abundance and mortality. Overall, the northern most stock regions (NNE for alewife, CAN-NNE for blueback herring) had more rivers with significant positive trends than the other stock-regions (Figure 236 - Figure 239). However, the NNE region for alewife also had the highest proportion of rivers where Z was above the Z threshold in recent years (Figure 240).

A potential explanation for this is that within the northeast region, significant work has been done to restore habitat access in the form of fishway improvements, dam removals, and other habitat restoration. The SAS compared recent (2017-2021) estimates of Z for Maine rivers that had some form of restoration to those without, and for rivers with active commercial fisheries to those with moratoria or no history of fishing (Figure 241 and Figure 242). Median estimates of Z were lower in rivers with some form of restoration and in rivers without commercial fishing, but overall, there was no statistically significant difference, reflecting the high degree of variability in Z estimates across rivers.

In addition, states in the SNE and MAT stock-regions have also conducted extensive habitat restoration efforts (Section 1.4), but trends in these rivers remain flat or negative, unlike in the NNE stock-region. This suggests that even though current productivity of these stocks is limited compared to an unaltered habitat, other factors are also influencing current population trends. Reid et al. (2022) found that bycatch was an important source of mortality for alewife and blueback herring from the SNE and MAT stock-regions. Bycatch caps have been implemented in the Atlantic mackerel and Atlantic herring fishery since 2014, but are based on historical bycatch levels rather than biological metrics and have rarely been exceeded.

The assessment of these species continues to suffer from a lack of data. Information on abundance and/or total mortality were available from 75 rivers or river systems, as well as the Atlantic Ocean, for one or both species, across all stock-regions. However, in the majority of cases, the time series were short compared to the history of the fishery, starting well after the collapse of the coastwide stocks. Most systems had only one type of data available: a run count, or an index of adult abundance, or an index of juvenile abundance, or an estimate of Z from age data. In addition, even where datasets existed to describe trends in abundance, they were often uncertain. Run counts were influenced by passage efficiency, which could vary over time as passage was improved or degraded with a lack of maintenance, or from year-to-year due to environmental conditions. Although the SAS strove to document these changes and account for them where possible, in many cases, the information on changes in passage efficiency or count efficiency was not available. Other than the spawning run counts, few of the fishery-independent surveys were designed to monitor river herring, and as a result, many had a low proportion positive and high CVs, resulting in low power to detect trends. The data to support traditional stock assessment models (catch-at-age by species and an index of adult abundance) was lacking for all but three systems, and there are no time-series of bycatch that can be attributed back to specific rivers, meaning that a potentially important source of mortality cannot be adequately included in those models.

However, this assessment still represents an improvement in our understanding of river herring dynamics on the coast. The number of rivers with some data on river herring abundance or mortality has increased, and a number of new fishery independent surveys were incorporated into the assessment. The methods to estimate Z were refined and brought in line with the best practices recommendations in the literature. The best understanding of genetic structure for each species was used to develop more comprehensive estimates of growth, maturity, and natural mortality at a biologically meaningful scale. The methods to estimate total mortality reference points were updated to better incorporate uncertainty in both the reference points and the final stock status.

Most significantly, a habitat model was developed to incorporate these improved estimates of life history parameters with information on habitat preferences and habitat availability for each species to understand the impact of historical habitat loss on the productivity of alewife and blueback herring along the coast. In addition to understanding the current relative productivity of each stock-region and major rivers, continued development of this model could provide a useful tool for understanding the relative impacts of habitat loss, directed fisheries, bycatch, and climate change on each species, and the most effective ways to rebuild these populations.

8 RESEARCH RECOMMENDATIONS AND TIMING OF NEXT ASSESSMENT

8.1 Progress on Recommendations from the 2012 Benchmark Assessment

8.1.1 Short Term Recommendations

Recommendation: Improved reporting of harvest by waterbody and gear.

> **Status:** No progress; there have been no changes to coastwide reporting requirements since the last benchmark assessment.

Recommendation: Improve methods to develop biological benchmarks used in assessment modeling (fecundity-at-age, mean weight-at-age for both sexes, partial recruitment vector/maturity schedules) for river herring stocks.

> **Status:** Developed hierarchical growth curves and length-weight relationships at the stock-region level; used the Maki method to estimate maturity schedules at the stock-region level; developed a stochastic approach to better incorporate uncertainty into the reference points

Recommendation: Continue to assess current aging techniques for river herring, using known-age fish, scales, otoliths and spawning marks.

> **Status:** Conducted a coastwide-ageing workshop and several exchanges for river herring to evaluate precision across structures (scales vs. otoliths) and readers (ASMFC 2014).

Recommendation: Encourage studies to quantify and improve fish passage efficiency and support the implementation of standard practices.

> **Status:** Some progress has been made to develop standards and guidance (e.g., through the USFWS National Fish Passage Program) but more work is needed to refine best practices and implement them

Recommendation: Continue genetic analyses to determine population stock structure along the coast and enable determination of river origin of incidental catch in non-targeted ocean fisheries.

> **Status:** Significant progress has been made on this topic since the last benchmark, most recently with the stock-region definitions of Reid et al. (2018). More work needs to be done to improve the determination of river-of-origin (as opposed to stock-region or reporting group).

Recommendation: Develop models to predict the potential impacts of climate change on river herring distribution and stock persistence.

> **Status:** In progress. The habitat model developed for this assessment has the potential to incorporate the potential effects of climate change at the river-level as those effects are quantified.

Recommendation: Develop and implement monitoring protocols and analyses to determine river herring population responses and targets for rivers undergoing restoration (dam removals, fishways, supplemental stocking, etc.).

Status: Significant progress on the analysis front has been made with the development of the habitat model in this assessment. Additional work needs to be done on the monitoring front.

Recommendation: Investigate additional sources of historic catch data of the U.S. small pelagic fisheries to better represent or construct earlier harvest of river herring.

Status: No progress since the last benchmark.

8.1.2 Long Term Recommendations

Recommendation: Conduct biannual aging workshops to maintain consistency and accuracy in aging fish sampled in state programs.

Status: River herring were added to the ASMFC QA/QC multi-species exchange process for several years, but the QA/QC WG recommended that they be removed due to the lack of a consistent ageing protocol across states. If more consistent methods can be developed and implemented, a river herring-specific exchange or workshop could be considered.

Recommendation: Explore use of peer-reviewed stock assessment models for use in additional river systems in the future as more data become available.

Status: No additional river systems had sufficient data to support traditional stock-assessment models, but the habitat model represents a significant improvement in the quantitative analysis of these species.

Recommendation: Expand observer and port sampling coverage to quantify additional sources of mortality for alosine species, including bait fisheries, as well as rates of incidental catch in other fisheries.

Status: Sampling intensity did increase after the last benchmark, but has since been reduced.

Recommendation: Determine and quantify which stocks are impacted by mixed stock fisheries (including bycatch fisheries). Methods to be considered could include otolith microchemistry, oxytetracycline otolith marking, genetic analysis, and/or tagging.

Status: Significant progress has been made in methods to identify the stock-regions and reporting groups that are impacted by mixed stock-fisheries (e.g., Reid et al. 2022); additional work is needed to monitor this stock composition over time.

Recommendation: Validate the different values of M for river herring stocks and improve methods for calculating M.

Status: No progress has been made in validating M, but the development of stock-region-specific growth curves and length-weight relationships has allowed the use of age-varying estimates of M for this assessment.

Recommendation: Summarize existing information on predation by striped bass and other species and quantify consumption through modeling (e.g., MSVPA), diet, and bioenergetics studies.

Status: Some progress has been made with additional studies on striped bass diets in Canada; the ASMFC Ecological Reference Point WG considered the inclusion of river herring in the 2025 benchmark assessment, but the fine spatial scale of river herring population dynamics and the limited data on abundance made it difficult to model.

Recommendation: Investigate the relation between juvenile river herring production and subsequent year class strength, with emphasis on the validity of juvenile abundance indices, rates and sources of immature mortality, migratory behavior of juveniles, and life history requirements.

Status: Progress has been made in understanding river herring recruitment and juvenile migratory behavior (e.g., Marjadi et al. 2018, Devine et al. 2021, Stevens et al. 2021) but more work needs to be done.

Recommendation: Evaluate and ultimately validate large-scale hydroacoustic methods to quantify river herring escapement (spawning run numbers) in major river systems.

Status: This method has been successfully deployed in several rivers in Maryland (see Section 3.1.8) and shows promise in developing run counts in rivers without traditional fish passage.

Recommendation: Develop comprehensive angler use and harvest survey techniques for use by Atlantic states with open or future fisheries to assess recreational harvest of river herring.

Status: No progress since the last benchmark.

Recommendation: Development of better fish culture techniques and supplemental stocking strategies for river herring.

Status: No progress since the last benchmark.

Recommendation: Evaluate the performance of hatchery fish in river herring restoration.

Status: No progress since the last benchmark.

Recommendation: Investigate contribution of landlocked versus anadromous produced fish.

Status: Some progress has been made, including Littrell et al. (2018), which indicated hybridization between landlocked and anadromous fish may increase in the future as habitat restoration brings these populations into contact again.

8.2 2024 Research Recommendations

8.2.1 High Priority Recommendations

Short Term Recommendations

- Develop consistent ageing protocols across all states
- Develop a database of existing data sources with documentation of time series length, current and past methodology, data quality, and recommended usage
- Continue development of species-distributions models like Turner et al. (2016, 2017) and Roberts et al. (2023) to identify potential time-area closures as an alternative to bycatch caps to mitigate river herring bycatch in ocean fisheries.

- Expand observer and port sampling coverage to quantify additional sources of mortality for alosine species, including bait fisheries, as well as rates of incidental catch in other fisheries
- Encourage studies to quantify and improve fish passage efficiency and support the implementation of standard practices
- Continue genetic analyses to monitor river origin of incidental catch in non-targeted ocean fisheries
- Continue develop models to predict the potential impacts of climate change on river herring distribution and stock persistence and develop targets for rivers undergoing restoration (dam removals, fishways, supplemental stocking, etc.)
- Evaluate and ultimately validate large-scale hydroacoustic methods to quantify river herring escapement (spawning run numbers) in major river systems

Long Term Recommendations

- Conduct exchanges or workshops to monitor the precision of ageing across states

- Conduct workshops on river herring spawning run count technologies and data quality.

8.2.2 Medium Priority Recommendations

Short Term Recommendations

- Investigate additional sources of historic catch data of the U.S. small pelagic fisheries to better represent or construct earlier harvest of river herring

Long Term Recommendations

- Incorporate river herring into ecosystem models like the model currently used for menhaden to better understand and manage river herring’s role in the ecosystem
- Improve methods for calculating or estimating M
- Develop comprehensive angler use and harvest survey techniques for use by Atlantic states with open or future fisheries to assess recreational harvest of river herring

8.3 Timing of Next Assessments

The SAS recommends that an assessment update be conducted in five years and a benchmark assessment in ten years. Due to the high variability of fisheries independent surveys, an assessment update at a shorter timeframe will likely not show any significant changes in indices of abundance. New datasets which would warrant a benchmark would require a time-series of at least seven years. If significant improvements to the habitat or other models are achieved before ten years, the benchmark could be accelerated.

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10 TABLES

Table 1. Current and historical river herring/shad catch caps for the Atlantic herring and Atlantic mackerel fisheries.

Species	Management Area	RH/S Catch Cap 2014-2015 (mt)	RH/S Catch Cap 2016-2024 (mt)
Atlantic herring	GOM Midwater Trawl	85.5	76.7
	CC Midwater Trawl	13.3	32.4
	SNE/MA Midwater Trawl	123.7	129.6
	SNE/MA Bottom Trawl	88.9	122.3
Atlantic mackerel	All areas/gears	2014: 236 2015: 89	2016 - 2019: 82 2020 - 2022: 129
		2015 Total: 400.4	**2022 Total: 490**

Table 2. US historical landings of river herring (mt and millions of fish), 1887-1949.

US Commercial Landings (US Fish Commission)		
Year	Metric tons	Millions of fish
1887	20,179.5	105.5
1888	49,966.6	249.5
1889	14,073.6	75.3
1890	23,626.6	122.3
1891	27,012.6	141.9
1892	3,875.7	21.3
1893	--	--
1894	--	--
1895	--	--
1896	28,152.9	146.8
1897	32,935.5	171.2
1898	4,365.4	23.7
1899	--	--
1900	--	--
1901	15,639.4	77.9
1902	9,089.4	49.9
1903	--	--
1904	14,386.6	72.2
1905	4,091.6	23.6
1906	--	--
1907	--	--
1908	6,899.9	37.6
1909	23,386.7	116.6
1910	--	--
1911	--	--
1912	--	--
1913	41.8	0.2
1914	--	--
1915	13,508.4	67.1
1916	9.9	0.1
1917	22.7	0.1
1918	6,605.2	34.9
1919	1,389.8	8.2
1920	10,813.9	52.9
1921	525.1	2.6
1922	33.3	0.2
1923	3,456.9	18.4
1924	1,851.4	10.7
1925	11,658.8	57.1
1926	1,131.9	6.2
1927	6,486.5	34.4
1928	5,858.6	31.9
1929	16,007.5	82.1
1930	18,476.1	93.6
1931	19,140.9	97.5
1932	14,360.4	72.9
1933	13,578.0	67.2
1934	11,969.5	61.9
1935	9,146.0	46.1
1936	11,079.4	56.4
1937	13,618.1	68.5
1938	17,747.6	89.8
1939	10,745.6	53.3
1940	9,613.3	48.1
1941	5,522.0	26.2
1942	4,713.9	22.8
1943	814.4	4.5
1944	9,191.8	44.7
1945	10,774.1	53.5
1946	6,082.0	29.4
1947	10,392.9	49.4
1948	9,193.7	43.8
1949	10,940.1	52.4

Table 3. Total removals of river herring in weight (mt) along the US Atlantic coast by data source, 1950-2022. NAFO landings do not include landings reported by the US.

Year	US Commercial Landings (ACCSP)	Foreign Fleet Commercial Landings (NAFO)	US Recreational Landings (MRIP)	US Bycatch (NEFOP)
1950	21,447.7	--	--	--
1951	26,160.6	--	--	--
1952	20,986.3	--	--	--
1953	23,212.0	--	--	--
1954	23,671.0	--	--	--
1955	21,388.9	--	--	--
1956	24,266.1	--	--	--
1957	25,948.7	--	--	--
1958	33,952.5	--	--	--
1959	22,600.7	--	--	--
1960	23,157.1	--	--	--
1961	23,949.7	--	--	--
1962	23,270.0	--	--	--
1963	25,495.3	--	--	--
1964	19,416.5	--	--	--
1965	29,186.4	--	--	--
1966	26,398.1	--	--	--
1967	26,793.2	6,512.0	--	--
1968	25,978.3	22,310.0	--	--
1969	26,211.0	36,154.0	--	--
1970	16,250.5	19,951.0	--	--
1971	13,074.2	23,057.0	--	--
1972	12,652.7	12,574.0	--	--
1973	10,489.5	6,757.0	--	--
1974	11,178.2	5,245.0	--	--
1975	10,717.3	3,775.0	--	--
1976	6,525.3	1,774.0	--	--
1977	6,426.8	189.0	--	--
1978	5,828.3	32.0	--	--
1979	4,568.8	12.0	--	--
1980	5,043.8	3.0	--	--
1981	3,779.1	10.0	--	--
1982	5,902.0	81.0	15.7	--
1983	4,456.8	77.0	13.2	--
1984	4,397.3	206.0	3.4	--
1985	6,388.8	180.0	4.4	--
1986	4,164.7	66.0	45.0	--
1987	2,619.5	104.0	277.8	--
1988	2,586.9	87.0	4.8	--
1989	1,571.8	47.0	119.5	81.8
1990	1,236.7	14.0	661.2	271.6

Year	US Commercial Landings (ACCSP)	Foreign Fleet Commercial Landings (NAFO)	US Recreational Landings (MRIP)	US Bycatch (NEFOP)
1991	1,325.6	0.0	125.1	433.6
1992	1,457.8	0.0	53.0	1,256.7
1993	879.5	0.0	21.9	1,126.6
1994	1,006.7	0.0	7.5	245.7
1995	841.2	0.0	1.1	356.8
1996	2,320.5	0.0	3.5	3,504.1
1997	611.2	0.0	11.1	1,643.0
1998	844.3	0.0	351.8	222.5
1999	891.6	0.0	24.0	365.3
2000	654.8	0.0	256.7	221.8
2001	901.5	0.0	101.8	499.5
2002	911.1	0.0	60.6	273.5
2003	705.6	0.0	252.6	914.9
2004	1,070.9	0.0	137.9	394.9
2005	924.2	0.0	22.5	659.1
2006	819.7	0.0	3.0	269.5
2007	1,100.7	0.0	16.1	731.8
2008	668.5	0.0	84.1	698.5
2009	786.8	0.0	32.3	348.7
2010	934.2	0.0	13.3	267.0
2011	646.7	0.0	11.5	125.1
2012	748.1	0.0	16.8	423.2
2013	688.1	0.0	8.4	267.7
2014	845.8	0.0	20.7	113.3
2015	960.3	0.0	2.0	206.3
2016	921.4	0.0	4.4	155.7
2017	1,058.9	10.0	11.1	223.5
2018	1,114.9	0.0	2.7	417.4
2019	1,182.5	0.0	13.4	235.2
2020	905.7	0.0	6.0	145.5
2021	935.7	0.0	0.2	52.1
2022	1,538.6	0.0	8.4	76.2

Table 4. Total removals of river herring in millions of fish along the US Atlantic coast by data source, 1950-2022. NAFO landings do not include landings reported by the US.

Year	US Commercial Landings (ACCSP)	Foreign Fleet Commercial Landings (NAFO)	US Recreational Landings (MRIP)	US Bycatch (NEFOP)
1950	107.06	--	--	--
1951	130.55	--	--	--
1952	104.67	--	--	--
1953	118.39	--	--	--
1954	119.36	--	--	--
1955	108.77	--	--	--
1956	125.46	--	--	--
1957	138.04	--	--	--
1958	184.62	--	--	--
1959	118.44	--	--	--
1960	123.56	--	--	--
1961	128.65	--	--	--
1962	119.14	--	--	--
1963	131.47	--	--	--
1964	97.43	--	--	--
1965	147.16	--	--	--
1966	135.40	--	--	--
1967	136.08	54.11	--	--
1968	129.23	185.38	--	--
1969	130.88	300.41	--	--
1970	81.46	165.77	--	--
1971	66.67	191.58	--	--
1972	61.58	104.48	--	--
1973	51.82	56.14	--	--
1974	56.27	43.58	--	--
1975	54.44	31.37	--	--
1976	32.57	14.74	--	--
1977	30.92	1.57	--	--
1978	27.95	0.27	--	--
1979	22.31	0.10	--	--
1980	24.30	0.02	--	--
1981	18.29	0.08	--	--
1982	29.08	0.67	0.09	--
1983	21.91	0.64	0.07	--
1984	22.95	1.71	0.02	--
1985	33.44	1.50	0.02	--
1986	23.32	0.55	0.25	--
1987	14.11	0.86	1.51	--
1988	14.48	0.72	0.03	--
1989	8.66	0.39	0.62	0.67
1990	6.64	0.12	3.44	2.17

Year	US Commercial Landings (ACCSP)	Foreign Fleet Commercial Landings (NAFO)	US Recreational Landings (MRIP)	US Bycatch (NEFOP)
1991	7.14	0.00	0.68	3.45
1992	7.83	0.00	0.29	9.55
1993	5.47	0.00	0.12	8.95
1994	5.74	0.00	0.04	1.86
1995	4.48	0.00	0.01	2.70
1996	12.57	0.00	0.02	27.25
1997	3.25	0.00	0.06	12.44
1998	4.72	0.00	1.84	1.85
1999	4.94	0.00	0.13	2.76
2000	3.64	0.00	1.35	1.81
2001	4.79	0.00	0.56	3.99
2002	4.83	0.00	0.33	2.07
2003	3.74	0.00	1.34	7.36
2004	5.76	0.00	0.76	3.17
2005	5.24	0.00	0.12	5.45
2006	4.43	0.00	0.02	2.13
2007	6.06	0.00	0.09	6.17
2008	3.60	0.00	0.46	5.45
2009	4.54	0.00	0.18	2.81
2010	5.16	0.00	0.07	2.17
2011	3.42	0.00	0.06	1.06
2012	4.04	0.00	0.09	3.40
2013	3.51	0.00	0.05	2.30
2014	4.29	0.00	0.11	0.95
2015	5.14	0.00	0.01	1.70
2016	4.71	0.00	0.02	1.29
2017	5.26	0.08	0.06	1.85
2018	5.69	0.00	0.01	3.41
2019	5.77	0.00	0.07	1.97
2020	4.47	0.00	0.03	1.19
2021	4.90	0.00	0.00	0.43
2022	8.35	0.00	0.05	0.64

Table 5. Proportion of incidental catch of river herring (alewife and blueback herring) by region, fleet and quarter for the dominant gears from 2005-2019 estimated with the standard discard estimation method implemented in Northeast Fisheries Science Center. Midwater trawl (MWT) estimates were only included beginning in 2005.

	Bottom Trawl			Gillnet			Paired MWT	Single MWT	Total MWT	Grand Total
	Small Mesh	Medium Mesh	Large Mesh	Small Mesh	Large Mesh	Extra-Large Mesh				
Mid-Atlantic	**0.111**	**0.002**	**0.003**	**0.000**	**0.000**	**0.000**	**0.230**	**0.059**	**0.289**	**0.406**
Q1	0.029	0.001	0.001	0.000	0.000	0.000	0.215	0.052	0.267	0.298
Q2	0.019	0.000	0.001	0.000	0.000	0.000	0.010	0.004	0.014	0.034
Q3	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.048
Q4	0.019	0.001	0.001	0.000	0.000	0.000	0.005	0.000	0.005	0.026
New England	**0.305**	**0.001**	**0.010**	**0.000**	**0.000**	**0.000**	**0.190**	**0.089**	**0.279**	**0.594**
Q1	0.086	0.000	0.003	0.000	0.000	0.000	0.026	0.011	0.037	0.126
Q2	0.063	0.000	0.003	0.000	0.000	0.000	0.038	0.033	0.071	0.137
Q3	0.098	0.000	0.002	0.000	0.000	0.000	0.045	0.013	0.058	0.158
Q4	0.058	0.000	0.002	0.000	0.000	0.000	0.082	0.031	0.113	0.173
Grand Total	**0.416**	**0.003**	**0.013**	**0.000**	**0.000**	**0.000**	**0.420**	**0.148**	**0.568**	**1.000**

Table 6. Proportion of incidental catch of river herring (alewife and blueback herring) by region, fleet and quarter for the dominant gears from 2020 - 2022 estimated with CAMS.

	Bottom Trawl			Gillnet				Paired MWT	Single MWT	Total MWT	Grand Total
	Small Mesh	Large Mesh	Other	Small Mesh	Large Mesh	Extra-Large Mesh	Other				
Mid-Atlantic	**0.055**	**0.073**	**0.040**	**0.012**	**0.034**	**0.016**	**0.454**	**0.000**	**0.001**	**0.002**	**0.685**
Q1	0.007	0.013	0.001	0.004	0.010	0.003	0.123	0.000	0.000	0.001	0.163
Q2	0.016	0.021	0.014	0.003	0.008	0.008	0.102	0.000	0.000	0.000	0.172
Q3	0.017	0.023	0.017	0.003	0.003	0.000	0.110	0.000	0.000	0.000	0.175
Q4	0.014	0.016	0.007	0.002	0.013	0.004	0.120	0.000	0.000	0.000	0.176
New England	**0.048**	**0.146**	**0.028**	**0.000**	**0.031**	**0.045**	**0.016**	**0.001**	**0.002**	**0.002**	**0.316**
Q1	0.004	0.026	0.001		0.001	0.003	0.000	0.000	0.000	0.001	0.037
Q2	0.015	0.042	0.008	0.000	0.008	0.013	0.007	0.000	0.000	0.001	0.094
Q3	0.018	0.047	0.012	0.000	0.017	0.021	0.006	0.000	0.000	0.001	0.123
Q4	0.011	0.031	0.007	0.000	0.005	0.008	0.002	0.000	0.000	0.001	0.064
Grand Total	**0.103**	**0.219**	**0.067**	**0.012**	**0.065**	**0.061**	**0.470**	**0.001**	**0.003**	**0.004**	**1.002**

Table 7. Number of observed trips and the number of trips that observed alewife and blueback herring for the Mid-Atlantic region by gear.

	Mid-Atlantic											
	Bottom Trawls			Gillnets			Midwater Trawls			Other Gears		
Year	Observed Trips	Trips with Alewife	Trips with Blueback Herring	Observed Trips	Trips with Alewife	Trips with Blueback Herring	Observed Trips	Trips with Alewife	Trips with Blueback Herring	Observed Trips	Trips with Alewife	Trips with Blueback Herring
2005	265	8	19	536	2	1	16	5	6	414	0	0
2006	229	15	8	518	1	4	17	2	4	150	0	0
2007	389	12	17	580	1	2	8	1	0	249	0	1
2008	290	11	7	390	1	0	23	6	6	528	0	0
2009	464	21	18	322	0	0	31	12	13	444	0	2
2010	579	39	22	388	0	0	27	12	11	292	1	1
2011	550	39	29	240	0	0	45	19	14	267	3	2
2012	351	24	8	220	0	0	18	7	8	230	0	0
2013	579	59	24	328	0	0	8	1	1	204	2	0
2014	647	51	16	408	0	0	1	1	1	321	2	0
2015	528	75	23	588	0	0	6	2	3	399	1	1
2016	942	55	22	949	1	2	7	3	3	565	0	0
2017	1283	78	28	908	0	2	8	3	4	560	2	1
2018	1076	112	50	650	0	2	6	4	5	331	0	0
2019	1146	186	42	846	1	0	3	3	3	313	0	0
2020	173	17	4	205	0	0	4	1	3	117	0	0
2021	293	11	6	91	0	0	0	0	0	177	1	1
2022	482	20	7	219	0	0	2	0	0	172	0	0

Table 8. Number of observed trips and the number of trips that observed alewife and blueback herring for the New England region by gear.

	New England											
	Bottom Trawls			Gillnets			Midwater Trawls			Other Gears		
Year	Observed Trips	Trips with Alewife	Trips with Blueback Herring	Observed Trips	Trips with Alewife	Trips with Blueback Herring	Observed Trips	Trips with Alewife	Trips with Blueback Herring	Observed Trips	Trips with Alewife	Trips with Blueback Herring
2005	1652	56	69	995	3	6	155	18	11	499	8	7
2006	732	46	45	453	0	0	37	3	2	261	11	2
2007	739	50	35	565	1	2	26	11	9	318	5	4
2008	838	62	33	478	0	3	57	18	10	375	8	5
2009	1161	134	60	507	1	3	108	22	22	252	12	7
2010	679	135	45	396	0	2	178	47	30	207	12	16
2011	705	118	40	586	1	1	154	19	14	267	1	3
2012	660	114	43	552	3	0	203	29	16	356	22	9
2013	610	152	32	381	1	0	121	22	8	424	25	9
2014	890	190	49	506	5	0	143	15	14	353	1	0
2015	707	121	30	414	3	0	26	4	2	559	1	0
2016	575	88	31	453	0	0	75	7	4	363	0	1
2017	1115	249	89	577	0	0	35	8	10	455	0	2
2018	896	207	69	383	0	0	9	2	3	518	4	4
2019	935	246	72	394	1	0	8	4	3	477	1	0
2020	178	49	4	69	0	0	4	1	0	105	1	0
2021	392	55	13	226	2	0	5	2	0	332	1	0
2022	343	43	18	245	0	0	14	4	4	441	4	4

Table 9. Species-specific total annual incidental catch (mt) and the associated coefficient of variation across all fleets and regions. Midwater trawl estimates were only included beginning in 2005. “Herring NK” is the incidental catch of Clupeidae fish that could not be identified to species level.

	Alewife		Blueback herring		American shad		Hickory shad		Herring NK	
	Catch	CV	Catch	CV	Catch	CV	Catch	CV	Catch	CV
1989	44.2	0.5	37.7	0.4	229.1	1.0	0.0		17.5	1.1
1990	101.6	0.9	170.0	0.5	45.2	0.3	0.0		681.3	0.6
1991	148.6	0.4	285.1	0.4	176.1	0.3	39.4	0.0	265.6	0.5
1992	65.7	0.4	1191.0	0.4	169.0	0.3	0.0		786.2	0.4
1993	381.1	2.4	745.6	0.3	211.3	1.0	0.0		135.9	4.8
1994	5.6	0.3	240.2	0.9	109.9	0.6	1.0	0.8	58.3	0.5
1995	8.4	0.6	348.3	0.4	127.4	0.4	0.5	0.6	99.9	1.2
1996	704.1	1.1	2800.0	2.1	64.5	0.4	222.5	1.0	451.4	0.4
1997	49.4	1.4	1593.6	0.7	66.0	0.6	20.6	1.3	90.3	5.1
1998	145.6	1.5	76.8	1.5	161.0	0.2	479.8	0.7	228.1	2.1
1999	6.1	1.2	359.2	0.6	82.0	0.4	208.8	0.9	3457.3	0.7
2000	112.2	0.8	109.6	0.5	262.4	0.8	2.4	0.8	71.0	0.8
2001	189.6	0.8	309.9	0.3	67.8	0.4	330.4	0.3	2.5	0.4
2002	4.4	3.4	269.1	0.3	43.8	0.4	1.9	0.8	124.1	1.9
2003	388.0	1.4	526.8	0.6	60.2	0.5	18.8	0.9	26.2	1.2
2004	163.2	0.6	231.7	0.5	53.1	0.4	401.8	1.1	237.1	0.7
2005	404.4	0.4	254.7	0.3	94.5	0.3	27.4	0.3	29.5	0.6
2006	78.7	0.8	190.8	0.7	78.2	9.7	25.1	0.8	267.8	1.1
2007	543.8	0.7	188.0	1.4	79.1	0.6	16.7	0.9	357.5	0.9
2008	159.2	0.4	539.3	0.6	74.0	0.3	2.9	0.9	1668.6	0.5
2009	153.8	0.3	194.9	0.3	106.5	2.0	10.0	0.7	351.4	0.7
2010	134.6	0.2	132.4	0.2	60.6	0.2	1.3	0.6	103.7	0.3
2011	96.7	0.3	28.4	0.3	103.6	0.1	0.1	0.8	126.7	0.3
2012	173.9	0.2	249.4	0.3	76.5	0.2	0.5	0.6	91.8	0.3
2013	238.8	0.3	28.9	0.5	73.4	0.4	0.4	0.8	75.0	0.7
2014	83.7	0.1	29.7	0.2	63.6	0.2	0.7	0.4	76.7	0.4
2015	123.7	0.3	82.6	0.5	46.4	0.2	2.3	0.8	40.5	0.8
2016	101.6	0.3	54.1	0.2	41.9	0.2	21.2	0.5	53.2	0.6
2017	141.0	0.2	82.5	0.3	44.2	0.1	2.8	0.3	182.3	0.3
2018	221.2	0.2	196.2	0.2	49.5	0.1	13.3	0.6	27.8	0.3
2019	162.4	0.4	72.7	0.1	117.0	0.3	6.8	0.2	42.3	0.8
2020	79.3	0.3	66.2	1.2	128.3	0.4	1.0	0.4	211.2	0.4
2021	29.3	0.4	22.8	1.6	60.6	0.2	3.1	0.4	34.4	0.5
2022	56.4	0.4	19.8	0.6	38.7	0.2	1.3	0.3	27.4	0.6

Table 10. MRIP estimates of recreational alewife catch on the US Atlantic coast.

Year	Harvest (Numbers)	Harvest PSE	Released Alive (Numbers)	Released Alive PSE	Total Catch (Numbers)	Total Catch (Numbers)PSE	Total Catch (MT)
1982	86,200	183%	0	.	86,200	183%	15.7
1983	0	.	4,748	101%	4,748	101%	0.9
1984	0	.	18,651	99%	18,651	99%	3.4
1985	23,998	54%	0	.	23,998	54%	4.4
1986	246,353	61%	0	.	246,353	61%	44.9
1987	1,134,742	72%	173,510	85%	1,308,252	64%	238.3
1988	22,657	78%	0	.	22,657	78%	4.1
1989	1,387	102%	5,097	104%	6,484	84%	1.2
1990	12,750	106%	0	.	12,750	106%	2.3
1991	554,263	61%	11,203	101%	565,466	61%	103.0
1992	231,473	86%	0	.	231,473	86%	42.2
1993	41,594	63%	0	.	41,594	63%	7.6
1994	1,669	102%	4,153	69%	5,822	71%	1.1
1995	3,171	85%	2,066	101%	5,237	65%	1.0
1996	1,362	105%	2,656	71%	4,018	77%	0.7
1997	9,648	92%	386	102%	10,034	88%	1.8
1998	141,362	69%	126,774	87%	268,136	55%	48.8
1999	3,019	102%	1,303	103%	4,323	78%	0.8
2000	344,425	53%	12,568	53%	356,994	52%	65.0
2001	466,833	66%	91,683	66%	558,516	64%	101.7
2002	220,011	56%	10,210	66%	230,221	54%	41.9
2003	454,499	82%	10,035	66%	464,534	80%	84.6
2004	743,546	74%	1,483	101%	745,029	74%	135.7
2005	0	.	66,430	98%	66,430	98%	12.1
2006	4,406	78%	12,024	106%	16,431	80%	3.0
2007	73,241	46%	11,412	90%	84,653	44%	15.4
2008	325,131	58%	69,885	81%	395,016	49%	72.0
2009	140,512	57%	36,105	79%	176,617	59%	32.2
2010	67,241	46%	1,427	100%	68,668	45%	12.5
2011	30,856	67%	24,507	86%	55,363	56%	10.1
2012	51,815	61%	40,240	86%	92,055	59%	16.8
2013	25,234	51%	20,967	87%	46,201	48%	8.4
2014	71,574	48%	21,574	66%	93,149	40%	17.0
2015	0	.	4,730	68%	4,730	68%	0.9
2016	15,487	80%	8,814	54%	24,302	56%	4.4
2017	10,235	68%	35,958	73%	46,193	60%	8.4
2018	14,207	82%	400	104%	14,607	80%	2.7
2019	18,729	66%	41,640	67%	60,368	50%	11.0
2020	4,595	57%	869	80%	5,465	50%	1.0
2021	0	.	975	107%	975	107%	0.2
2022	42,188	67%	347	100%	42,535	66%	7.7

Table 11. MRIP estimates of blueback herring recreational catch on the US Atlantic coast.

Year	Harvest (Numbers)	Harvest PSE	Released Alive (Numbers)	Released Alive PSE	Total Catch (Numbers)	Total Catch (Numbers)PSE	Total Catch (MT)
1982	28	104%	0	.	28	104%	0.01
1983	64,292	100%	0	.	64,292	100%	12.37
1984	0	.	0	.	0	.	0
1985	0	.	0	.	0	.	0
1986	576	101%	0	.	576	101%	0.11
1987	172,175	74%	33,397	103%	205,573	76%	39.55
1988	0	.	3,423	97%	3,423	97%	0.66
1989	590,827	89%	24,207	93%	615,034	85%	118.31
1990	3,261,141	47%	164,014	50%	3,425,155	47%	658.89
1991	80,244	82%	34,768	99%	115,012	65%	22.12
1992	45,746	70%	10,408	92%	56,154	60%	10.80
1993	68,790	56%	5,643	71%	74,433	54%	14.32
1994	24,405	69%	9,166	90%	33,571	56%	6.46
1995	684	70%	0	.	684	70%	0.13
1996	14,259	91%	0	.	14,259	91%	2.74
1997	48,270	101%	0	.	48,270	101%	9.29
1998	1,570,858	102%	4,208	100%	1,575,066	102%	302.99
1999	65,882	58%	54,853	97%	120,735	65%	23.23
2000	988,715	60%	7,589	103%	996,304	60%	191.66
2001	267	103%	0	.	267	103%	0.05
2002	44,211	99%	53,023	103%	97,234	72%	18.70
2003	820,555	75%	52,842	95%	873,397	70%	168.01
2004	9,746	102%	1,851	98%	11,597	87%	2.23
2005	42,042	94%	12,129	90%	54,171	76%	10.42
2006	60	102%	146	105%	206	80%	0.04
2007	1,270	103%	2,330	97%	3,600	73%	0.69
2008	13,925	100%	49,118	97%	63,043	79%	12.13
2009	401	59%	74	103%	475	49%	0.09
2010	486	100%	3,560	101%	4,046	89%	0.78
2011	7,196	98%	0	.	7,196	98%	1.38
2012	42	103%	0	.	42	103%	0.01
2013	64	104%	0	.	64	104%	0.01
2014	19,591	67%	0	.	19,591	67%	3.77
2015	0	.	6,130	111%	6,130	111%	1.18
2016	0	.	1	24%	1	24%	0.00
2017	1,297	91%	12,566	81%	13,863	77%	2.67
2018	0	.	0	.	0	.	0
2019	12,421	82%	318	98%	12,738	80%	2.45
2020	25,956	56%	.	.	25,956	56%	4.99
2021	0	.	0	.	0	.	0
2022	3,183	104%	130	103%	3,314	100%	0.64

Table 12. Number of total lengths and ages available by structure used to fit growth models for alewife and blueback herring.

Alewife			Blueback herring		
Age	Otolith	Scale	Age	Otolith	Scale
1	0	2	1	9	10
2	124	171	2	610	286
3	10,182	9,901	3	7,184	7,108
4	11,345	40,148	4	6,225	17,907
5	5,878	25,777	5	3,931	15,547
6	1,494	10,197	6	1,970	5,867
7	371	2,626	7	613	1,377
8	111	501	8	150	266
9	29	65	9	35	54
10	12	1	10	5	3
11	1	0	11	0	1
			12	1	0
Total	29,547	89,382	Total	20,733	48,426

Table 13. Estimated parameters from the sex-specific von Bertalanffy growth functions for alewife stock-regions by aging structures and sex. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals.

Region	Structure	Parameter	Female	Male
NNE	Otolith	*K*	0.66 (0.47—0.78)	0.70 (0.50—0.83)
		L_∞	300.24 (287.62—324.06)	286.55 (274.50—309.25)
		t_0	-0.39 (-0.50—-0.20)	-0.38 (-0.50—-0.19)
	Scale	*K*	0.68 (0.49—0.81)	0.73 (0.52—0.86)
		L_∞	291.78 (279.63—314.95)	278.48 (266.87—300.59)
		t_0	-0.39 (-0.50—-0.20)	-0.38 (-0.50—-0.19)
SNE	Otolith	*K*	0.45 (0.36—0.58)	0.48 (0.39—0.62)
		L_∞	324.75 (291.04—344.65)	309.94 (277.75—328.93)
		t_0	-0.54 (-0.69—-0.42)	-0.54 (-0.68—-0.42)
	Scale	*K*	0.47 (0.38—0.60)	0.50 (0.40—0.65)
		L_∞	315.70 (282.94—334.98)	301.29 (270.04—319.72)
		t_0	-0.54 (-0.69—-0.42)	-0.53 (-0.68—-0.42)
MAT	Otolith	*K*	0.49 (0.34—0.70)	0.52 (0.36—0.74)
		L_∞	315.78 (290.15—336.77)	301.37 (276.94—321.41)
		t_0	-0.50 (-1.10—-0.37)	-0.49 (-1.09—-0.37)
	Scale	*K*	0.51 (0.35—0.72)	0.54 (0.38—0.77)
		L_∞	306.92 (282.08—327.32)	292.91 (269.23—312.40)
		t_0	-0.50 (-1.10—-0.37)	-0.49 (-1.09—-0.36)

Table 14. $Z_{40\%SPR}$ results by species and stock region from the stochastic SPR models. Deterministic SPR results are provided for comparison only and were not used when considering the probabilities of Z being above or below $Z_{40\%SPR}$. The deterministic results are not directly comparable to the stochastic results because the deterministic approach assumes selectivity is 100% for all ages, as was done in the 2012 benchmark assessment, while the median selectivity of the stochastic SPR model is lower on younger ages.

Stock-Region	Stochastic $Z_{40\%SPR}$ Median (2.5th – 97.5th percentiles)	Deterministic $Z_{40\%SPR}$	Species
NNE	0.96 (0.76-1.67)	0.79	ALE
SNE	0.98 (0.78-1.58)	0.81	ALE
MAT	0.97 (0.76-1.54)	0.79	ALE
CAN-NNE	1.15 (0.85-2.01)	0.90	BBH
MNE	1.05 (0.79-1.67)	0.85	BBH
SNE	1.04 (0.83-1.69)	0.88	BBH
MAT	1.02 (0.80-1.65)	0.83	BBH
SAT	0.99 (0.74-1.53)	0.82	BBH

Table 15. Mann-Kendall trend analysis results for alewife mean length in the NNE stock-region. N is the number of years in the time series, S is the Mann-Kendall statistic, and p is the two-tailed probability of significance.

				Full time series					Recent time series				
Region	**State**	**River**	**Sex**	**Trend**	**Years**	**N**	**S**	**p**	**Trend**	**Years**	**N**	**S**	**p**
NNE	ME	ME C2	Female	No Trend	2008-2021	10	7	0.59	-	-	-	-	-
NNE	ME	ME C3	Female	No Trend	2008-2021	13	22	0.20	No Trend	2010-2021	11	13	0.35
NNE	ME	ME C3	Male	No Trend	2008-2021	13	24	0.16	No Trend	2010-2021	11	7	0.64
NNE	ME	ME C4	Female	No Trend	2010-2021	11	-9	0.53	No Trend	2010-2021	11	-9	0.53
NNE	ME	ME C4	Male	No Trend	2010-2021	10	-3	0.86	No Trend	2010-2021	10	-3	0.86
NNE	ME	ME C5	Female	No Trend	2008-2021	13	12	0.50	No Trend	2010-2021	12	14	0.37
NNE	ME	ME C5	Male	No Trend	2008-2021	13	4	0.85	No Trend	2010-2021	12	6	0.73
NNE	ME	ME C6	Female	No Trend	2010-2021	10	-13	0.28	No Trend	2010-2021	10	-13	0.28
NNE	ME	ME C7	Female	No Trend	2008-2021	14	31	0.10	No Trend	2010-2021	12	12	0.45
NNE	ME	ME C7	Male	No Trend	2008-2021	14	35	0.06	No Trend	2010-2021	12	16	0.30
NNE	ME	ME C8	Male	No Trend	2010-2021	10	19	0.11	No Trend	2010-2021	10	19	0.11
NNE	ME	ME C10	Female	No Trend	2008-2021	14	17	0.38	No Trend	2010-2021	12	6	0.73
NNE	ME	ME C10	Male	No Trend	2008-2021	13	24	0.16	No Trend	2010-2021	11	11	0.44
NNE	ME	ME C15	Female	No Trend	2010-2021	12	26	0.09	No Trend	2010-2021	12	26	0.09
NNE	ME	ME C15	Male	No Trend	2010-2021	12	28	0.06	No Trend	2010-2021	12	28	0.06
NNE	ME	ME N8	Female	**Positive**	2010-2021	10	27	0.02	**Positive**	2010-2021	10	27	0.02
NNE	ME	ME N8	Male	**Positive**	2010-2021	10	27	0.02	**Positive**	2010-2021	10	27	0.02
NNE	ME	ME N13	Female	**Positive**	2011-2021	10	27	0.02	**Positive**	2011-2021	10	27	0.02
NNE	ME	ME N13	Male	**Positive**	2011-2021	10	29	0.01	**Positive**	2011-2021	10	29	0.01
NNE	ME	ME N14	Male	No Trend	2011-2021	11	3	0.88	No Trend	2011-2021	11	3	0.88
NNE	NH	Cocheco	Female	No Trend	1992-2021	28	80	0.12	**Positive**	2010-2021	12	42	0.00
NNE	NH	Cocheco	Male	No Trend	1992-2021	30	53	0.35	No Trend	2010-2021	12	28	0.06
NNE	NH	Oyster	Female	No Trend	2011-2021	11	-7	0.64	No Trend	2011-2021	11	-7	0.64
NNE	NH	Oyster	Male	No Trend	2010-2021	12	10	0.54	No Trend	2010-2021	12	10	0.54
NNE	NH	Lamprey	Female	No Trend	1992-2021	30	89	0.12	No Trend	2010-2021	12	24	0.11
NNE	NH	Lamprey	Male	No Trend	1992-2021	30	41	0.48	No Trend	2010-2021	12	22	0.15
NNE	NH	Exeter	Female	No Trend	1992-2021	14	9	0.66	-	-	-	-	-
NNE	NH	Exeter	Male	No Trend	1992-2021	21	-52	0.12	-	-	-	-	-

Table 16. Results of the Mann-Kendall test for alewife trends in mean length by river, species, sex and age in the NNE stock-region. N = sample size, S is the Mann-Kendall test statistics, and p is the two-tailed probability. Shaded cells indicate a significant result.

					Full time series					Recent time series				
State	**River**	**Sex**	**Age**	**Structure**	**Trend**	**Years**	**N**	**S**	**p**	**Trend**	**Years**	**N**	**S**	**p**
ME	ME C2	Female	4	Scale	No Trend	2008-2021	10	7	0.59	-	-	-	-	-
ME	ME C3	Female	4	Scale	No Trend	2008-2021	13	28	0.10	No Trend	2010-2021	11	13	0.35
ME	ME C3	Female	5	Scale	No Trend	2008-2021	13	26	0.13	No Trend	2010-2021	11	15	0.28
ME	ME C3	Male	3	Scale	No Trend	2008-2021	11	9	0.53	No Trend	2010-2021	10	3	0.86
ME	ME C3	Male	4	Scale	No Trend	2008-2021	13	26	0.13	No Trend	2010-2021	11	7	0.64
ME	ME C3	Male	5	Scale	No Trend	2008-2021	11	9	0.53	-	-	-	-	-
ME	ME C4	Female	4	Scale	No Trend	2010-2021	11	-7	0.64	No Trend	2010-2021	11	-7	0.64
ME	ME C4	Female	5	Scale	No Trend	2010-2021	11	-17	0.21	No Trend	2010-2021	11	-17	0.21
ME	ME C4	Male	4	Scale	No Trend	2010-2021	10	-7	0.59	No Trend	2010-2021	10	-7	0.59
ME	ME C4	Male	5	Scale	No Trend	2010-2021	10	-11	0.37	No Trend	2010-2021	10	-11	0.37
ME	ME C5	Female	3	Scale	No Trend	2008-2020	10	3	0.86	-	-	-	-	-
ME	ME C5	Female	4	Scale	No Trend	2008-2021	13	6	0.76	No Trend	2010-2021	12	10	0.54
ME	ME C5	Male	3	Scale	No Trend	2008-2021	11	9	0.53	No Trend	2010-2021	10	17	0.15
ME	ME C5	Male	4	Scale	No Trend	2008-2021	13	2	0.95	No Trend	2010-2021	12	6	0.73
ME	ME C6	Female	4	Scale	No Trend	2010-2021	10	7	0.59	No Trend	2010-2021	10	7	0.59
ME	ME C6	Female	5	Scale	No Trend	2010-2021	10	9	0.47	No Trend	2010-2021	10	9	0.47
ME	ME C7	Female	4	Scale	No Trend	2008-2021	14	27	0.15	No Trend	2010-2021	12	6	0.73
ME	ME C7	Female	5	Scale	No Trend	2008-2021	13	24	0.16	No Trend	2010-2021	12	12	0.45
ME	ME C7	Male	4	Scale	No Trend	2008-2021	14	29	0.13	No Trend	2010-2021	12	14	0.37
ME	ME C7	Male	5	Scale	**Positive**	2008-2021	13	34	0.04	No Trend	2010-2021	12	22	0.15
ME	ME C8	Male	4	Scale	**Positive**	2010-2021	10	31	0.01	**Positive**	2010-2021	10	31	0.01
ME	ME C10	Female	4	Scale	No Trend	2008-2021	14	31	0.10	No Trend	2010-2021	12	18	0.24
ME	ME C10	Female	5	Scale	No Trend	2008-2021	14	29	0.13	No Trend	2010-2021	12	16	0.30
ME	ME C10	Female	6	Scale	No Trend	2008-2021	10	15	0.21	-	-	-	-	-
ME	ME C10	Male	4	Scale	No Trend	2008-2021	13	26	0.13	No Trend	2010-2021	11	17	0.21
ME	ME C10	Male	5	Scale	No Trend	2008-2021	12	29	0.05	No Trend	2010-2021	10	10	0.42
ME	ME C15	Female	4	Scale	No Trend	2010-2021	12	0	1.00	No Trend	2010-2021	12	0	1.00
ME	ME C15	Female	5	Scale	No Trend	2010-2021	12	6	0.73	No Trend	2010-2021	12	6	0.73
ME	ME C15	Male	4	Scale	No Trend	2010-2021	12	18	0.24	No Trend	2010-2021	12	18	0.24
ME	ME C15	Male	5	Scale	No Trend	2010-2021	12	14	0.37	No Trend	2010-2021	12	14	0.37

					Full time series					**Recent time series**				
State	**River**	**Sex**	**Age**	**Structure**	**Trend**	**Years**	**N**	**S**	**p**	**Trend**	**Years**	**N**	**S**	**p**
ME	ME N8	Female	4	Scale	No Trend	2010-2021	10	17	0.15	No Trend	2010-2021	10	17	0.15
ME	ME N8	Male	4	Scale	No Trend	2010-2021	10	13	0.28	No Trend	2010-2021	10	13	0.28
ME	ME N13	Female	4	Scale	**Positive**	2011-2021	10	29	0.01	**Positive**	2011-2021	10	29	0.01
ME	ME N13	Female	5	Scale	No Trend	2011-2021	10	15	0.21	No Trend	2011-2021	10	15	0.21
ME	ME N13	Male	4	Scale	**Positive**	2011-2021	10	31	0.01	**Positive**	2011-2021	10	31	0.01
ME	ME N14	Male	3	Scale	No Trend	2011-2021	10	13	0.28	No Trend	2011-2021	10	13	0.28
ME	ME N14	Male	4	Scale	No Trend	2011-2021	11	9	0.53	No Trend	2011-2021	11	9	0.53
NH	Cocheco	Female	4	Scale	**Negative**	1992-2019	24	-152	0.00	-	-	-	-	-
NH	Cocheco	Female	5	Scale	**Negative**	1992-2021	28	-198	0.00	No Trend	2010-2021	12	-28	0.06
NH	Cocheco	Female	6	Scale	No Trend	1992-2021	25	-60	0.17	**Negative**	2010-2021	12	-36	0.02
NH	Cocheco	Female	7	Scale	No Trend	1998-2021	18	23	0.40	No Trend	2010-2021	12	-10	0.54
NH	Cocheco	Male	4	Scale	**Negative**	1992-2021	28	-206	0.00	No Trend	2010-2021	10	-13	0.28
NH	Cocheco	Male	5	Scale	**Negative**	1992-2021	29	-258	0.00	**Negative**	2010-2021	11	-29	0.03
NH	Cocheco	Male	6	Scale	**Negative**	1992-2021	23	-85	0.03	No Trend	2010-2021	11	-17	0.21
NH	Cocheco	Male	7	Scale	No Trend	2006-2021	10	7	0.59	-	-	-	-	-
NH	Lamprey	Female	4	Scale	**Negative**	1992-2021	28	-195	0.00	No Trend	2010-2021	10	17	0.15
NH	Lamprey	Female	5	Scale	**Negative**	1992-2021	30	-201	0.00	No Trend	2010-2021	12	-12	0.45
NH	Lamprey	Female	6	Scale	No Trend	1992-2021	28	-58	0.26	No Trend	2010-2021	12	-22	0.15
NH	Lamprey	Female	7	Scale	No Trend	1999-2021	19	43	0.14	No Trend	2010-2021	10	1	1.00
NH	Lamprey	Male	3	Scale	**Negative**	1992-2014	13	-49	0.00	-	-	-	-	-
NH	Lamprey	Male	4	Scale	**Negative**	1992-2021	29	-200	0.00	No Trend	2010-2021	11	7	0.64
NH	Lamprey	Male	5	Scale	**Negative**	1992-2021	30	-167	0.00	**Negative**	2010-2021	12	-32	0.03
NH	Lamprey	Male	6	Scale	No Trend	1993-2021	26	31	0.51	No Trend	2010-2021	12	14	0.37
NH	Lamprey	Male	7	Scale	**Positive**	1998-2021	20	82	0.01	No Trend	2011-2021	11	7	0.64

Table 17. Repeat spawner trends for alewife from the NNE stock-region by sex. The number and range of years is the maximum of the available time series by sex and some river-sex combinations may be shorter than what is listed. Recent time series results are not presented when the full time series is equal to or shorter than the recent time series cutoffs.

				Full time series					**Recent time series**				
State	**River**	**Sex**	**Survey Type**	**Trend**	**Number of Years**	**Years**	**Mann-Kendall value**	**p -value**	**Trend**	**Number of Years**	**Years**	**Mann-Kendall value**	**p -value**
ME	ME C2	Female	FD	No Trend	11	2008-2021	19	0.16	-	-	-	-	-
ME	ME C2	Male	FD	No Trend	10	2008-2021	11	0.37	-	-	-	-	-
ME	ME C3	Female	FD	No Trend	14	2008-2021	29	0.13	No Trend	12	2010-2021	24	0.11
ME	ME C3	Male	FD	**Positive**	14	2008-2021	41	0.03	No Trend	12	2010-2021	24	0.11
ME	ME C4	Female	FD	No Trend	11	2010-2021	7	0.64	No Trend	11	2010-2021	7	0.64
ME	ME C4	Male	FD	No Trend	11	2010-2021	9	0.53	No Trend	11	2010-2021	9	0.53
ME	ME C5	Female	FD	No Trend	14	2008-2021	20	0.30	No Trend	12	2010-2021	7	0.68
ME	ME C5	Male	FD	No Trend	14	2008-2021	33	0.08	No Trend	12	2010-2021	14	0.37
ME	ME C6	Female	FD	No Trend	12	2008-2021	-26	0.09	No Trend	11	2010-2021	-15	0.28
ME	ME C6	Male	FD	No Trend	11	2010-2021	-17	0.21	No Trend	11	2010-2021	-17	0.21
ME	ME C7	Female	FD	**Positive**	14	2008-2021	39	0.04	No Trend	12	2010-2021	24	0.11
ME	ME C7	Male	FD	**Positive**	14	2008-2021	41	0.03	**Positive**	12	2010-2021	30	0.05
ME	ME C8	Female	FD	No Trend	13	2009-2021	4	0.85	No Trend	12	2010-2021	-4	0.84
ME	ME C8	Male	FD	No Trend	13	2009-2021	-4	0.85	No Trend	12	2010-2021	2	0.95
ME	ME C10	Female	FD	No Trend	14	2008-2021	-7	0.74	No Trend	12	2010-2021	-2	0.95
ME	ME C10	Male	FD	No Trend	14	2008-2021	-10	0.62	No Trend	12	2010-2021	-1	1.00
ME	ME C13	Female	FD	No Trend	13	2009-2021	-6	0.76	No Trend	12	2010-2021	-6	0.73
ME	ME C13	Male	FD	No Trend	14	2008-2021	-1	1.00	No Trend	12	2010-2021	0	1.00
ME	ME C14	Female	FD	No Trend	14	2008-2021	7	0.74	No Trend	12	2010-2021	26	0.09
ME	ME C14	Male	FD	No Trend	14	2008-2021	21	0.27	**Positive**	12	2010-2021	42	0.00
ME	ME C15	Female	FD	No Trend	13	2009-2021	19	0.27	Positive	12	2010-2021	31	0.04
ME	ME C15	Male	FD	No Trend	13	2009-2021	12	0.50	No Trend	12	2010-2021	18	0.24
ME	ME C16	Female	FD	No Trend	13	2009-2022	4	0.85	No Trend	12	2010-2022	-8	0.63
State	**River**	**Sex**	**Survey Type**	**Trend**	**Number of Years**	**Years**	**Mann-Kendall value**	**p -value**	**Trend**	**Number of Years**	**Years**	**Mann-Kendall value**	**p -value**

				Full time series					Recent time series				
ME	ME C16	Male	FD	No Trend	13	2009-2022	28	0.10	No Trend	12	2010-2022	16	0.30
ME	ME C18	Female	FD	No Trend	12	2010-2021	14	0.37	No Trend	12	2010-2021	14	0.37
ME	ME C18	Male	FD	**Positive**	12	2010-2021	32	0.03	**Positive**	12	2010-2021	32	0.03
ME	ME N1	Female	FI	**Positive**	12	2008-2021	30	0.05	**Positive**	10	2010-2021	23	0.05
ME	ME N1	Male	FI	**Positive**	12	2008-2021	34	0.02	**Positive**	10	2010-2021	23	0.05
ME	ME N8	Female	FI	**Positive**	11	2010-2021	35	0.01	**Positive**	11	2010-2021	35	0.01
ME	ME N8	Male	FI	**Positive**	11	2010-2021	33	0.01	**Positive**	11	2010-2021	33	0.01
ME	ME N13	Female	FI	No Trend	11	2011-2021	17	0.21	No Trend	11	2011-2021	17	0.212912
ME	ME N13	Male	FI	No Trend	11	2011-2021	20	0.14	No Trend	11	2011-2021	20	0.137902
ME	ME N14	Female	FI	No Trend	11	2011-2021	-13	0.35	No Trend	11	2011-2021	-13	0.350201
ME	ME N14	Male	FI	No Trend	11	2011-2021	-14	0.31	No Trend	11	2011-2021	-14	0.310044
NH	Cocheco	Female	FI	No Trend	22	2000-2021	54	0.13	No Trend	12	2010-2021	0	1
NH	Cocheco	Male	FI	No Trend	22	2000-2021	66	0.07	No Trend	12	2010-2021	5	0.783364
NH	Oyster	Female	FI	No Trend	11	2011-2021	-19	0.16	No Trend	11	2011-2021	-19	0.158578
NH	Oyster	Male	FI	No Trend	13	2009-2021	-31	0.07	No Trend	12	2010-2021	-21	0.169229
NH	Lamprey	Female	FI	No Trend	22	2000-2021	27	0.46	No Trend	12	2010-2021	2	0.94533
NH	Lamprey	Male	FI	No Trend	22	2000-2021	2	0.98	No Trend	12	2010-2021	-8	0.631222
NH	Exeter	Female	FI	No Trend	17	2000-2021	34	0.17	-	-	-	-	-
NH	Exeter	Male	FI	No Trend	17	2000-2021	-6	0.84	-	-	-	-	-
NH	Winnicut	Male	FI	No Trend	12	2000-2019	8	0.63	-	-	-	-	-

Table 18. Summary of ARIMA model fits for the terminal years of fishery-independent surveys and run counts. $P(i_f>Q_{25})$ is the probability of the terminal year of the index being greater than the bootstrapped 25th percentile reference point and $P(i_f>i_{2009})$ is the probability of the terminal year of the index being greater than the bootstrapped 2009 reference point. Means are averaged across all surveys and run counts within a species/region/life stage combination.

Species	Stock-Region	Life Stage	Fraction with $P(i_f>Q_{25})>0.50$	Mean $P(i_f>Q_{25})$	Fraction with $P(i_f>i_{2009})>0.50$	Mean $P(i_f>i_{2009})$
**_Considering all surveys regardless of the normality of the residuals from the ARIMA model fit_						
Alewife	NNE	Adult	4/5	0.76	4/5	0.74
		Juvenile	2/2	0.99	2/2	0.88
	SNE	Adult	8/11	0.70	7/8	0.60
		Juvenile	0/1	0.28	0/1	<0.01
	MAT	Adult	9/12	0.72	5/8	0.59
		Juvenile	10/11	0.74	7/10	0.64
	Mixed (ocean)	Adult	9/9	0.83	5/8	0.62
Blueback	CAN-NNE	Adult	1/1	1.00	1/1	0.98
	MNE	Adult	3/3	0.94	3/3	0.67
		Juvenile	1/1	0.94	1/1	0.96
	MAT	Adult	15/17	0.78	8/10	0.72
		Juvenile	12/14	0.75	12/13	0.76
	SAT	Adult	3/4	0.74	2/4	0.53
		Juvenile	1/1	1.00	1/1	1.00
	Mixed (ocean)	Adult	7/8	0.81	4/7	0.54
Combined	NNE	Adult	5/5	0.98	5/5	0.98
	SNE	Adult	8/10	0.77	7/8	0.69
**_Considering only those surveys whose residuals from the ARIMA model fit were normal_						
Alewife	NNE	Adult	2/3	0.62	2/3	0.60
		Juvenile	2/2	0.99	2/2	0.88
	SNE	Adult	7/10	0.69	6/7	0.59
		Juvenile	0/1	0.28	0/1	<0.01
	MAT	Adult	7/10	0.70	5/7	0.61
		Juvenile	3/4	0.59	2/3	0.59
	Mixed (ocean)	Adult	4/4	0.75	2/3	0.62
Blueback	CAN-NNE	Adult				
	MNE	Adult	2/2	0.91	2/2	0.51
		Juvenile				
	MAT	Adult	12/14	0.77	5/7	0.71
		Juvenile	6/8	0.67	6/7	0.72
	SAT	Adult	1/2	0.53	0/2	0.12
		Juvenile	1/1	1.00	1/1	1.00
	Mixed (ocean)	Adult	7/8	0.81	4/7	0.54
Combined	NNE	Adult	3/3	0.97	3/3	0.97
	SNE	Adult	7/8	0.83	6/6	0.76

Table 19. Estimates of Z relative to $Z_{40\%SPR}$ for alewife in the NNE stock-region. $P(Z)>Z_{40\%SPR}$ is the probability that Z is above the $Z_{40\%SPR}$. Maine rivers are anonymized to protect data confidentiality.

State	River	Terminal Year	*Z* (95% CIs)	$Z_{40\%SPR}$ (95% CIs)	P(Z)> Z40%SPR	Ageing Structure
ME	ME C2	2021	1.04 (0.66-1.42)	0.96 (0.75-1.62)	58.8%	Scales
ME	ME C3	2020	1.44 (0.97-1.92)		91.8%	Scales
ME	ME C4	2021	0.86 (0.56-1.16)		28.3%	Scales
ME	ME C6	2020	1.85 (1.25-2.45)		97.6%	Scales
ME	ME C7	2021	1.97 (1.28-2.65)		98.1%	Scales
ME	ME C8	2020	0.99 (0.67-1.31)		53.1%	Scales
ME	ME C10	2021	0.99 (0.65-1.32)		51.2%	Scales
ME	ME C13	2020	1.75 (1.16-2.35)		96.9%	Scales
ME	ME C14	2021	0.73 (0.23-1.23)		18.9%	Scales
ME	ME C15	2021	1.64 (1.13-2.15)		96.0%	Scales
ME	ME C16	2020	1.72 (1.21-2.23)		97.0%	Scales
ME	ME N2	2019	2.18 (1.53-2.84)		99.1%	Scales
ME	ME N6	2021	1.89 (1.35-2.44)		98.1%	Scales
ME	ME N8	2021	1.36 (0.99-1.73)		91.5%	Scales
ME	ME N13	2021	1.29 (0.92-1.65)		87.7%	Scales
ME	ME N18	2019	1.99 (1.54-2.44)		98.7%	Scales
ME	ME N20	2019	1.17 (0.79-1.55)		77.0%	Scales
ME	ME N23	2019	0.77 (0.52-1.01)		12.1%	Scales
ME	ME N25	2019	1.15 (0.82-1.48)		76.7%	Scales
ME	ME N29	2021	1.48 (1.04-1.91)		93.9%	Scales
ME	ME N31	2021	0.84 (0.60-1.08)		22.0%	Scales
ME	ME N32	2021	1.85 (1.38-2.31)		98.1%	Scales
ME	ME N33	2021	0.87 (0.60-1.15)		29.1%	Scales
NH	Cocheco River	2021	0.54 (0.35-0.73)		0.1%	Scales
NH	Oyster River	2021	1.17 (0.97-1.36)		83.9%	Scales
NH	Lamprey River	2021	0.81 (0.63-0.99)		14.4%	Scales
NH	Exeter River	2021	1.21 (0.92-1.51)		85.2%	Scales
NH	Pickpocket River	2020	0.76 (0.45-1.06)		14.0%	Scales
NH	Winnicut River	2019	1.15 (0.90-1.39)		80.3%	Scales

Table 20. Number of rivers within each alewife stock-region that have a higher than 50% probability of being above the *Z* reference point.

Region	$Z_{40\%SPR}$ (95% CIs)	# of Rivers	# of Rivers $P(Z)>Z_{40SPR\%}$ >50%	% of Rivers $P(Z)>Z_{40SPR\%}$ >50%	Species
NNE	0.96 (0.76-1.67)	29	21	72.4%	ALE
SNE	0.98 (0.78-1.58)	9	7	77.8%	ALE
MAT	0.97 (0.76-1.54)	6	0	0.0%	ALE

Table 21. Total habitat (km^2), unobstructed habitat below first dams, difference in habitat, and percent reduction in habitat within stock-regions for alewife.

Region	Total habitat	Unobstructed	Difference	% Difference
NNE	2,684	380	2,304	86
SNE	912	166	746	82
MAT	3,933	1,404	2,529	64
Total	7,529	1,949	5,580	74

Table 22. Estimates of Z relative to $Z_{40\%SPR}$ for alewife in the SNE stock-region. $P(Z)>Z_{40\%SPR}$ is the probability that Z is above the $Z_{40\%SPR}$.

State	River	Terminal Year	Z (95% CIs)	Z40%SPR (95% CIs)	P(Z)> Z40%SPR	Ageing Structure
MA	Parker River	2022	0.88 (0.64-1.11)	0.97 (0.78-1.59)	26.8%	Otoliths
MA	Mystic River	2021	1.04 (0.77-1.31)		61.2%	Otoliths
MA	Back River	2022	1.37 (1.03-1.71)		92.4%	Otoliths
MA	Town Brook	2022	0.89 (0.72-1.06)		27.1%	Otoliths
MA	Monument River	2022	1.03 (0.67-1.39)		56.4%	Otoliths
MA	Nemasket River	2020	3.29 (2.65-3.93)		100.0%	Otoliths
RI	Nonquit River	2018	1.92 (1.49-2.35)		98.8%	Scales
RI	Gilbert-Stuart River	2017	1.01 (0.79-1.22)		54.7%	Scales
CT	Mattabesset River	2019	1.55 (1.11-2)		95.9%	Otoliths

Table 23. Mann-Kendall trend analysis results for full and recent time series of alewife mean length in the SNE and MAT stock-regions. N is the number of years in the time series, S is the Mann-Kendall statistic, and p is the two-tailed probability of significance. Shaded cells indicate a significant result.

				Full time series					Recent time series				
Region	**State**	**River**	**Sex**	**Trend**	**Years**	**N**	**S**	**p**	**Trend**	**Years**	**N**	**S**	**p**
SNE	MA	Parker	Female	No Trend	2012-2022	10	-9	0.47	No Trend	2012-2022	10	-9	0.47
SNE	MA	Parker	Male	No Trend	2012-2022	11	-1	1.00	No Trend	2012-2022	11	-1	1.00
SNE	MA	Mystic	Female	**Positive**	2004-2022	16	64	0.005	No Trend	2011-2022	12	18	0.24
SNE	MA	Mystic	Male	**Positive**	2004-2022	16	66	0.003	No Trend	2011-2022	12	18	0.24
SNE	MA	Town Brook	Female	No Trend	2004-2022	18	45	0.10	No Trend	2010-2022	13	2	0.95
SNE	MA	Town Brook	Male	No Trend	2004-2022	18	15	0.60	No Trend	2010-2022	13	-10	0.58
SNE	MA	Monument	Female	No Trend	1993-2022	29	46	0.40	No Trend	2010-2022	13	12	0.50
SNE	MA	Monument	Male	No Trend	1993-2022	29	4	0.96	No Trend	2010-2022	13	12	0.50
SNE	MA	Nemasket	Female	No Trend	2004-2022	19	9	0.78	No Trend	2010-2022	13	-16	0.36
SNE	MA	Nemasket	Male	No Trend	2004-2022	19	-11	0.73	No Trend	2010-2022	13	-8	0.67
MAT	NY	Hudson	Female	**Positive**	2001-2022	17	56	0.02	No Trend	2010-2022	12	28	0.06
MAT	NY	Hudson	Male	No Trend	1990-2022	21	28	0.41	No Trend	2010-2022	12	26	0.09
MAT	MD	Nanticoke	Female	No Trend	1989-2021	29	-52	0.34	No Trend	2010-2021	10	11	0.37
MAT	MD	Nanticoke	Male	No Trend	1989-2021	28	-72	0.16	-	-	-	-	-
MAT	NC DMF	Chowan	Female	**Negative**	1972-2021	37	-260	0.001	No Trend	2010-2021	12	2	0.95
MAT	NC DMF	Chowan	Male	**Negative**	1972-2021	38	-267	0.001	No Trend	2010-2021	12	10	0.54
MAT	NC DMF	Roanoke	Female	No Trend	1973-2019	14	-7	0.74	-	-	-	-	-
MAT	NC DMF	Roanoke	Male	No Trend	1973-2019	13	2	0.95	-	-	-	-	-

Table 24. Results of the Mann-Kendall test for alewife trends in mean length by river (state), species, sex and age in the SNE region. N = sample size, S is the Mann-Kendall test statistics, and p is the two-tailed probability. Shaded cells indicate a significant result.

						Full time series					Recent time series				
Region	**State**	**River**	**Sex**	**Age**	**Structure**	**Trend**	**Years**	**N**	**S**	**p**	**Trend**	**Years**	**N**	**S**	**p**
SNE	MA	Parker	Female	3	Oto	No Trend	2012-2022	10	-11	0.37	No Trend	2012-2022	10	-11	0.37
SNE	MA	Parker	Female	4	Oto	No Trend	2012-2022	10	-11	0.37	No Trend	2012-2022	10	-11	0.37
SNE	MA	Parker	Female	5	Oto	No Trend	2012-2022	10	-19	0.11	No Trend	2012-2022	10	-19	0.11
SNE	MA	Parker	Male	3	Oto	No Trend	2012-2022	11	-9	0.53	No Trend	2012-2022	11	-9	0.53
SNE	MA	Parker	Male	4	Oto	No Trend	2012-2022	11	-13	0.35	No Trend	2012-2022	11	-13	0.35
SNE	MA	Parker	Male	5	Oto	No Trend	2012-2022	11	-9	0.53	No Trend	2012-2022	11	-9	0.53
SNE	MA	Mystic	Female	3	Oto	No Trend	2012-2022	11	-5	0.76	No Trend	2012-2022	11	-5	0.76
SNE	MA	Mystic	Female	4	Oto	No Trend	2012-2022	11	5	0.76	No Trend	2012-2022	11	5	0.76
SNE	MA	Mystic	Female	5	Oto	No Trend	2012-2022	11	3	0.88	No Trend	2012-2022	11	3	0.88
SNE	MA	Mystic	Male	3	Oto	No Trend	2012-2022	11	-3	0.88	No Trend	2012-2022	11	-3	0.88
SNE	MA	Mystic	Male	4	Oto	No Trend	2012-2022	11	17	0.21	No Trend	2012-2022	11	17	0.21
SNE	MA	Mystic	Male	5	Oto	No Trend	2012-2022	10	-5	0.72	No Trend	2012-2022	10	-5	0.72
SNE	MA	Town Brook	Female	3	Oto	No Trend	2013-2022	10	-11	0.37	No Trend	2013-2022	10	-11	0.37
SNE	MA	Town Brook	Female	4	Oto	No Trend	2013-2022	10	-1	1.00	No Trend	2013-2022	10	-1	1.00
SNE	MA	Town Brook	Female	5	Oto	No Trend	2013-2022	10	9	0.47	No Trend	2013-2022	10	9	0.47
SNE	MA	Town Brook	Female	6	Oto	No Trend	2013-2022	10	-4	0.79	No Trend	2013-2022	10	-4	0.79
SNE	MA	Town Brook	Male	3	Oto	No Trend	2013-2022	10	-11	0.37	No Trend	2013-2022	10	-11	0.37
SNE	MA	Town Brook	Male	4	Oto	No Trend	2013-2022	10	5	0.72	No Trend	2013-2022	10	5	0.72
SNE	MA	Town Brook	Male	5	Oto	No Trend	2013-2022	10	3	0.86	No Trend	2013-2022	10	3	0.86
SNE	MA	Monument	Female	3	Oto	No Trend	2013-2022	10	-9	0.47	No Trend	2013-2022	10	-9	0.47
SNE	MA	Monument	Female	4	Oto	No Trend	2013-2022	10	3	0.86	No Trend	2013-2022	10	3	0.86
SNE	MA	Monument	Male	3	Oto	No Trend	2013-2022	10	-3	0.86	No Trend	2013-2022	10	-3	0.86
SNE	MA	Monument	Male	4	Oto	No Trend	2013-2022	10	7	0.59	No Trend	2013-2022	10	7	0.59
SNE	MA	Nemasket	Female	3	Oto	No Trend	2012-2022	11	-11	0.44	No Trend	2012-2022	11	-11	0.44
SNE	MA	Nemasket	Female	4	Oto	No Trend	2012-2022	11	-17	0.21	No Trend	2012-2022	11	-17	0.21
SNE	MA	Nemasket	Female	5	Oto	**Negative**	2012-2022	11	-29	0.03	**Negative**	2012-2022	11	-29	0.03
SNE	MA	Nemasket	Male	3	Oto	No Trend	2012-2022	11	-15	0.28	No Trend	2012-2022	11	-15	0.28
SNE	MA	Nemasket	Male	4	Oto	No Trend	2012-2022	11	-13	0.35	No Trend	2012-2022	11	-13	0.35
SNE	MA	Nemasket	Male	5	Oto	No Trend	2012-2022	11	-25	0.06	No Trend	2012-2022	11	-25	0.06

Table 25. Results of the Mann-Kendall test for alewife trends in mean length by river (state), species, sex and age in the MAT region. N = sample size, S is the Mann-Kendall test statistics, and p is the two-tailed probability. Shaded cells indicate a significant result.

						Full time series					Recent time series				
Region	**State**	**River**	**Sex**	**Age**	**Structure**	**Trend**	**Years**	**N**	**S**	**p**	**Trend**	**Years**	**N**	**S**	**p**
MAT	MD	Nanticoke	Female	3	Scale	No Trend	1989-2019	13	2	0.95	-	-	-	-	-
MAT	MD	Nanticoke	Female	4	Scale	No Trend	1989-2021	29	-36	0.51	No Trend	2010-2021	10	7	0.59
MAT	MD	Nanticoke	Female	5	Scale	No Trend	1989-2021	29	-64	0.24	No Trend	2010-2021	10	11	0.37
MAT	MD	Nanticoke	Female	6	Scale	No Trend	1989-2021	29	-50	0.36	No Trend	2010-2021	10	17	0.15
MAT	MD	Nanticoke	Female	7	Scale	**Negative**	1989-2021	24	-86	0.03	-	-	-	-	-
MAT	MD	Nanticoke	Male	3	Scale	No Trend	1989-2019	23	-55	0.15	-	-	-	-	-
MAT	MD	Nanticoke	Male	4	Scale	No Trend	1989-2021	28	-62	0.23	-	-	-	-	-
MAT	MD	Nanticoke	Male	5	Scale	**Negative**	1989-2021	28	-104	0.04	-	-	-	-	-
MAT	MD	Nanticoke	Male	6	Scale	No Trend	1989-2021	26	-19	0.69	-	-	-	-	-
MAT	NC	Chowan	Female	3	Scale	**Negative**	1972-2018	10	-25	0.03	-	-	-	-	-
MAT	NC	Chowan	Female	4	Scale	**Negative**	1972-2021	36	-322	0.00	No Trend	2010-2021	12	-6	0.73
MAT	NC	Chowan	Female	5	Scale	**Negative**	1972-2021	36	-270	0.00	No Trend	2010-2021	12	-4	0.84
MAT	NC	Chowan	Female	6	Scale	**Negative**	1972-2021	34	-153	0.02	No Trend	2010-2021	12	2	0.95
MAT	NC	Chowan	Female	7	Scale	No Trend	1972-2021	20	-48	0.13	No Trend	2010-2021	10	11	0.37
MAT	NC	Chowan	Male	3	Scale	**Negative**	1972-2021	28	-234	0.00	No Trend	2011-2021	10	-9	0.47
MAT	NC	Chowan	Male	4	Scale	**Negative**	1972-2021	38	-403	0.00	No Trend	2010-2021	12	-12	0.45
MAT	NC	Chowan	Male	5	Scale	**Negative**	1972-2021	38	-283	0.00	No Trend	2010-2021	12	-4	0.84
MAT	NC	Chowan	Male	6	Scale	**Negative**	1972-2021	29	-114	0.03	No Trend	2010-2021	11	15	0.28
MAT	NC	Chowan	Male	7	Scale	No Trend	1980-2021	11	5	0.76	-	-	-	-	-

Table 26. Repeat spawner trends for alewife from the MAT stock-region by sex. The number and range of years is the maximum of the available time series by sex and some river-sex combinations may be shorter than what is listed. Recent time series results are not presented when the full time series is equal to or shorter than the recent time series cutoffs. Shaded cells indicate significant results.

				Full time series					Recent time series				
State	**River**	**Sex**	**Survey Type**	**Trend**	**Number of Years**	**Years**	**Mann-Kendall value**	**p -value**	**Trend**	**Number of Years**	**Years**	**Mann-Kendall value**	**p -value**
NY	Hudson	Female	FI	**Positive**	12	2009-2022	30	0.05	No Trend	11	2010-2022	25	0.06
NY	Hudson	Male	FI	**Positive**	12	2009-2022	38	0.01	**Positive**	11	2010-2022	33	0.01
MD	Nanticoke	Female	FD	**Negative**	29	1989-2021	-112	0.04	**Negative**	10	2010-2021	-23	0.05
MD	Nanticoke	Male	FD	**Negative**	29	1989-2021	-138	0.01	No Trend	10	2010-2021	-1	1.00
NC DMF	Chowan	Female	FD	**Positive**	42	1972-2021	266	0.00	No Trend	12	2010-2021	-8	0.63
NC DMF	Chowan	Male	FD	**Positive**	42	1972-2021	233	0.01	No Trend	12	2010-2021	6	0.73
NC DMF	Scuppernong	Female	Both	No Trend	23	1972-2012	62	0.11	-	-	-	-	-
NC DMF	Scuppernong	Male	Both	No Trend	23	1972-2009	27	0.49	-	-	-	-	-
NC DMF	Alligator	Female	Both	No Trend	27	1972-2017	22	0.66	-	-	-	-	-
NC DMF	Alligator	Male	Both	No Trend	26	1972-2019	1	1.00	-	-	-	-	-

Table 27. Estimates of Z relative to $Z_{40\%SPR}$ for alewife in the MAT stock-region. $P(Z)>Z_{40\%SPR}$ is the probability that Z is above the $Z_{40\%SPR}$.

State	River	Terminal Year	Z (95% CIs)	$Z_{40\%SPR}$ (95% CIs)	$P(Z)>Z_{40\%SPR}$	Ageing Structure
NY	Hudson River	2022	0.5 (0.37-0.62)	0.97 (0.76-1.56)	0.0%	Otoliths
MD	Nanticoke River	2021	0.94 (0.76-1.11)		39.8%	Scales
MD	North East River	2021	0.95 (0.81-1.09)		42.4%	Scales
VA	Rappahannock River	2021	0.92 (0.75-1.09)		35.8%	Otoliths
VA	James River	2021	0.9 (0.76-1.05)		29.7%	Otoliths
NC	Chowan River	2021	0.73 (0.58-0.88)		3.1%	Scales

Table 28. Summary of abundance and Z trends for alewife by stock-region and river.

Stock-Region	River	Ages	Years	Mann-Kendall Trend (time series)	Mann-Kendall Trend (2009+)	p(I>Q25)	p(I>I2009)	p(Z > Z40%)
CAN-NNE	**St. Croix**							
	Run counts (mixed spp)	Adults	1981-2022	n.s.	n.s.	100%	100%	
NNE	**Union**							
	Run counts	Adults	1982-2022	↑	n.s.	98%	95%	
NNE	**Damariscotta**							
	Run counts	Adults	1977-2021	↑	↑	96%	97%	
NNE	**Kennebec**							
	Run counts (mixed spp)	Adults	2006-2022	↑	n.s.	95%	95%	
NNE	**Penobscot**							
	Run counts (mixed spp)	Adults	2015-2022	n.s.	n.s.			
NNE	**Saco**							
	Run counts (mixed spp)	Adults	1993-2021	↑	↑	99%	98%	
NNE	**Sebasticook**							
	Run counts (mixed spp)	Adults	2000-2021	↑	↑	100%	100%	
NNE	**Androscoggin**							
	Run counts (mixed spp)	Adults	1983-2022	↑	n.s.	97%	94%	
NNE	**Merrymeeting Bay**							
	ME DMR Juvenile Alosine Seine Survey	YOY	1982-2021	n.s.	↑	97%	83%	
NNE	**Cocheco**							
	Run counts	Adults	2004-2021	n.s.	n.s.	0%	0%	1.2%
NNE	**Exeter**							
	Run counts	Adults	2004-2016	↑	n.s.	100%	100%	73%
NNE	**Lamprey**							
	Run counts	Adults	2004-2021	n.s.	n.s.	92%	91%	21%
NNE	**Oyster**							
	Run counts	Adults	2004-2021	↑	n.s.	95%	89%	84%
NNE	**Hamton-Seabrook/Great Bay Estuaries**							
	NH Juvenile Finfish Survey	YOY	1997-2021	n.s.	n.s.	100%	98%	
SNE	**Agawam**							
	Run counts (mixed spp)	Adults	2006-2021	n.s.	n.s.	97%	94%	

Stock-Region	River	Ages	Years	Mann-Kendall Trend (time series)	Mann-Kendall Trend (2009+)	p(I>Q25)	p(I>I2009)	p(Z > Z40%)
SNE	**Back**							
	Run counts (mixed spp)	Adults	1986-2021	n.s.	n.s.	85%	83%	93%
SNE	**Herring**							
	Run counts (mixed spp)	Adults	2012-2021	n.s.	n.s.	100%		
SNE	**Mattapoissett**							
	Run counts (mixed spp)	Adults	1988-2021	↓	n.s.	4%	4%	
SNE	**Monument**							
	Run counts (mixed spp)	Adults	1980-2021	n.s.	n.s.	64%	70%	55%
SNE	**Mystic**							
	Run counts (mixed spp)	Adults	2012-2021	↑	n.s.			54%
SNE	**Nemasket**							
	Run counts (mixed spp)	Adults	2012-2021	↑	n.s.	95%	94%	100%
SNE	**Parker**							
	Run counts (mixed spp)	Adults	2013-2022	*	*	*	*	33%
SNE	**Stony Brook**							
	Run counts (mixed spp)	Adults	2007-2019	n.s.	n.s.	95%	95%	
SNE	**Town Brook**							
	Run counts (mixed spp)	Adults	2011-2021	n.s.	n.s.	79%		35%
SNE	**Wankinco**							
	Run counts (mixed spp)	Adults	2007-2021	↑	n.s.	100%	100%	
SNE	**Nonquit**							
	Run counts	Adults	1999-2022	↓	n.s.	18%	16%	99%
SNE	**Gilbert-Stuart**							
	Run counts	Adults	1999-2021	n.s.	n.s.	81%	63%	
SNE	**Buckeye Brook**							
	Run counts	Adults	2003-2021	n.s.	n.s.	100%	99%	
SNE	**Hunt Forge**							
	Run counts	Adults	2010 - 2021	n.s.	n.s.	79%		
SNE	**Ten Mile**							
	Run counts	Adults	2015-2021	n.s.	n.s.			
SNE	**Woonasquatucket**							

Stock-Region	River	Ages	Years	Mann-Kendall Trend (time series)	Mann-Kendall Trend (2009+)	p(I>Q25)	p(I>I2009)	p(Z > Z40%)
	Run counts	Adults	2010-2021	n.s.	n.s.	87%		
SNE	**Narrow**							
	RI Coastal Ponds Survey	YOY	1994-2022	n.s.	n.s.	29%	6%	
SNE	**Bride Lake**							
	Run counts	Adults	2011-2022	n.s.	n.s.	99%		
SNE	**East**							
	Run counts	Adults	2015-2021	n.s.	n.s.			
SNE	**Eight Mile**							
	Run counts	Adults	2014-2021	n.s.	n.s.			
SNE	**Latimer Brook**							
	Run counts	Adults	2006-2022	↑	n.s.	82%	84%	
SNE	**Mianus**							
	Run counts	Adults	2008-2021	↓	n.s.			
SNE	**Mill Brook**							
	Run counts	Adults	2003-2022	n.s.	n.s.	91%	89%	
SNE	**Pequonnock**							
	Run counts	Adults	2014-2021	n.s.	n.s.			
SNE	**Queach Brook**							
	Run counts	Adults	2006-2022	↓	n.s.	29%	25%	
SNE	**Quinnipiac**							
	Run counts	Adults	2013-2022	↓	n.s.	25%		
SNE	**Shetucket**							
	Run counts	Adults	2007-2022	n.s.	n.s.	85%	37%	
MAT	**Hudson**							
	NY DEC 300' Haul Seine Survey	Adults	2012-2022	n.s.	n.s.	91%	97%	0.4%
	NY DEC Juvenile Beach Seine	YOY	1980-2022	↑	n.s.	97%	26%	
MAT	**Delaware Bay/River**							
	DE Bay 30' Trawl	Age-1	1990-2021	n.s.	n.s.	93%	84%	
	DE Bay 16' Trawl	Age-1	1991-2021	↓	n.s.	77%	61%	
	NJ Striped Bass Seine Survey	YOY	1987-2021	↓	n.s.	66%	58%	
MAT	**Nanticoke**							

Stock-Region	River	Ages	Years	Mann-Kendall Trend (time series)	Mann-Kendall Trend (2009+)	p(I>Q25)	p(I>I2009)	p(Z > Z40%)
	MD Commercial CPUE	Adults	1991-2021	↓	n.s.	36%	20%	40%
	MD DNR Juvenile Estuarine Finfish Survey	YOY	1959-2021	↓	n.s.	68%	38%	
	DE Juvenile Seine Survey	YOY	1999-2021	n.s.	n.s.	14%	35%	
MAT	**North East**							
	MD Gillnet Survey	Adults	2015-2021	n.s.	n.s.	75%		43%
MAT	**Choptank**							
	MD DNR Juvenile Estuarine Finfish Survey	YOY	1959-2021	n.s.	n.s.	73%	71%	
MAT	**Potomac**							
	MD DNR Juvenile Estuarine Finfish Survey	YOY	1959-2021	n.s.	n.s.	82%	85%	
MAT	**Appomattox**							
	VA DWR Electrofishing Survey	Adults	2000-2018	n.s.	n.s.	11%	14%	
MAT	**James**							
	VA DWR Electrofishing Survey	Adults	2002-2022	n.s.	n.s.	98%	92%	
	VIMS River Herring Gillnet Survey	Adults	2015-2021	n.s.	n.s.	80%		32%
MAT	**Chickahominy**							
	VA DWR Electrofishing Survey	Adults	2011-2022	n.s.	n.s.	74%		
	VIMS Surface Trawl Survey	YOY	2014-2022	n.s.	n.s.	65%		
MAT	**Rappahannock**							
	VA DWR Electrofishing Survey	Adults	2001-2022	n.s.	n.s.	90%	40%	38%
MAT	**Albemarle Sound**							
	NC DMF P135 Gillnet Survey	Adults	1991-2019	↑	n.s.	100%	94%	
	NC DMF P100 Seine Survey	YOY	1972-2021	n.s.	n.s.	89%	83%	
MAT	**Chowan**							
	NC WRC Electrofishing Survey	Adults	2006-2022	↑	n.s.	100%	100%	9%
MAT	**Neuse**							
	NC WRC Electrofishing Survey	Adults	2006-2022	↑	n.s.	100%	100%	50%

Table 29. Total habitat (km^2), unobstructed habitat below first dams, difference in habitat, and percent reduction in habitat within HUC4 watersheds for alewife.

HUC4 watershed	Total habitat	Unobstructed	Difference	% Difference
Androscoggin	188	5	184	97
Cape Fear	154	58	95	62
Chowan-Roanoke	301	191	110	36
Connecticut	231	32	198	86
Connecticut Coastal	328	30	298	91
Delaware-Mid Atlantic Coastal	740	187	552	75
Kennebec	405	56	349	86
Lower Chesapeake	522	201	321	61
Lower Hudson-Long Island	280	62	218	78
Maine Coastal	897	249	648	72
Massachusetts-RI Coastal	302	87	215	71
Merrimack	490	3	487	99
Neuse-Pamlico	468	304	164	35
Pee Dee	234	160	74	32
Penobscot	263	41	222	85
Potomac	163	82	81	50
Saco	473	27	447	94
Southeastern Lake Ontario	<1	<1	<1	56
Susquehanna	721	12	709	98
Upper Chesapeake	125	71	54	43
Upper Hudson	246	91	155	63

Table 30. Estimated coastwide parameters from the sex-specific von Bertalanffy growth functions for alewife by ageing structure and sex. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals.

Structure	Parameter	Female	Male
Otolith	K	0.47 (0.36—0.73)	0.50 (0.39—0.78)
	L_∞	319.95 (288.36—343.37)	305.35 (275.19—327.70)
	t_0	-0.52 (-0.69—-0.22)	-0.51 (-0.69—-0.21)
Scale	K	0.48 (0.37—0.76)	0.52 (0.40—0.81)
	L_∞	311.04 (280.35—333.78)	296.84 (267.55—318.54)
	t_0	-0.52 (-0.69—-0.22)	-0.51 (-0.68—-0.21)

Table 31. Coastwide bycatch caps for alewife and blueback herring produced using different methods and input data.

Index	Method	Alewife Cap	Blueback Herring Cap
NEFSC & NEAMAP	iSmooth	79.9	31.5
	iSlope 1	85.2	41.4
	iSlope 2	74.5	36.3
	iSlope 3	63.9	31.1
	iSlope 4	64.9	38.2
Stock-Region Run Counts	iSmooth	34.4	20.9
	iSlope 1	79.2	55.7
	iSlope 2	69.3	48.8
	iSlope 3	59.4	41.8
	iSlope 4	62.6	43.6

Table 32. Estimated regional parameters from the sex-specific von Bertalanffy growth functions for blueback herring stock-regions by aging structure and sex. Parameters included Brody growth coefficient (K), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals.

Region	Structure	Parameter	Female	Male
CAN-NNE	Otolith	K	0.53 (0.41—0.68)	0.60 (0.46—0.76)
		L_∞	289.19 (261.89—318.77)	272.29 (246.57—300.14)
		t_0	-0.43 (-0.57—-0.32)	-0.41 (-0.55—-0.31)
	Scale	K	0.59 (0.46—0.75)	0.67 (0.52—0.85)
		L_∞	279.99 (253.57—308.65)	263.63 (238.74—290.59)
		t_0	-0.40 (-0.55—-0.30)	-0.38 (-0.53—-0.28)
SNE	Otolith	K	-0.36 (-0.46—-0.31)	-0.34 (-0.44—-0.29)
		L_∞	299.61 (284.44—309.30)	282.11 (267.87—291.24)
		t_0	-0.38 (-0.51—-0.30)	-0.37 (-0.50—-0.29)
	Scale	K	0.63 (0.52—0.79)	0.71 (0.59—0.89)
		L_∞	290.22 (275.24—299.40)	273.27 (259.20—281.90)
		t_0	-0.36 (-0.49—-0.28)	-0.34 (-0.47—-0.26)
MNE	Otolith	K	0.57 (0.47—0.71)	0.64 (0.53—0.80)
		L_∞	0.66 (0.43—0.74)	0.74 (0.49—0.83)
		t_0	271.73 (269.27—298.92)	255.77 (253.57—281.39)
	Scale	K	-0.38 (-0.49—-0.33)	-0.36 (-0.47—-0.32)
		L_∞	0.73 (0.48—0.83)	0.82 (0.54—0.93)
		t_0	263.29 (260.63—289.36)	247.86 (245.44—272.40)
MAT	Otolith	K	0.51 (0.35—0.84)	0.57 (0.40—0.95)
		L_∞	305.20 (282.09—336.69)	287.35 (265.60—317.02)
		t_0	-0.39 (-0.77—-0.30)	-0.37 (-0.75—-0.28)
	Scale	K	0.56 (0.39—0.94)	0.64 (0.44—1.05)
		L_∞	295.54 (273.15—326.03)	278.25 (257.20—306.99)
		t_0	-0.36 (-0.75—-0.27)	-0.34 (-0.73—-0.25)
SAT	Otolith	K	0.59 (0.54—0.82)	0.66 (0.61—0.92)
		L_∞	301.35 (284.68—317.42)	283.74 (268.03—298.85)
		t_0	-0.35 (-0.42—-0.25)	-0.34 (-0.40—-0.23)
	Scale	K	0.65 (0.60—0.91)	0.74 (0.68—1.02)
		L_∞	291.76 (275.79—307.23)	274.72 (259.67—289.23)
		t_0	-0.33 (-0.40—-0.23)	-0.31 (-0.38—-0.21)

Table 33. Mann-Kendall trend analysis results for full and recent time series of blueback herring mean length. N is the number of years in the time series, S is the Mann-Kendall statistic, and p is the two-tailed probability of significance.

				Full time series					**Recent time series**				
Region	**State**	**River**	**Sex**	**Trend**	**Years**	**N**	**S**	**p**	**Trend**	**Years**	**N**	**S**	**p**
CAN-NNE				*Insufficient data for time-series analysis*									
MNE	NH	Oyster	Female	**Negative**	1992-2021	30	-115	0.04	No Trend	2010-2021	12	22	0.15
MNE	NH	Oyster	Male	**Negative**	1992-2021	30	-151	0.01	-	-	-	-	-
MNE	MA	Parker	Male	No Trend	2011-2022	11	5	0.76	No Trend	2011-2022	11	5	0.76
SNE	MA	Mystic	Female	No Trend	2005-2022	18	31	0.26	No Trend	2010-2022	13	2	0.95
SNE	MA	Mystic	Male	**Positive**	2005-2022	18	59	0.03	No Trend	2010-2022	13	12	0.50
SNE	MA	Monument	Female	No Trend	1997-2022	22	-17	0.65	No Trend	2010-2022	13	20	0.25
SNE	MA	Monument	Male	No Trend	1997-2022	24	36	0.39	No Trend	2010-2022	13	22	0.20
MAT	NY	Hudson	Female	No Trend	2012-2022	10	7	0.59	No Trend	2012-2022	10	7	0.59
MAT	NY	Hudson	Male	**Positive**	2010-2022	12	40	0.01	**Positive**	2010-2022	12	40	0.01
MAT	MD	Nanticoke	Female	**Negative**	1989-2021	27	-149	0.00	-	-	-	-	-
MAT	MD	Nanticoke	Male	**Negative**	1989-2019	25	-130	0.00	-	-	-	-	-
MAT	NC	Chowan	Female	**Negative**	1972-2021	50	-519	0.00	**Positive**	2010-2021	12	48	0.00
MAT	NC	Chowan	Male	**Negative**	1972-2021	50	-581	0.00	**Positive**	2010-2021	12	50	0.00
MAT	NC	Roanoke	Female	No Trend	1972-2019	20	-40	0.21	-	-	-	-	-
MAT	NC	Roanoke	Male	No Trend	1972-2019	14	3	0.91	-	-	-	-	-
MAT	NC	Neuse	Female	No Trend	1978-2021	16	-4	0.89	**Positive**	2010-2021	11	41	0.00
MAT	NC	Neuse	Male	No Trend	1978-2021	16	4	0.89	**Positive**	2010-2021	11	43	0.00
SAT	NC	Cape Fear	Male	**Positive**	2006-2021	14	57	0.00	**Positive**	2010-2021	11	45	0.00
SAT	SC	Santee-Cooper	Female	**Positive**	2011-2021	10	27	0.02	**Positive**	2011-2021	10	27	0.02
SAT	SC	Santee-Cooper	Male	**Positive**	2011-2021	11	31	0.02	**Positive**	2011-2021	11	31	0.02

Table 34. Results of the Mann-Kendall test for blueback herring trends in mean length-at-age by river, species, sex and age in the MNE and SNE stock-regions. N = sample size, S is the Mann-Kendall test statistics, and p is the two-tailed probability. Shaded cells indicate a significant result.

						Full time series					Recent time series				
Region	**State**	**River**	**Sex**	**Age**	**Structure**	**Trend**	**Years**	**N**	**S**	**p**	**Trend**	**N**	**Years**	**S**	**p**
MNE	NH	Oyster	Female	3	Scale	**Negative**	1992-2011	13	-38	0.02	-	-	-	-	-
MNE	NH	Oyster	Female	4	Scale	**Negative**	1992-2016	22	-81	0.02	-	-	-	-	-
MNE	NH	Oyster	Female	5	Scale	**Negative**	1993-2016	22	-105	0.00	-	-	-	-	-
MNE	NH	Oyster	Female	6	Scale	**Negative**	1992-2016	11	-31	0.02	-	-	-	-	-
MNE	NH	Oyster	Male	3	Scale	**Negative**	1992-2017	21	-136	0.00	-	-	-	-	-
MNE	NH	Oyster	Male	4	Scale	**Negative**	1992-2020	25	-166	0.00	-	-	-	-	-
MNE	NH	Oyster	Male	5	Scale	**Negative**	1992-2020	24	-122	0.00	-	-	-	-	-
MNE	NH	Oyster	Male	6	Scale	No Trend	1992-2020	10	-11	0.37	-	-	-	-	-
MNE	MA	Parker	Male	3	Oto	No Trend	2012-2022	10	-9	0.47	No Trend	2012-2022	10	-9	0.47
MNE	MA	Parker	Male	4	Oto	No Trend	2012-2022	10	3	0.86	No Trend	2012-2022	10	3	0.86
SNE	MA	Mystic	Female	3	Oto	No Trend	2012-2022	11	-13	0.35	No Trend	2012-2022	11	-13	0.35
SNE	MA	Mystic	Female	4	Oto	No Trend	2012-2022	10	3	0.86	No Trend	2012-2022	10	3	0.86
SNE	MA	Mystic	Male	3	Oto	No Trend	2012-2022	11	1	1.00	No Trend	2012-2022	11	1	1.00
SNE	MA	Mystic	Male	4	Oto	No Trend	2012-2022	11	9	0.53	No Trend	2012-2022	11	9	0.53
SNE	MA	Monument	Female	3	Oto	No Trend	2013-2022	10	-11	0.37	No Trend	2013-2022	10	-11	0.37
SNE	MA	Monument	Female	4	Oto	No Trend	2013-2022	10	-3	0.86	No Trend	2013-2022	10	-3	0.86
SNE	MA	Monument	Male	3	Oto	No Trend	2013-2022	10	-11	0.37	No Trend	2013-2022	10	-11	0.37
SNE	MA	Monument	Male	4	Oto	No Trend	2013-2022	10	-3	0.86	No Trend	2013-2022	10	-3	0.86

Table 35. Repeat spawner trends for blueback herring by stock-region and sex. The number and range of years is the maximum of the available time series by sex and some river-sex combinations may be shorter than what is listed. Recent time series results are not presented when the full time series is equal to or shorter than the recent time series, or does not include data since the last assessment update.

					Full time series					Recent time series				
Region	**State**	**River**	**Sex**	**Survey Type**	**Trend**	**Number of Years**	**Years**	**Mann-Kendall value**	**p - value**	**Trend**	**Number of Years**	**Years**	**Mann-Kendall value**	**p - value**
NNE	ME	ME C10	Female	FD	No Trend	11	2010-2021	15	0.28	No Trend	11	2010-2021	15	0.28
	ME	ME C10	Male	FD	No Trend	12	2009-2021	3	0.89	No Trend	11	2010-2021	-4	0.81
MNE	NH	Oyster	Female	FI	No Trend	22	2000-2021	-33	0.37	No Trend	12	2010-2021	-16	0.30
	NH	Oyster	Male	FI	No Trend	22	2000-2021	-43	0.24	No Trend	12	2010-2021	-20	0.19
	NH	Winnicut	Male	FI	No Trend	12	2000-2019	8	0.63	-	-	-	-	-
SNE	MA	Monument	Female	FI	No Trend	19	1993-2013	-4	0.92	-	-	-	-	-
	MA	Monument	Male	FI	No Trend	20	1993-2013	-18	0.58	-	-	-	-	-
MAT	NY	Hudson	Female	Both	No Trend	11	1989-2022	15	0.28	-	-	-	-	-
	NY	Hudson	Male	FI	No Trend	14	1989-2022	27	0.15	**Positive**	11	2010-2022	33	0.01
	MD	Nanticoke	Female	FD	**Negative**	28	1989-2021	-175	0.00	No Trend	10	2010-2021	-11	0.37
	MD	Nanticoke	Male	FD	**Negative**	26	1989-2019	-169	0.00	-	-	-	-	-
	NC	Chowan	Female	FD	No Trend	50	1972-2021	-21	0.87	No Trend	12	2010-2021	-2	0.95
	NC	Chowan	Male	FD	No Trend	50	1972-2021	-18	0.89	No Trend	12	2010-2021	-10	0.54
	NC	Roanoke	Female	Both	No Trend	11	1972-2019	3	0.88	-	-	-	-	-
	NC	Scuppernong	Female	Both	No Trend	23	1972-2009	51	0.19	-	-	-	-	-
	NC	Scuppernong	Male	Both	**Positive**	23	1972-2009	77	0.04	-	-	-	-	-
SAT	SC	Santee-Cooper	Female	FD	**Positive**	11	2011-2021	39	0.00	**Positive**	11	2011-2021	39	0.00
	SC	Santee-Cooper	Male	FD	**Positive**	11	2011-2021	41	0.00	**Positive**	11	2011-2021	41	0.00

Table 36. Results of the Mann-Kendall test for blueback herring trends in mean length-at-age by river, species, sex and age in the MAT and SAT stock-regions. N = sample size, S is the Mann-Kendall test statistics, and p is the two-tailed probability. Shaded cells indicate a significant result.

						Full time series					Recent time series				
Region	**State**	**River**	**Sex**	**Age**	**Structure**	**Trend**	**Years**	**N**	**S**	**p**	**Trend**	**N**	**Years**	**S**	**p**
MAT	MD	Nanticoke	Female	4	Scale	No Trend	1989-2019	23	-37	0.34	-	-	-	-	-
MAT	MD	Nanticoke	Female	5	Scale	No Trend	1989-2019	23	-43	0.27	-	-	-	-	-
MAT	MD	Nanticoke	Female	6	Scale	**Negative**	1989-2019	19	-61	0.04	-	-	-	-	-
MAT	MD	Nanticoke	Male	3	Scale	No Trend	1989-2019	19	15	0.62	-	-	-	-	-
MAT	MD	Nanticoke	Male	4	Scale	No Trend	1989-2019	24	-10	0.82	-	-	-	-	-
MAT	MD	Nanticoke	Male	5	Scale	No Trend	1989-2019	23	-33	0.40	-	-	-	-	-
MAT	MD	Nanticoke	Male	6	Scale	No Trend	1989-2019	15	-17	0.43	-	-	-	-	-
MAT	NC	Chowan	Female	3	Scale	**Negative**	1972-2020	18	-75	0.01	No Trend	2010-2020	10	1	1.00
MAT	NC	Chowan	Female	4	Scale	**Negative**	1972-2021	48	-642	0.00	No Trend	2010-2021	12	4	0.84
MAT	NC	Chowan	Female	5	Scale	**Negative**	1972-2021	50	-569	0.00	No Trend	2010-2021	12	22	0.15
MAT	NC	Chowan	Female	6	Scale	**Negative**	1972-2021	45	-412	0.00	No Trend	2010-2021	12	26	0.09
MAT	NC	Chowan	Female	7	Scale	No Trend	1973-2016	14	-23	0.23	-	-	-	-	-
MAT	NC	Chowan	Male	3	Scale	**Negative**	1972-2020	33	-274	0.00	**Positive**	2010-2020	10	23	0.05
MAT	NC	Chowan	Male	4	Scale	**Negative**	1972-2021	49	-782	0.00	No Trend	2010-2021	12	8	0.63
MAT	NC	Chowan	Male	5	Scale	**Negative**	1972-2021	49	-586	0.00	No Trend	2010-2021	12	24	0.11
MAT	NC	Chowan	Male	6	Scale	**Negative**	1972-2021	32	-226	0.00	-	-	-	-	-
SAT	SC	Santee-Cooper	Female	5	Scale	No Trend	2011-2021	10	21	0.07	No Trend	2011-2021	10	21	0.07
SAT	SC	Santee-Cooper	Male	5	Scale	**Positive**	2011-2021	11	27	0.04	**Positive**	2011-2021	11	27	0.04
SAT	SC	Santee-Cooper	Male	6	Scale	No Trend	2011-2021	10	21	0.07	No Trend	2011-2021	10	21	0.07

Table 37. Estimates of Z relative to $Z_{40\%SPR}$ for blueback herring by stock-region. P(Z)>$Z_{40\%SPR}$ is the probability that Z is above the $Z_{40\%SPR}$.

Region	State	River	Terminal Year	Z (95% CIs)	Z40%SPR (95% CIs)	P(Z)> $Z_{40\%SPR}$	Ageing Structure
MNE	NH	Oyster River	2021	1.29 (0.95-1.62)	1.05 (0.79-1.66)	79.4%	Scales
SNE	MA	Mystic River	2020	1.94 (1.43-2.44)	1.04 (0.83-1.68)	98.3%	Otoliths
SNE	MA	Monument River	2020	1.44 (1.15-1.73)		93.3%	Otoliths
MAT	CT	Chicopee River	2021	0.98 (0.59-1.36)	1.02 (0.80-1.63)	39.5%	Otoliths
MAT	CT	Farmington River	2021	0.74 (0.36-1.11)		8.9%	Otoliths
MAT	CT	Wethersfield Cove	2021	0.73 (0.47-0.99)		5.2%	Otoliths
MAT	NY	Hudson River	2022	0.65 (0.44-0.85)		0.7%	Otoliths
MAT	MD	Nanticoke River	2019	1.21 (0.96-1.46)		78.9%	Scales
MAT	MD	North East River	2021	0.9 (0.62-1.18)		24.5%	Scales
MAT	VA	Rappahannock River	2021	0.87 (0.69-1.05)		16.1%	Otoliths
MAT	VA	James River	2021	1.03 (0.67-1.39)		47.4%	Otoliths
MAT	NC	Chowan River	2021	1.26 (1.03-1.5)		84.9%	Scales
MAT	NC	Neuse River	2018	1.36 (0.85-1.87)		83.6%	Otoliths
SAT	SC	Santee-Cooper River	2021	1.85 (1.11-2.58)	0.99 (0.74-1.57)	96.9%	Otoliths

Table 38. Number of rivers within each blueback herring stock region where the most recent estimate of *Z* has a higher than 50% probability of being above the *Z* reference point. There were no estimates of Z for the CAN-NNE stock-region, as none of the rivers had sufficient sample size of ages.

Region	$Z_{40\%SPR}$ (95% CIs)	# of Rivers	# of Rivers $P(Z)>Z_{40SPR\%}$ >50%	% of Rivers $P(Z)>Z_{40SPR\%}$ >50%	Species
CAN-NNE	1.15 (0.85-2.01)	--	--	--	BBH
MNE	1.05 (0.79-1.67)	1	1	100.0%	BBH
SNE	1.04 (0.83-1.69)	2	2	100.0%	BBH
MAT	1.02 (0.80-1.65)	10	3	33.3%	BBH
SAT	0.99 (0.74-1.53)	1	1	100.0%	BBH

Table 39. Summary of abundance and Z trends for blueback herring by stock-region and river.

Stock-Region	River	Ages	Years	Mann-Kendall Trend (time series)	Mann-Kendall Trend (2009+)	p(I>Q25)	p(I>I2009)	p(Z > Z40%)
CAN-NNE	**St. Croix**							
	Run counts (mixed spp)	Adults	1981-2022	n.s.	n.s.	100%	100%	
CAN-NNE	**Kennebec**							
	Run counts (mixed spp)	Adults	2006-2022	↑	n.s.	95%	95%	
CAN-NNE	**Penobscot**							
	Run counts (mixed spp)	Adults	2015-2022	n.s.	n.s.			
CAN-NNE	**Saco**							
	Run counts (mixed spp)	Adults	1993-2021	↑	↑	99%	98%	
CAN-NNE	**Sebasticook**							
	Run counts (mixed spp)	Adults	2000-2021	↑	↑	100%	100%	
CAN-NNE	**Androscoggin**							
	Run counts (mixed spp)	Adults	1983-2022	↑	n.s.	97%	94%	
CAN-NNE	**Merrymeeting Bay**							
	ME DMR Juvenile Alosine Seine Survey	YOY	1982-2021	↑	↑	100%	98%	
MNE	**Cocheco**							
	Run counts	Adults	2004-2021	n.s.	n.s.	91%	81%	
MNE	**Exeter**							
	Run counts	Adults	2004-2016	n.s.	n.s.	100%	100%	
MNE	**Lamprey**							
	Run counts	Adults	2004-2021	n.s.	n.s.	100%	100%	
MNE	**Oyster**							
	Run counts	Adults	2004-2021	↓	n.s.	92%	16%	79%
MNE	**Winnicut**							
MNE	**Hamton-Seabrook/Great Bay Estuaries**							
	NH Juvenile Finfish Survey	YOY	1997-2021	↓	n.s.	97%	96%	
SNE	**Agawam**							
	Run counts (mixed spp)	Adults	2006-2021	n.s.	n.s.	97%	94%	
SNE	**Back**							

Stock-Region	River	Ages	Years	Mann-Kendall Trend (time series)	Mann-Kendall Trend (2009+)	p(I>Q25)	p(I>I2009)	p(Z > Z40%)
	Run counts (mixed spp)	Adults	1986-2021	n.s.	n.s.	85%	83%	
SNE	**Mattapoissett**							
	Run counts (mixed spp)	Adults	1988-2021	↓	n.s.	4%	4%	
SNE	**Monument**							
	Run counts (mixed spp)	Adults	1980-2021	n.s.	n.s.	64%	70%	93%
SNE	**Mystic**							
	Run counts (mixed spp)	Adults	2012-2021	↑	n.s.			98%
SNE	**Parker**							
	Run counts (mixed spp)	Adults	2013-2022	*	*	*	*	
SNE	**Stony Brook**							
	Run counts (mixed spp)	Adults	2007-2019	n.s.	n.s.	95%	95%	
SNE	**Town Brook**							
	Run counts (mixed spp)	Adults	2011-2021	n.s.		79%		
SNE	**Wankinko**							
	Run counts (mixed spp)	Adults	2007-2021	↑	n.s.	100%	100%	
MAT	**Connecticut River**							
	Run counts	Adults	1976-2022	↓	n.s.	75%	100%	
	USFWS CT River Electrofishing Survey	Adults	2013-2022	n.s.	n.s.	87%		
	CT River Beach Seine Survey	YOY	1979-2021	↓	n.s.	67%	86%	
	Chicopee River	Adults	2013-2022					40%
	Farmington River	Adults	2013-2022					9%
	Wethersfield Cove	Adults	2013-2022					5%
MAT	**Eight Mile**							
	Run counts	Adults	2014-2022	n.s.	n.s.			
MAT	**Mianus**							
	Run counts	Adults	2008-2021	n.s.	n.s.			
MAT	**Quinnipiac**							
	Run counts	Adults	2013-2022	n.s.	n.s.	75%		
MAT	**Hudson**							
	NY DEC 300' Haul Seine Survey	Adults	2012-2022	n.s.	n.s.	85%		1%

Stock-Region	River	Ages	Years	Mann-Kendall Trend (time series)	Mann-Kendall Trend (2009+)	p(I>Q25)	p(I>I2009)	p(Z > Z40%)
	NY DEC Juvenile Beach Seine	YOY	1980-2022	n.s.	n.s.	80%	64%	
MAT	**Delaware Bay/River**							
	DE Bay 30' Trawl	Age-1	1990-2021	n.s.	n.s.	75%	69%	
	NJ Striped Bass Seine Survey	YOY	1987-2021	↓	n.s.	55%	39%	
MAT	**Nanticoke**							
	MD Commercial CPUE	Adults	1991-2021	↓	n.s.	26%	21%	79%
	MD DNR Juvenile Estuarine Finfish Survey	YOY	1959-2021	↓	n.s.	46%	54%	
	DE Juvenile Seine Survey	YOY	1999-2021	n.s.	n.s.	90%	76%	
MAT	**North East**							
	MD Gillnet Survey	Adults	2015-2021	n.s.	n.s.	67%		25%
MAT	**Choptank**							
	MD DNR Juvenile Estuarine Finfish Survey	YOY	1959-2021	↑	n.s.	84%	87%	
MAT	**Potomac**							
	MD DNR Juvenile Estuarine Finfish Survey	YOY	1959-2021	n.s.	n.s.	84%	87%	
MAT	**Appomattox**							
	VA DWR Electrofishing Survey	Adults	2000-2018	n.s.	n.s.	58%	53%	
MAT	**James**							
	VA DWR Electrofishing Survey	Adults	2002-2022	↑	n.s.	100%	100%	
	VIMS River Herring Gillnet Survey	Adults	2015-2021	n.s.	n.s.	80%		47%
	VIMS Striped Bass Seine Survey	YOY	1967-2022	n.s.	n.s.	87%	86%	
MAT	**Chickahominy**							
	VA DWR Electrofishing Survey	Adults	2011-2022	n.s.	n.s.	76%		12%
	VIMS Surface Trawl Survey	YOY	2014-2022	n.s.	n.s.	2%		
MAT	**Rappahannock**							
	VA DWR Electrofishing Survey	Adults	2001-2022	↑	n.s.	90%	74%	16%
MAT	**Albemarle Sound**							
	NC DMF P135 Gillnet Survey	Adults	1991-2019	n.s.	↑	100%	100%	
	NC DMF P100 Seine Survey	YOY	1972-2021	↓	n.s.	89%	87%	
MAT	**Chowan**							

Stock-Region	River	Ages	Years	Mann-Kendall Trend (time series)	Mann-Kendall Trend (2009+)	p(I>Q25)	p(I>I2009)	p(Z > Z40%)
	NC WRC Electrofishing Survey	Adults	2006-2022	n.s.	n.s.	100%	100%	85%
MAT	**Neuse**							
	NC WRC Electrofishing Survey	Adults	2006-2022	↑	n.s.	100%	100%	84%
SAT	**Cape Fear**							
	NC WRC Electrofishing Survey	Adults	2006-2022	n.s.	n.s.	88%	88%	
SAT	**Santee-Cooper**							
	Run counts	Adults	2013-2022	↓	↓	16%	3%	97%
SAT	**St. Johns**							
	FL FWC Pushnet Survey	YOY	2006-2021	↑	ns	100%	93%	

Table 40. Total habitat (km^2), unobstructed habitat below first dams, difference in habitat, and percent reduction in habitat within stock-regions for blueback herring.

Region	Total Habitat	Unobstructed	Difference	% Difference
CAN-NNE	320	120	200	62
MNE	147	20	127	86
SNE	47	18	29	61
MAT	1469	900	570	39
SAT	1406	953	453	32
Total	3389	2011	1378	41

Table 41. Total habitat (km²), unobstructed habitat below first dams, difference in habitat, and percent reduction in habitat within HUC4 watersheds for blueback herring.

HUC4 watershed	Total habitat	Unobstructed	Difference	% Difference
Altamaha-St. Marys	354	242	112	32
Androscoggin	64	4	59	93
Cape Fear	117	109	8	7
Chowan-Roanoke	207	142	64	31
Connecticut	129	31	98	76
Connecticut Coastal	93	14	79	85
Delaware-Mid Atlantic Coastal	189	150	39	20
Edisto-Santee	268	155	113	42
Kennebec	89	29	60	68
Lower Chesapeake	291	156	135	46
Lower Hudson-Long Island	95	61	33	35
Maine Coastal	95	61	34	36
Massachusetts-RICoastal	41	17	24	59
Merrimack	60	3	58	95
Neuse-Pamlico	139	128	12	8
Ogeechee-Savannah	285	154	131	46
Pee Dee	252	166	86	34
Penobscot	73	26	47	64
Potomac	92	80	12	13
Saco	87	17	69	80
St. Johns	115	113	3	2
Susquehanna*	58	12	47	80
Suwannee	<1	<1	<1	<1
Upper Chesapeake	70	53	17	24
Upper Hudson	126	87	39	31

*: The SAS noted the low level of total habitat for the Susquehanna River for blueback herring compared to alewife; part of this is due to the removal of lacustrine habitat, but it may also be related to the perceived/understood historical range of blueback herring, and should be examined further.

Table 42. Estimated coastwide parameters from the sex-specific von Bertalanffy growth functions for blueback herring by ageing structure and sex. Parameters included Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Estimates for parameters are means and numbers in parentheses are limits to the 95% credible intervals.

Structure	Parameter	Female	Male
Otolith	K	0.54 (0.38—0.75)	0.60 (0.43—0.84)
	L_∞	295.35 (268.81—324.11)	278.10 (253.13—305.13)
	t_0	-0.40 (-0.72—-0.30)	-0.38 (-0.70—-0.28)
Scale	K	0.60 (0.42—0.84)	0.67 (0.47—0.94)
	L_∞	285.93 (260.23—313.73)	269.22 (245.05—295.40)
	t_0	-0.37 (-0.69—-0.27)	-0.35 (-0.67—-0.25)

11 FIGURES

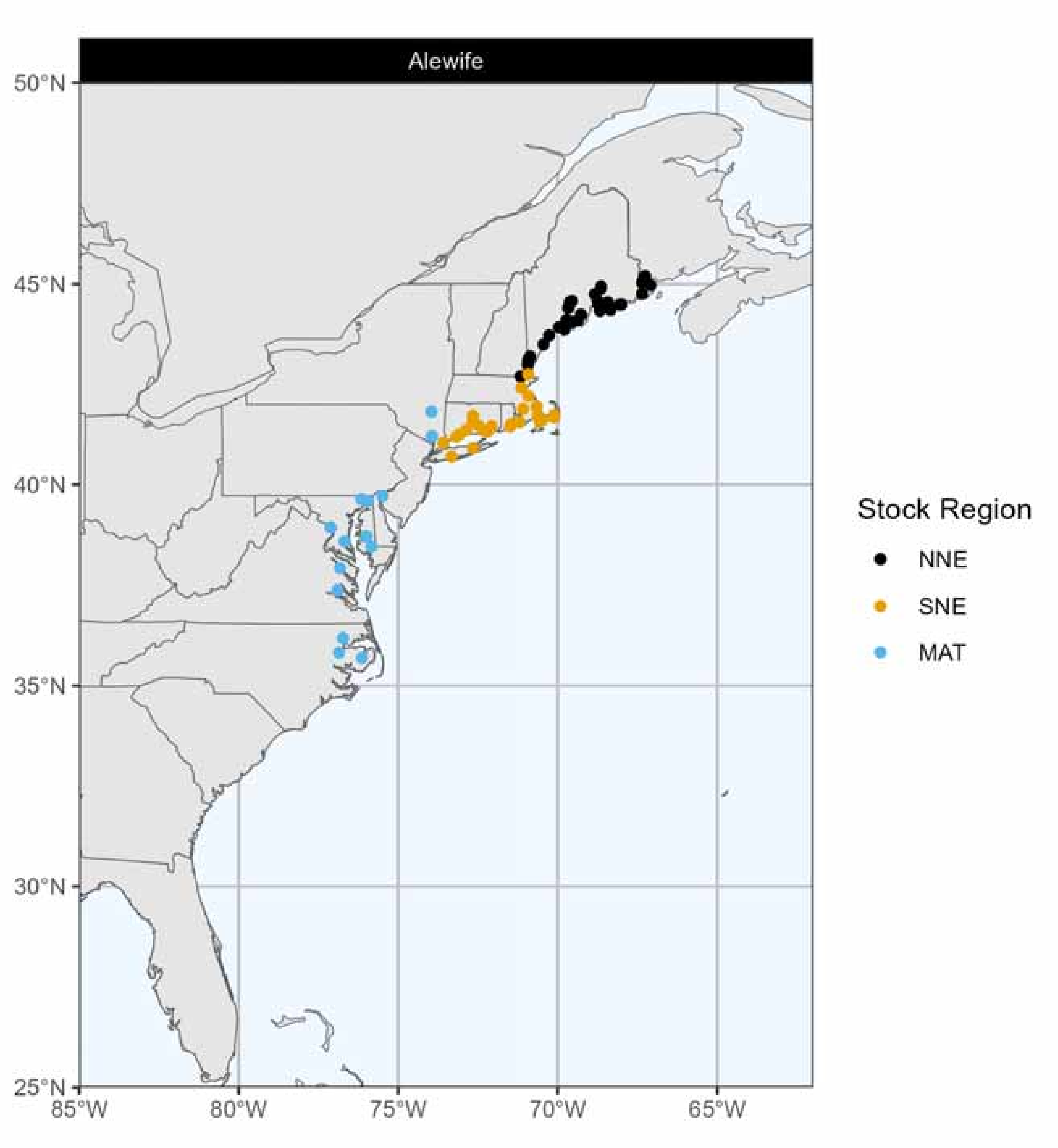


Figure 5. Genetic stock-regions of alewife on the US Atlantic coast, from Reid et al. 2018.

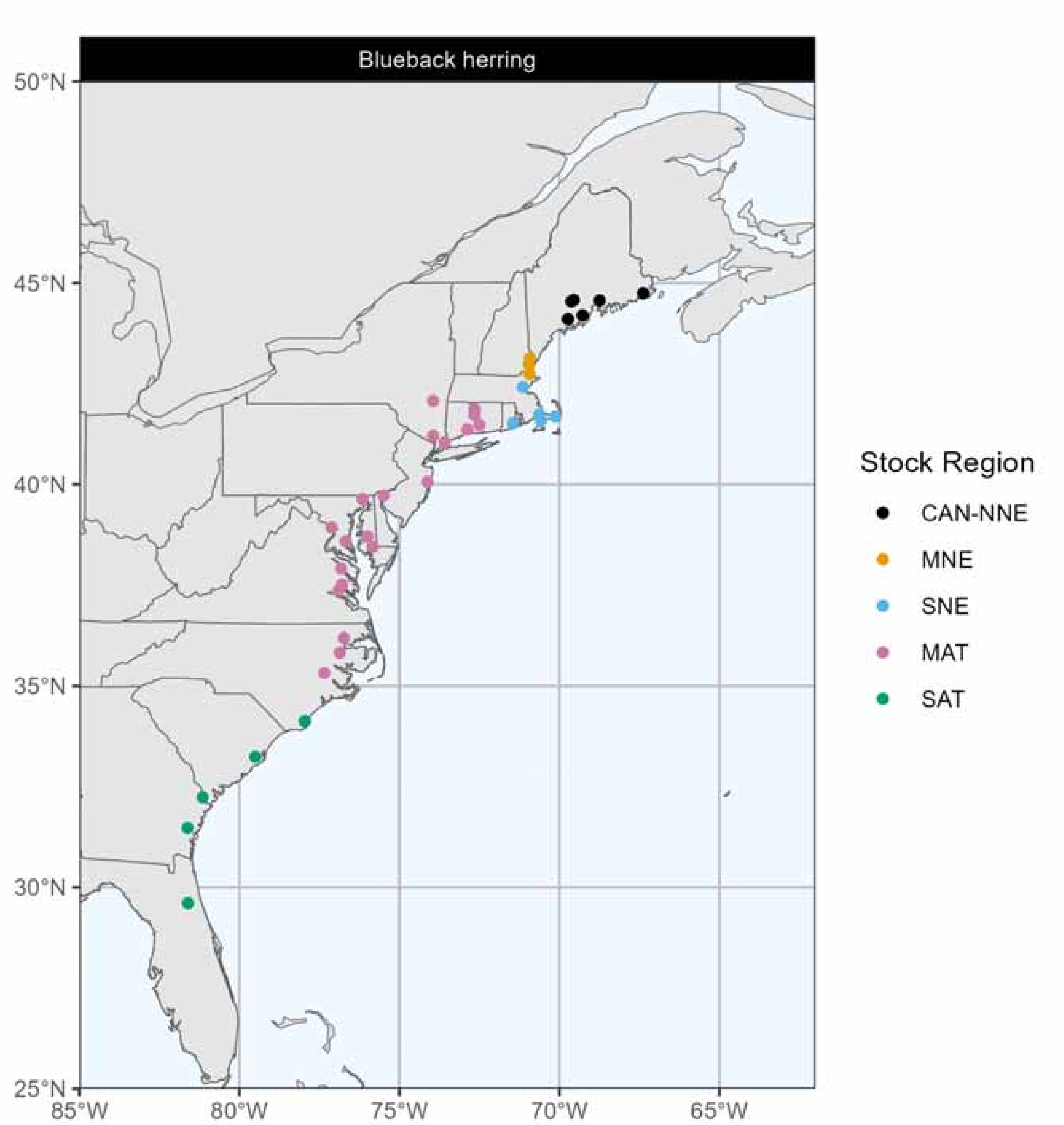


Figure 6. Genetic stock-regions of blueback herring on the US Atlantic coast, from Reid et al. 2018.

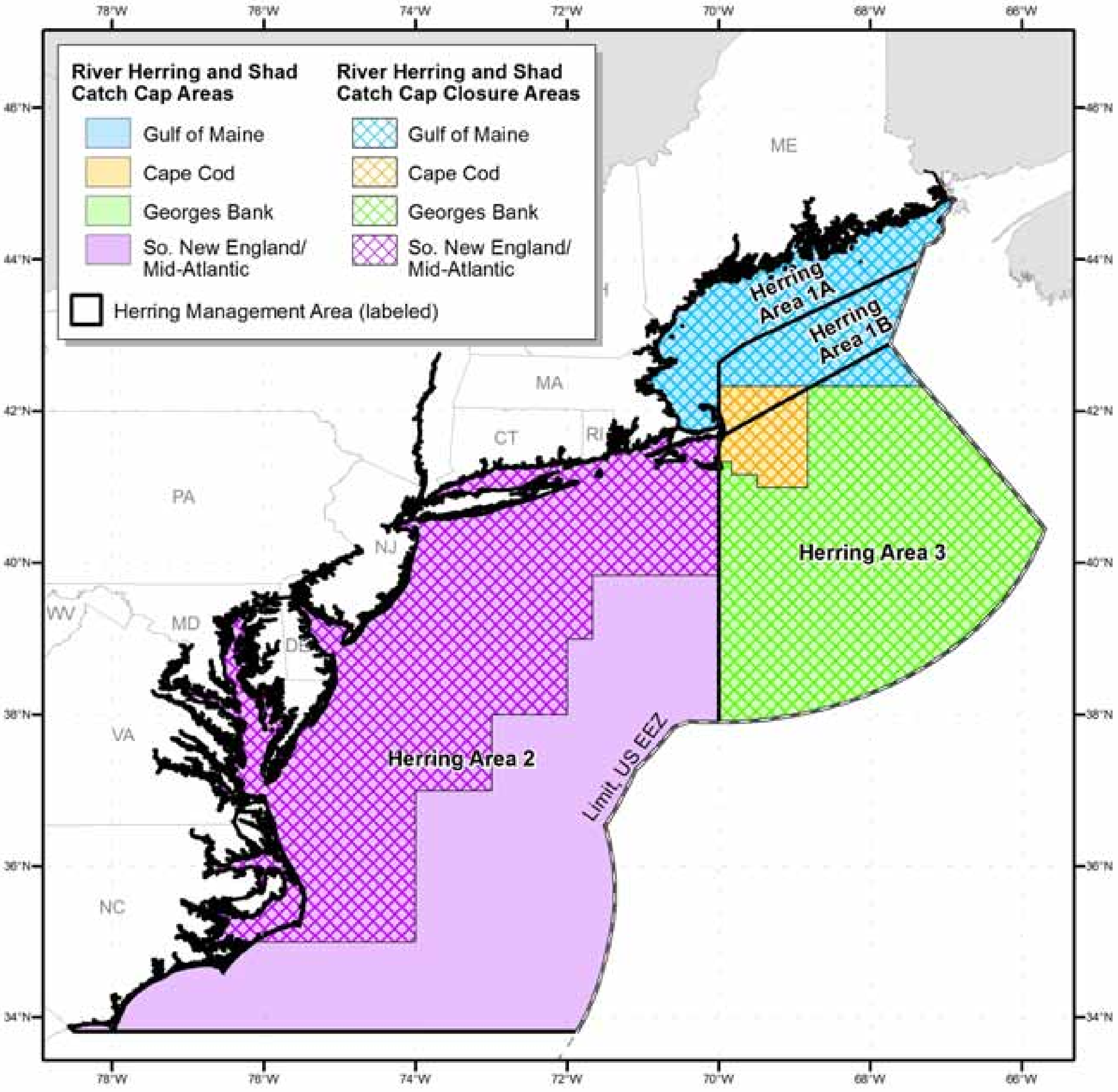


Figure 7. River herring and shad catch cap areas for the Atlantic herring fishery. From https://www.fisheries.noaa.gov/new-england-mid-atlantic/sustainable-fisheries/atlantic-herring-catch-cap

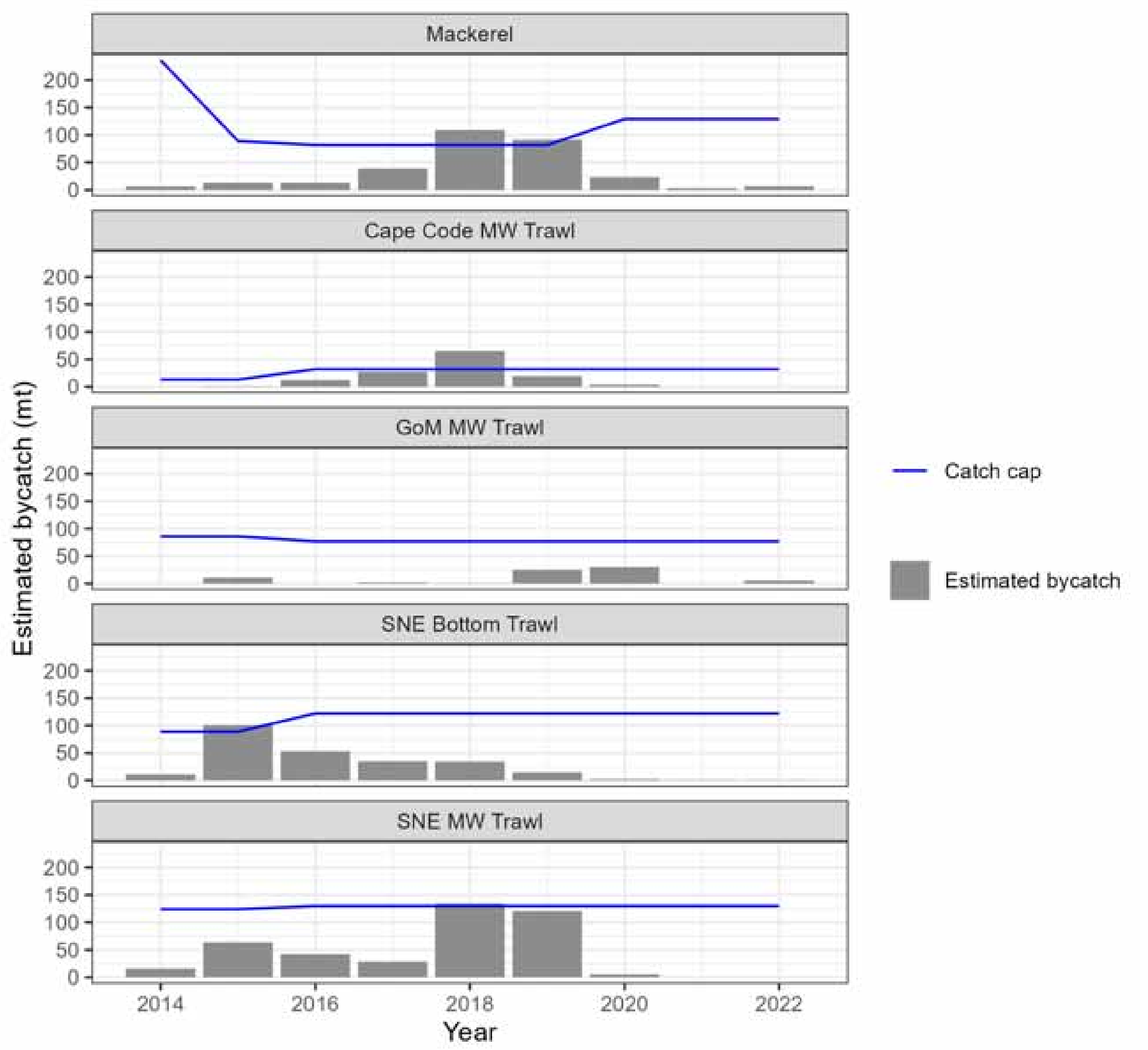


Figure 8. River herring and shad bycatch caps for the Atlantic mackerel and Atlantic herring fisheries plotted with the annual estimated bycatch in each fishery

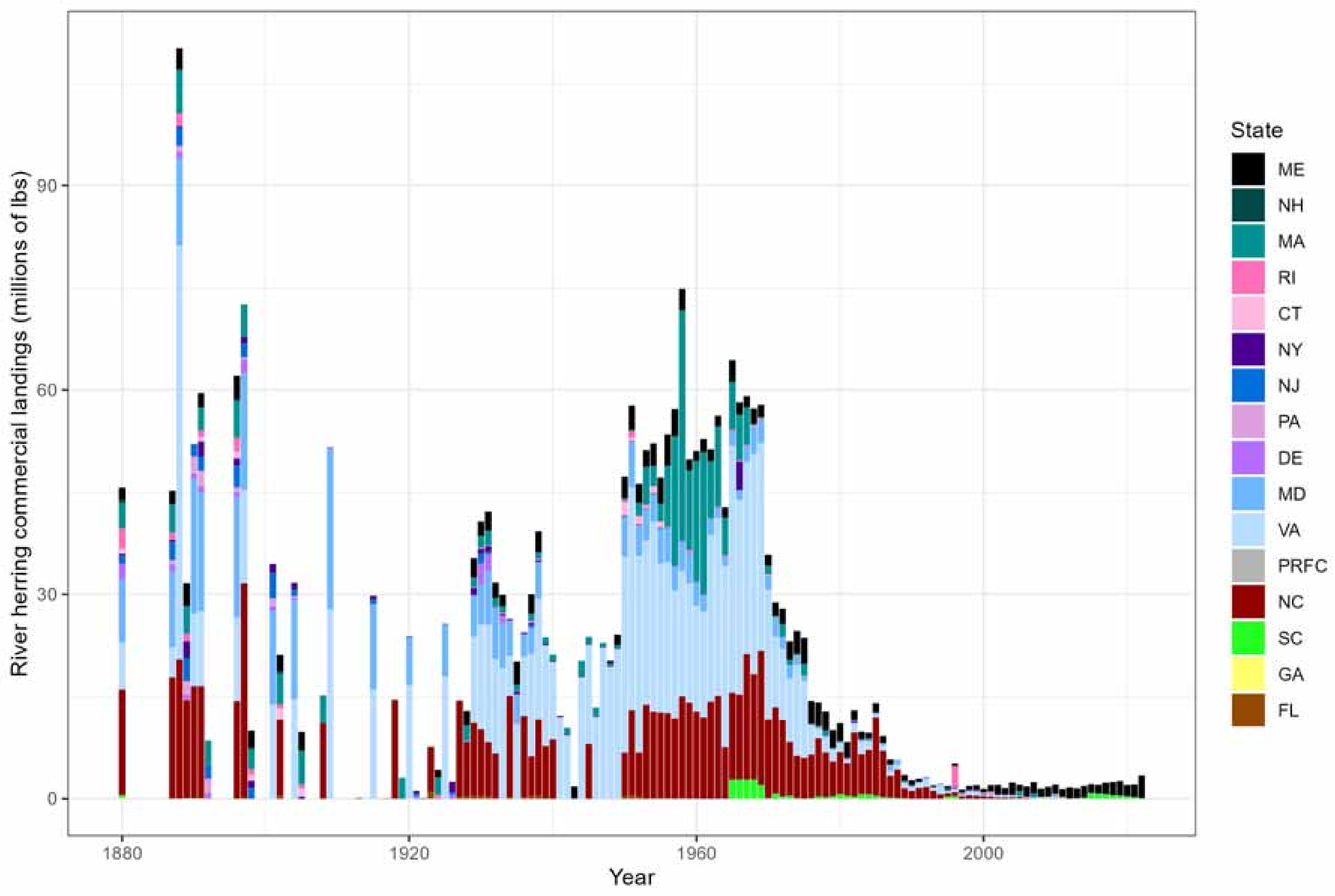


Figure 9. US commercial landings of river herring by state, 1887-2022. Data prior to 1950 are from the US Fish Commission reports; data from 1950-2022 are from ACCSP.

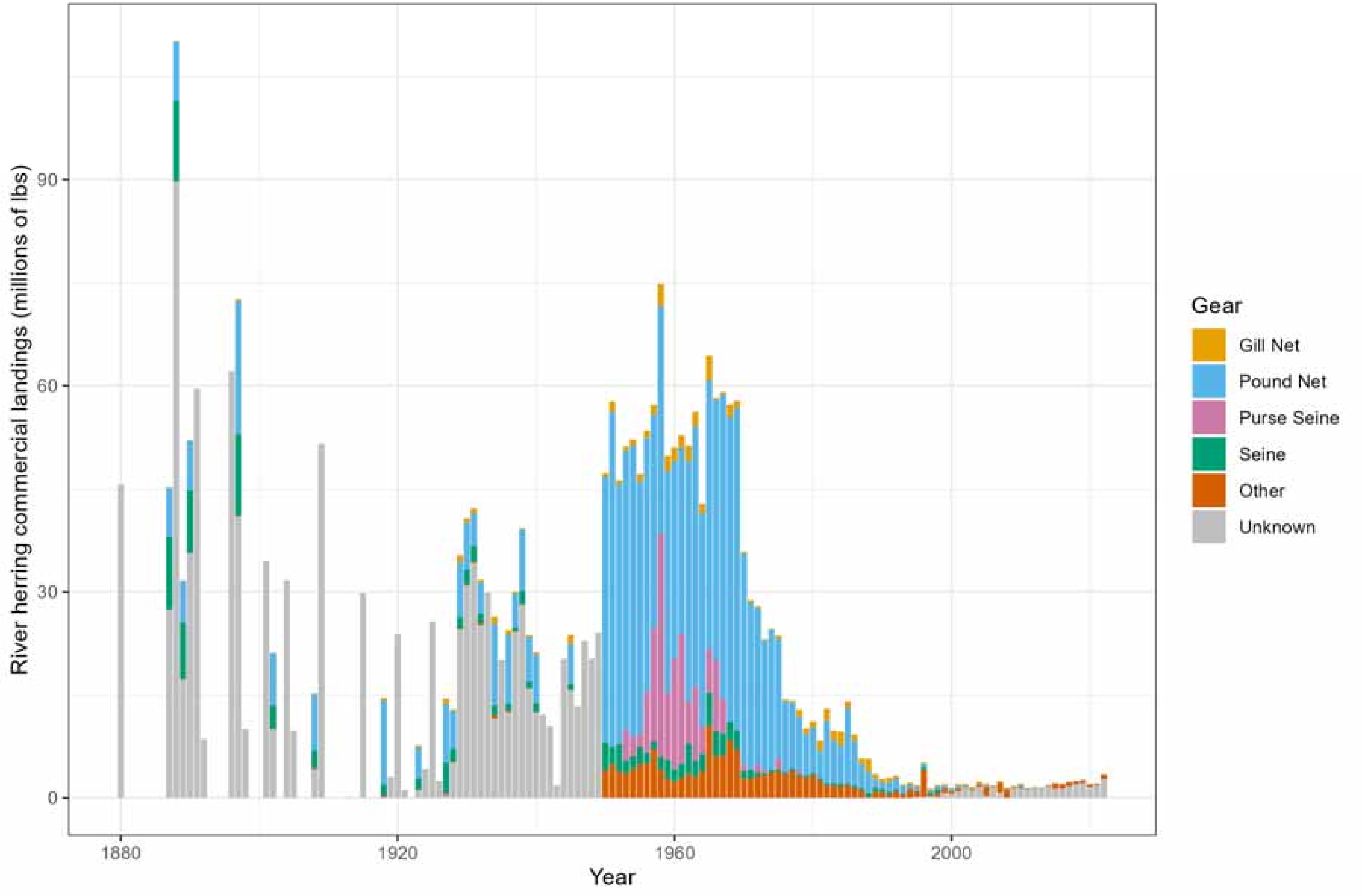


Figure 10. US commercial landings of river herring by gear, 1887-2022.Data prior to 1950 are from the US Fish Commission reports; data from 1950-2022 are from ACCSP.

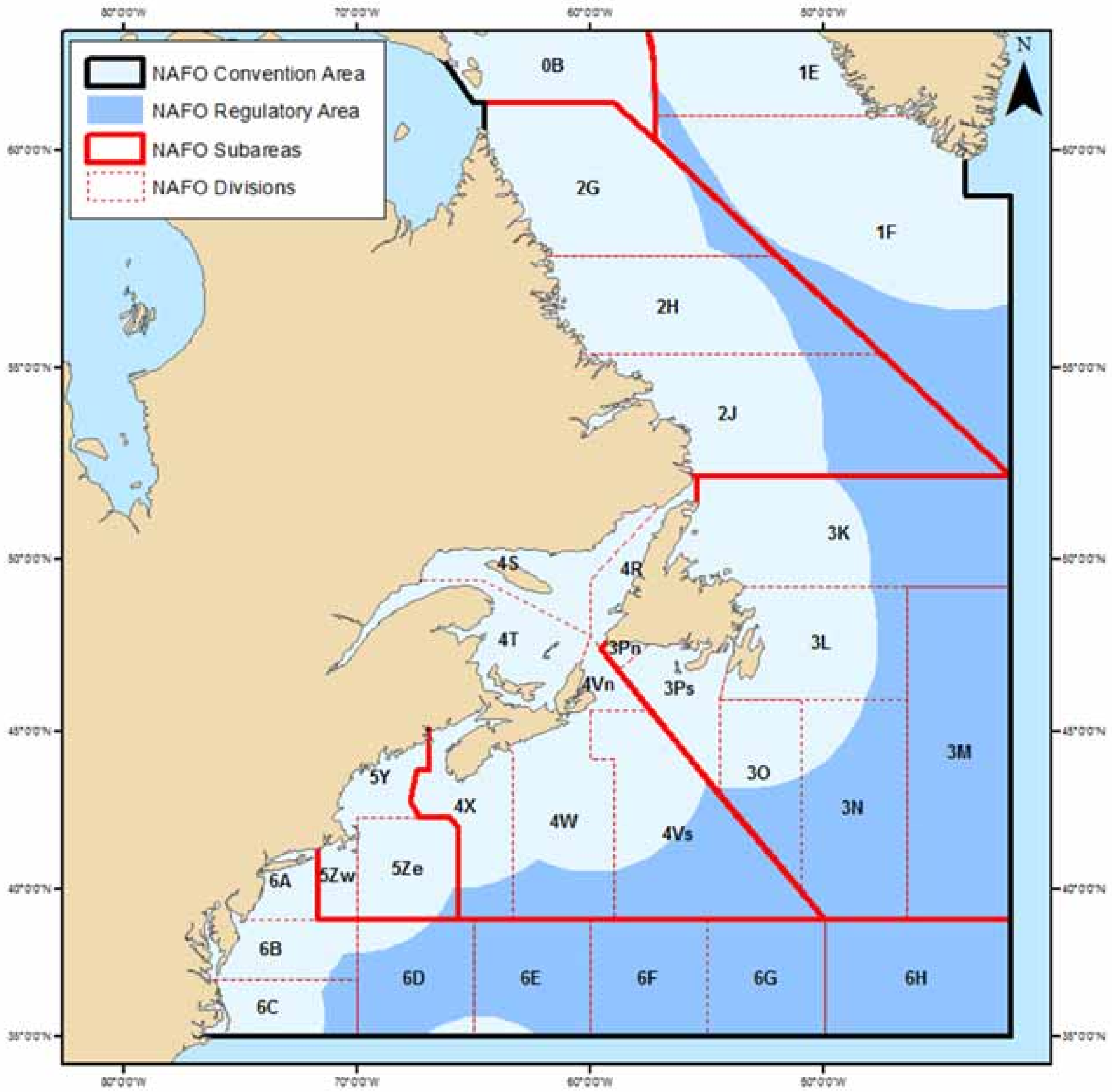


Figure 11. Map of NAFO divisions and subareas. Subareas 5 and 6 were queried for foreign fleet landings of river herring off the US coast.

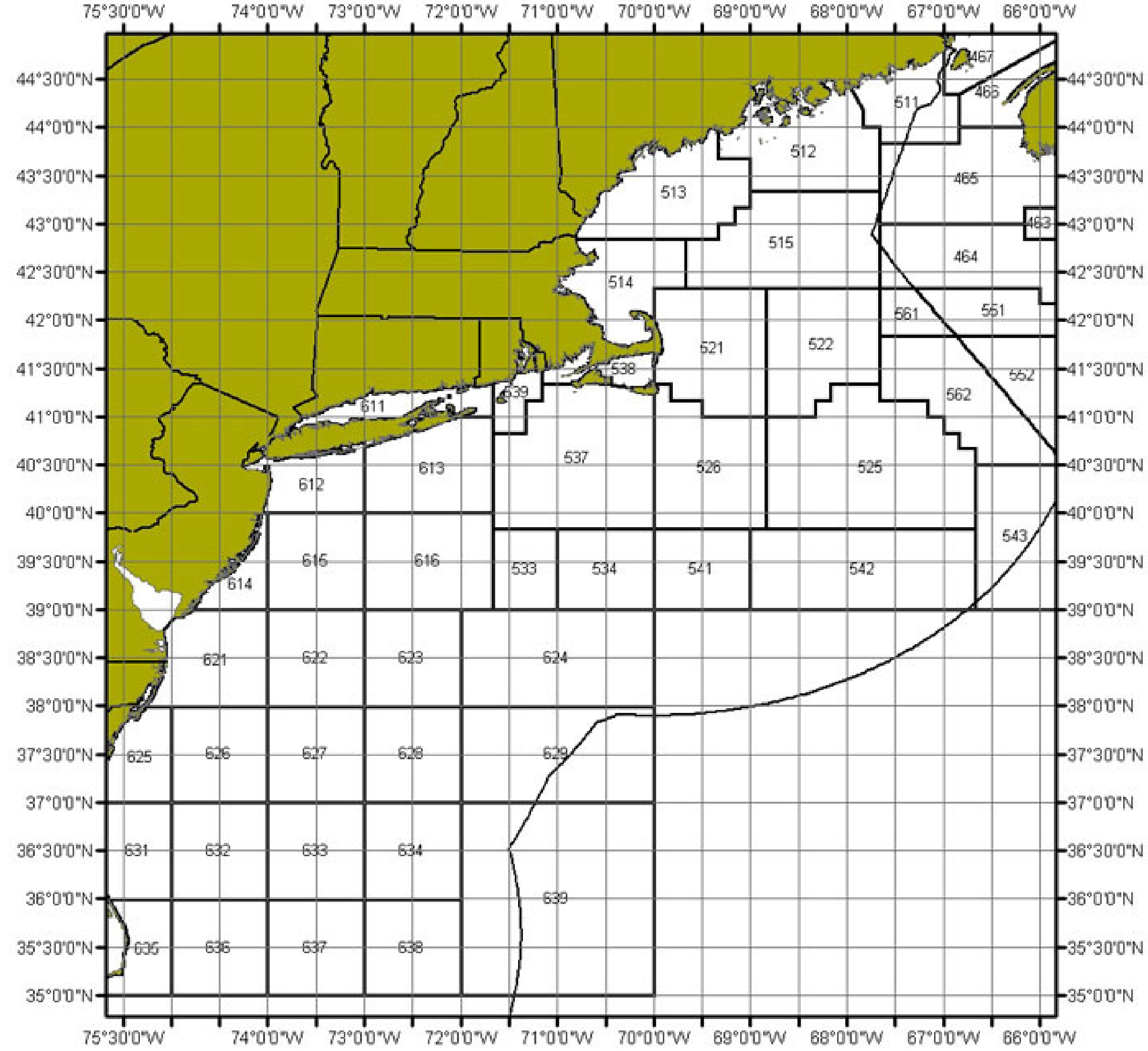


Figure 12. NOAA Greater Atlantic Region statistical areas. Areas 600 and higher are considered part of the Mid-Atlantic region; areas less than 600 are part of the New England region.

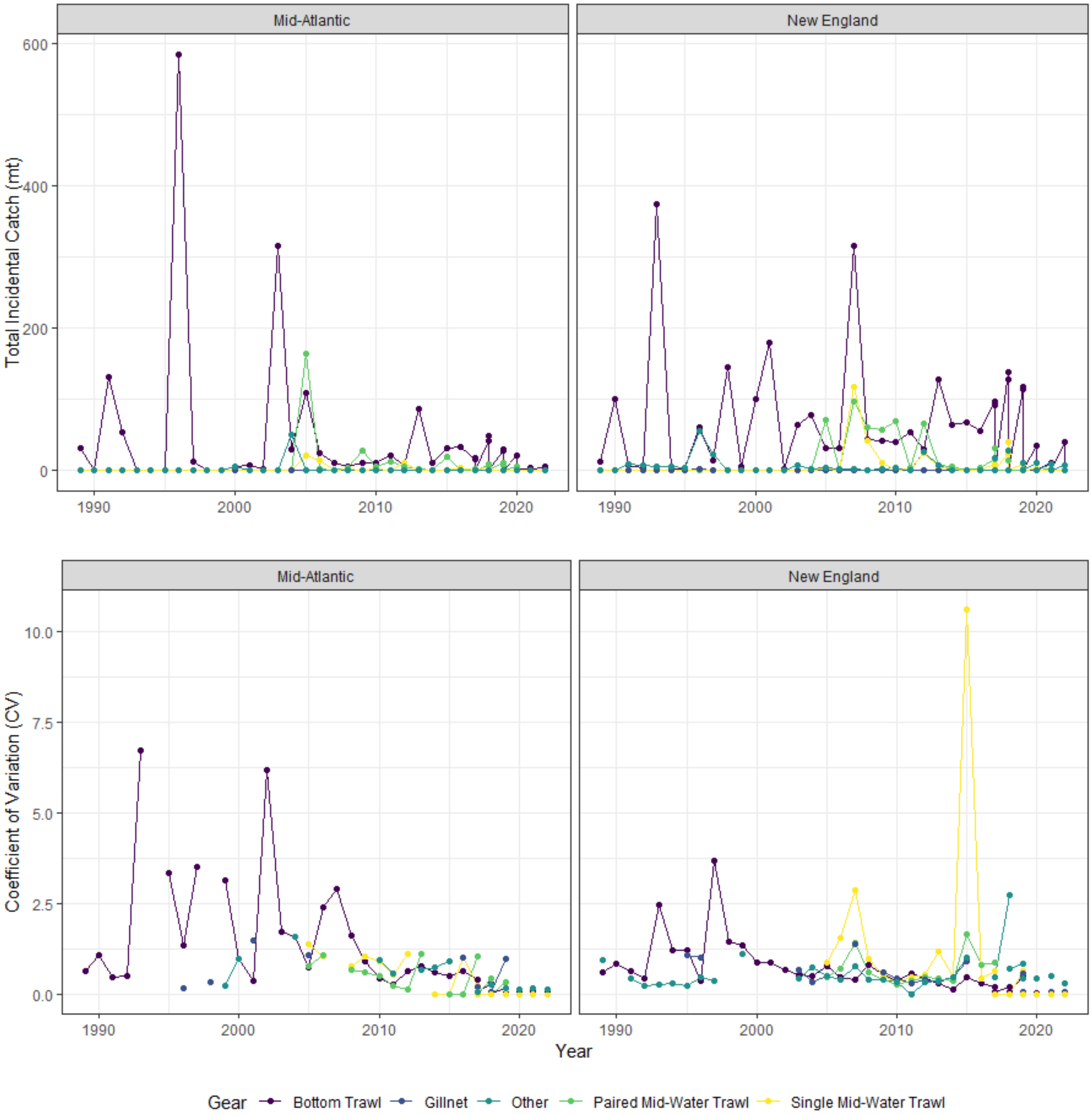


Figure 13. Alewife total annual incidental catch (mt) by region for the four gears with the largest catches from 1989 – 2022 (top) and the corresponding estimates of precision (bottom). Midwater trawl estimates are only included beginning in 2005.

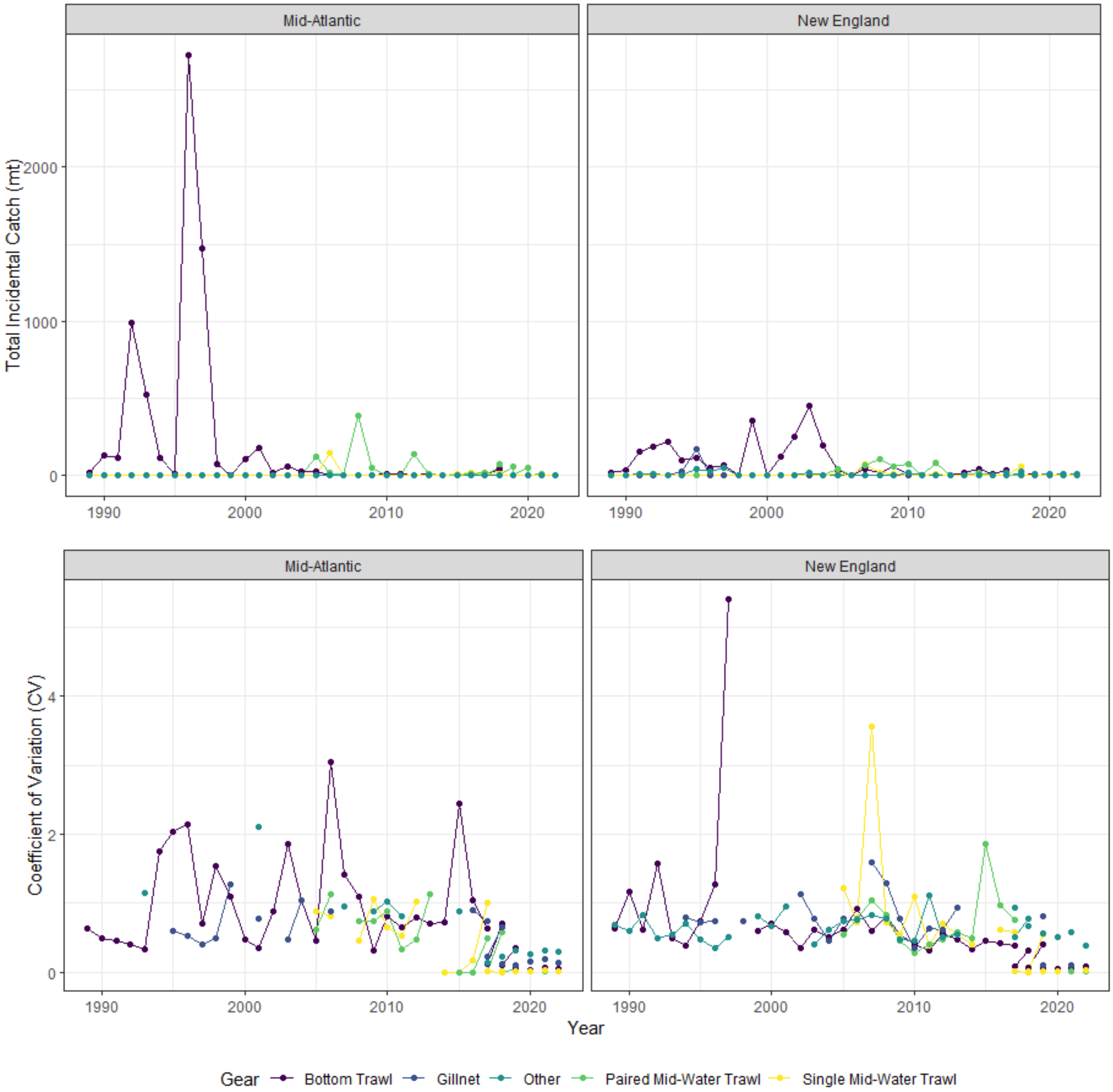


Figure 14. Blueback herring total annual incidental catch (mt) by region for the four gears with the largest catches from 1989 – 2022 (top) and the corresponding estimates of precision (bottom). Midwater trawl estimates are only included beginning in 2005.

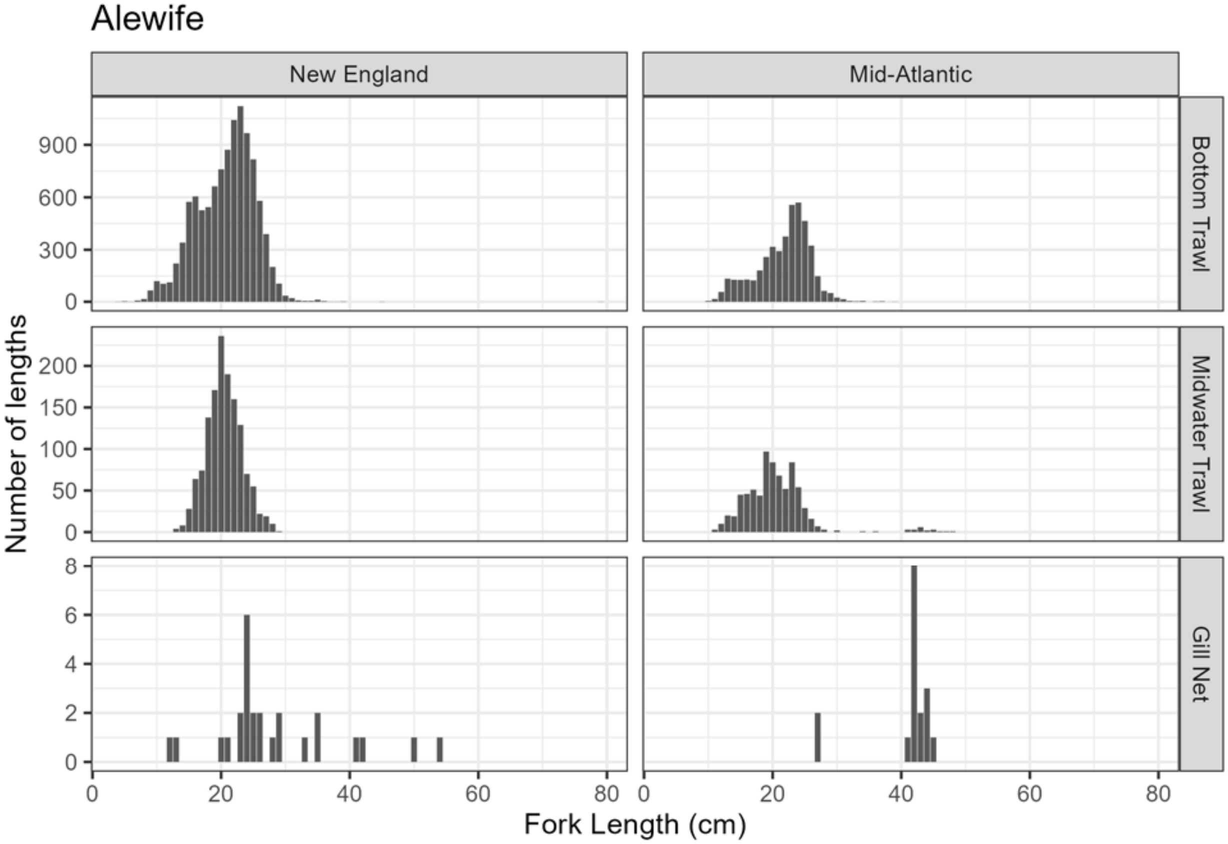


Figure 15. Length frequency of alewife bycatch samples collected by the NEFOP by region and gear. Note the difference in scale across gears.

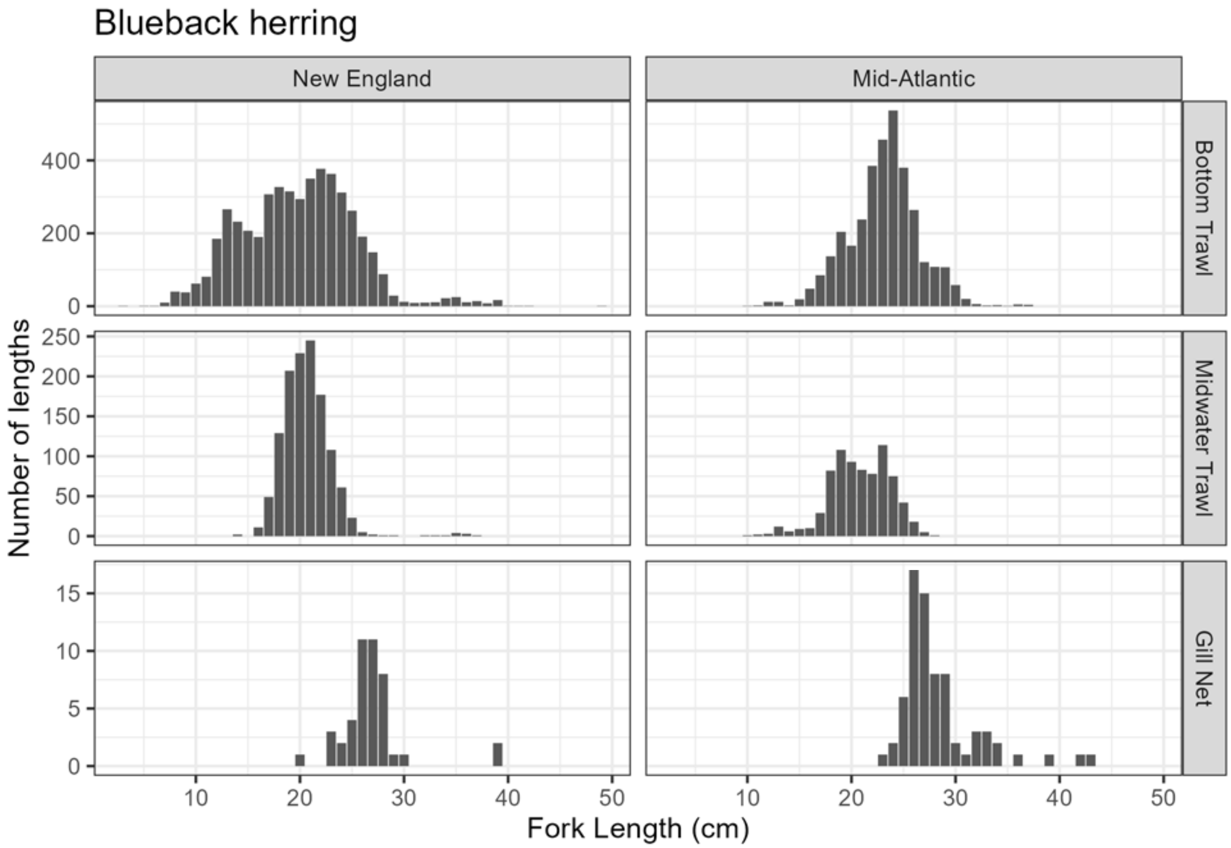


Figure 16. Length frequency of blueback herring bycatch samples collected by the NEFOP by region and gear. Note the difference in scale across gears.

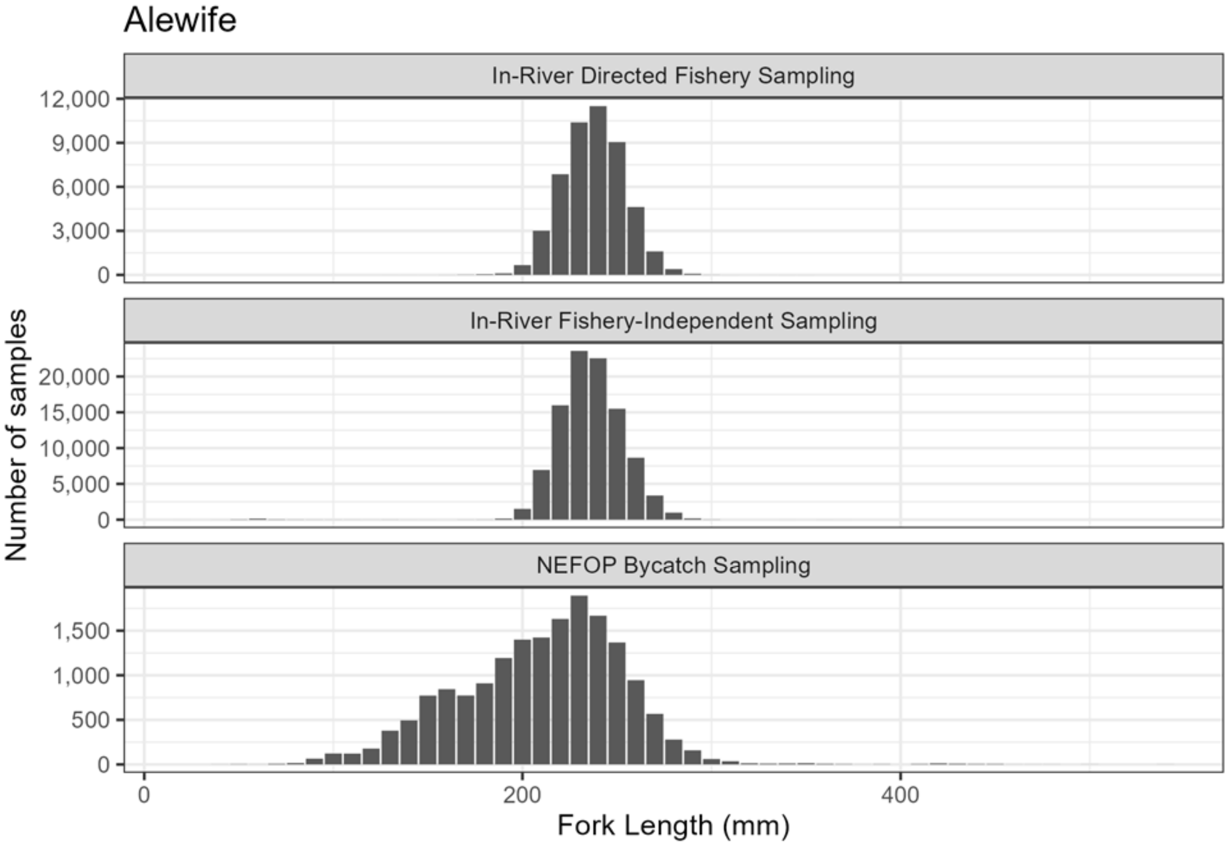


Figure 17. Comparison of length frequencies of alewife from in-river sampling and NEFOP bycatch sampling.

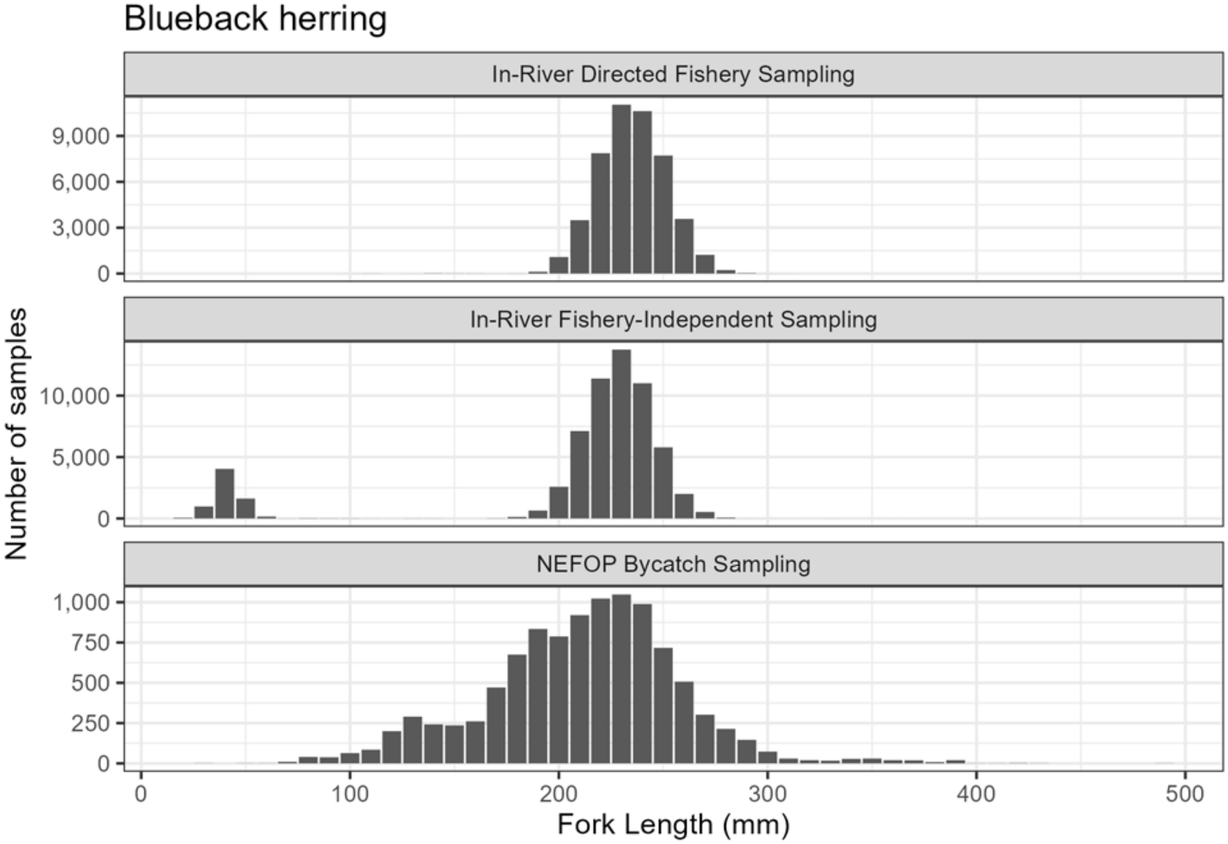


Figure 18. Comparison of length frequencies of blueback herring from in-river sampling and NEFOP bycatch sampling.

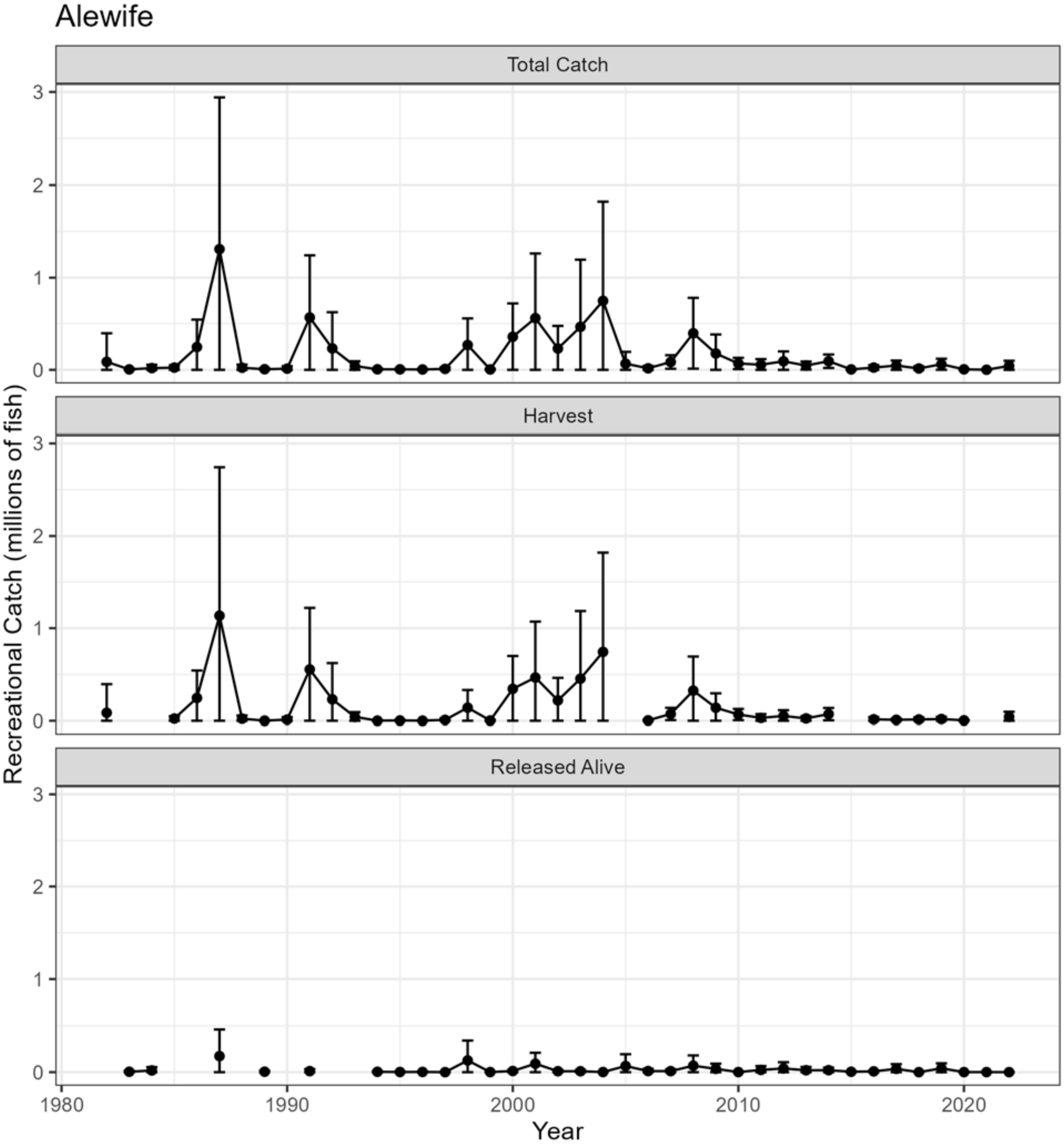


Figure 19. MRIP estimates of total recreational catch of alewife on the US Atlantic coast. Error bars are 95% confidence intervals.

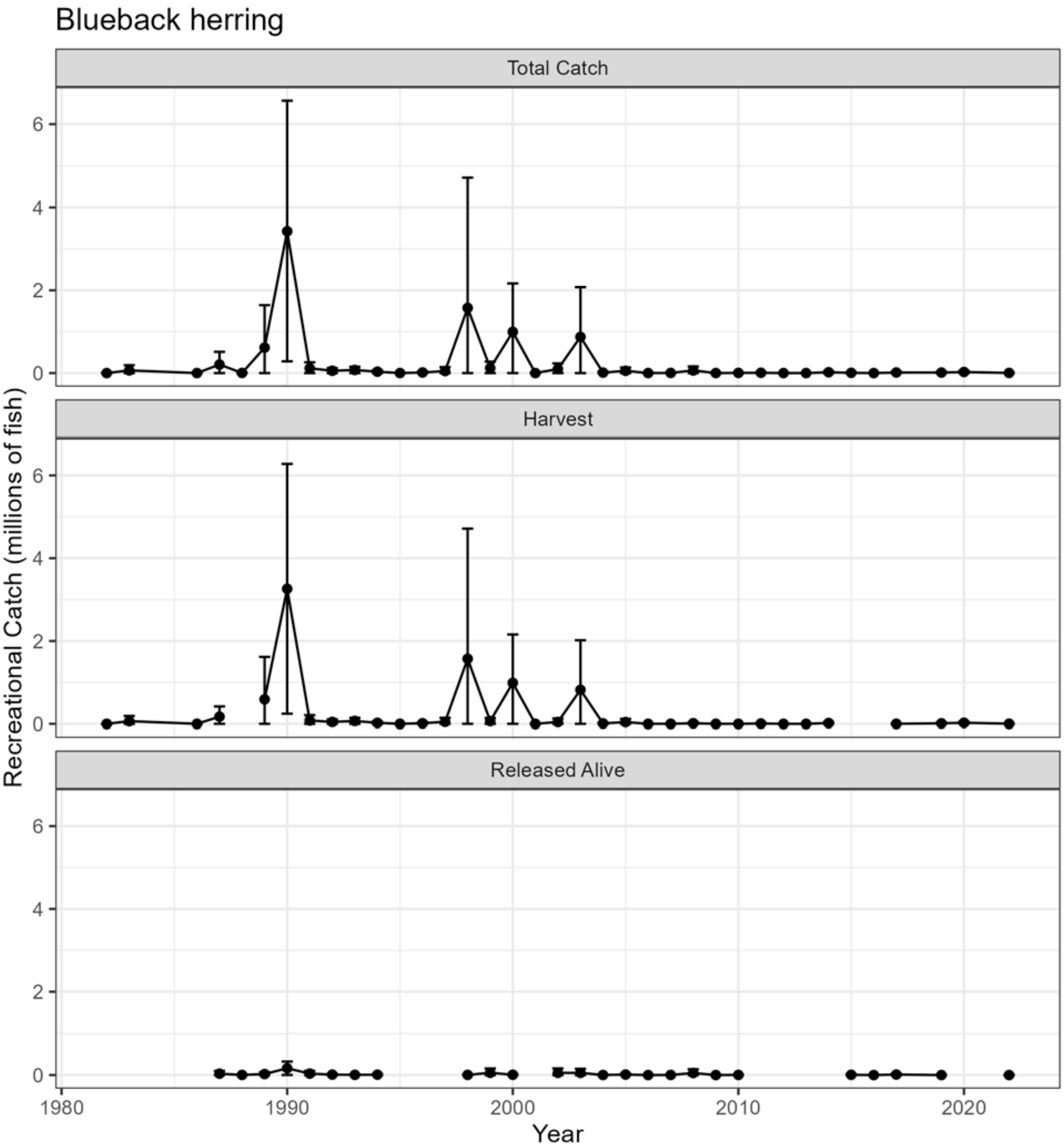


Figure 20. MRIP estimates of total recreational catch of blueback herring on the US Atlantic coast. Error bars are 95% confidence intervals

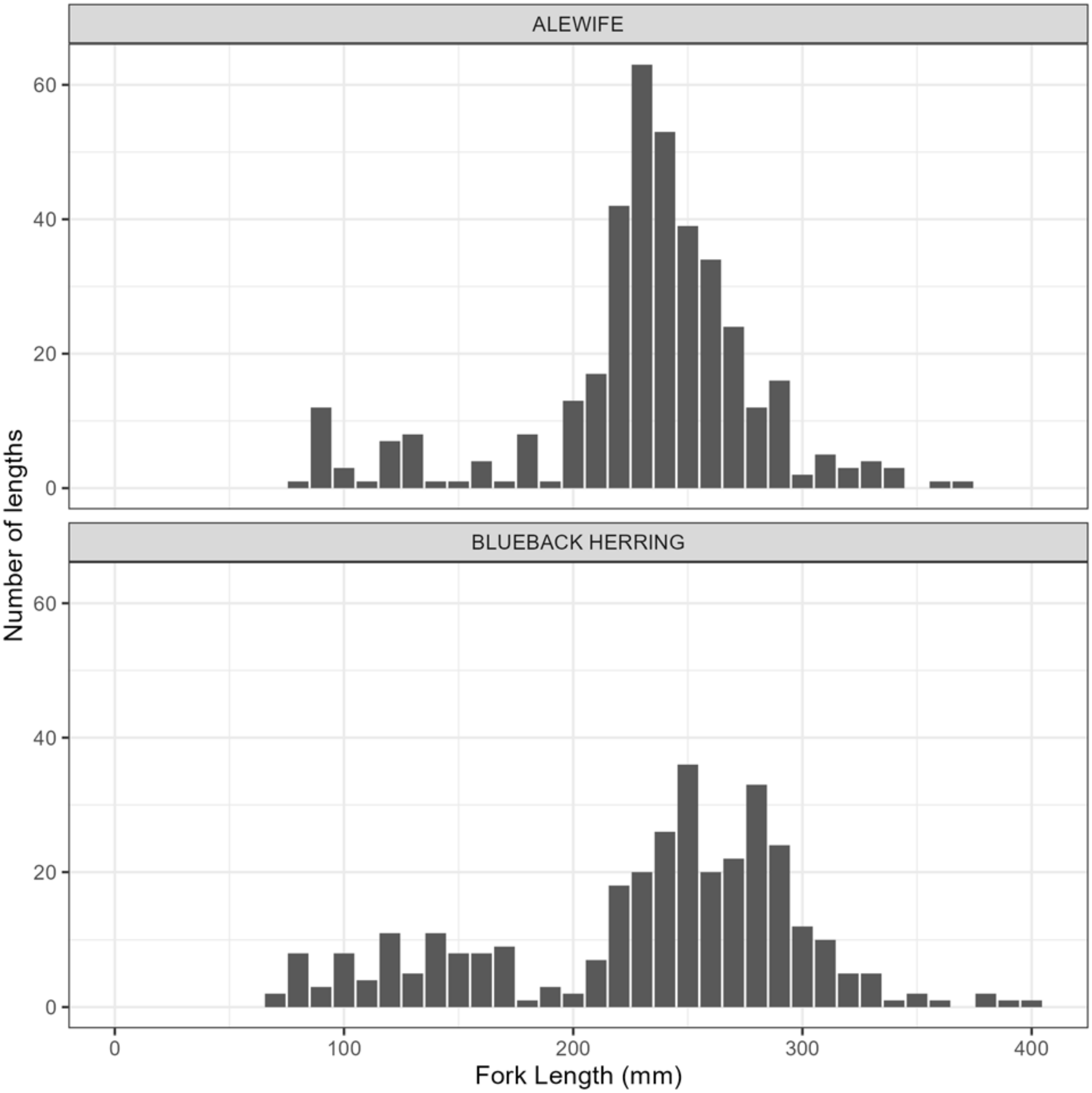


Figure 21. Length frequencies of recreationally harvested river herring measured by MRIP on the US Atlantic coast.

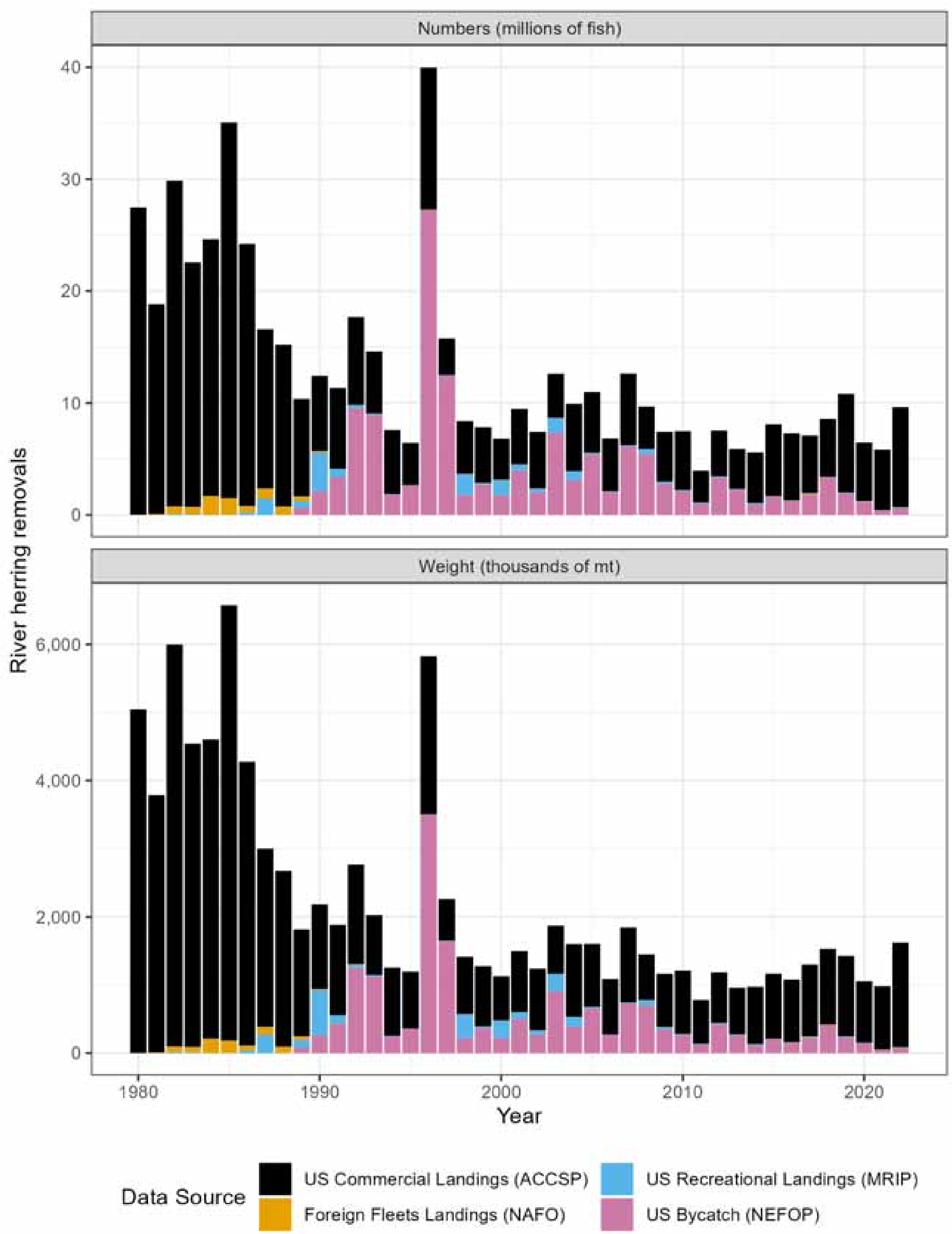


Figure 22. Coastwide removals of river herring by data source, 1980-2022 in numbers (top) and weight (bottom).

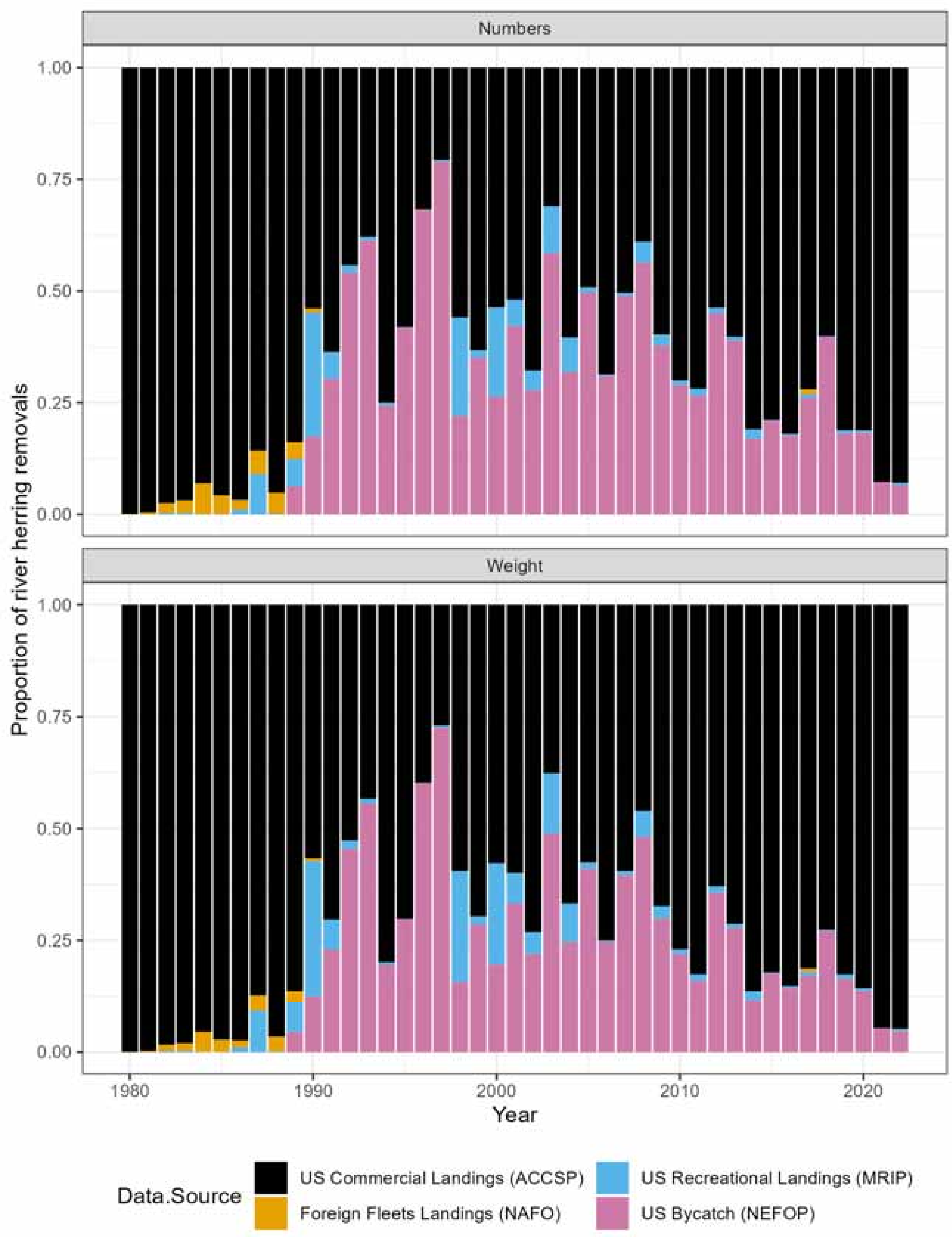


Figure 23. Proportion of coastwide removals in numbers (top) and weight (bottom) of river herring by data source, 1980-2022

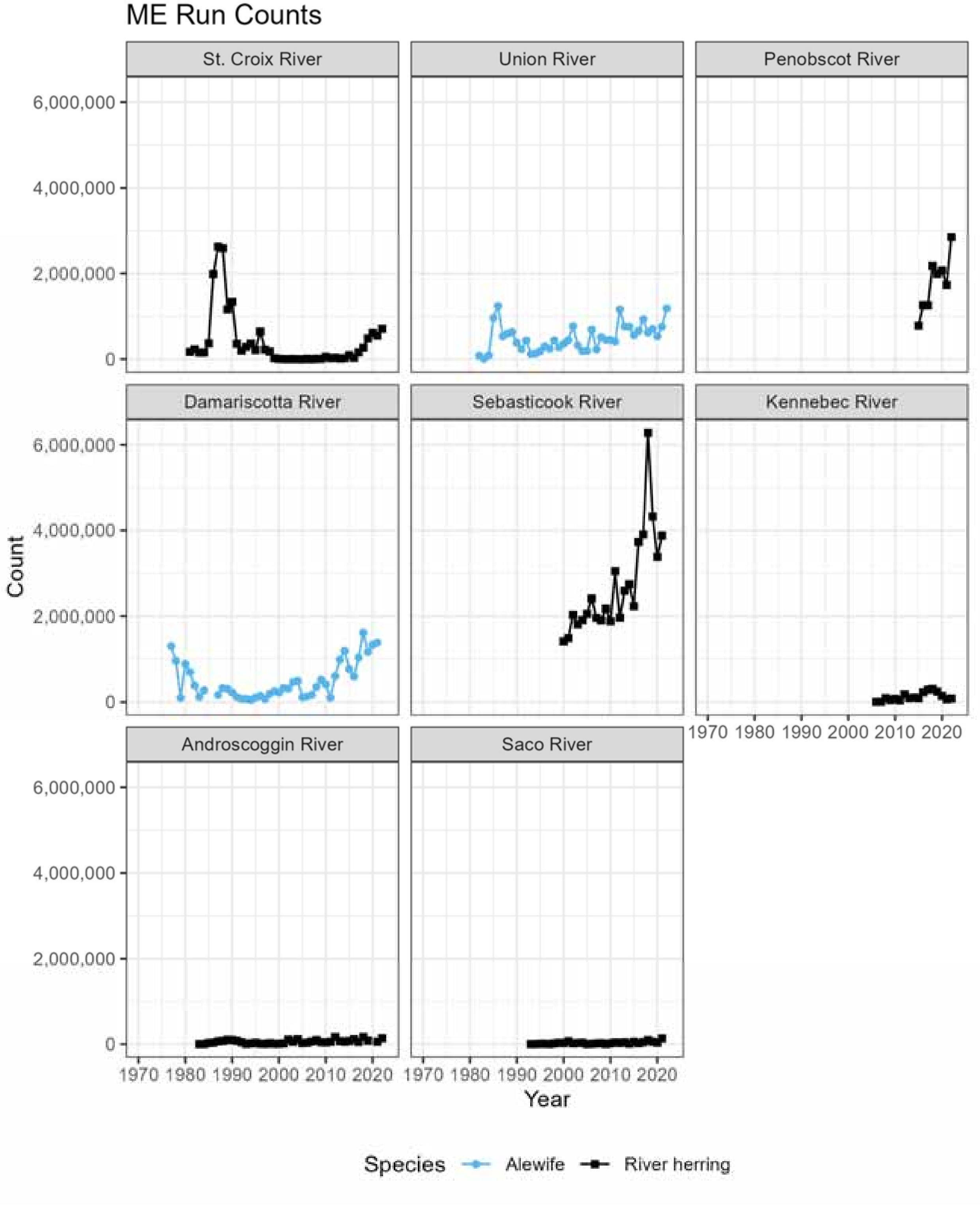


Figure 24. River herring run counts by species from Maine rivers, plotted with the same y-axes to show relative scale across rivers.

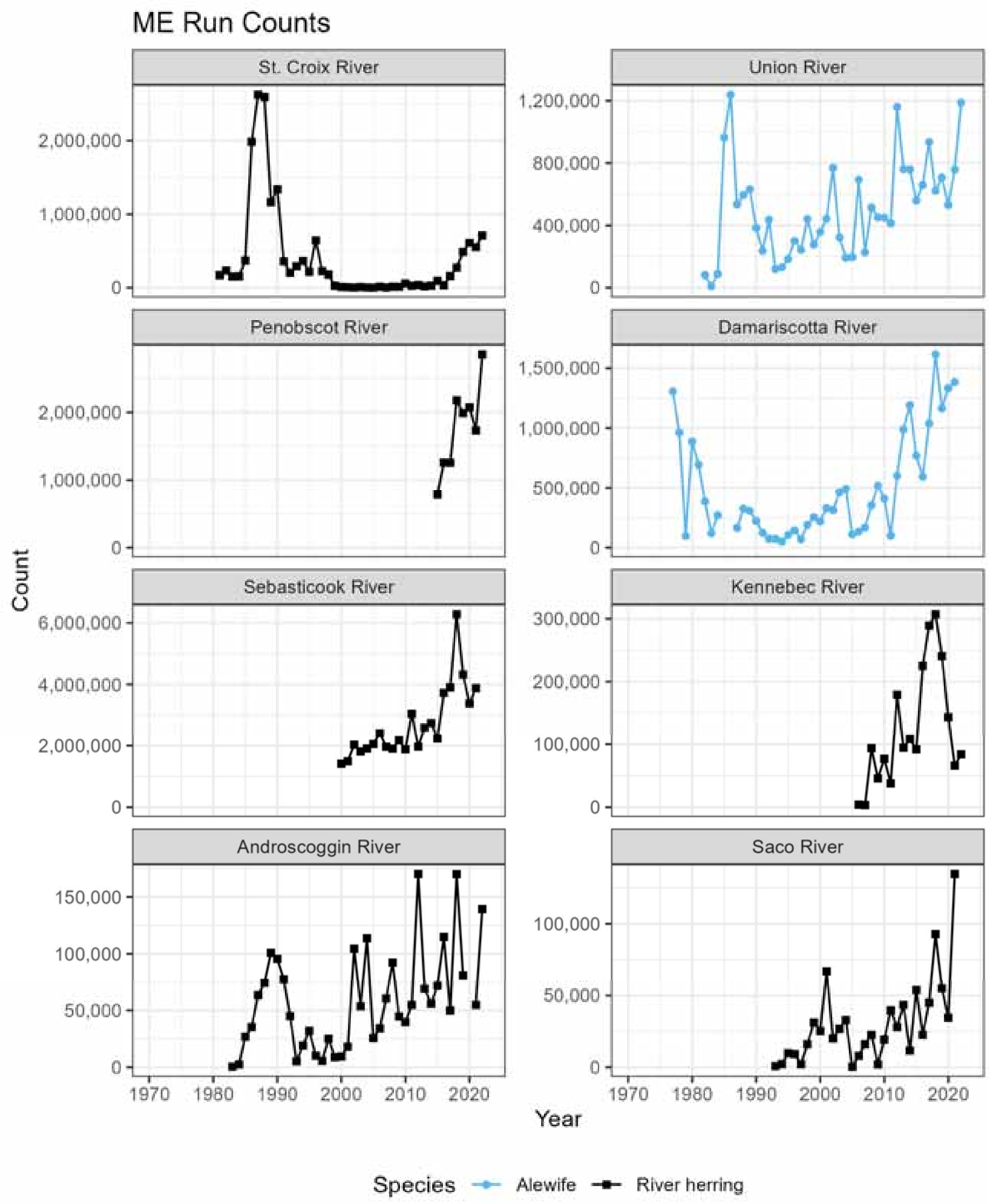


Figure 25. River herring run counts by species from Maine rivers, plotted on different y-axes.

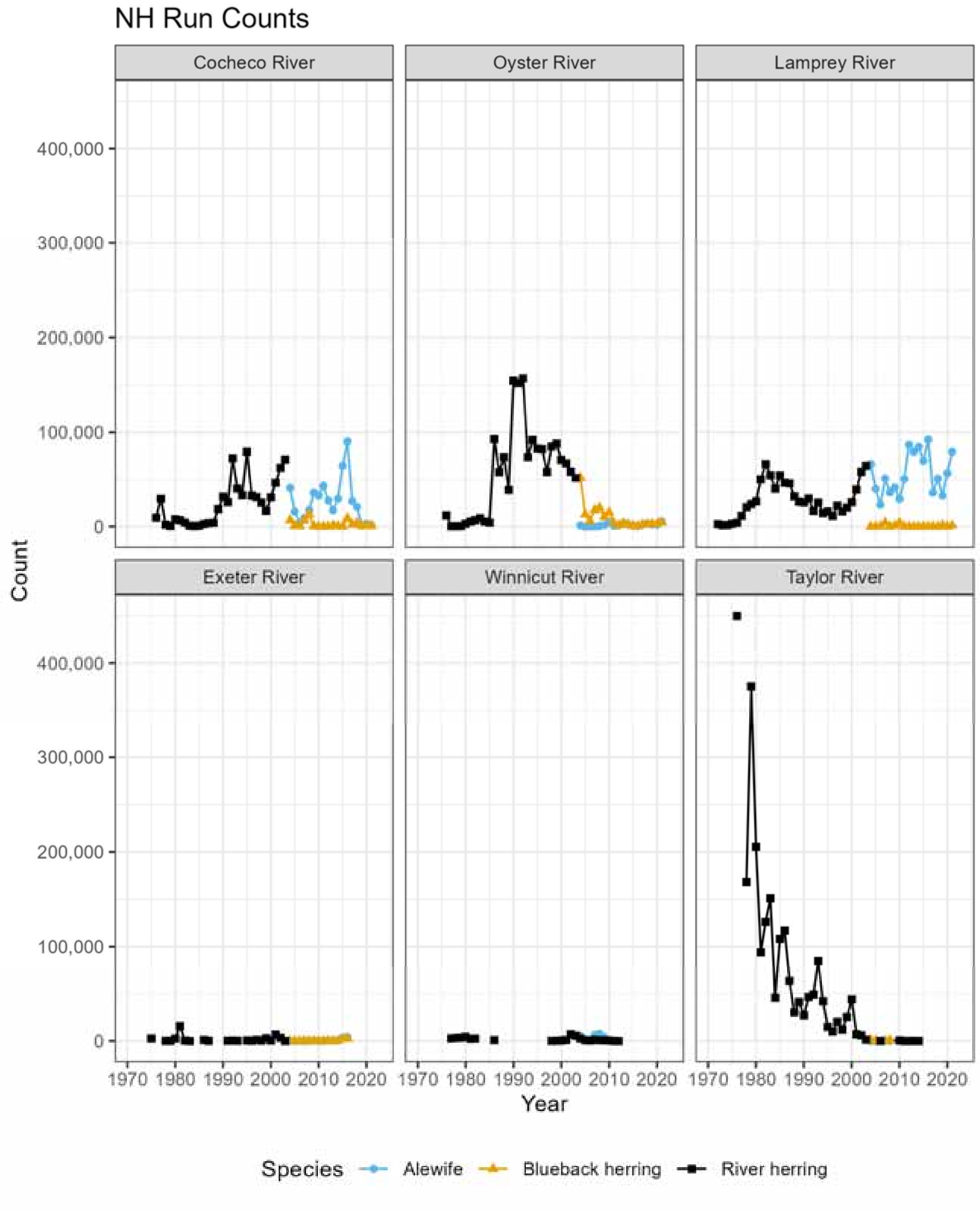


Figure 26. Run counts by species for New Hampshire rivers, plotted with the same y-axes to show relative scale across rivers.

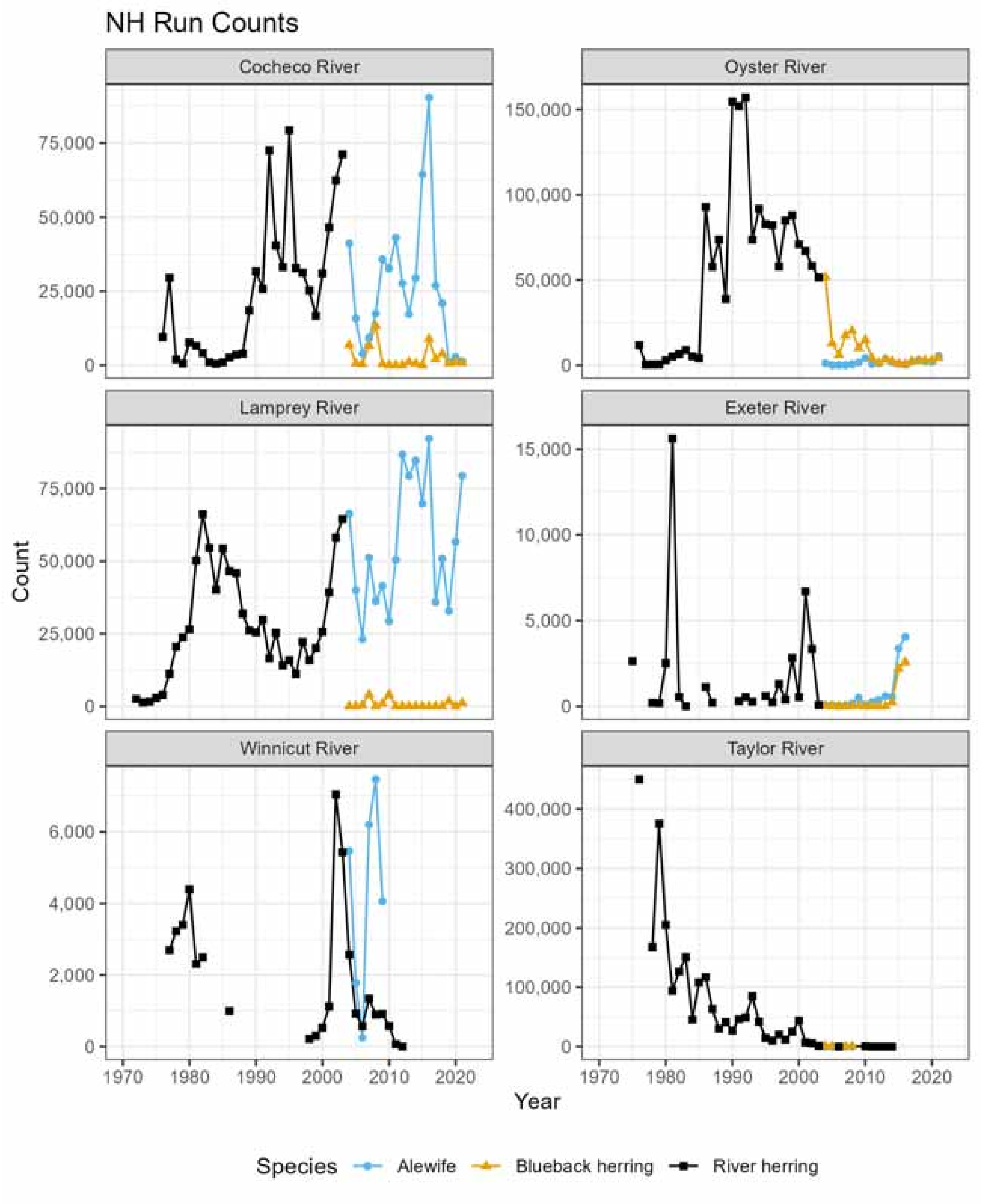


Figure 27. Run counts by species for New Hampshire rivers, plotted with different y-axes.

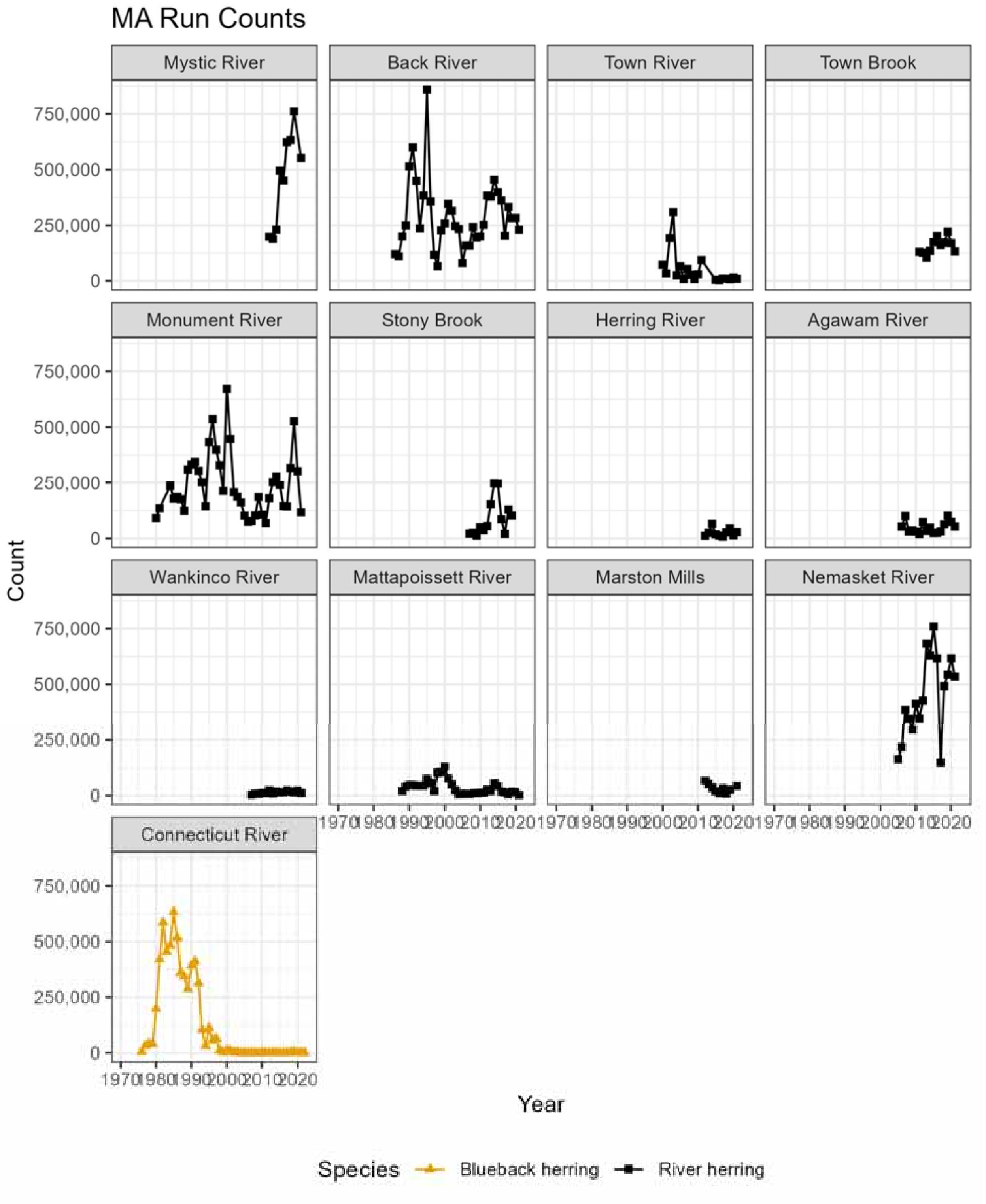


Figure 28. Run counts by species for Massachusetts rivers, plotted with the same y-axes to show relative scale across rivers.

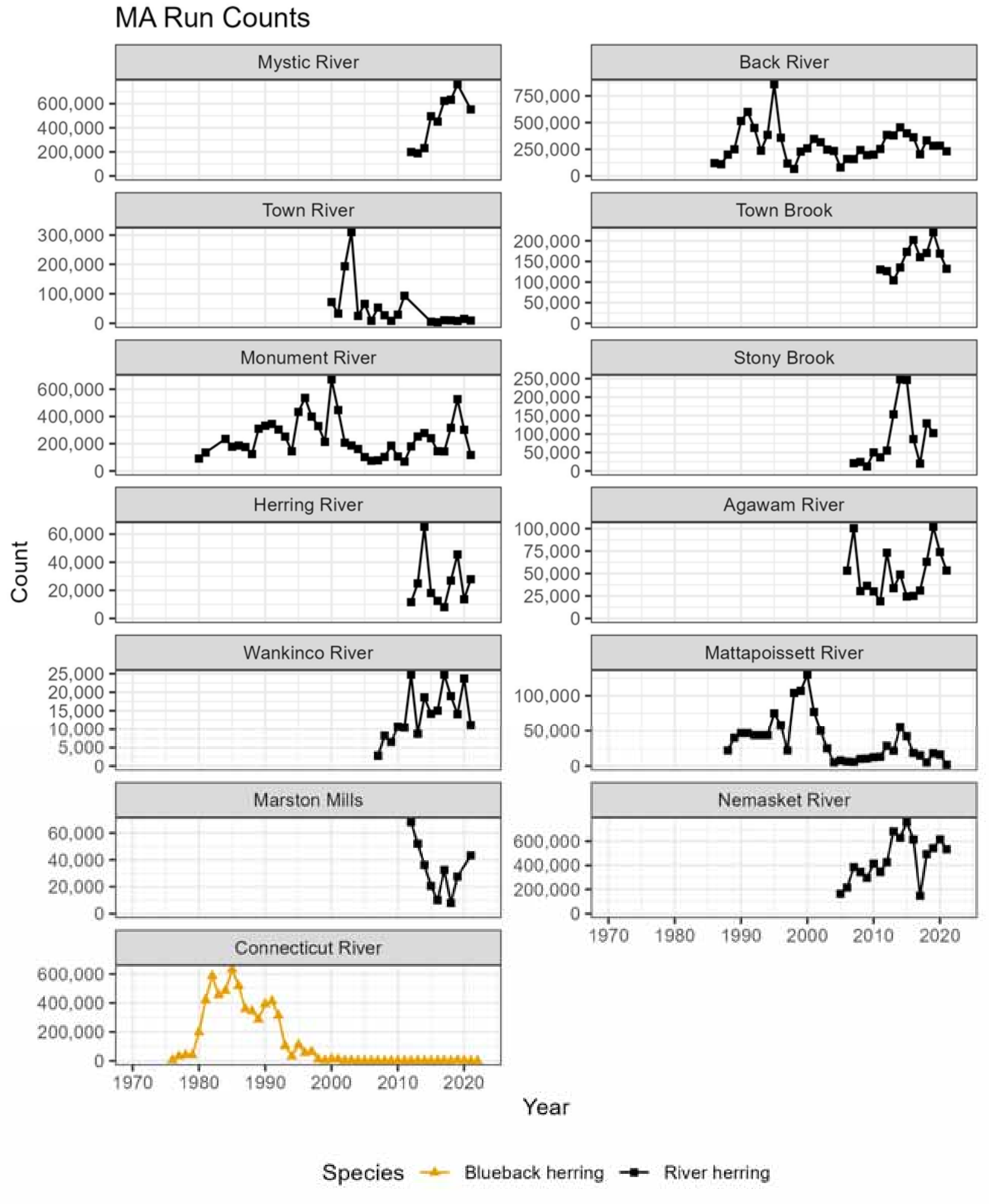


Figure 29. Run counts by species for Massachusetts rivers, plotted with different y-axes.

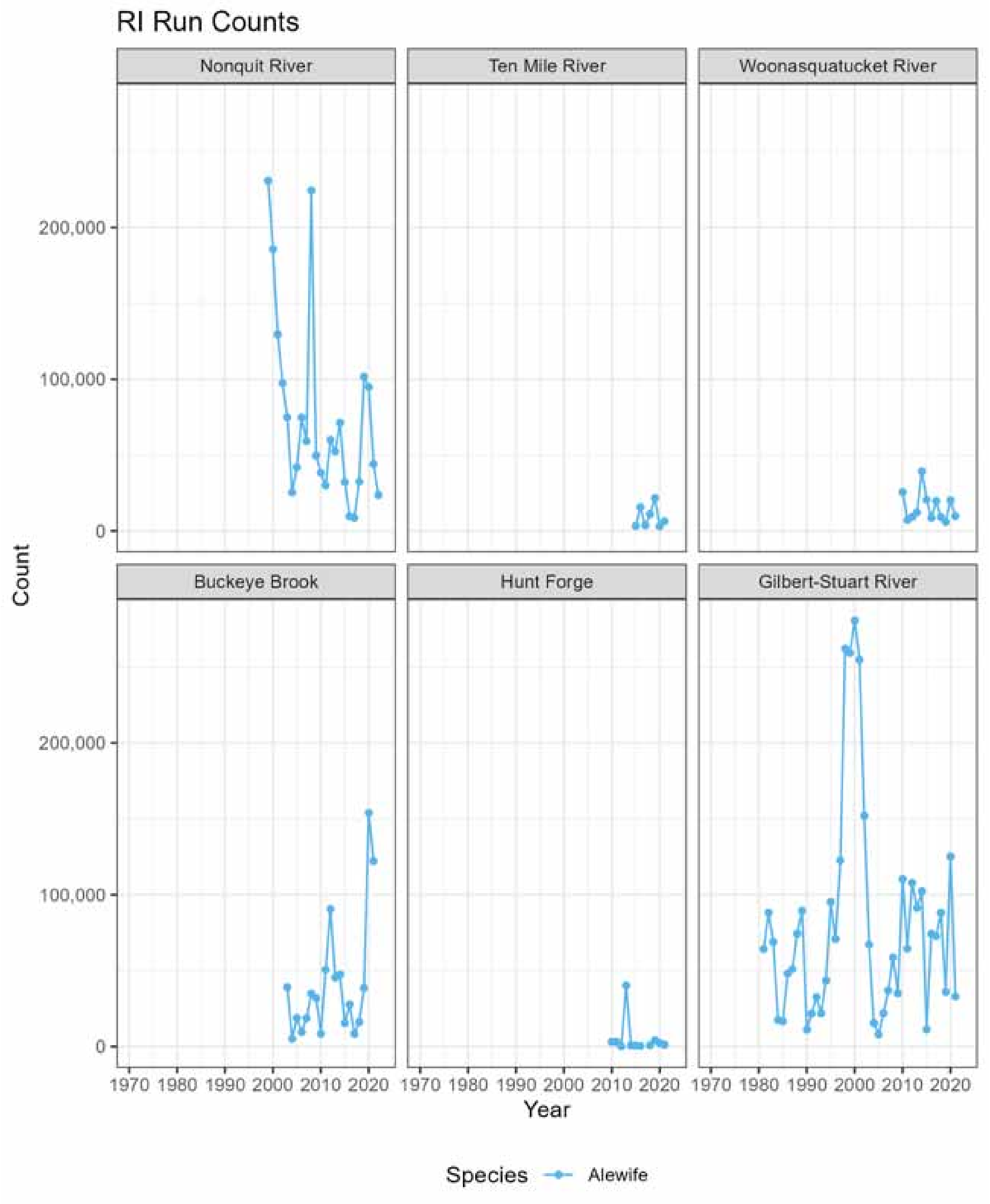


Figure 30. Run counts by species for Rhode Island rivers, plotted with the same y-axes to show relative scale across rivers.

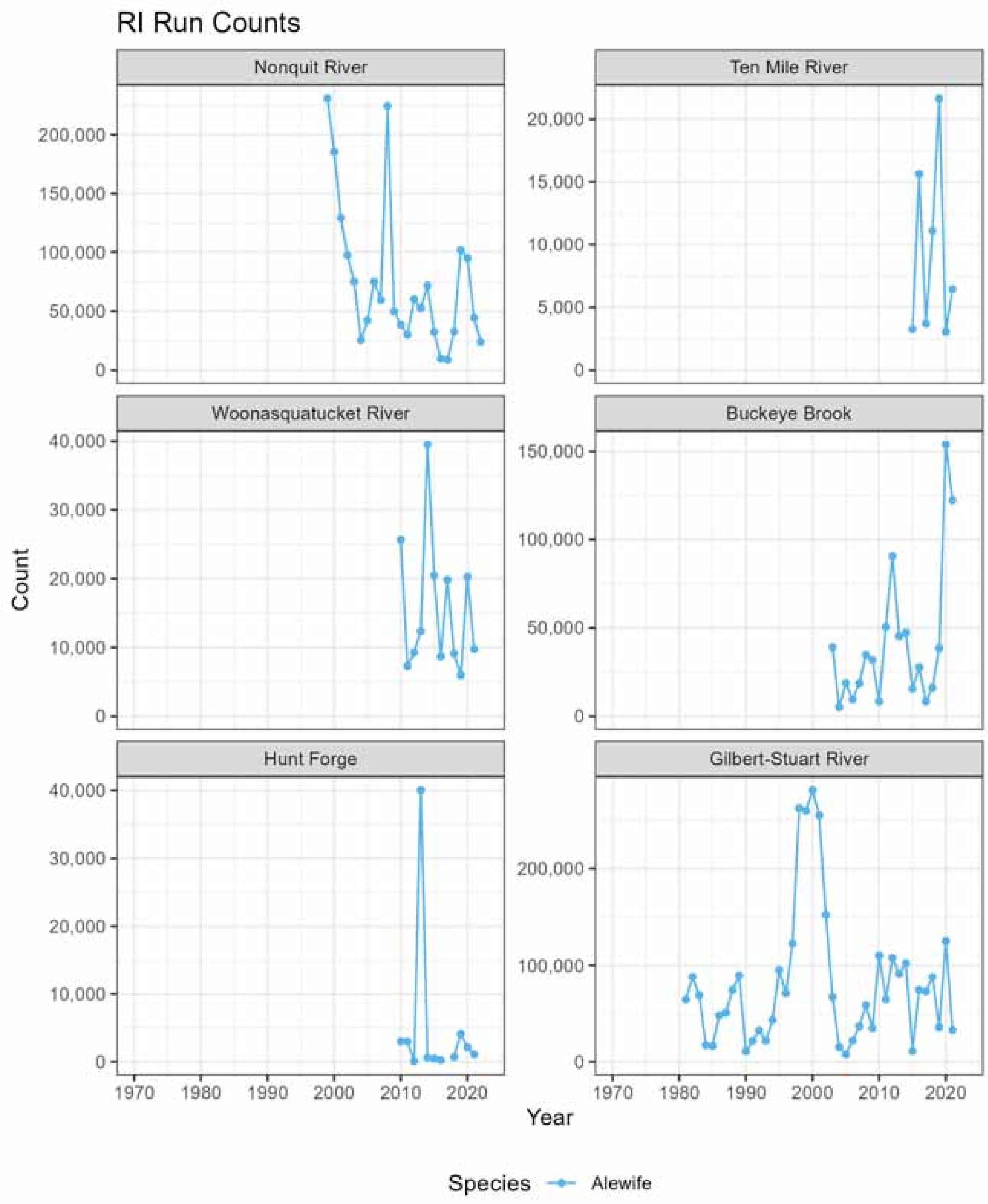


Figure 31. Run counts by species for Rhode Island rivers, plotted with different y-axes.

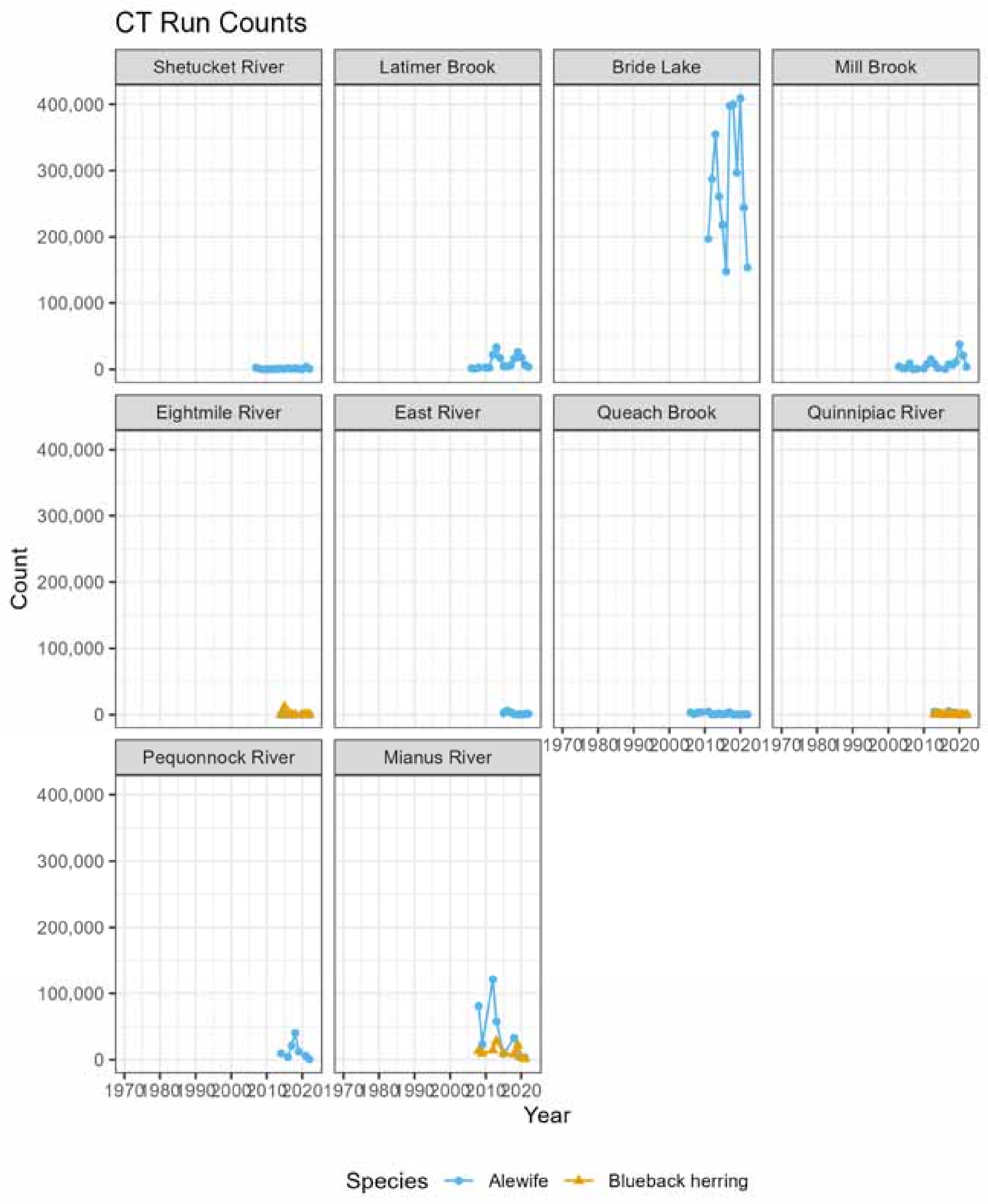


Figure 32. Run counts by species for Connecticut rivers, plotted with the same y-axes to show relative scale across rivers.

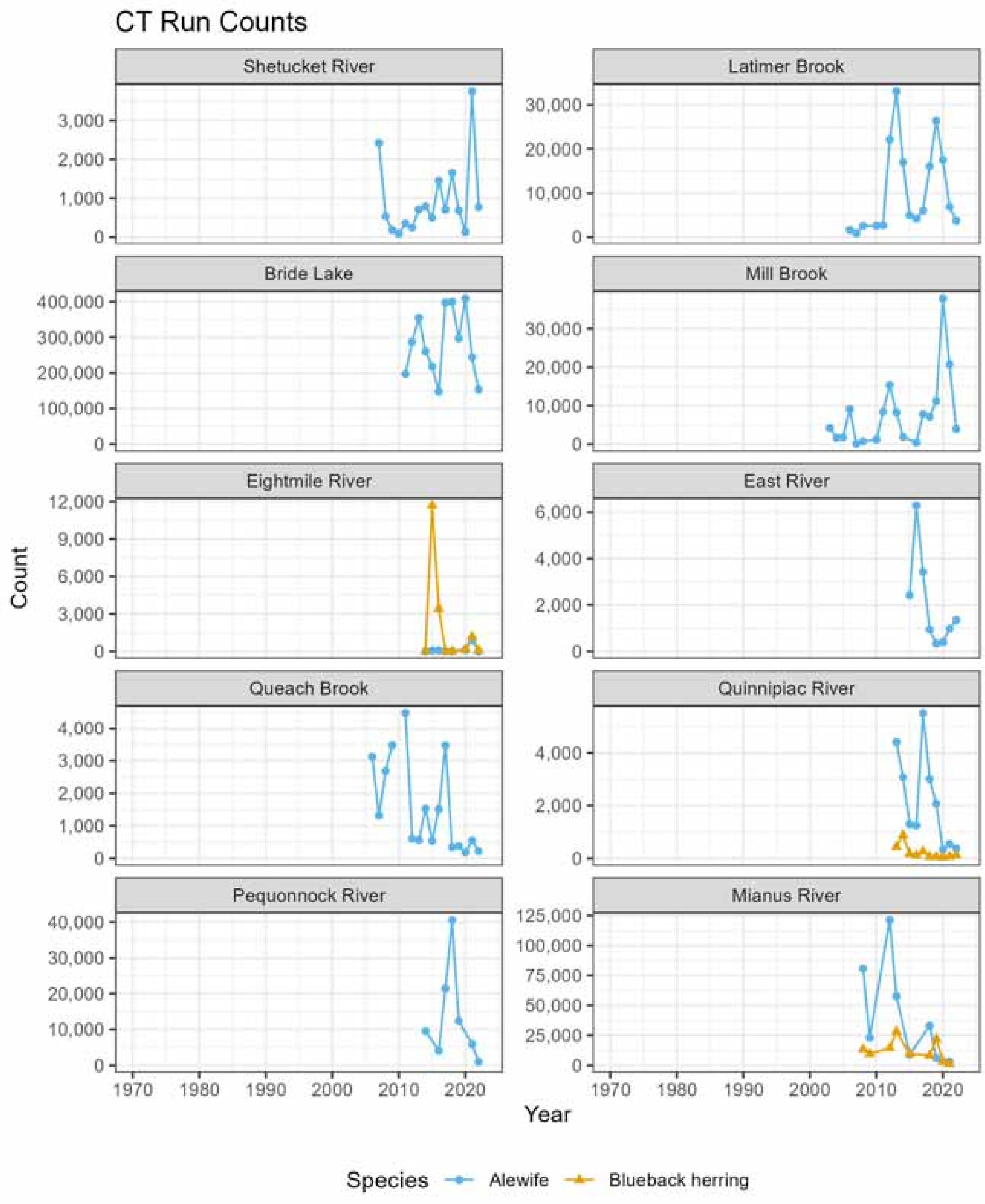


Figure 33. Run counts by species for Connecticut rivers, plotted with different y-axes.

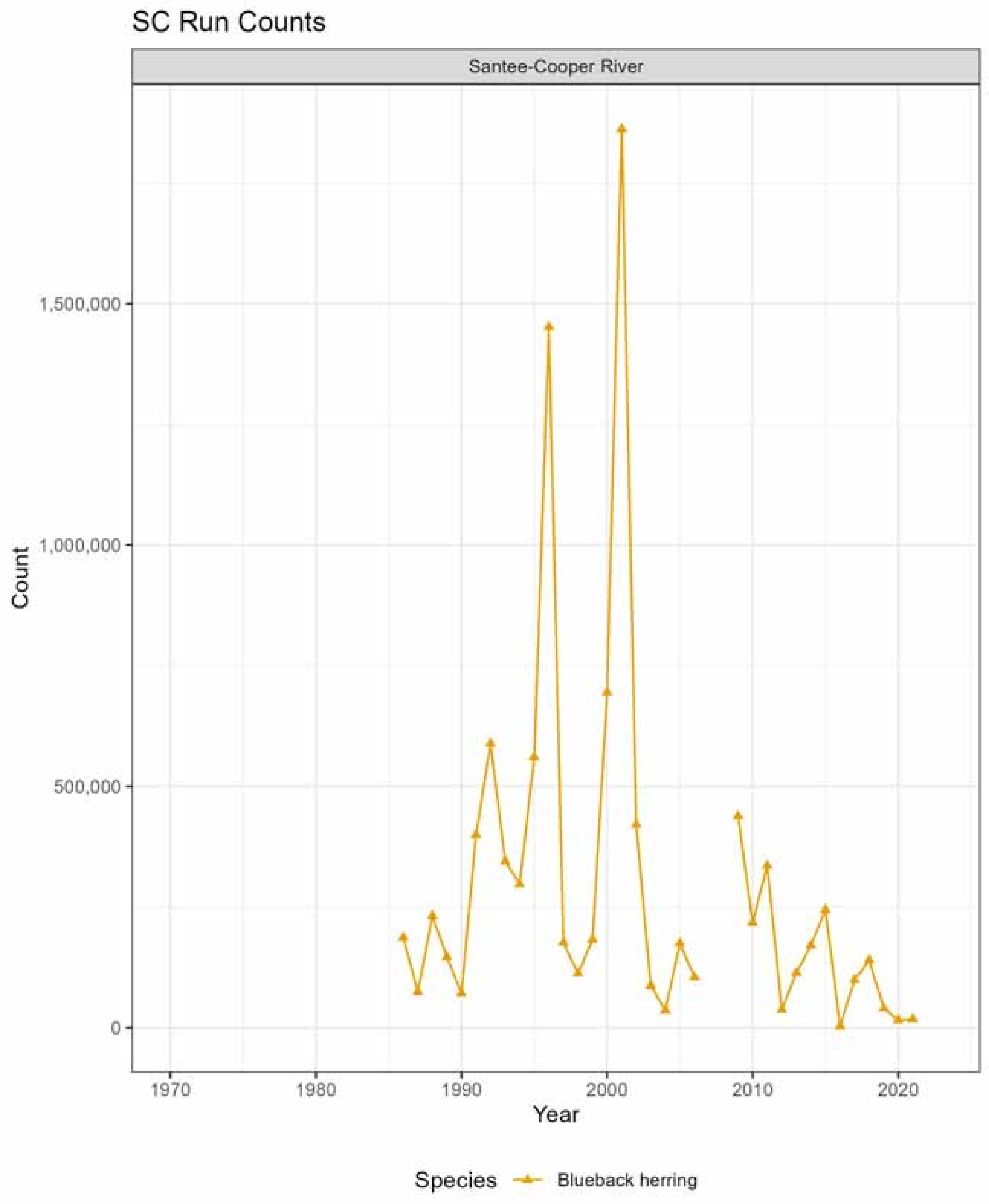


Figure 34. Blueback herring run counts for the Santee-Cooper River in South Carolina.

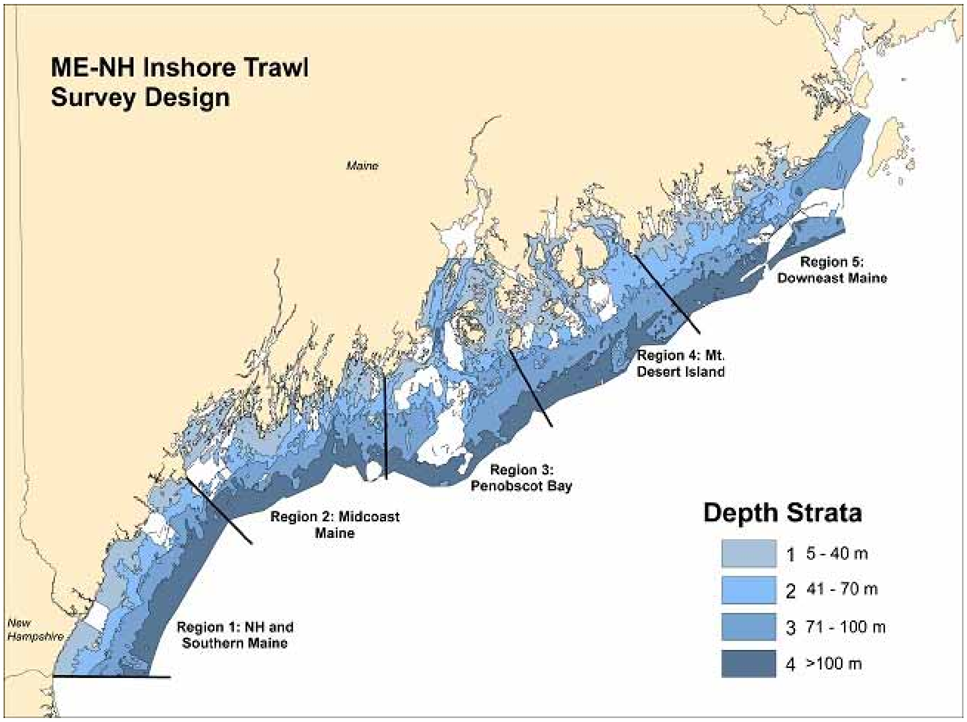


Figure 35. Survey area of the Maine-New Hampshire Inshore Trawl Survey.

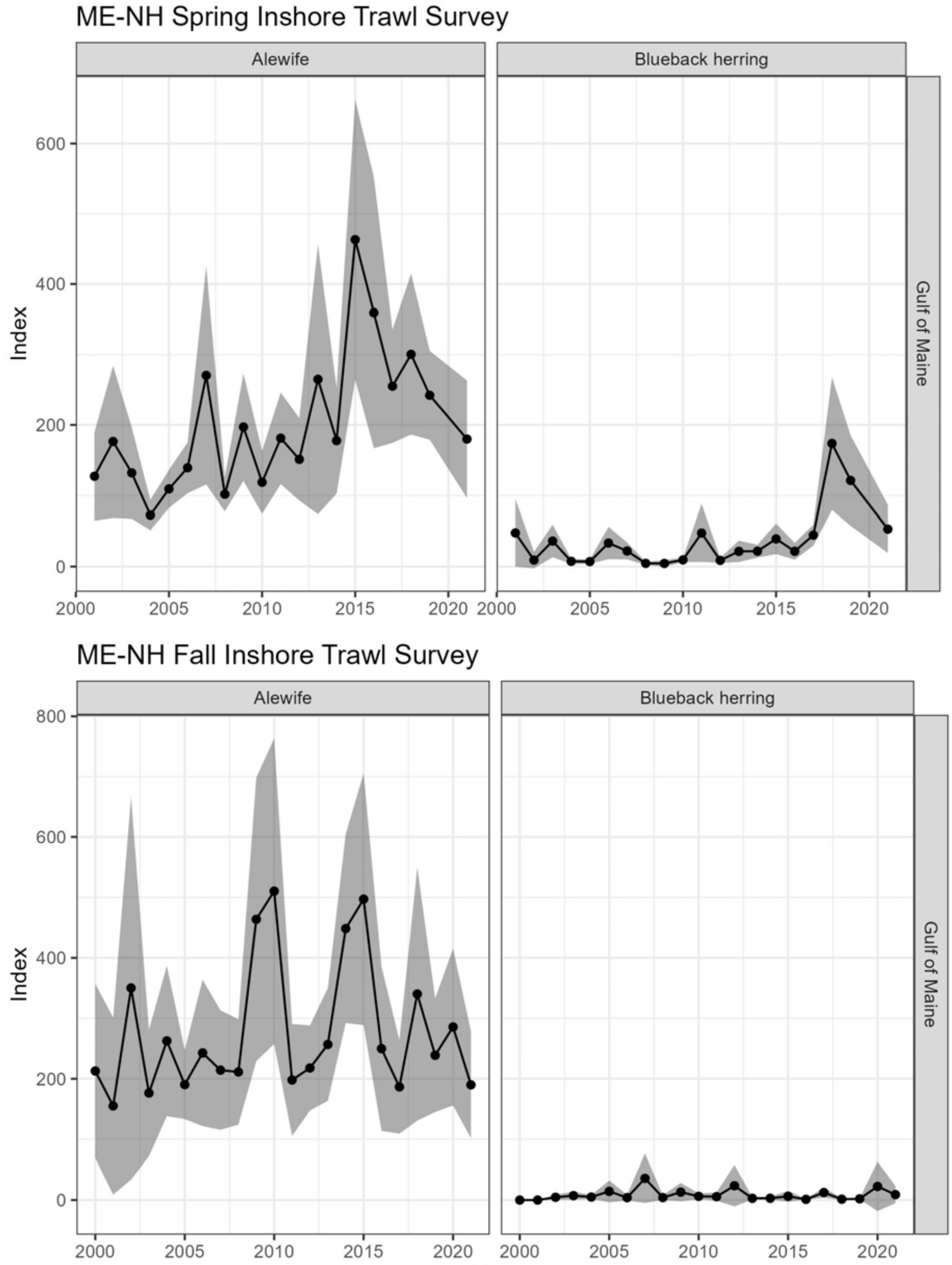


Figure 36. Indices of abundance from the ME-NH Inshore Trawl Survey for the spring (top) and fall (bottom) cruises.

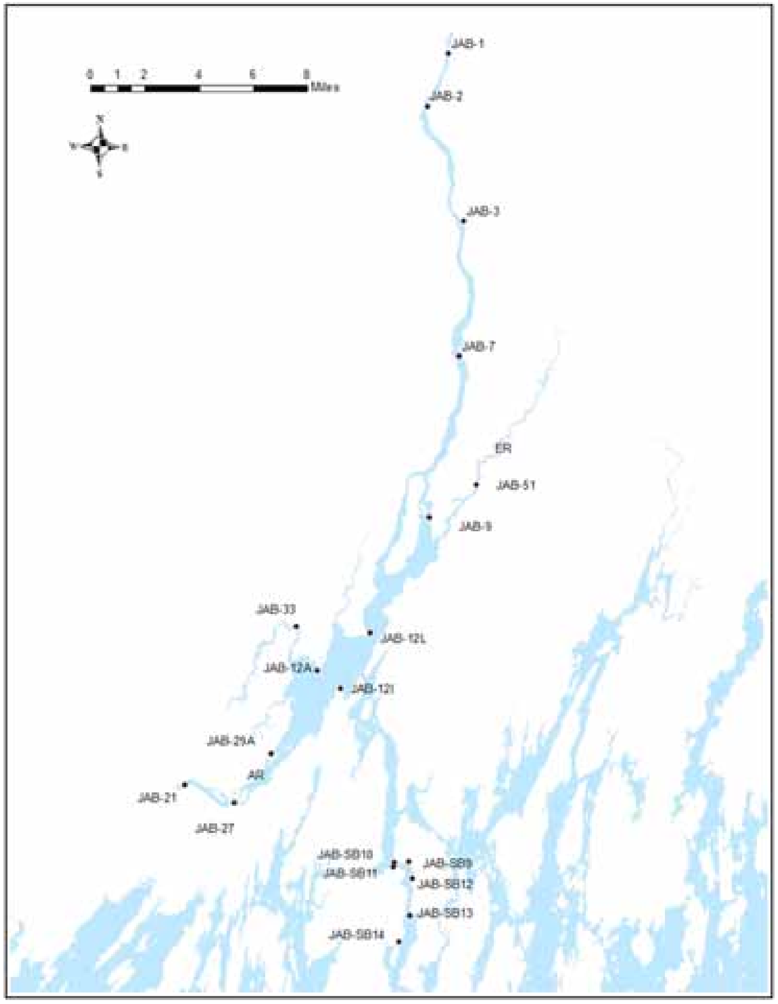


Figure 37. Sample sites for the Maine Juvenile Alosine Seine Survey.

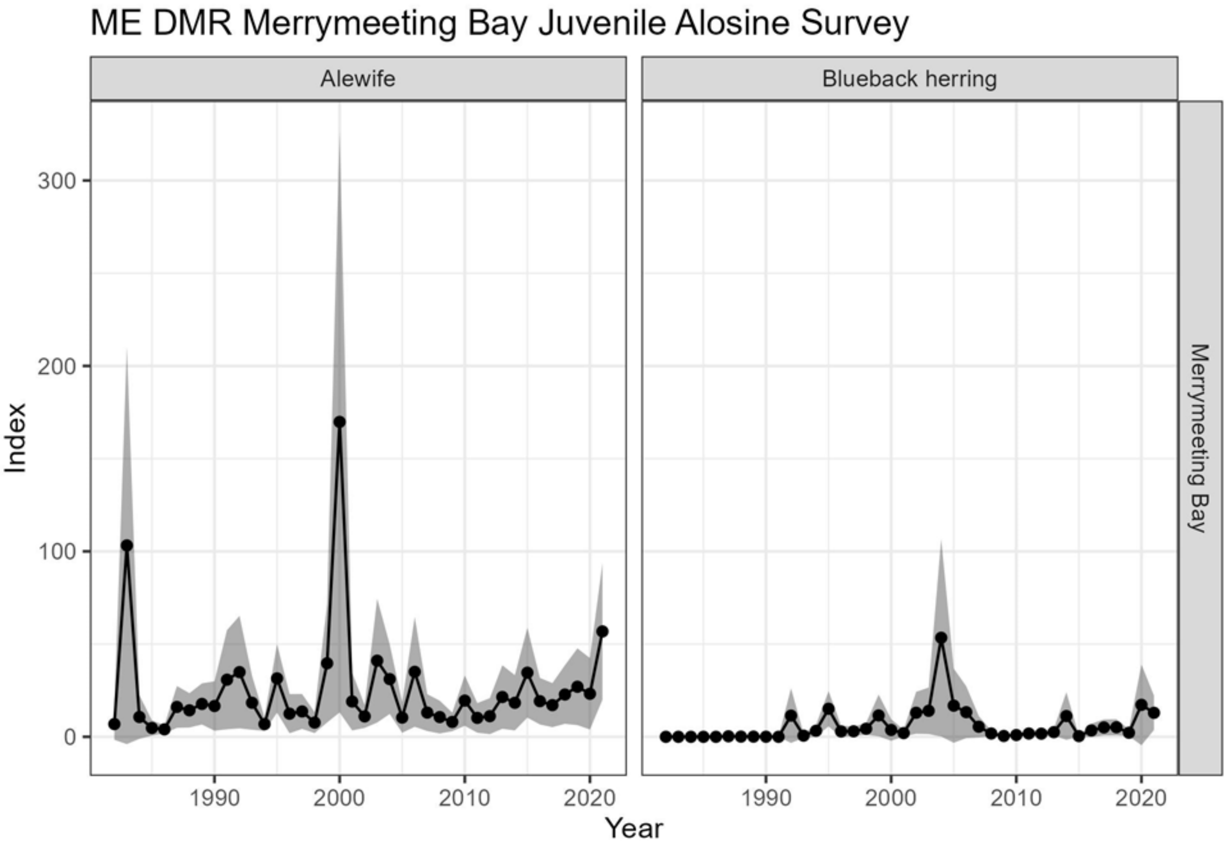


Figure 38. Indices of abundance from the ME DMR Merrymeeting Bay Juvenile Alosine Survey.

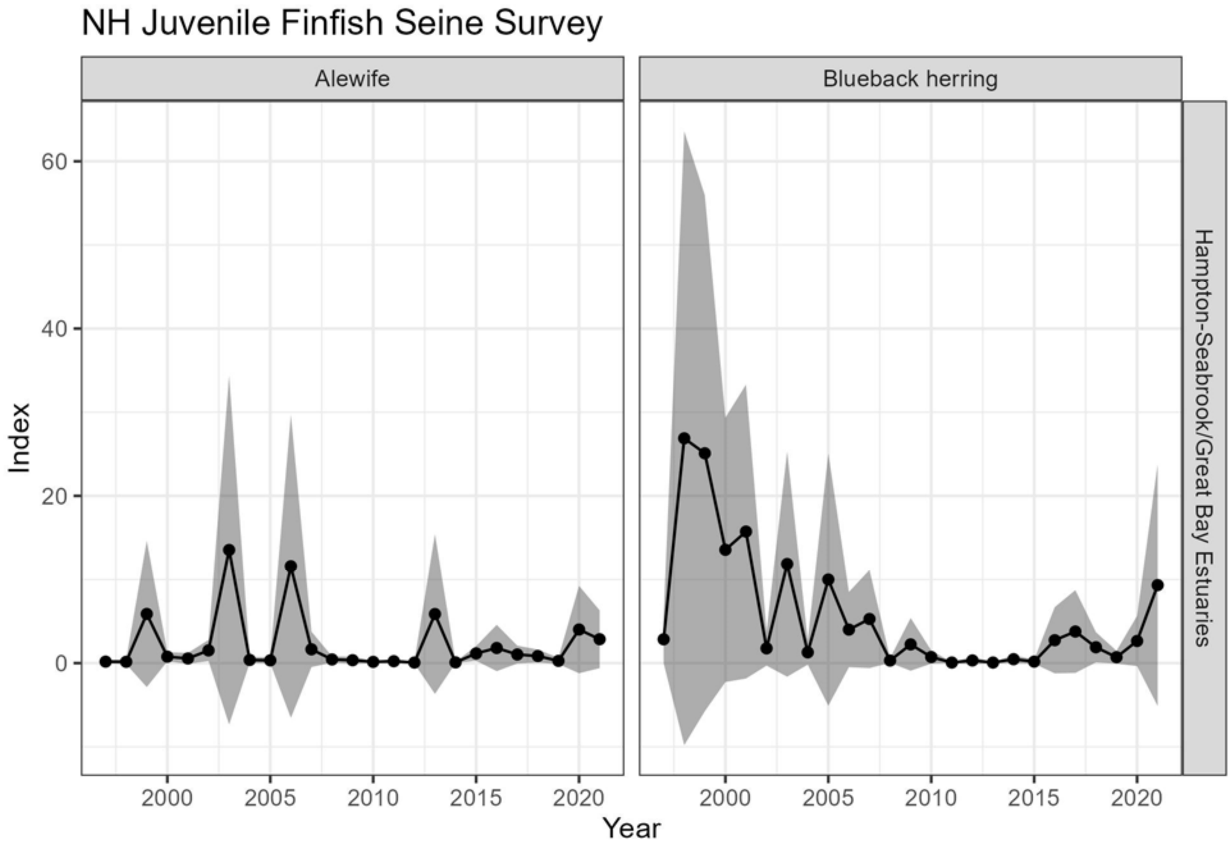


Figure 39. Indices of abundance from the NH Juvenile Finfish Seine Survey.

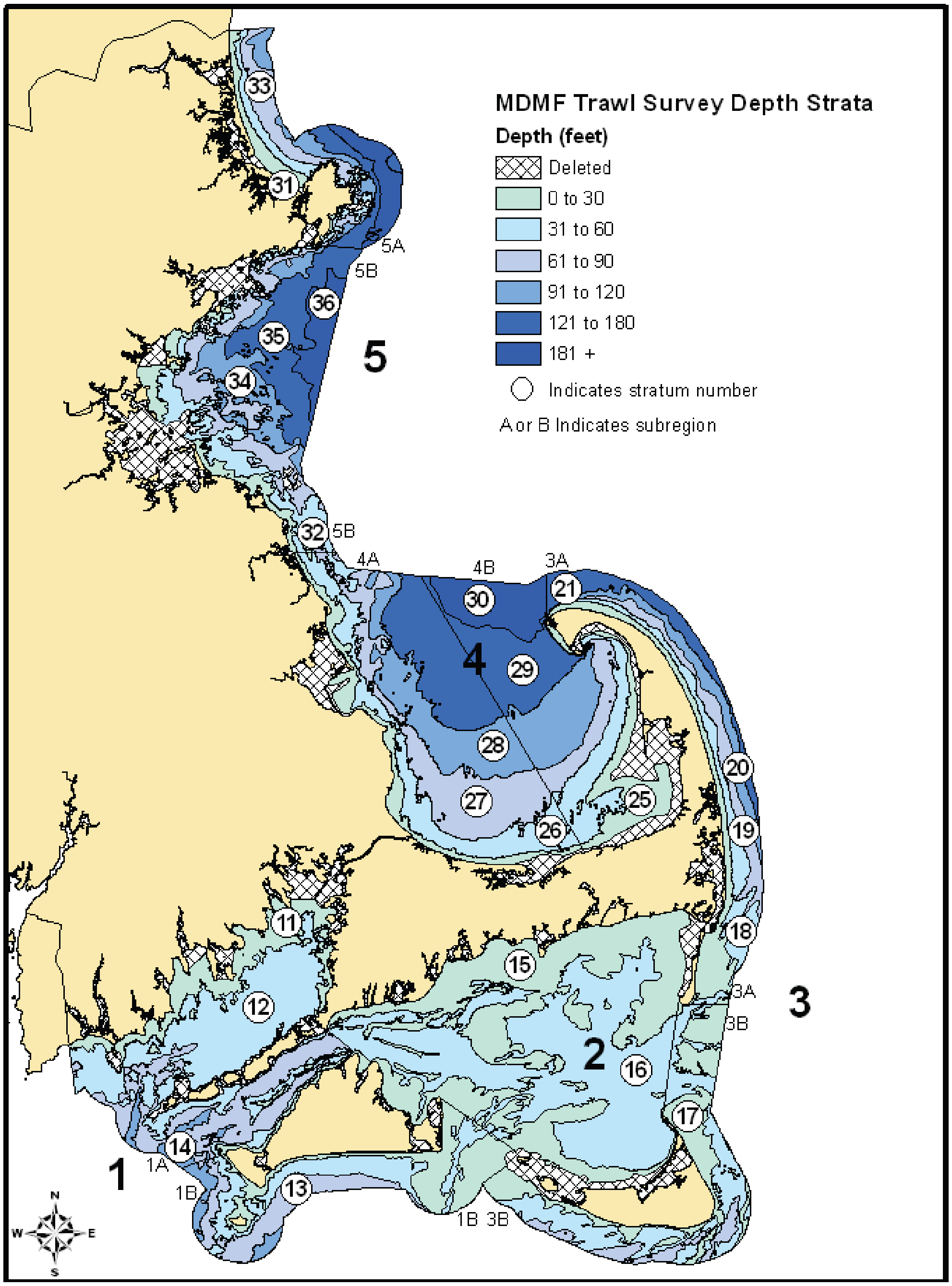


Figure 40. Survey area of the Massachusetts Trawl Survey.

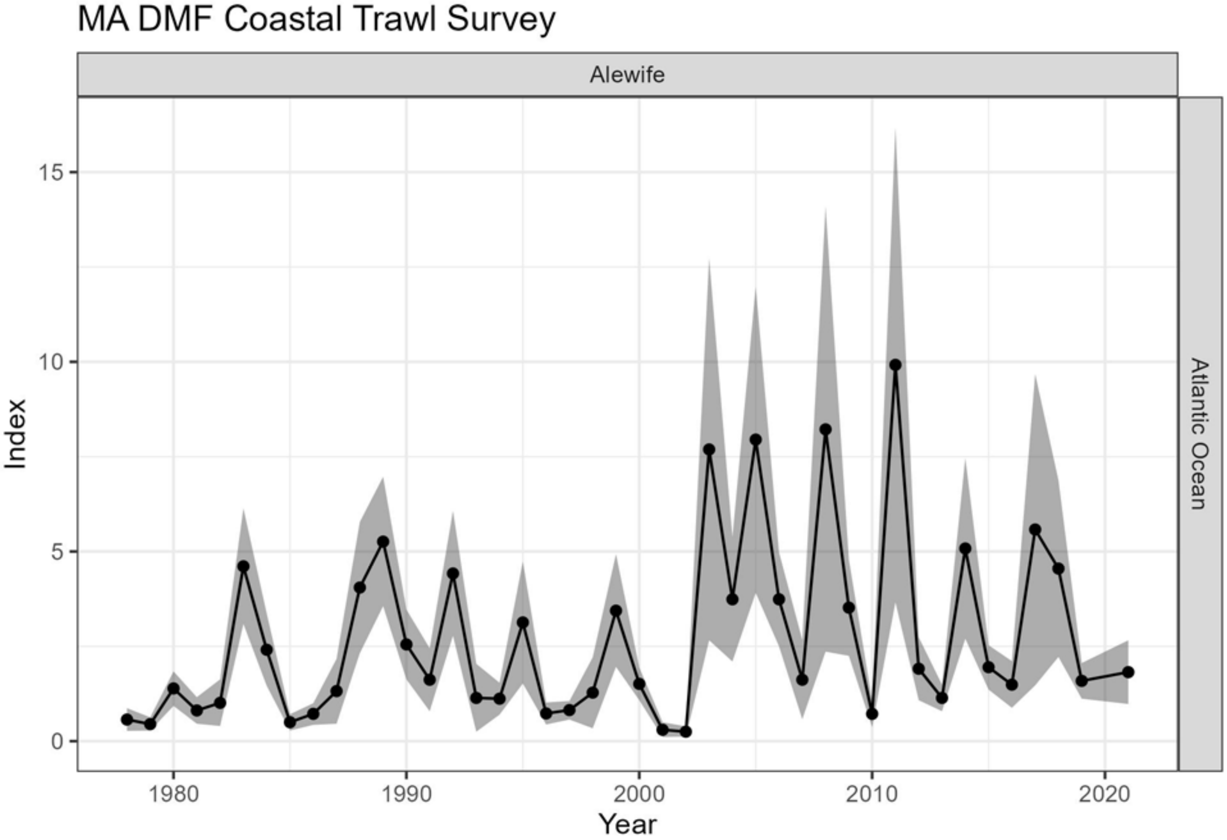


Figure 41. Index of alewife abundance from the MA DMF Coastal Trawl Survey.

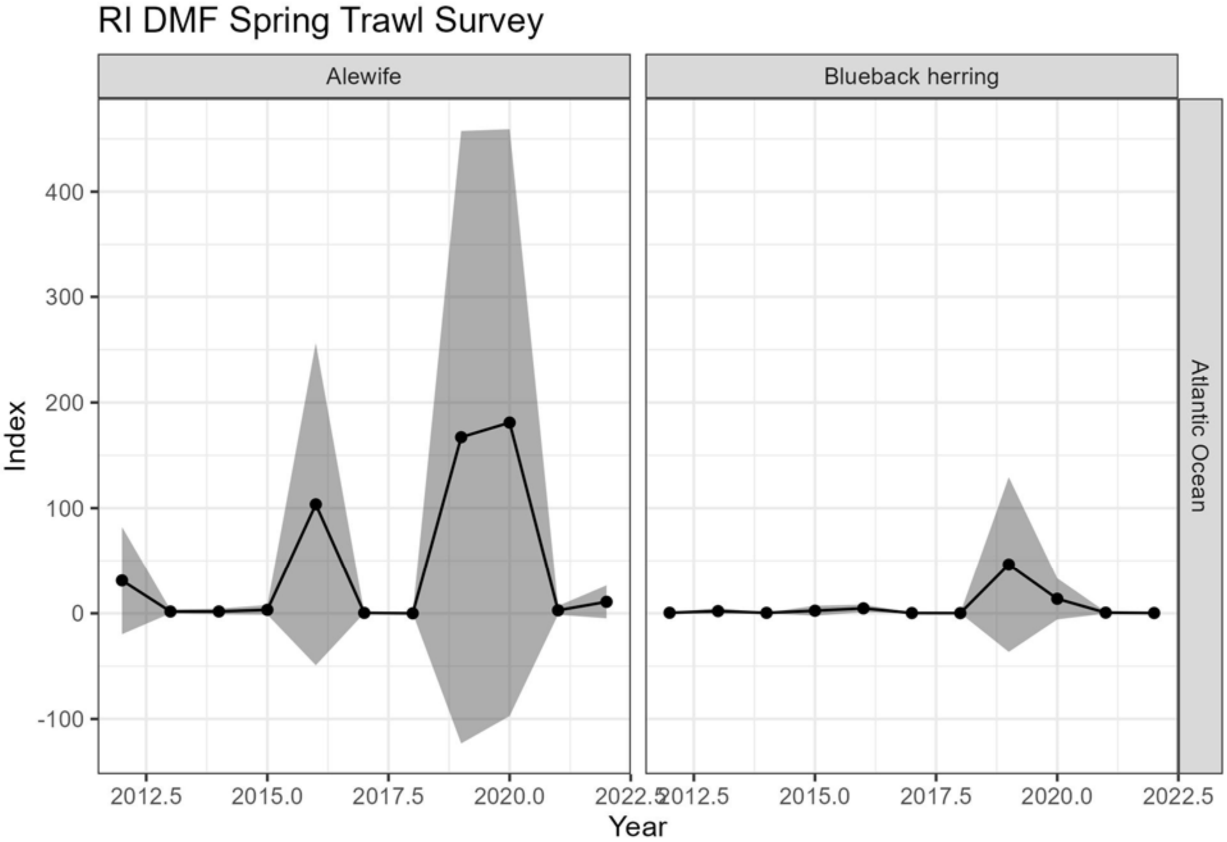


Figure 42. Indices of abundance from the RI DMF Trawl Survey.

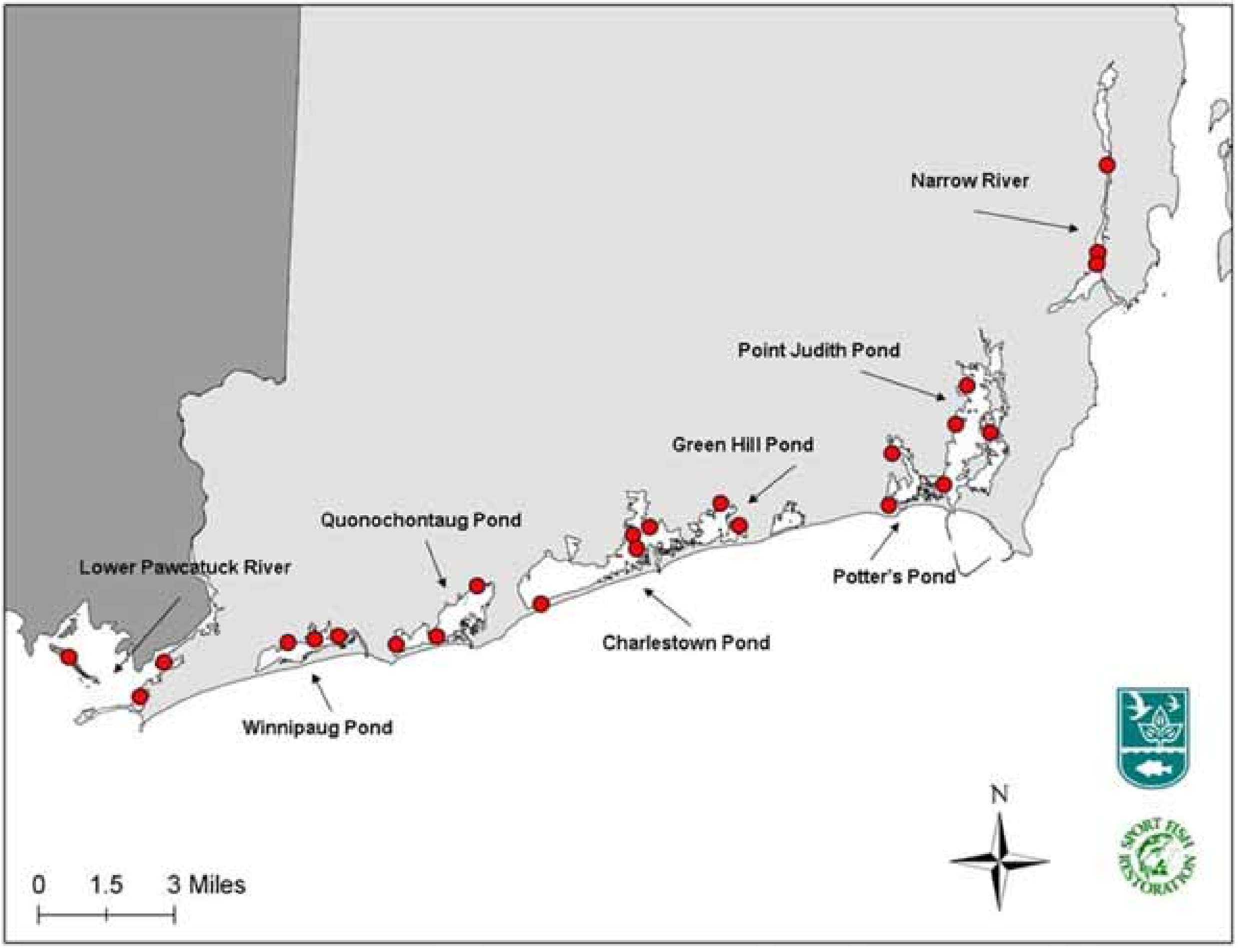


Figure 43. Sample sites for the Rhode Island Coastal Pond Seine Survey.

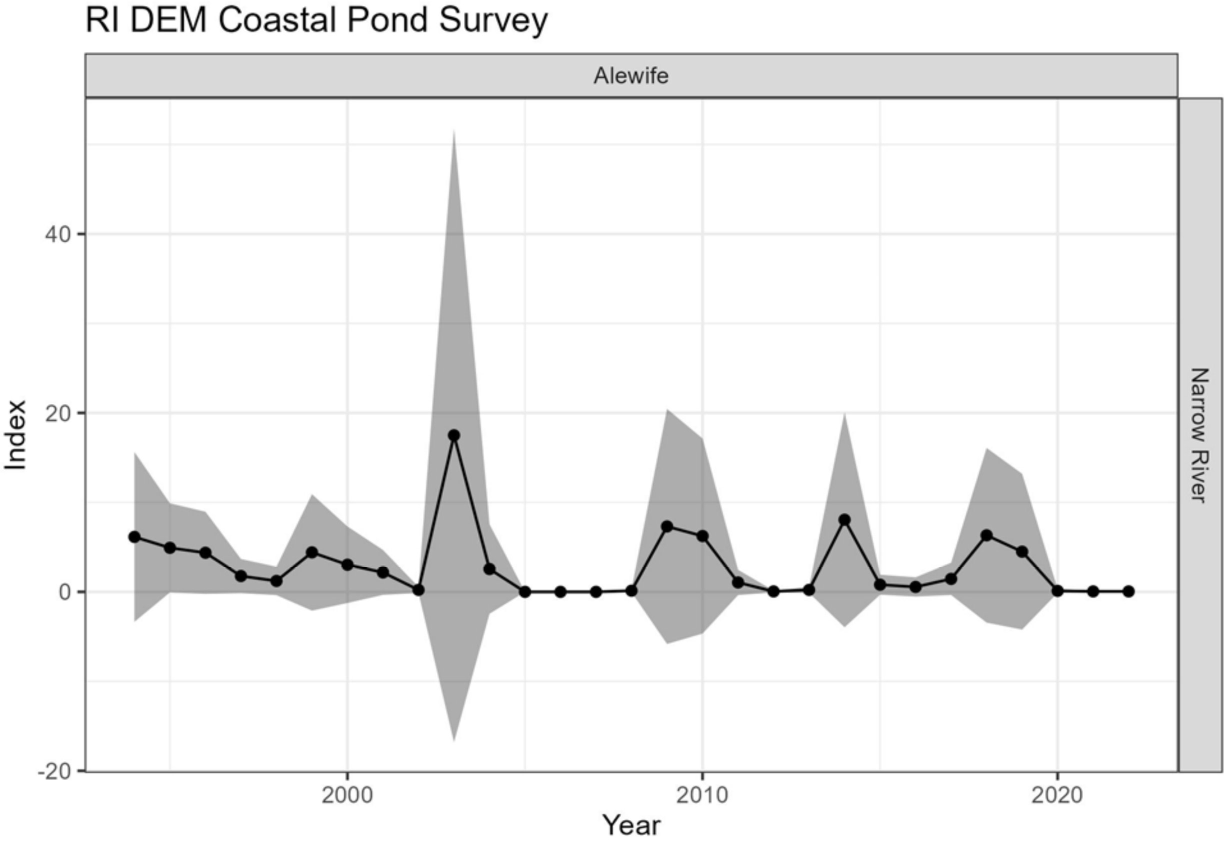


Figure 44. Index of alewife abundance from the RI DEM Coastal Pond Survey in the Narrow River.

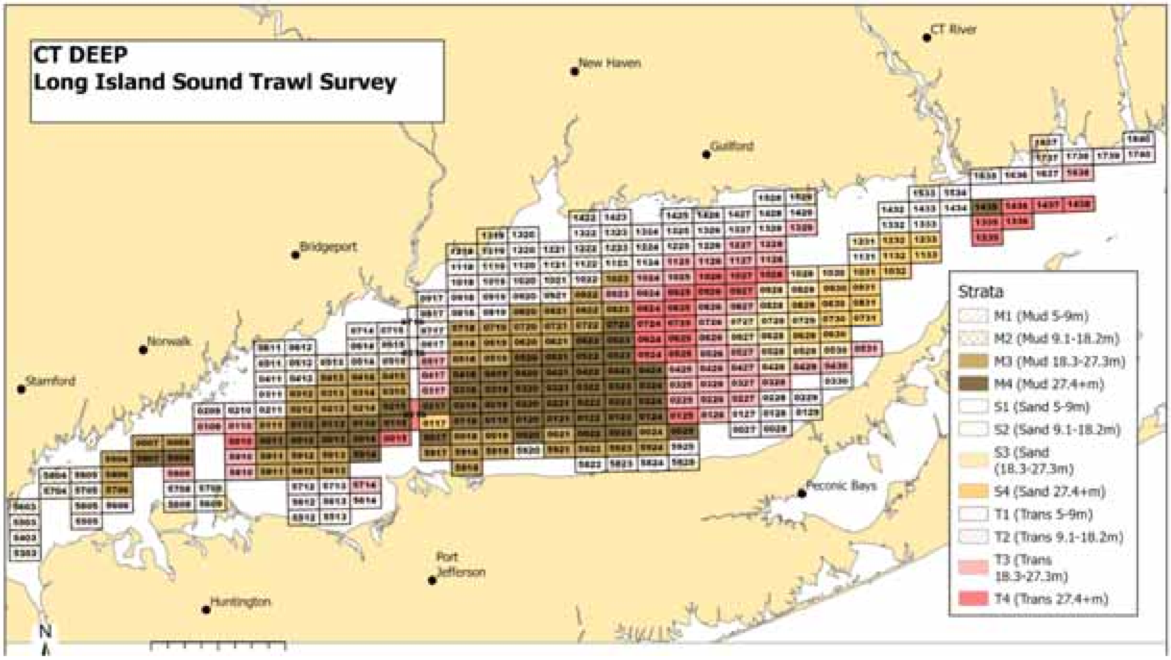


Figure 45. Survey area of the Connecticut Long Island Sound Trawl Survey.

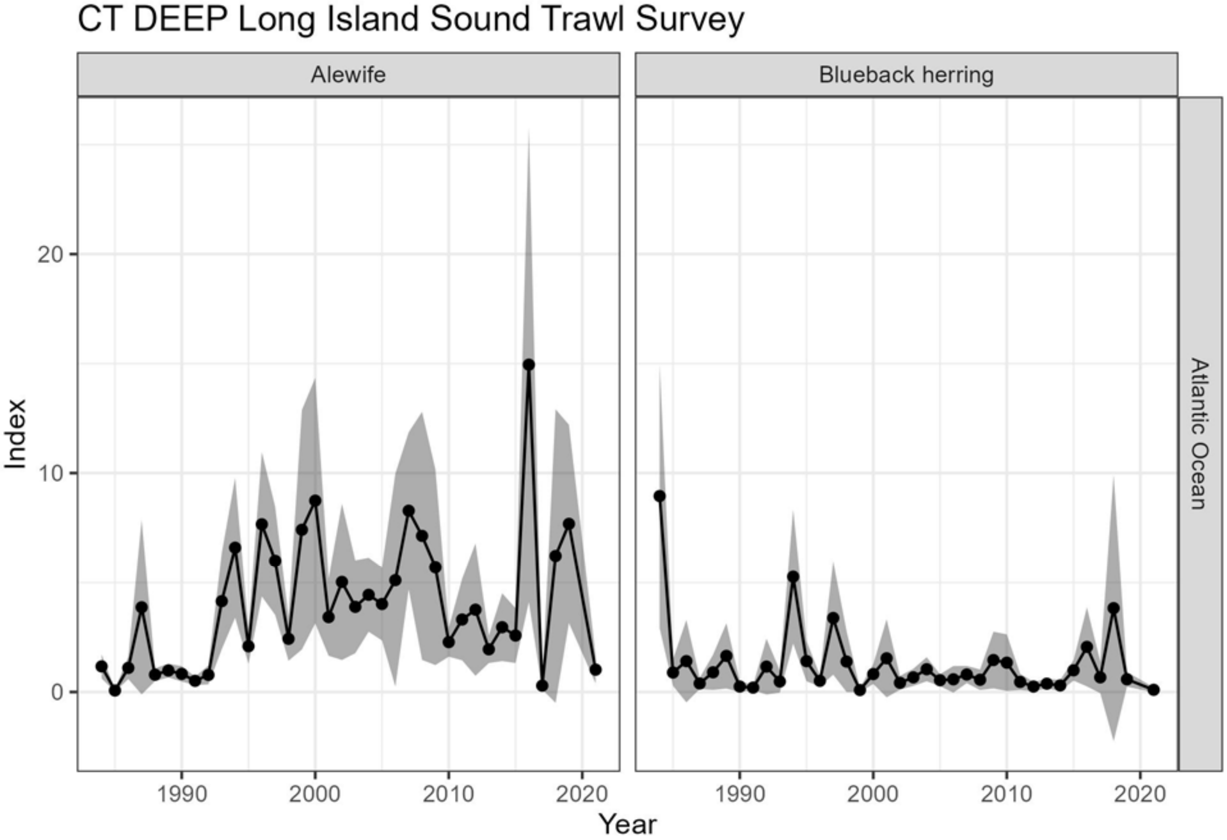


Figure 46. Indices of abundance from the CT DEEP Long Island Sound Trawl Survey.

Figure 47. Sample sites for the Connecticut River Seine Survey.

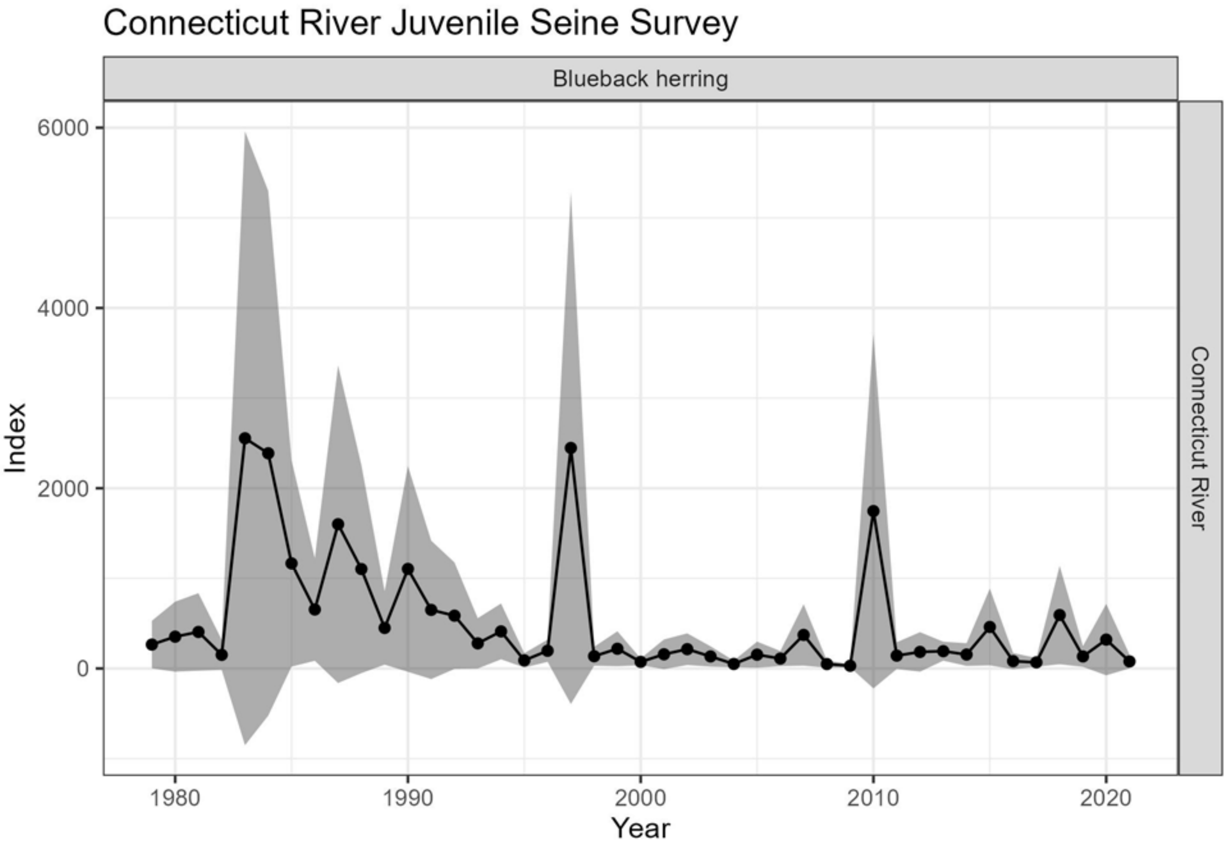


Figure 48. Index of blueback herring abundance from the CT DEEP Connecticut River Juvenile Seine Survey.

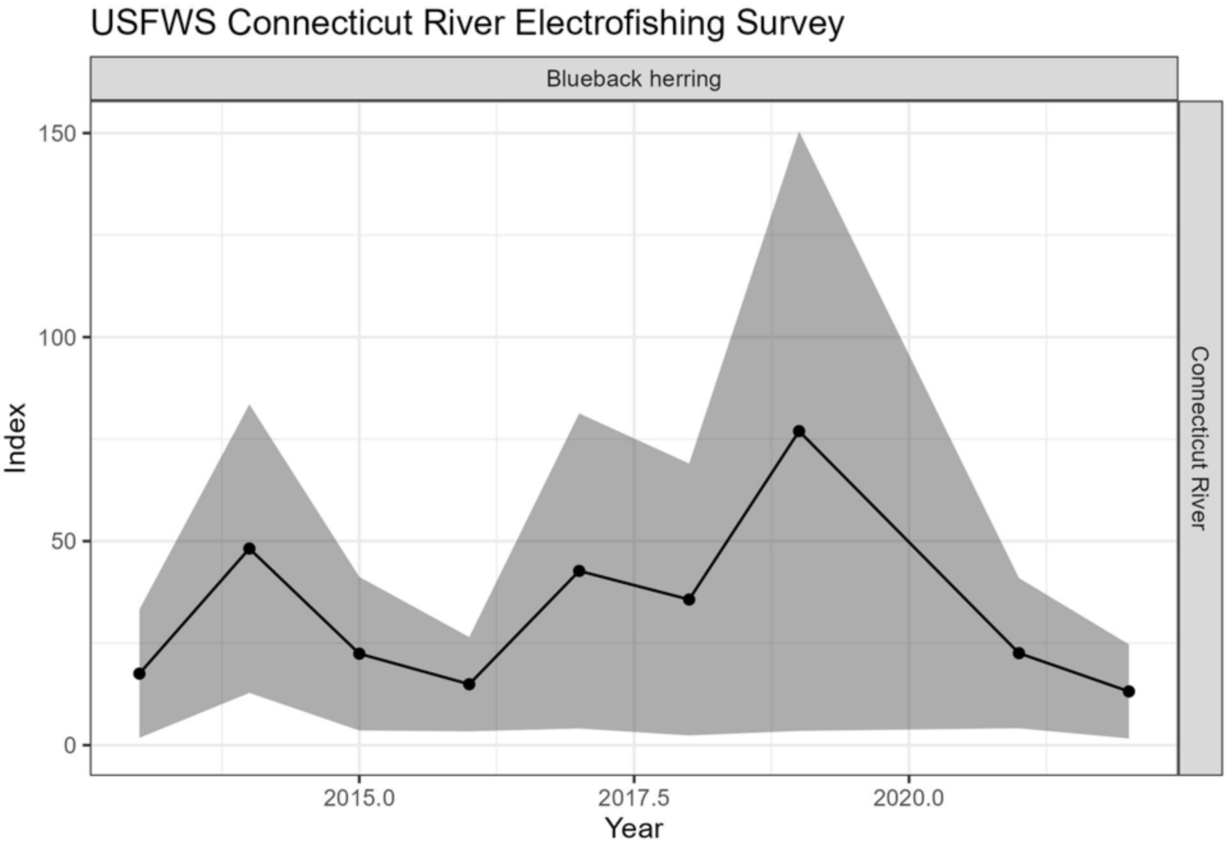


Figure 49. Index of blueback herring abundance from the USFWS Connecticut River Electrofishing Survey.

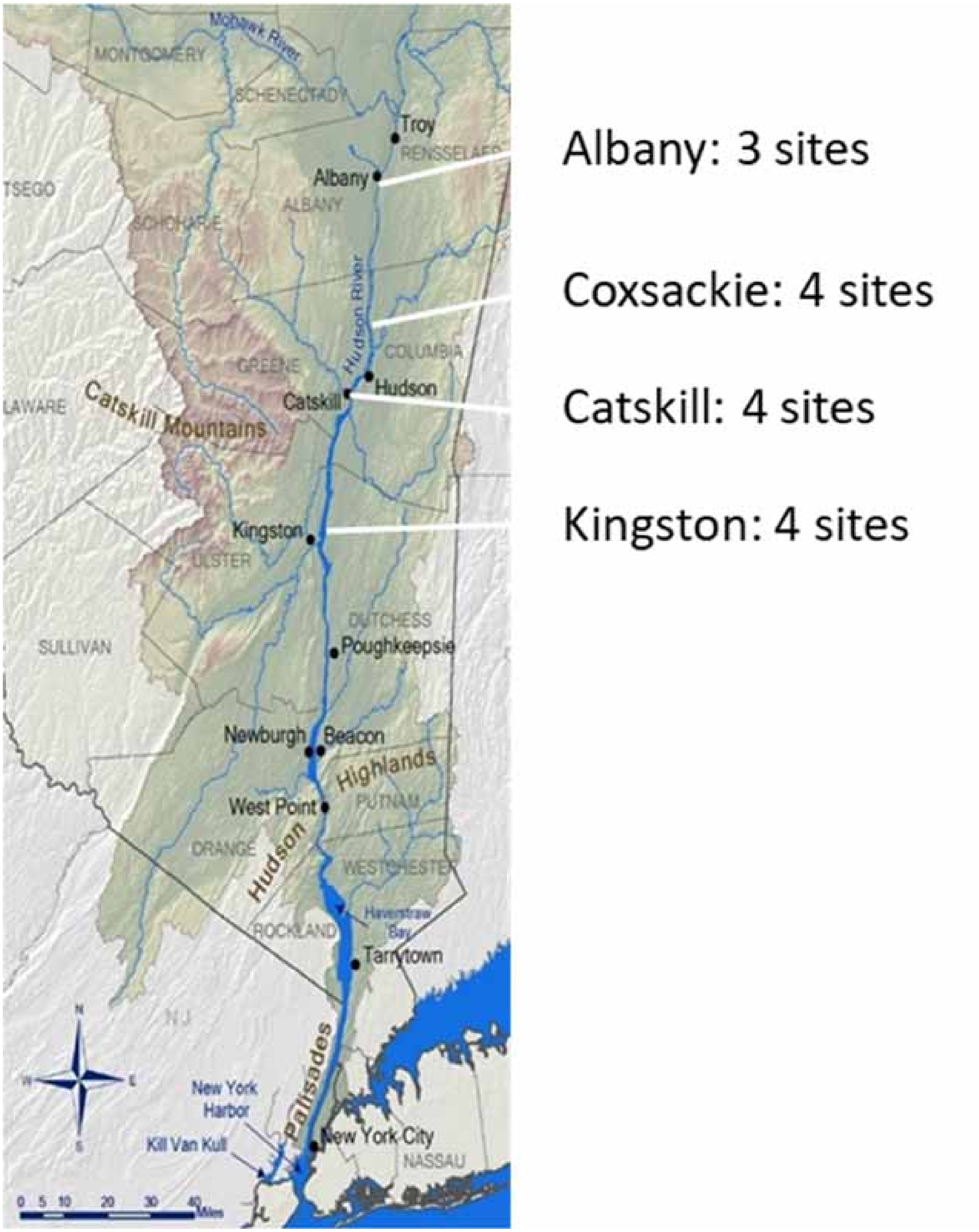


Figure 50. Sample sites for the New York River Herring Spawning Stock Survey.

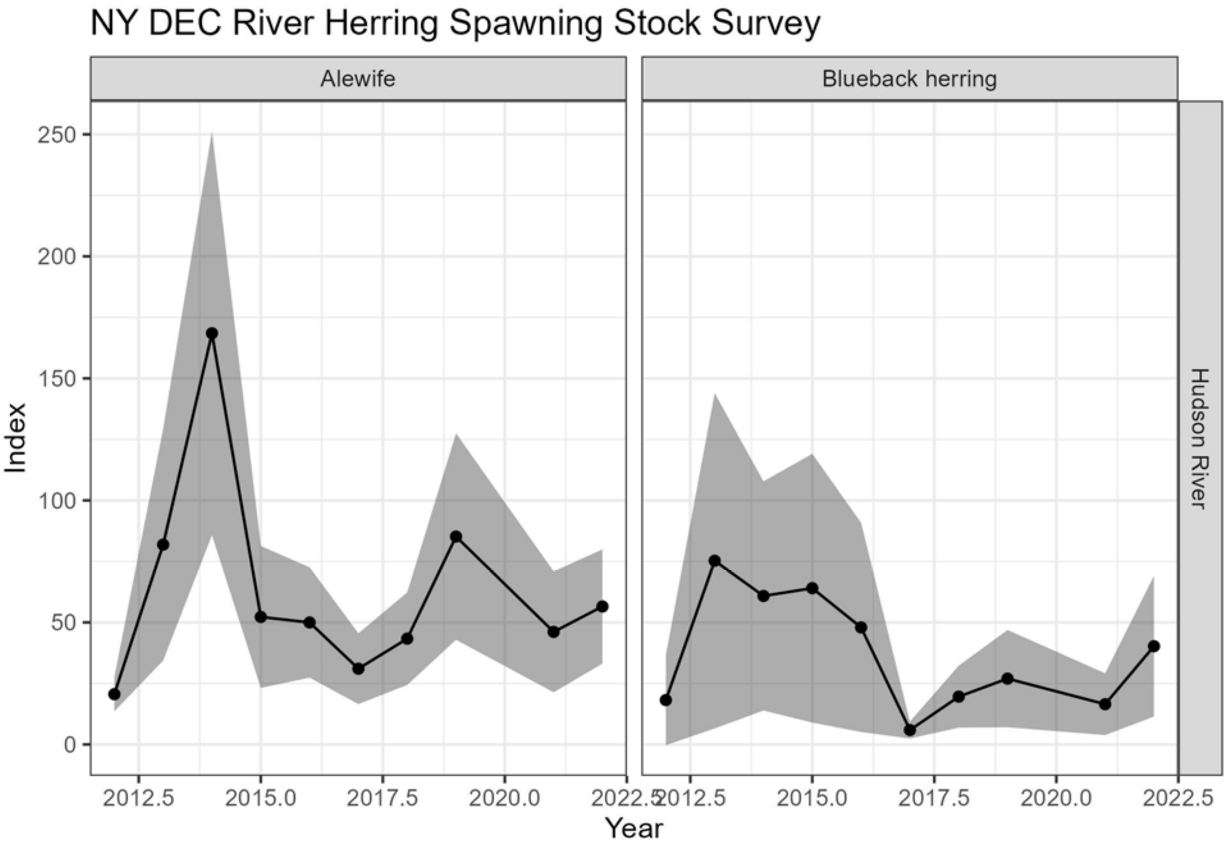


Figure 51. Indices of abundance for the NY DEC River Herring Spawning Stock Survey.

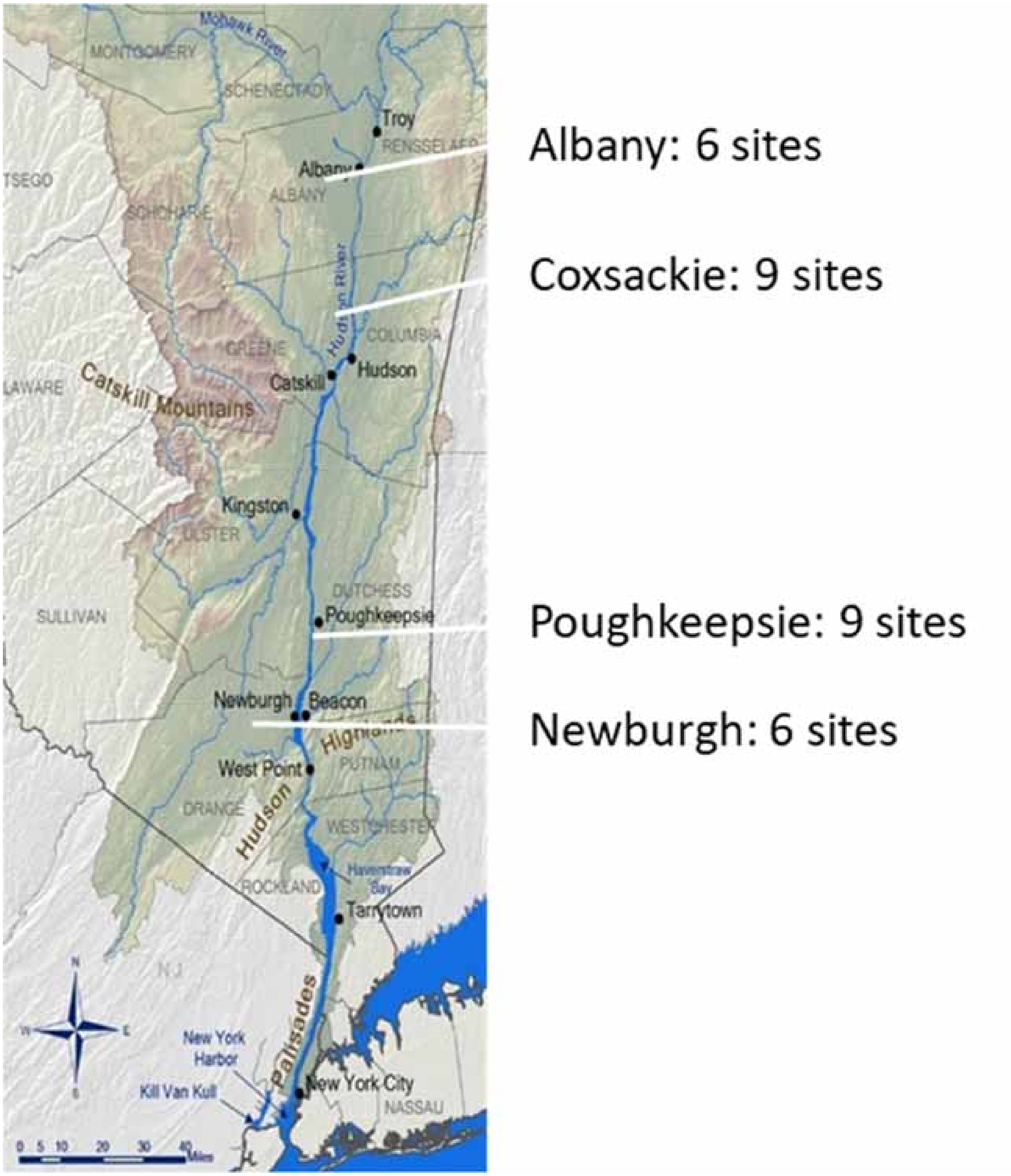


Figure 52. Sample sites for the New York Hudson River Seine Survey.

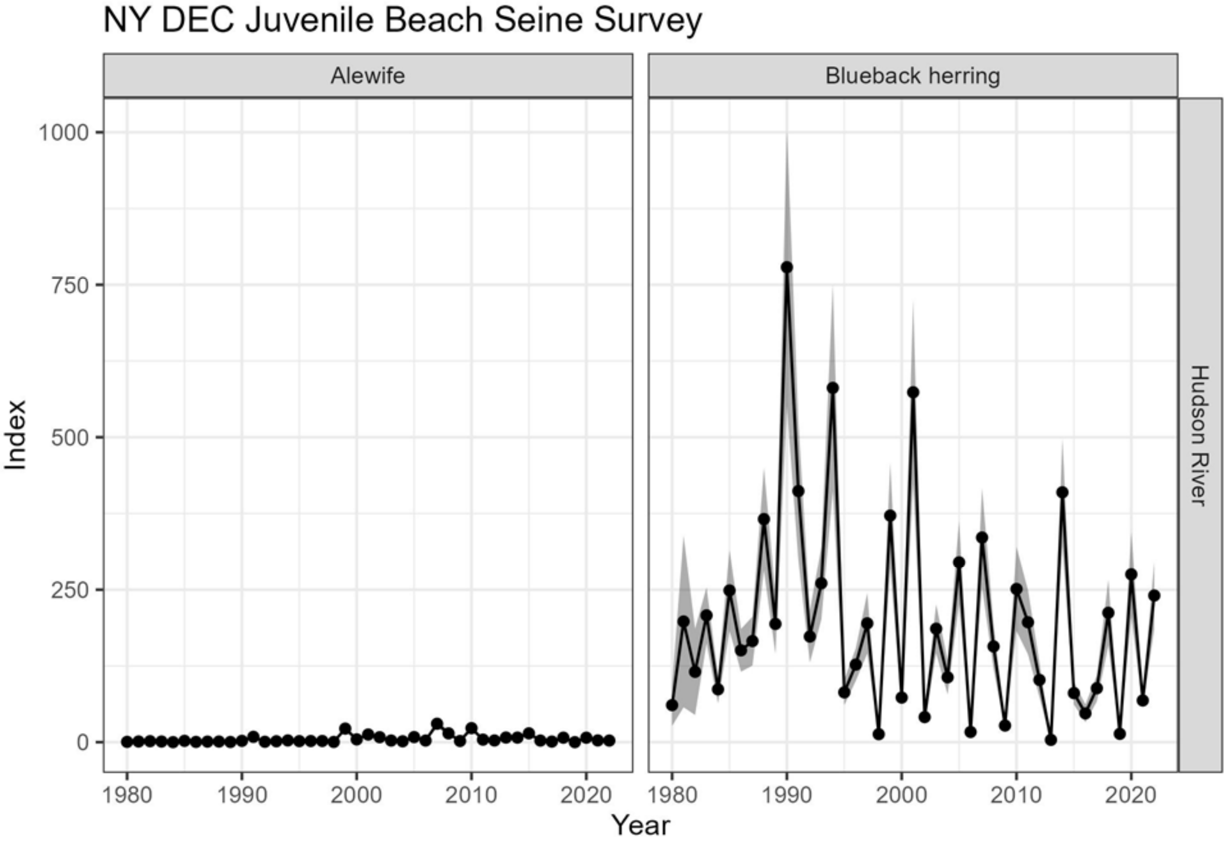


Figure 53. Indices of abundance from the NY DEC Juvenile Beach Seine Survey.

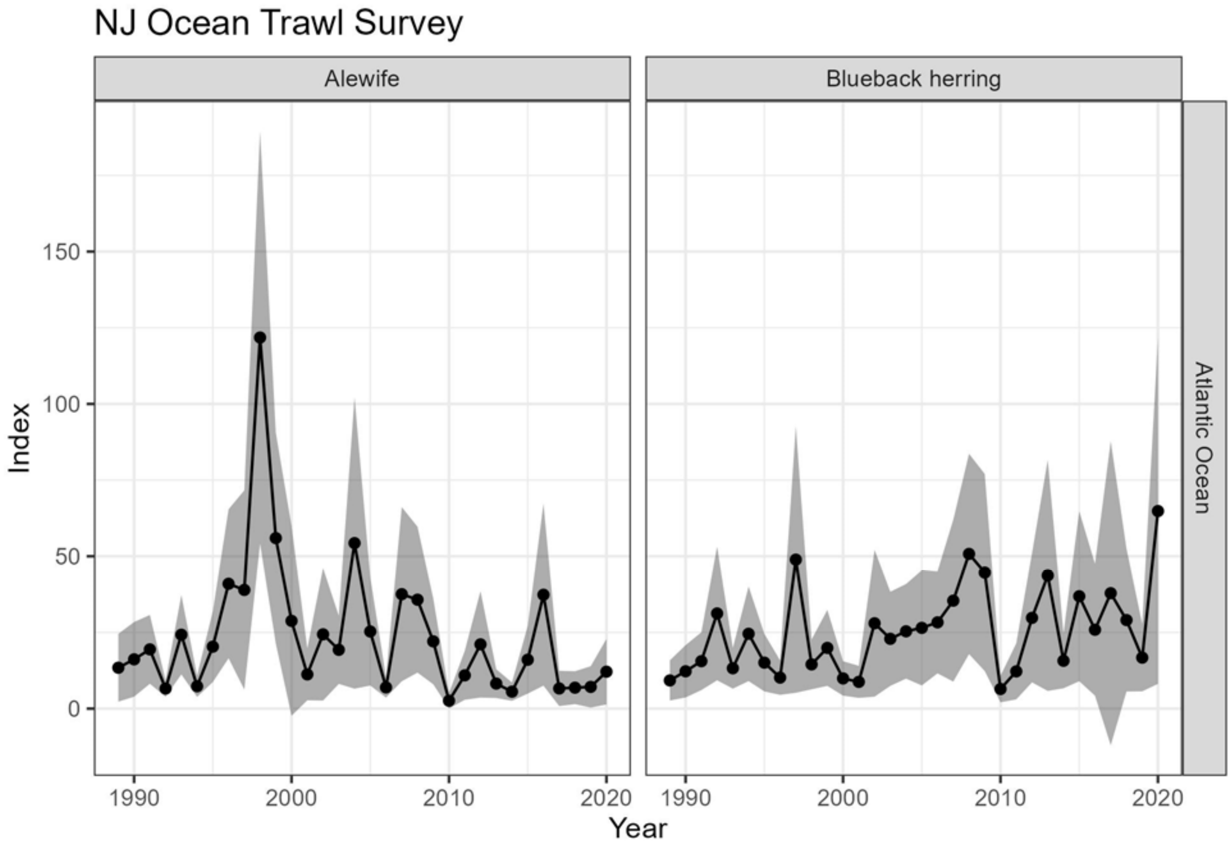


Figure 54. Indices of abundance from the NJ Ocean Trawl Survey.

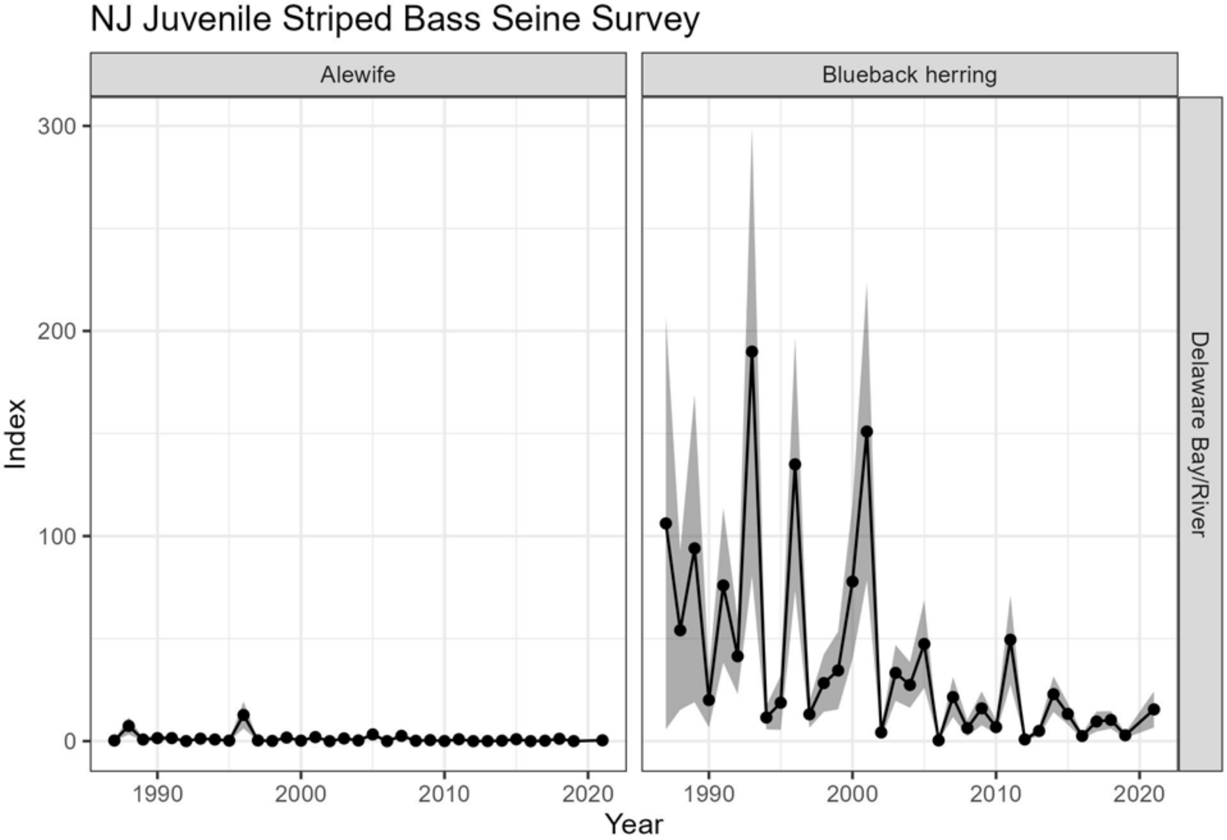


Figure 55. Indices of abundance from the NJ Striped Bass Seine Survey.

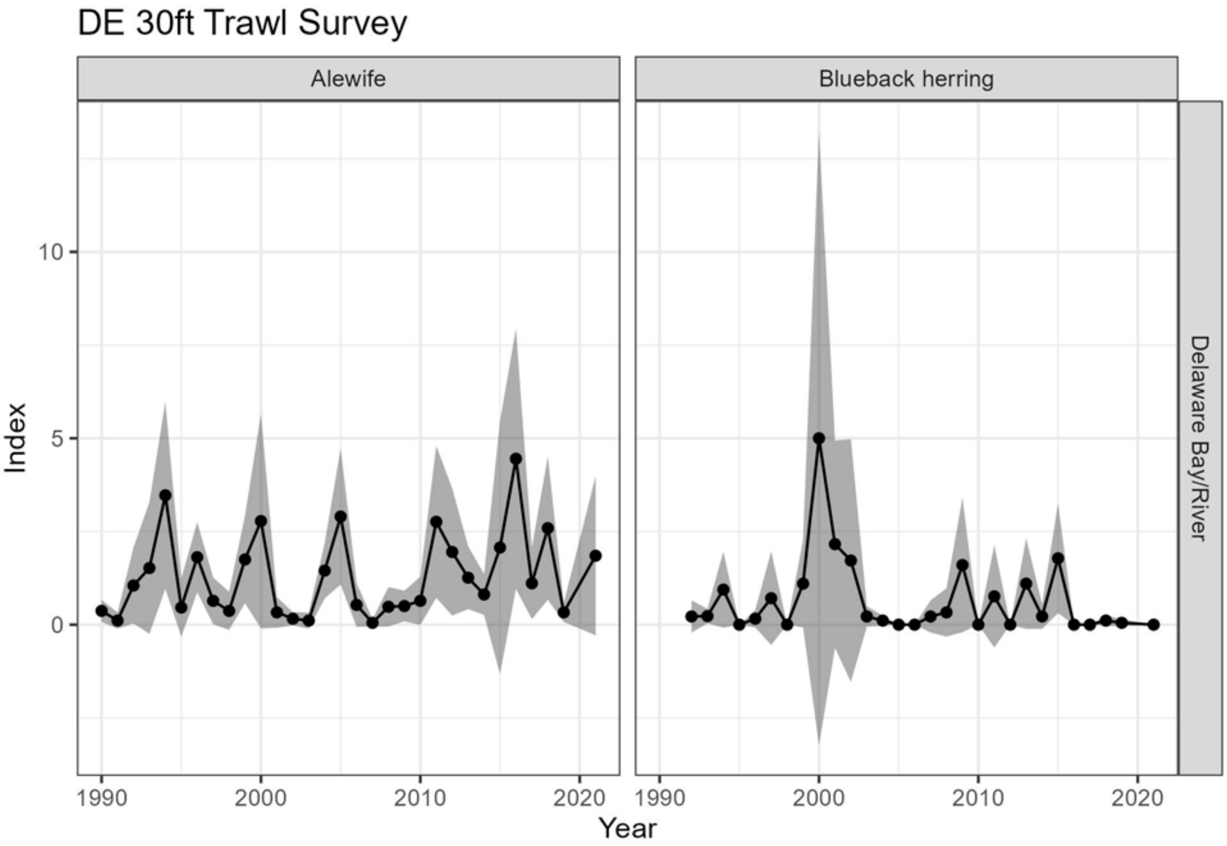


Figure 56. Indices of abundance from the DE 30’ Trawl Survey.

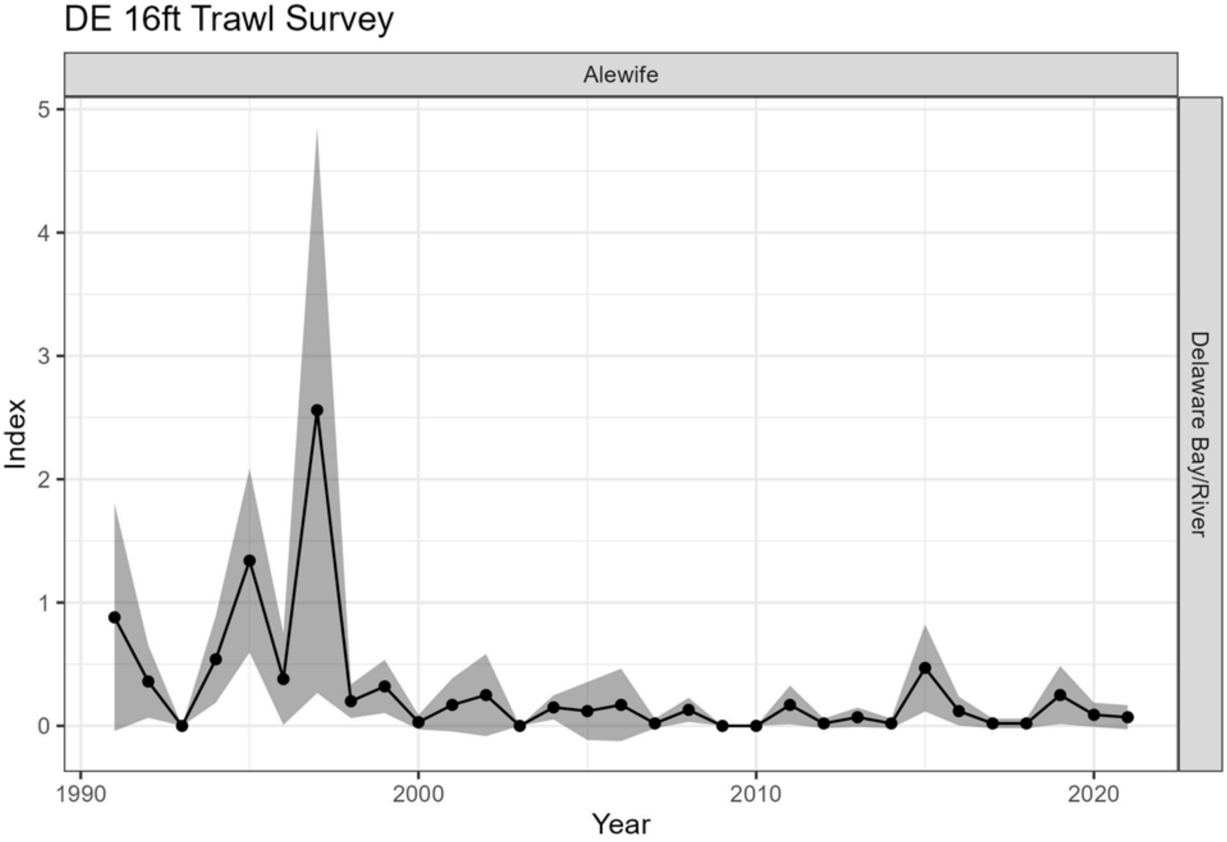


Figure 57. Indices of alewife abundance from the DE 16' Trawl Survey.

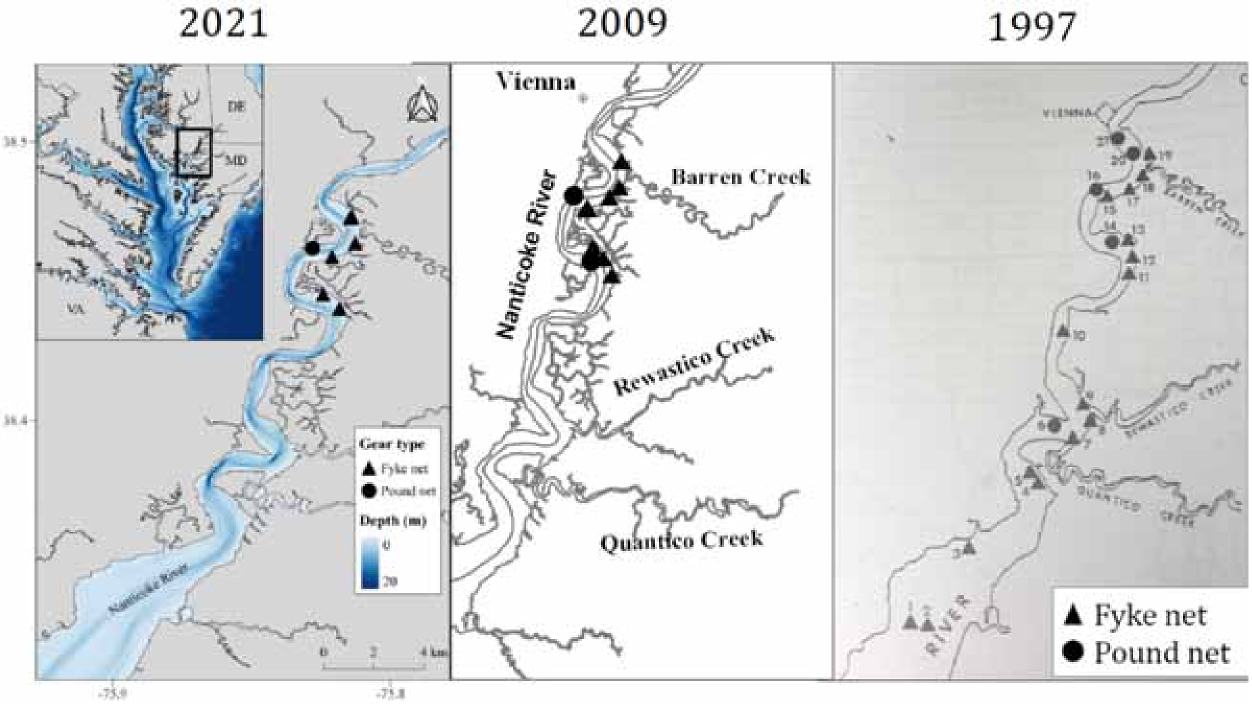


Figure 58. Sample sites for the Nanticoke River pound net/fyke net CPUE.

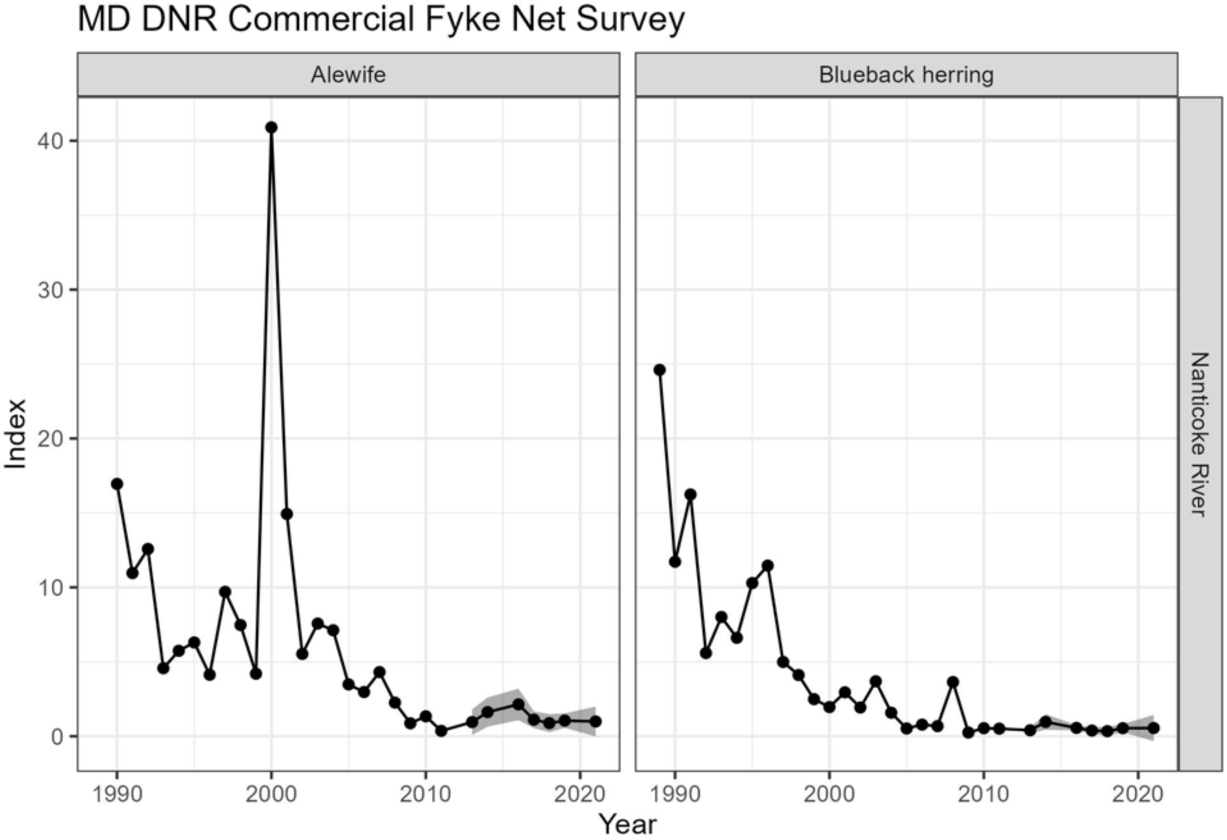


Figure 59. Indices of abundance for the MD DNR Commercial Fyke Net Survey.

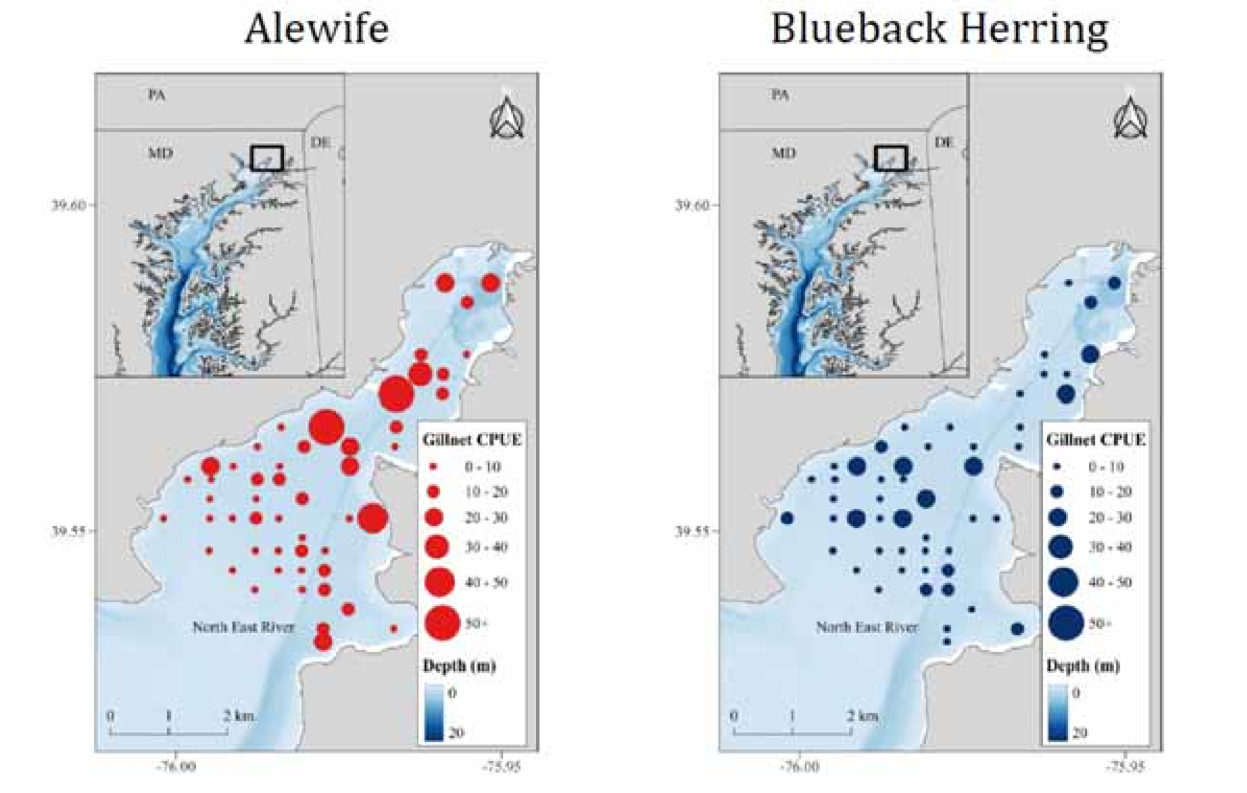


Figure 60. Sample sites of the Maryland North East River Gillnet Survey.

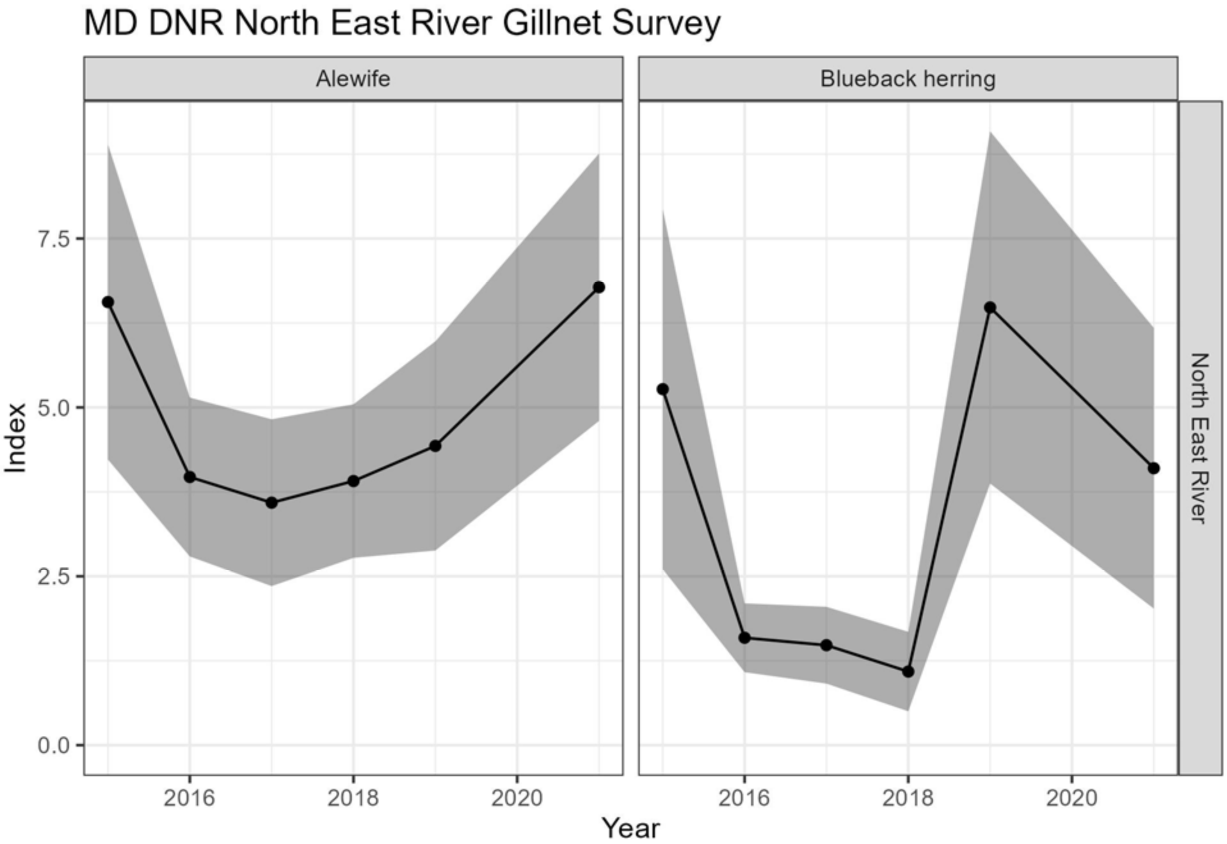


Figure 61. Indices of abundance from the MD DNR North East River Gillnet Survey.

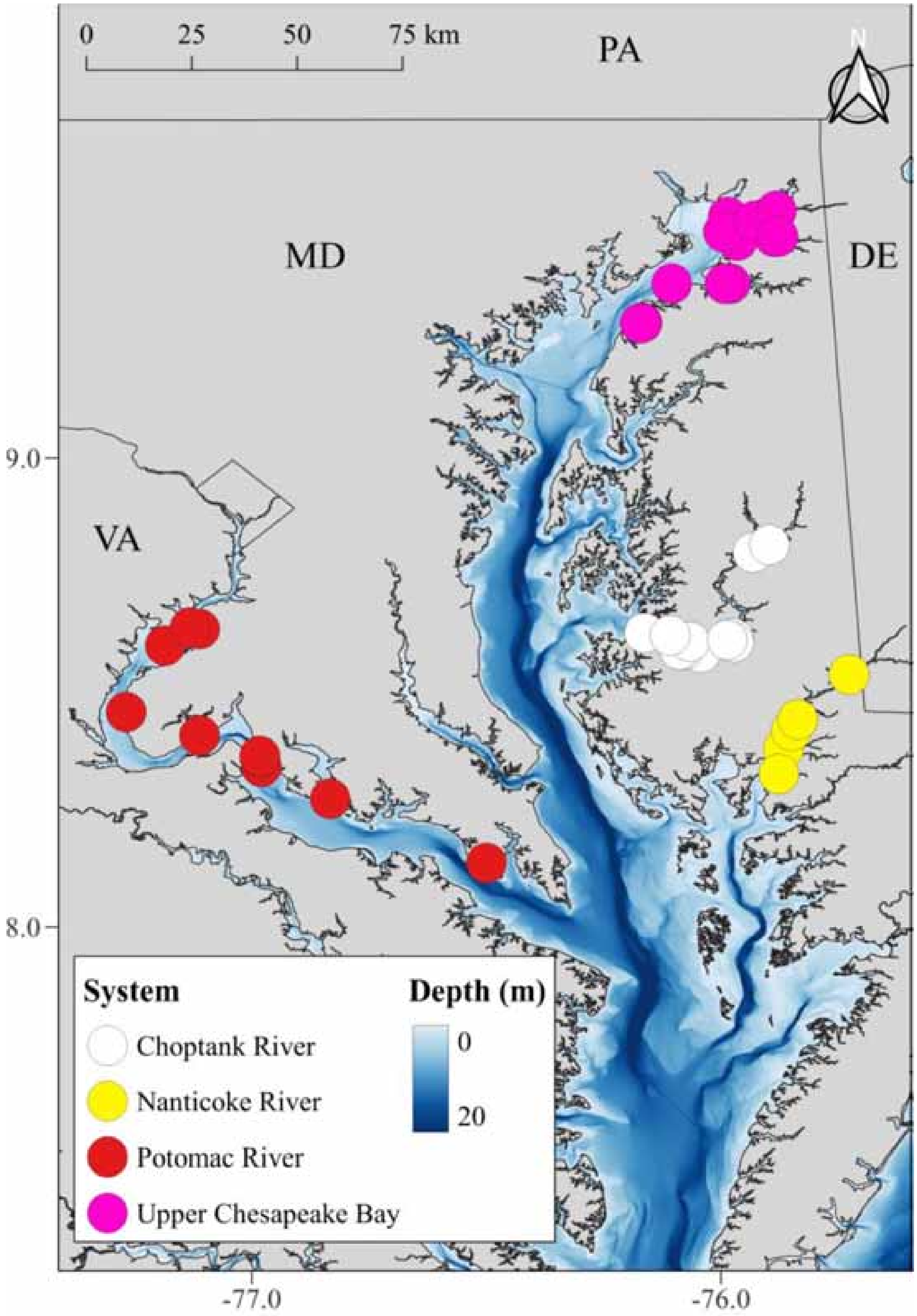


Figure 62. Sample sites of the Maryland Juvenile Finfish Seine Survey.

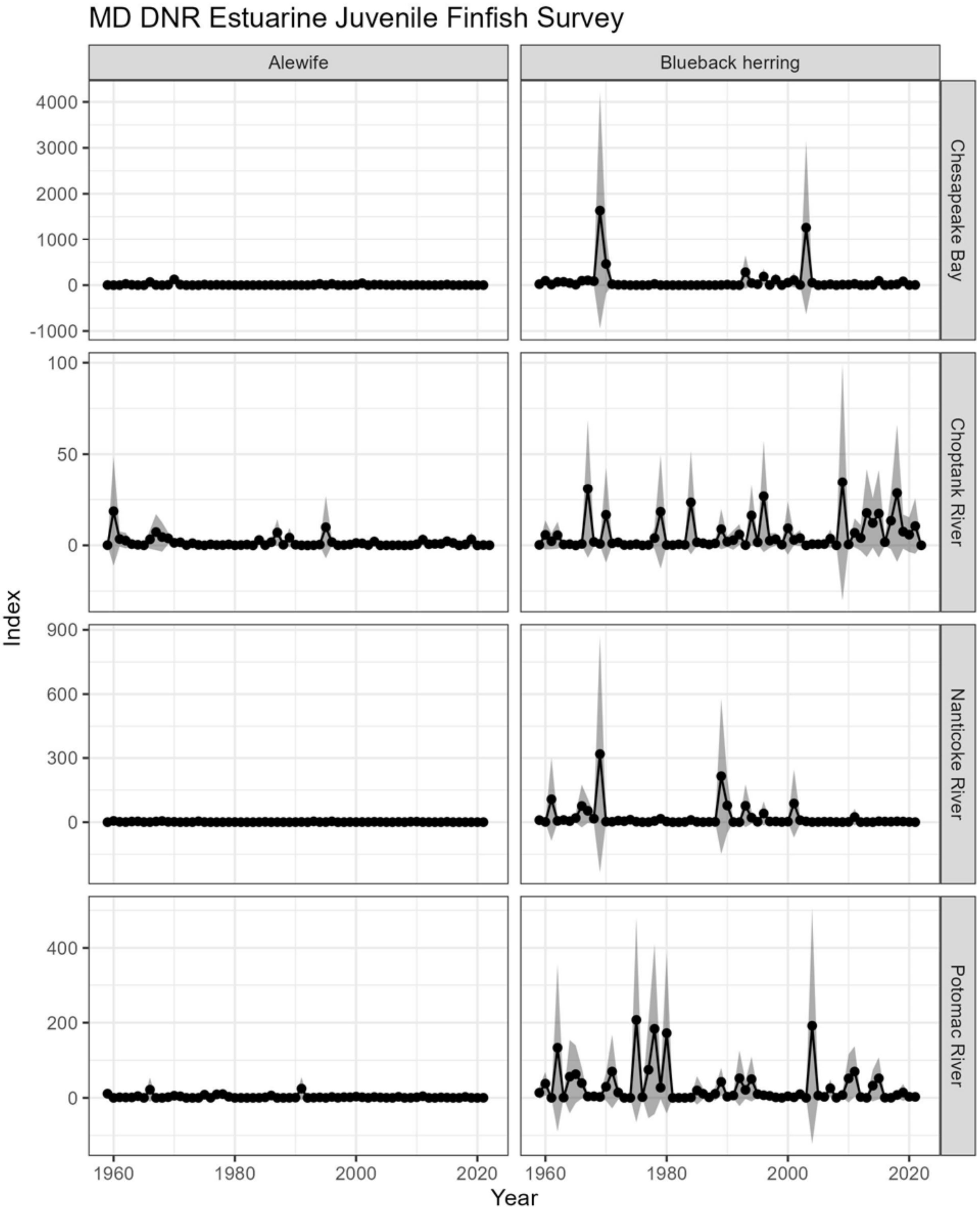


Figure 63. Indices of abundance from the MD DNR Estuarine Juvenile Finfish Survey by river.

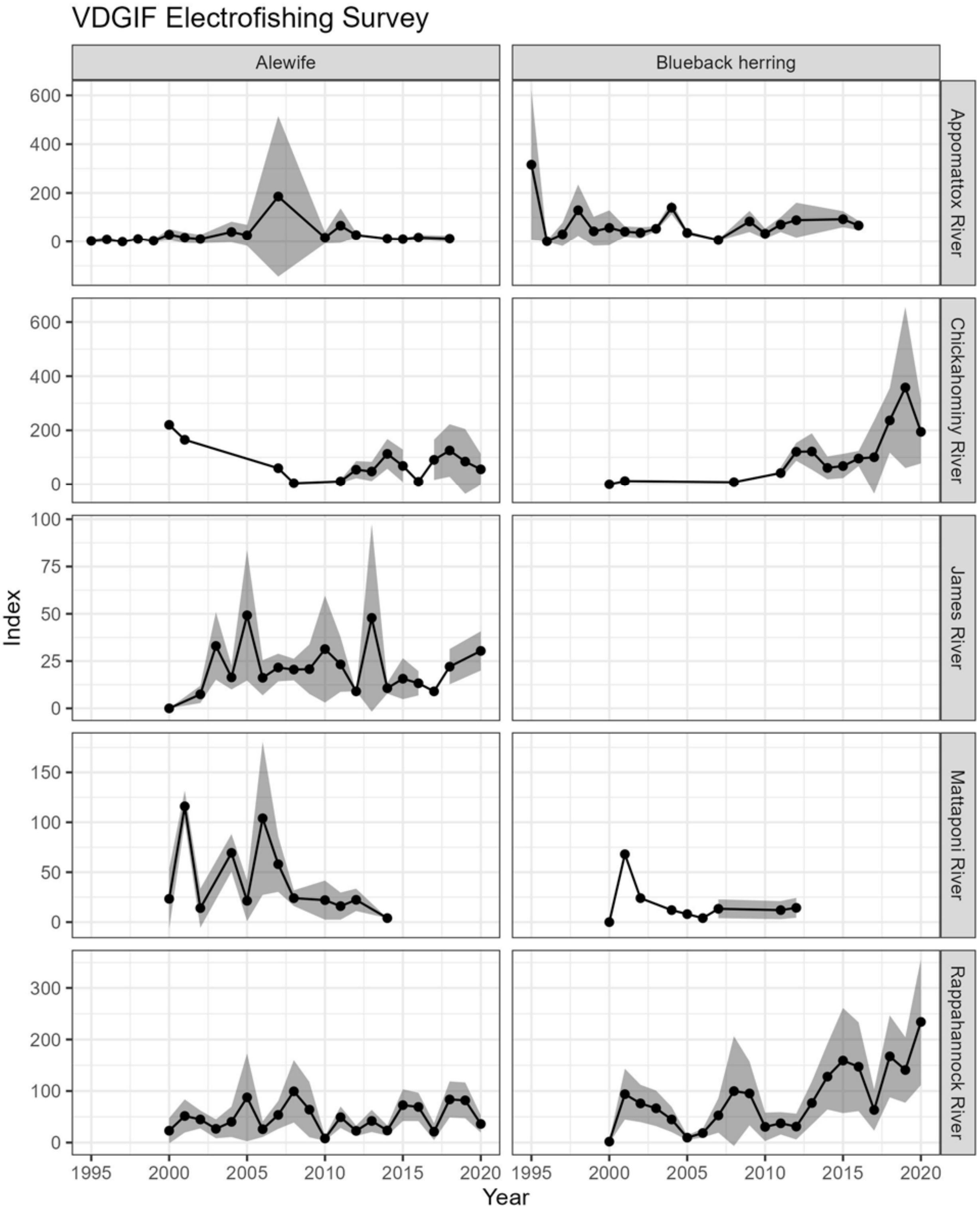


Figure 64. Indices of abundance from the VDGIF Electrofishing Survey by species and river.

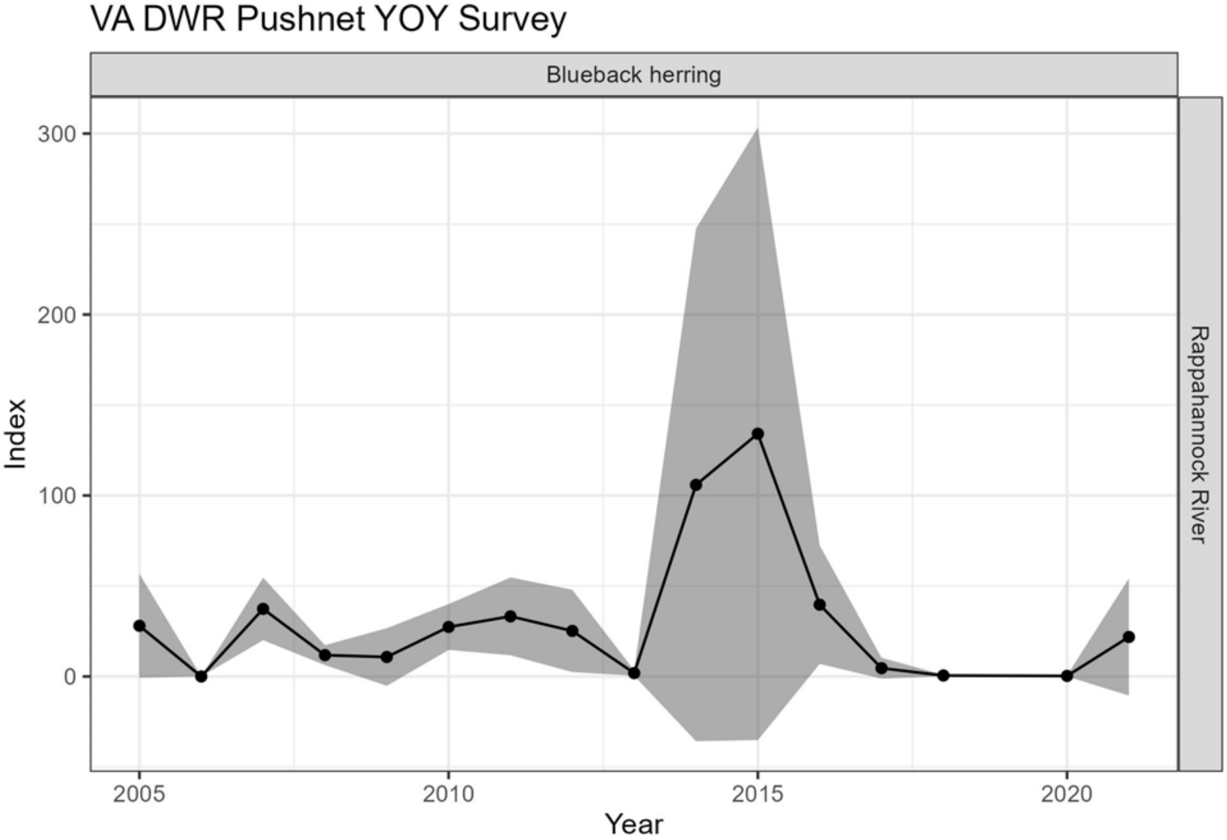


Figure 65. Index of blueback herring abundance from the VA DWR Pushnet YOY Survey.

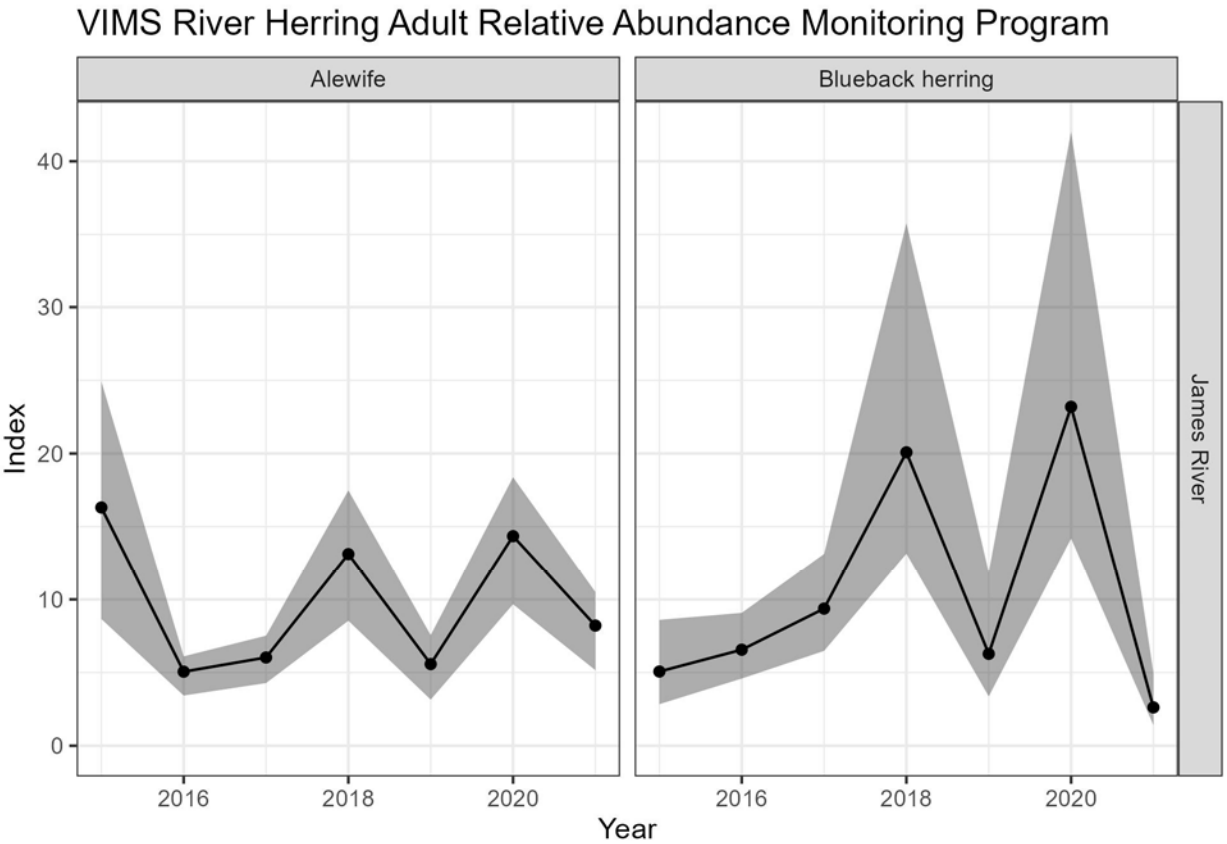


Figure 66. Indices of abundance from the VIMS River Herring Adult Relative Abundance Monitoring Program.

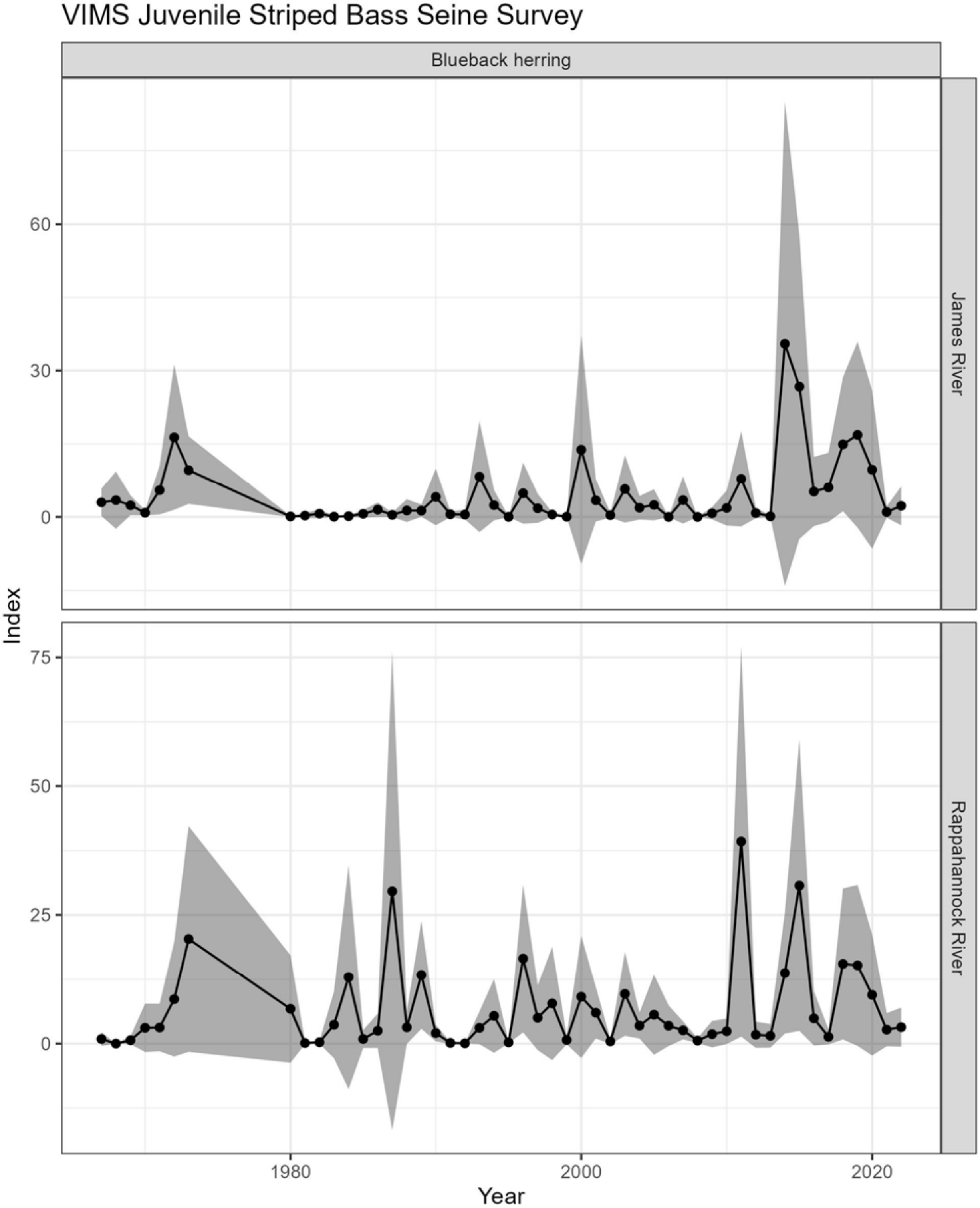


Figure 67. Indices of blueback herring abundance by river from the VIMS Juvenile Striped Bass Seine Survey.

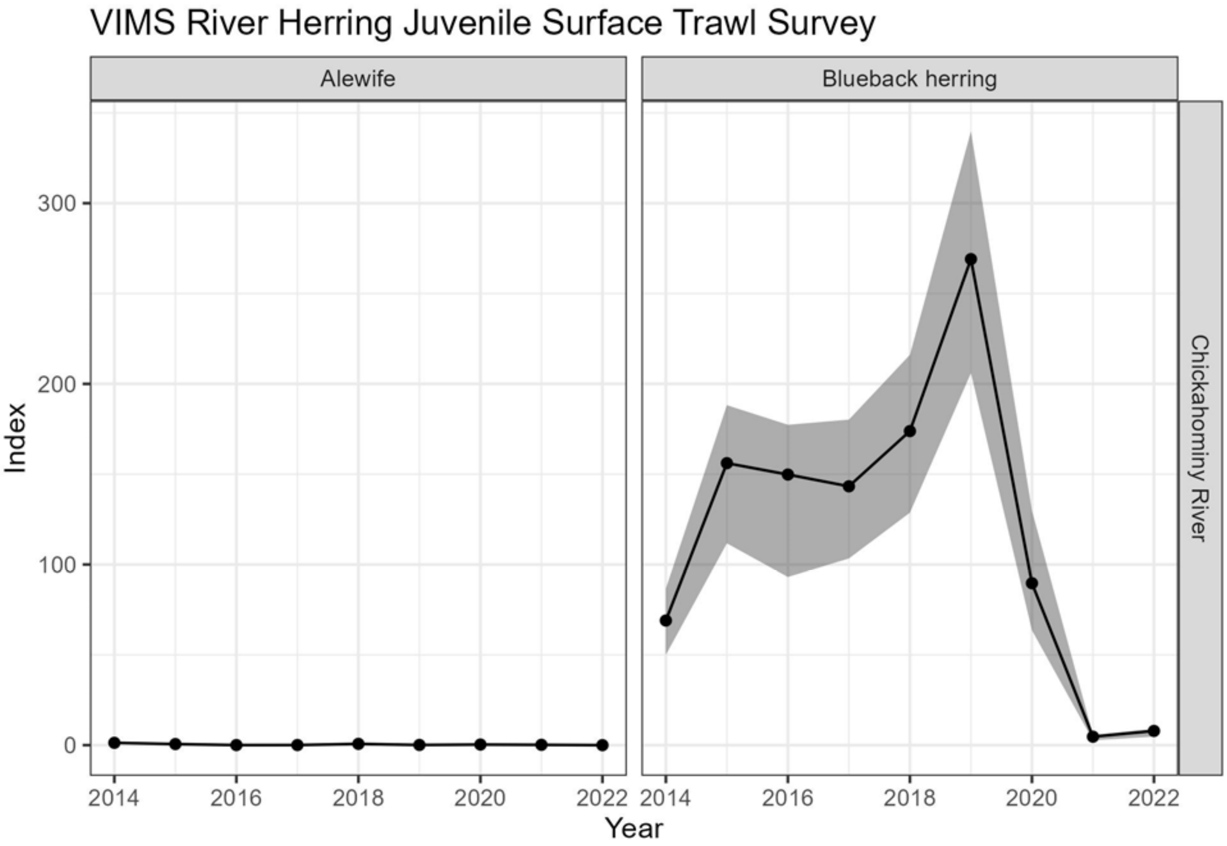


Figure 68. Indices of abundance from the VIMS River Herring Juvenile Surface Trawl Survey.

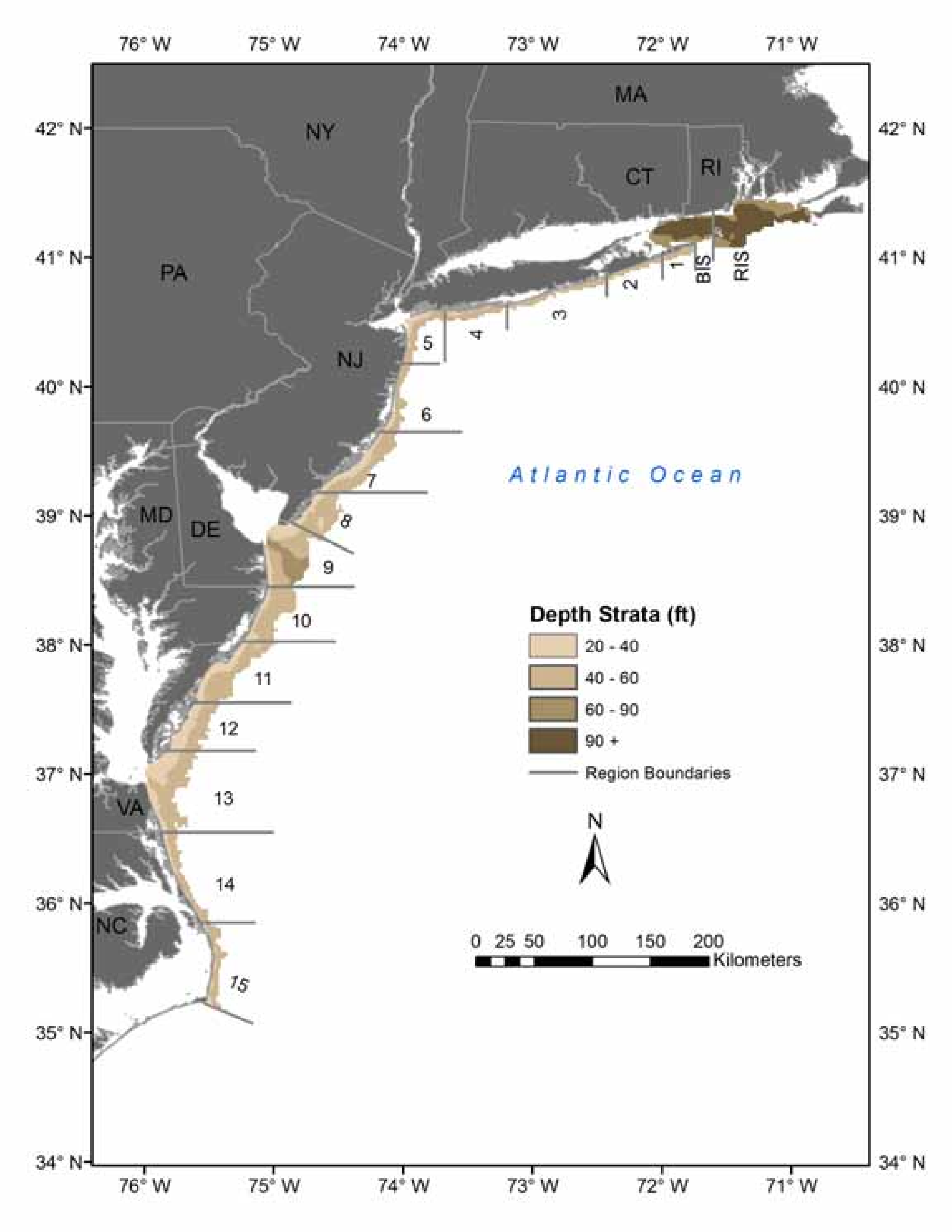


Figure 69. Strata for the VIMS NEAMAP Trawl Survey.

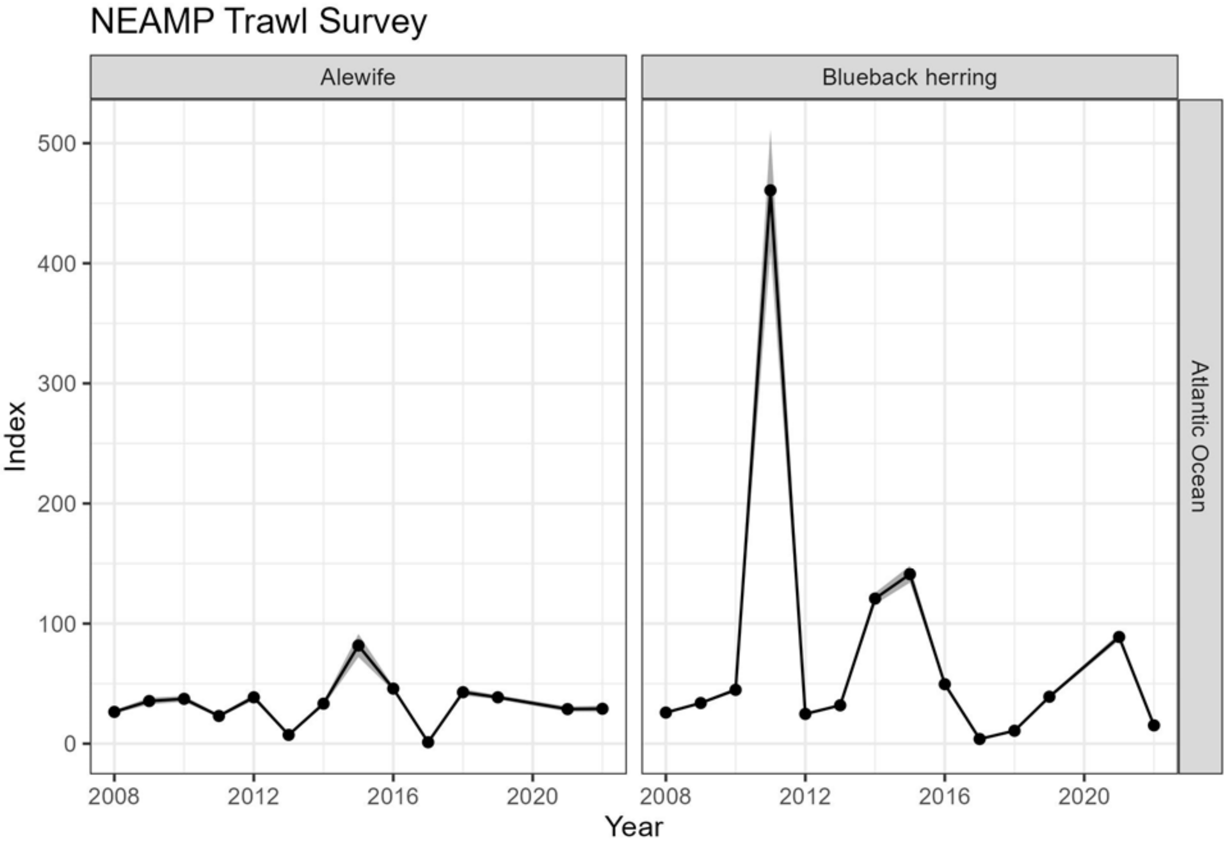


Figure 70. Indices of abundance from the VIMS NEAMAP Trawl Survey.

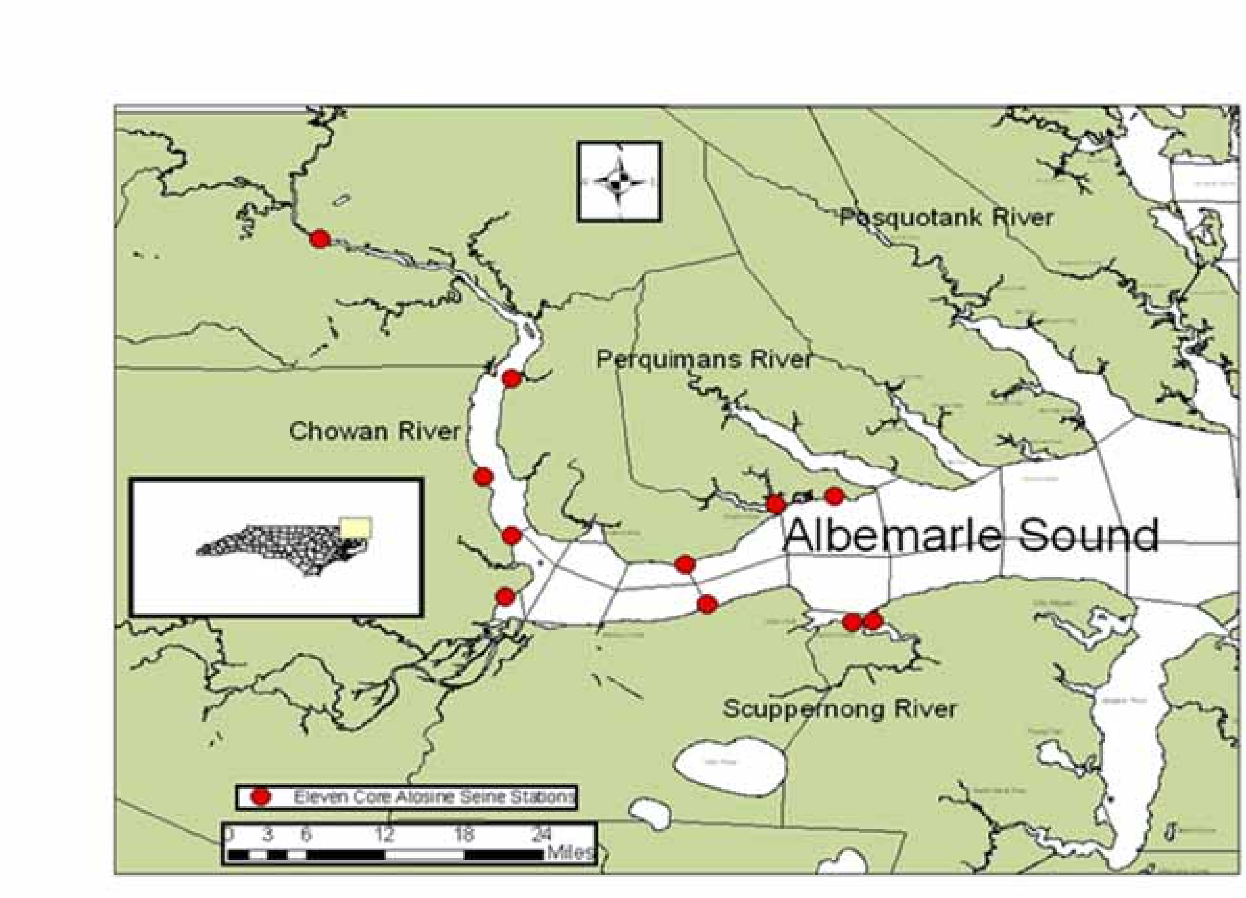


Figure 71. Sample sites for North Carolina P100 Albemarle Sound Juvenile Survey.

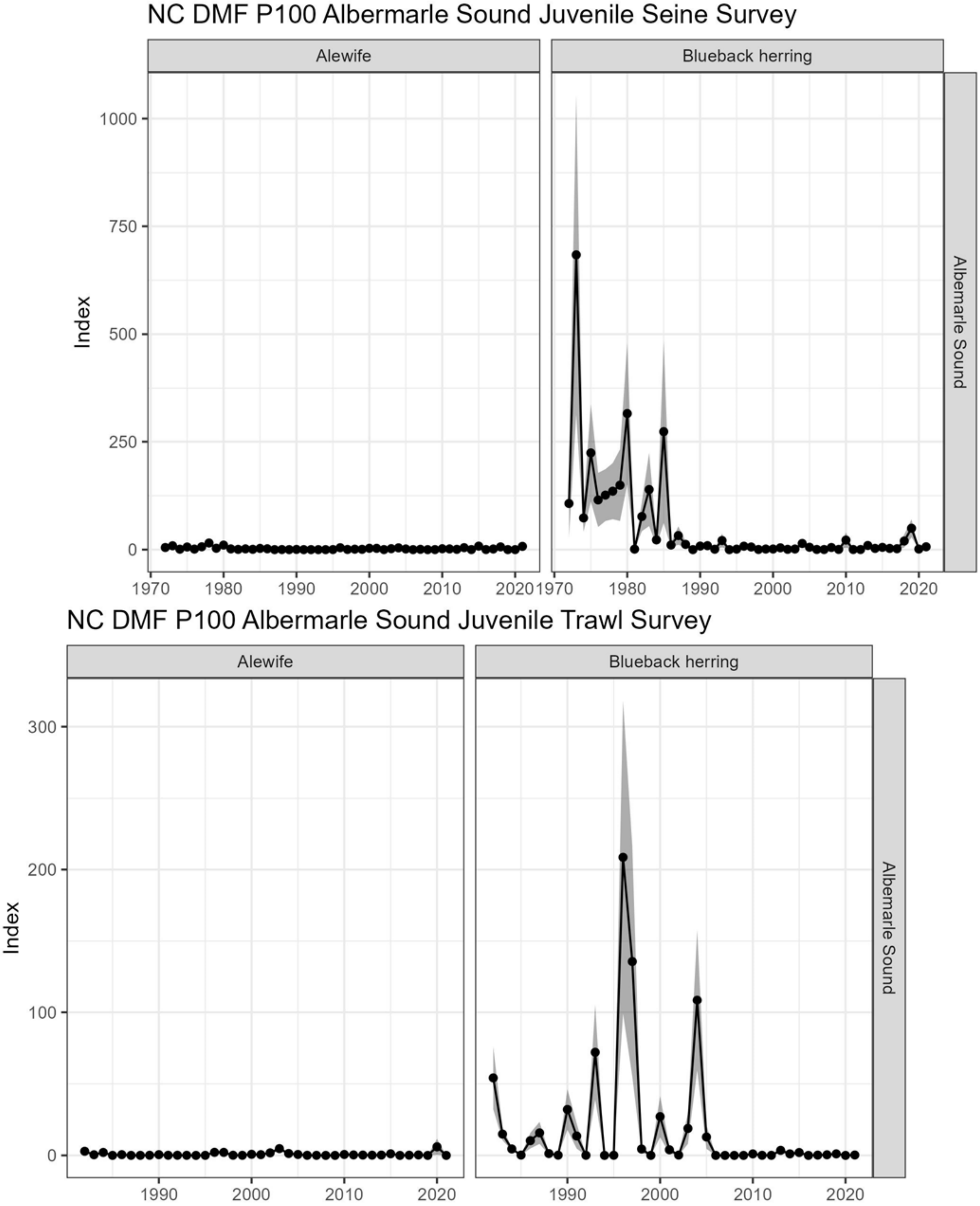


Figure 72. Indices of abundance from the NC DMF P100 Albemarle Sound Juvenile Seine Survey (top) and Trawl Survey (bottom).

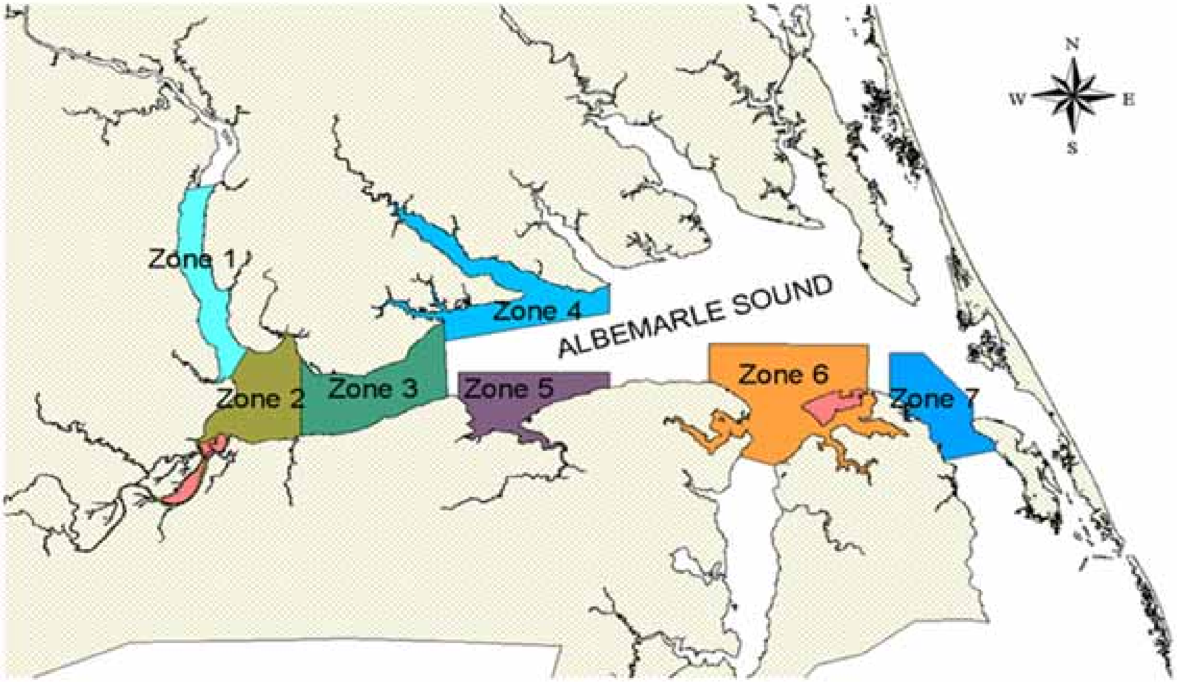


Figure 73. Strata for North Carolina Program 135 Albemarle Sound Independent Gillnet Survey.

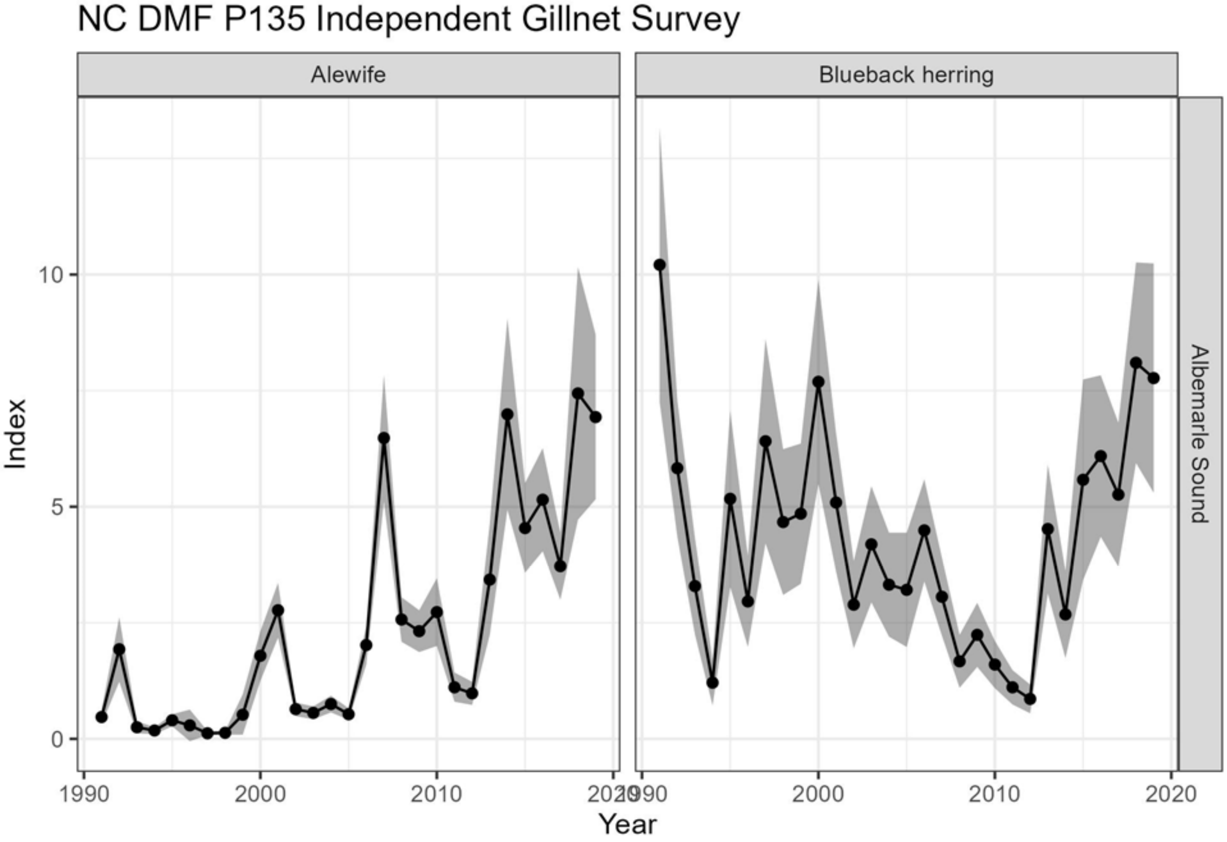


Figure 74. Indices of abundance from the NC DMF P135 Independent Gillnet Survey.

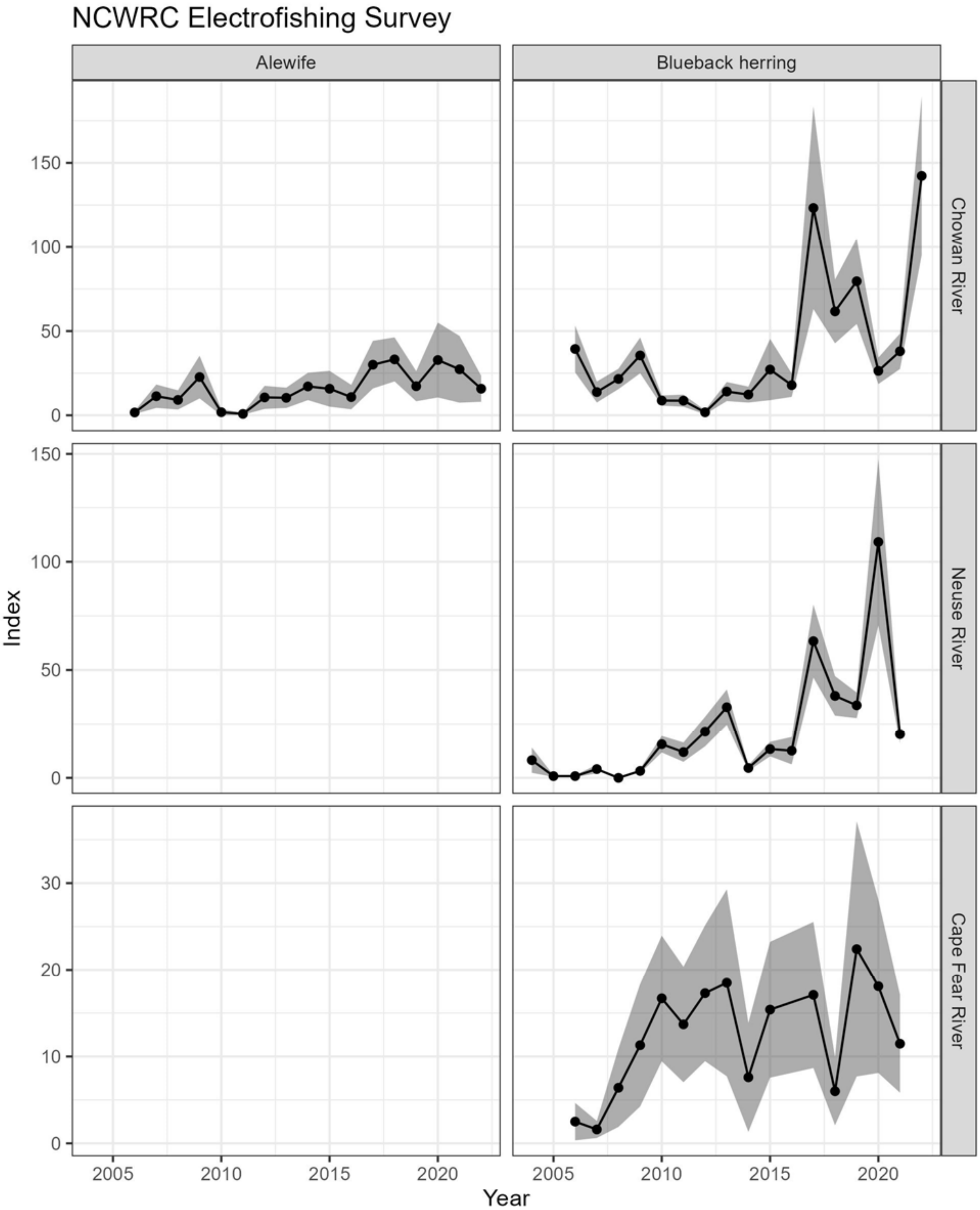


Figure 75. Indices of abundance from the NC WRC Electrofishing Survey.

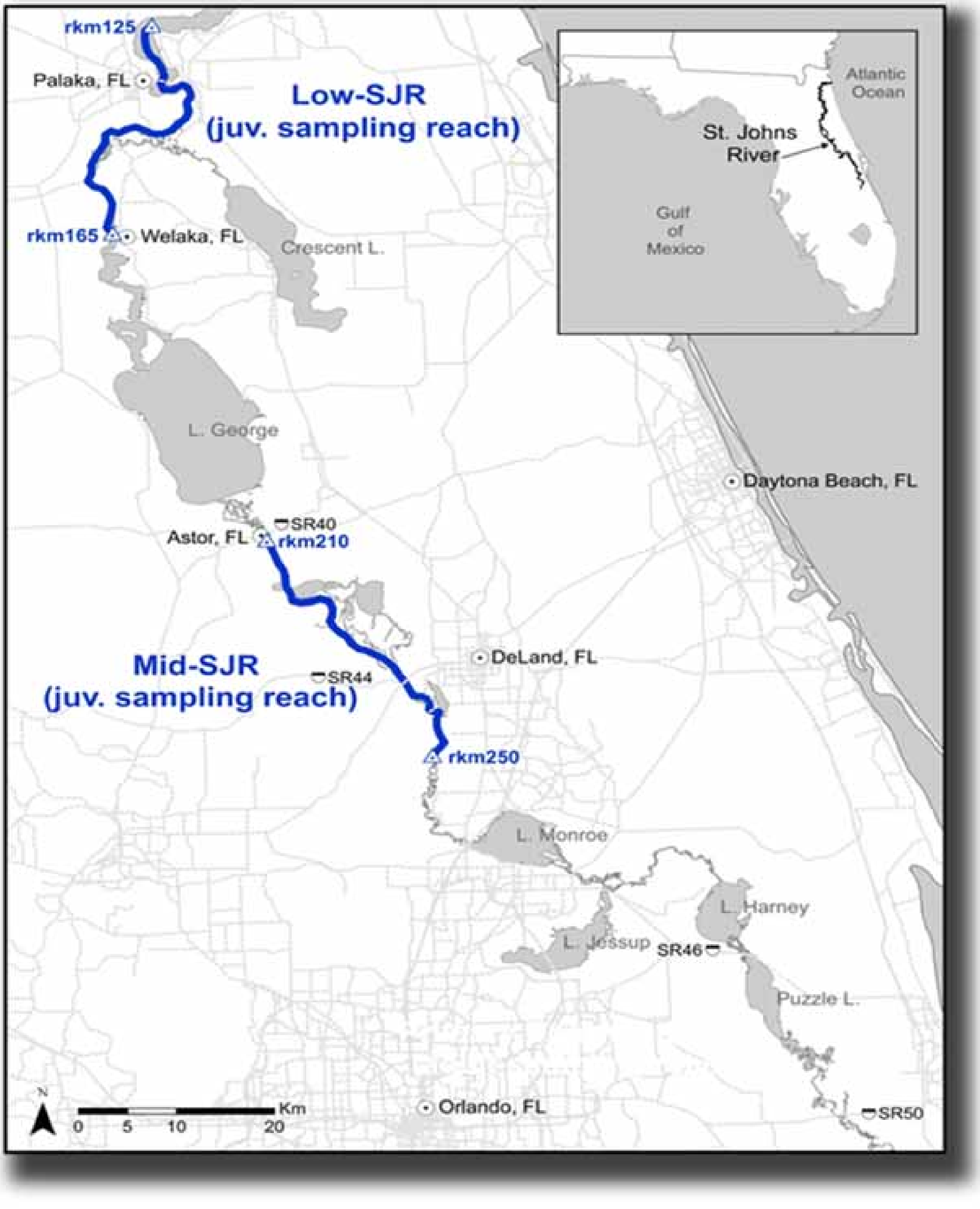


Figure 76. Sampling area for the Florida St. Johns River Juvenile Pushnet Survey.

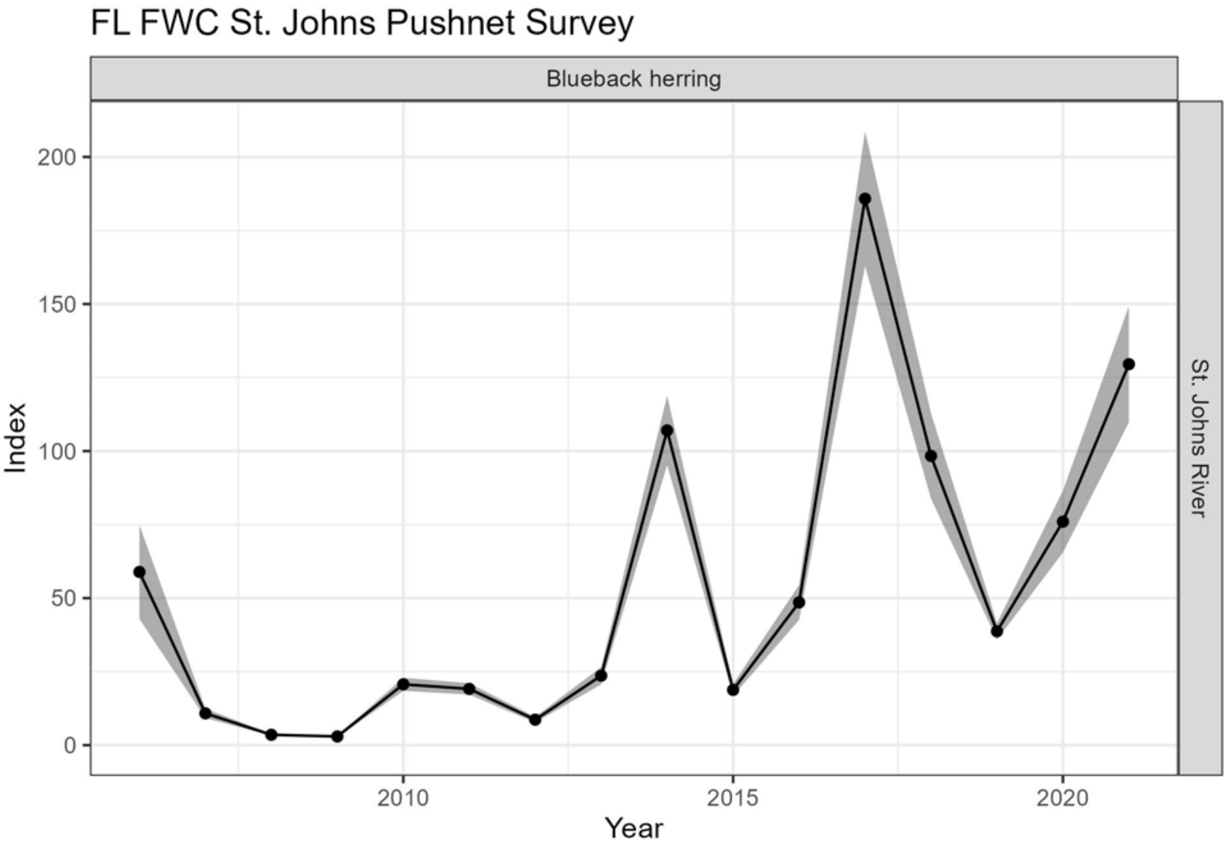


Figure 77. Index of YOY blueback herring abundance from the FL FWC St. Johns Pushnet Survey.

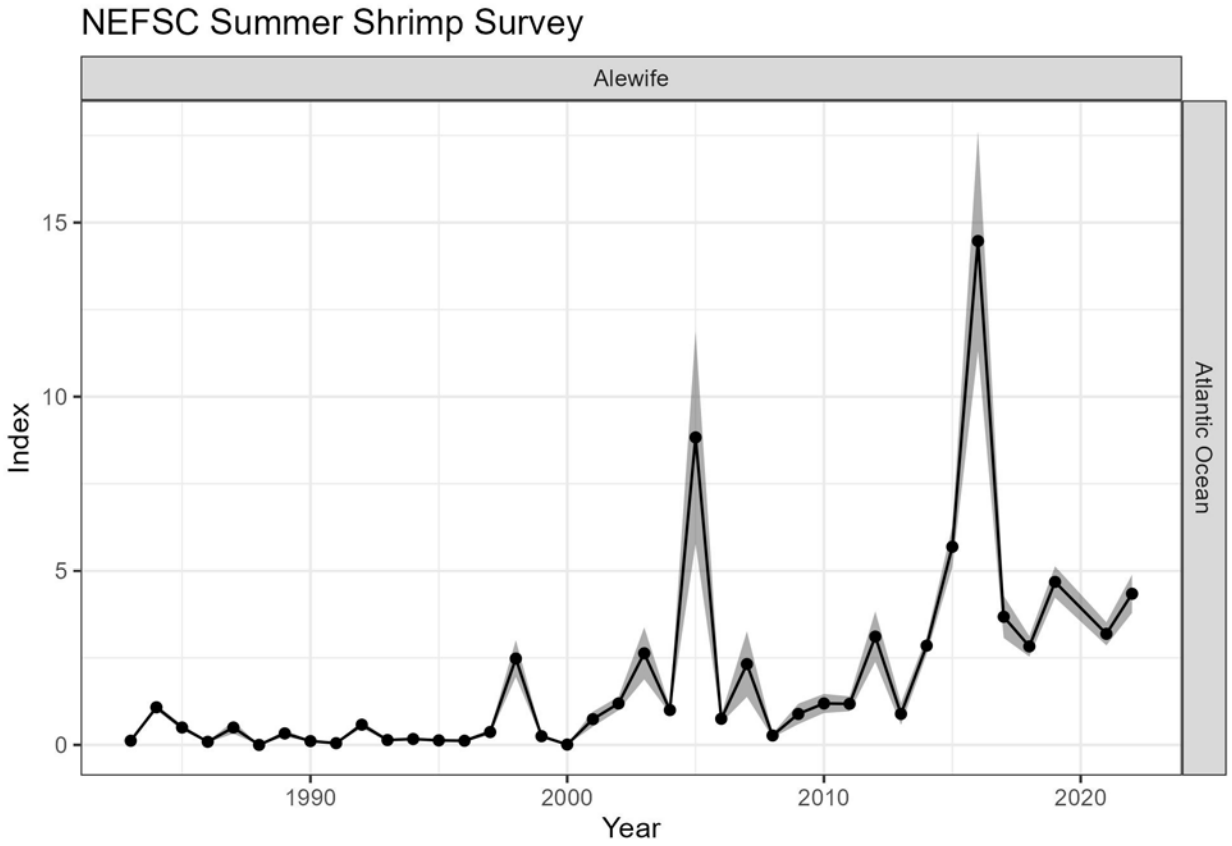


Figure 78. Index of alewife abundance from the NEFSC Summer Shrimp Survey.

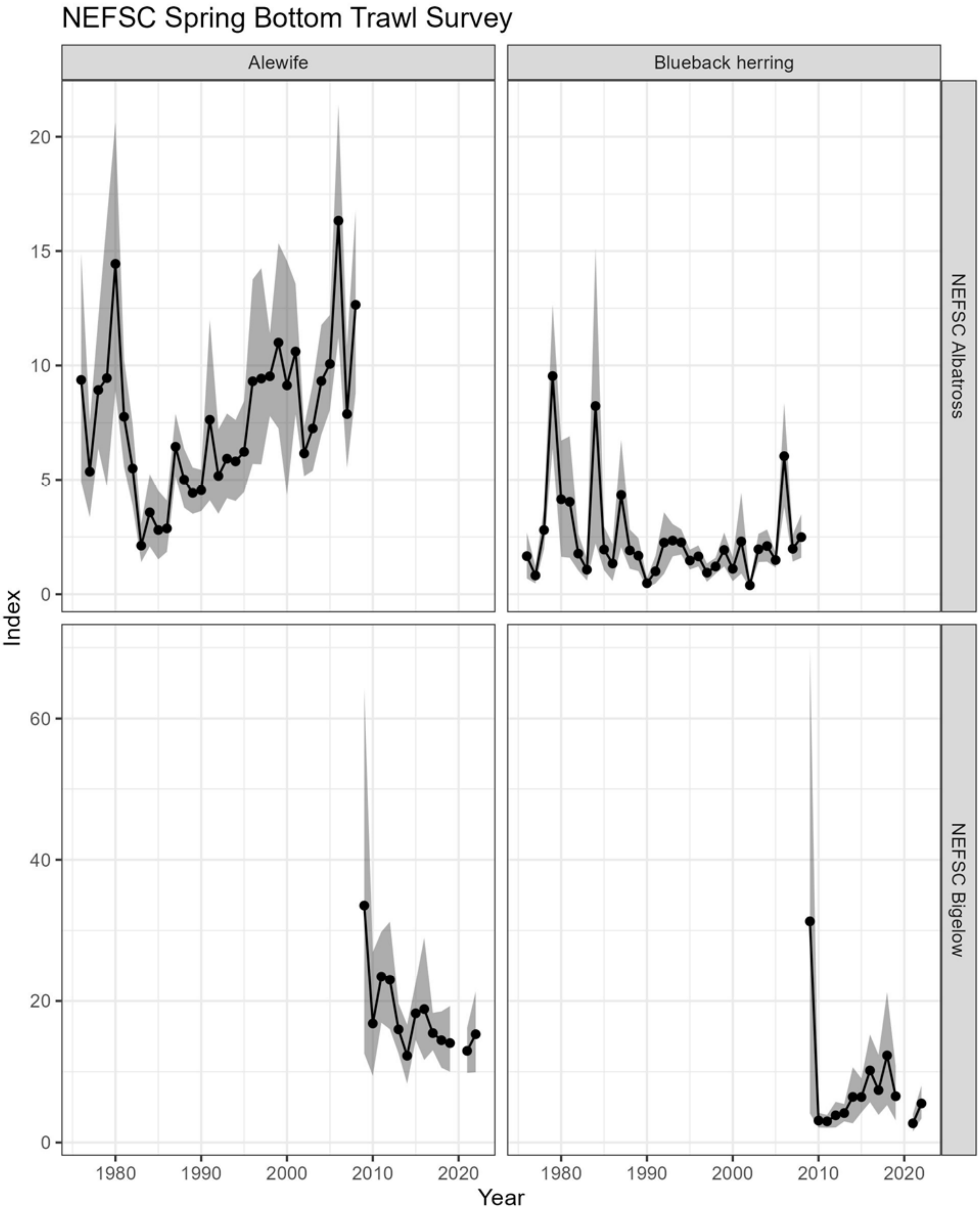


Figure 79. Indices of abundance from the NEFSC Spring Bottom Trawl Survey by species and vessel.

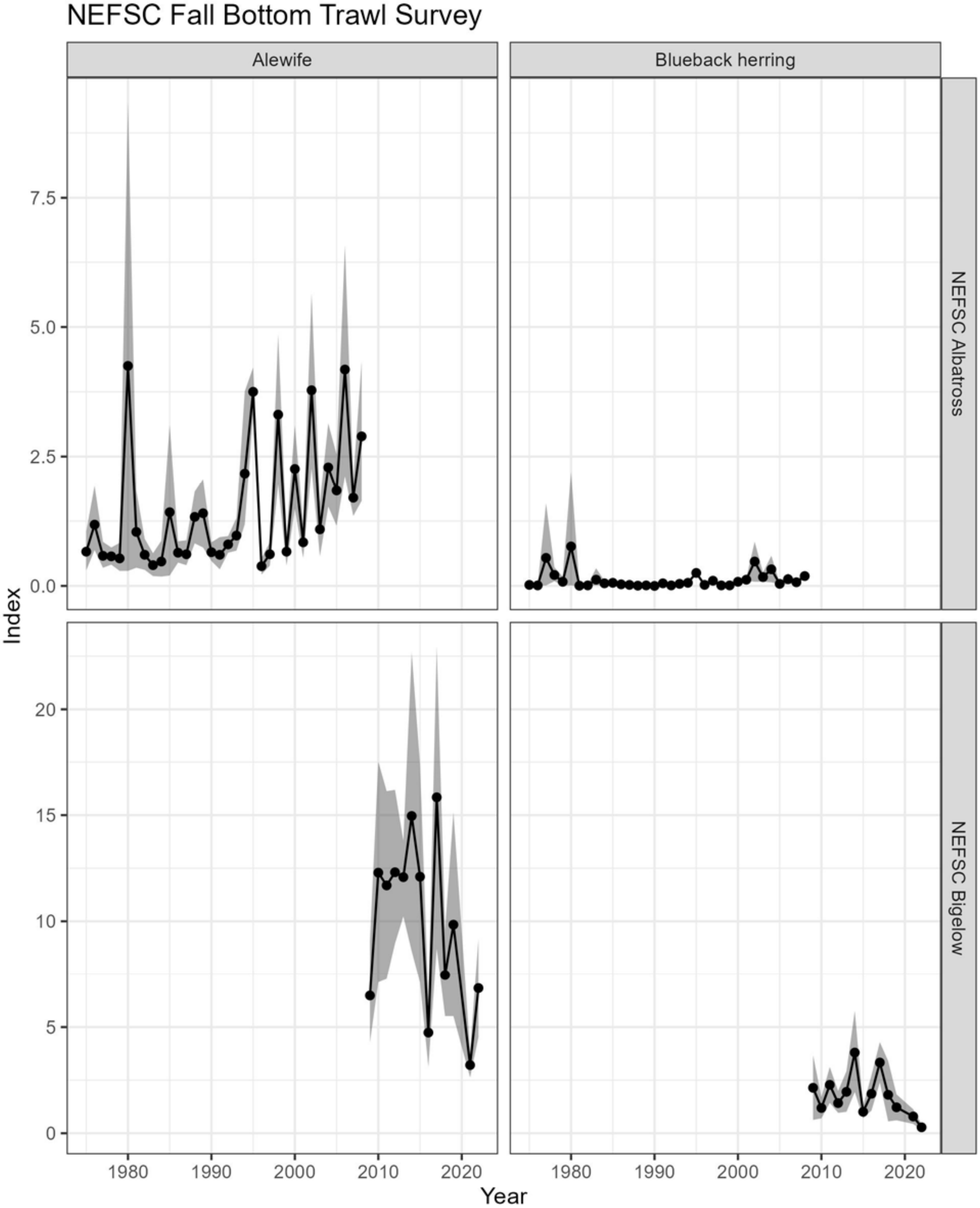


Figure 80. Indices of abundance from the NEFSC Fall Bottom Trawl Survey by species and vessel.

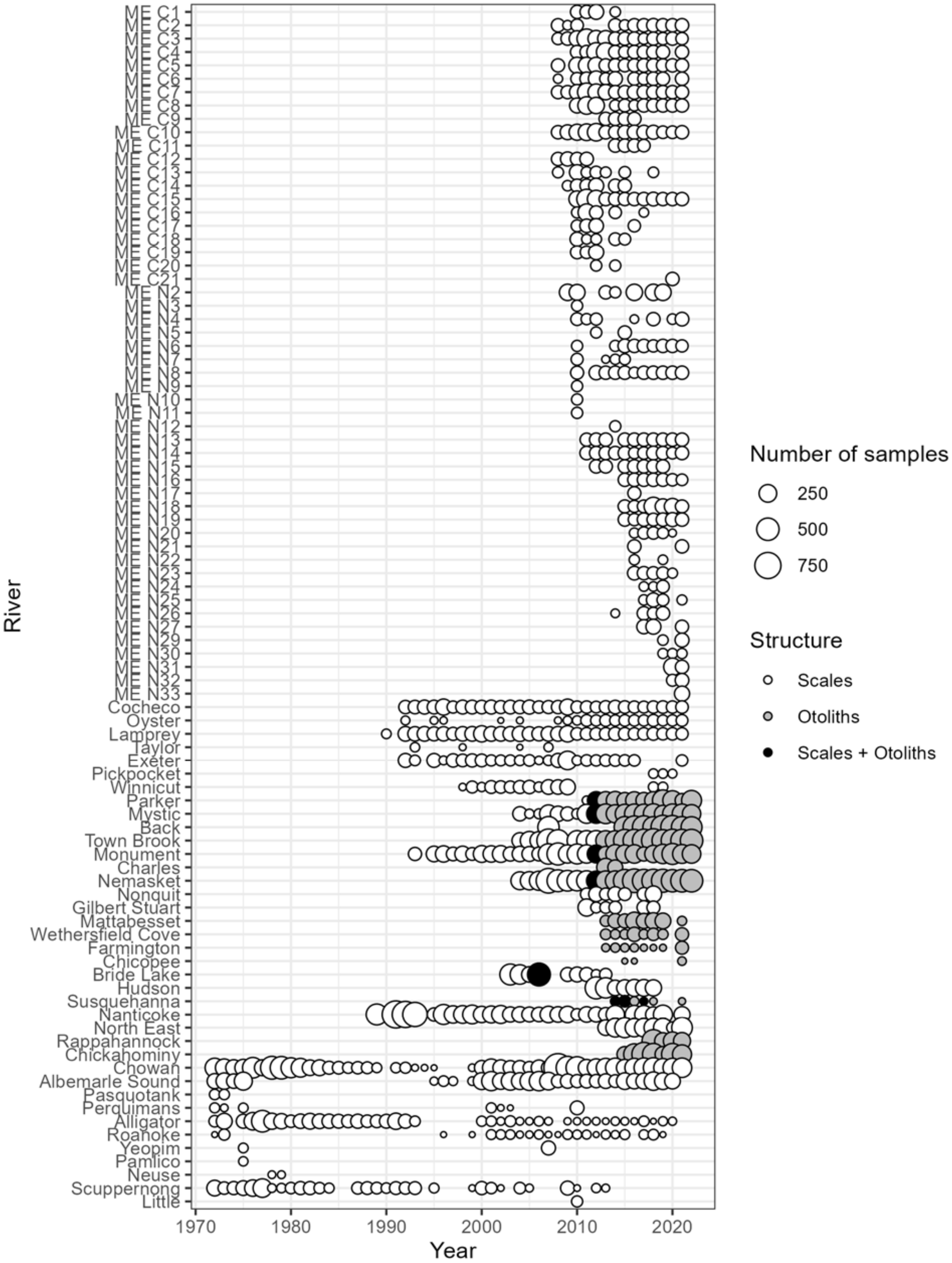


Figure 81. Ageing structures used to assign alewife ages each year in each river system.

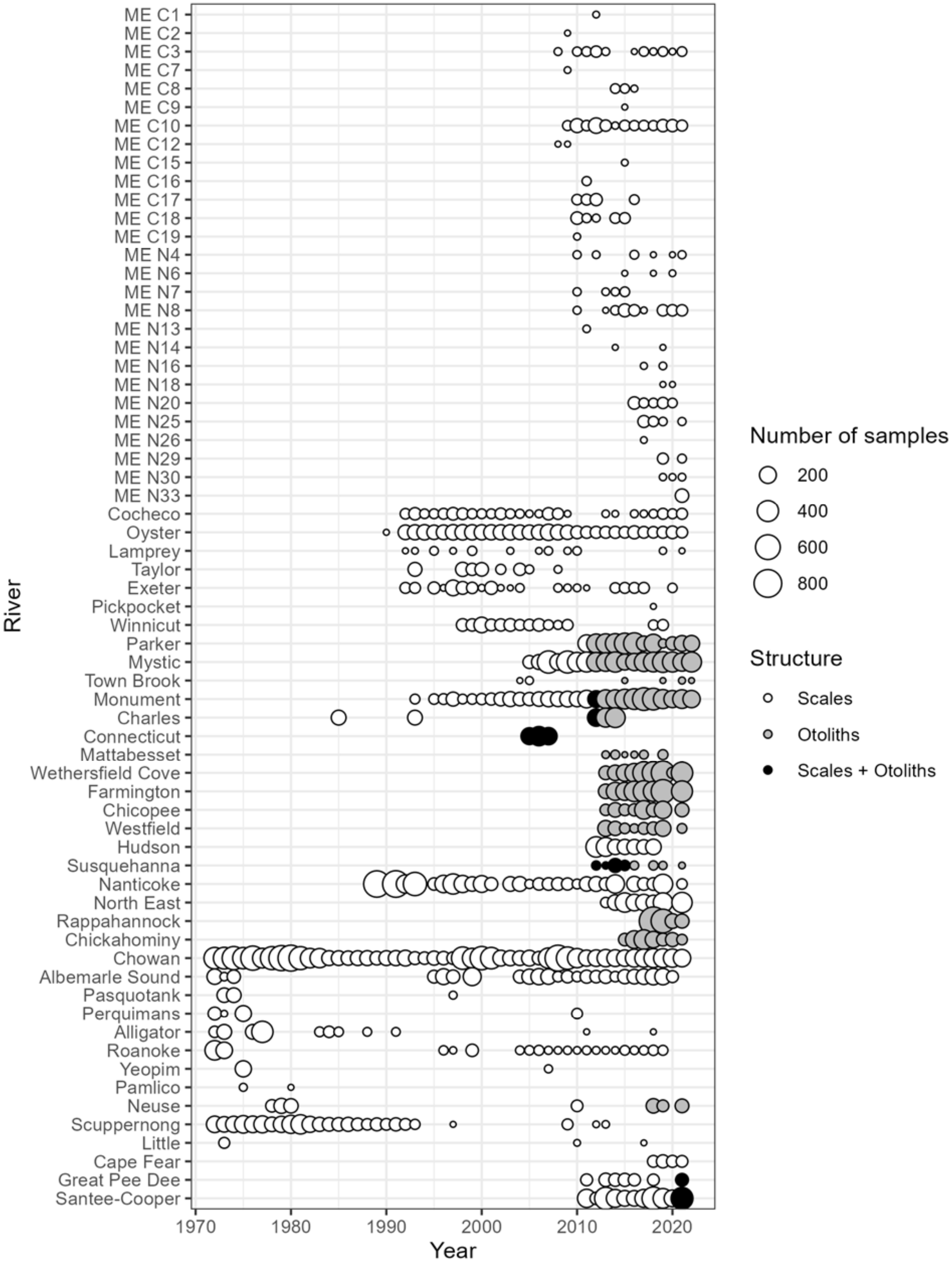


Figure 82. Ageing structures used to assign blueback herring ages each year in each river system.

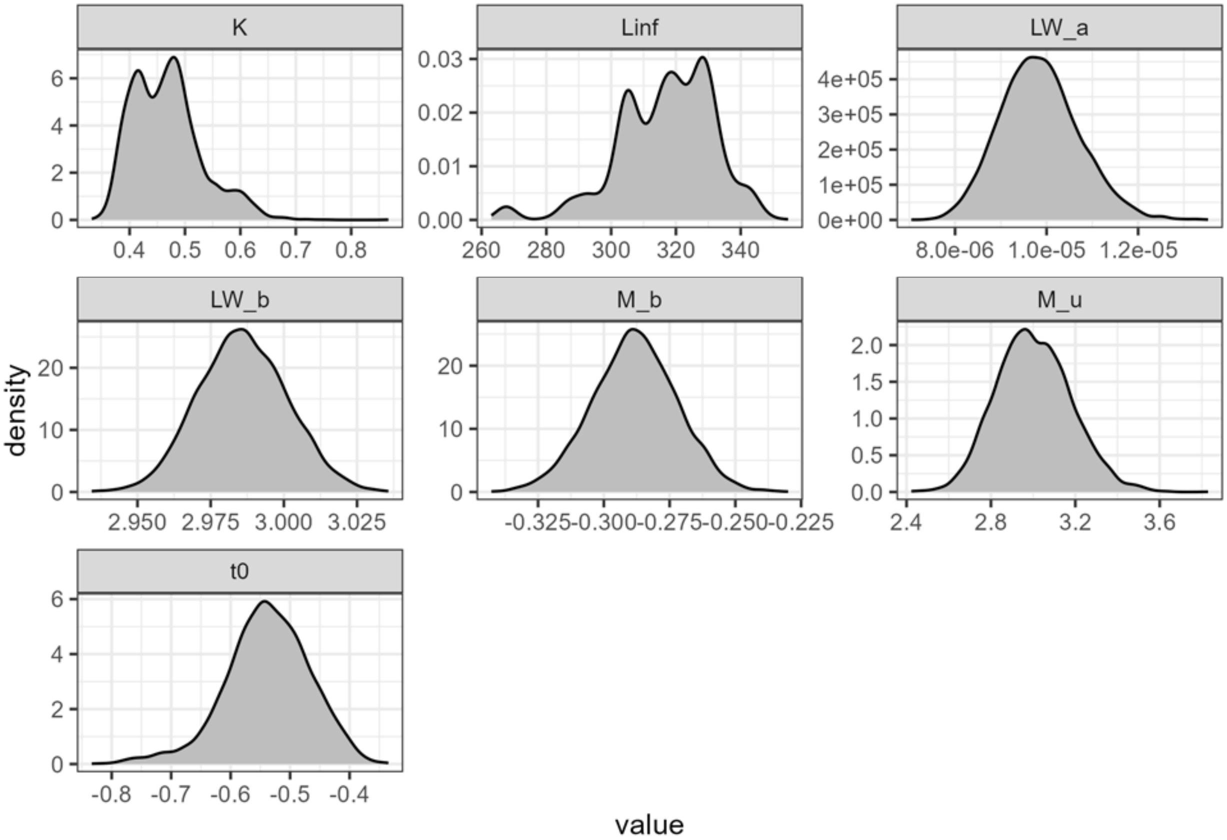


Figure 83. Density plots of drawn life history parameters from NNE Alewife for the stochastic SPR.

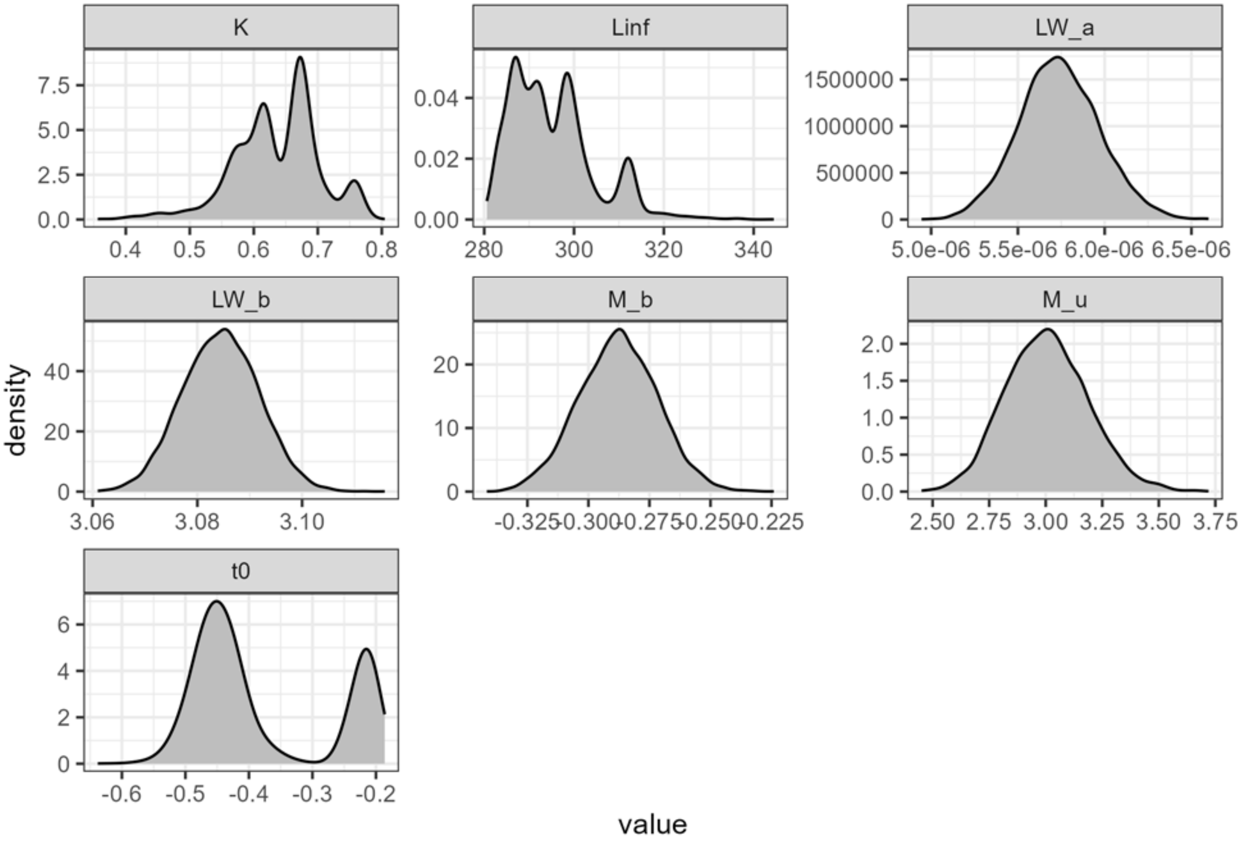


Figure 84. Density plots of drawn life history parameters from SNE Alewife for the stochastic SPR.

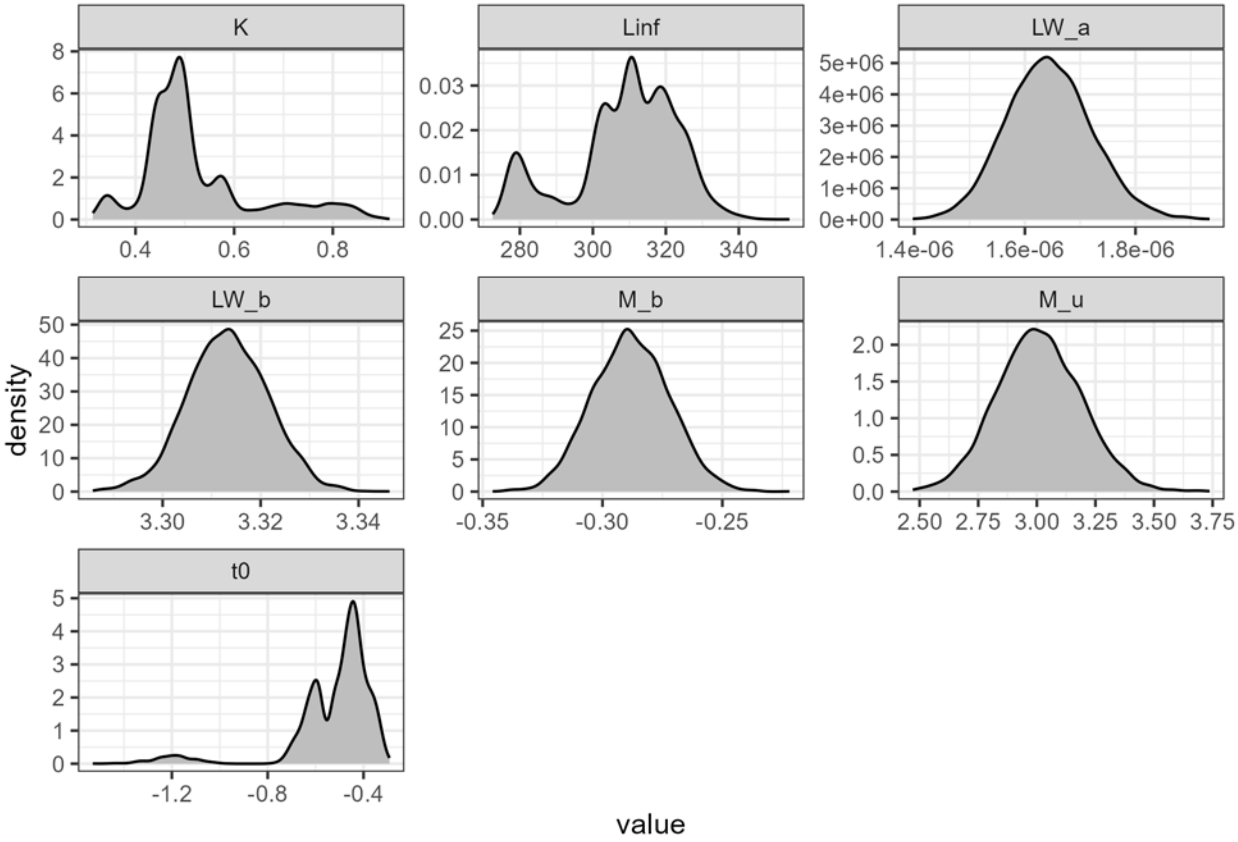


Figure 85. Density plots of drawn life history parameters from MAT Alewife for the stochastic SPR.

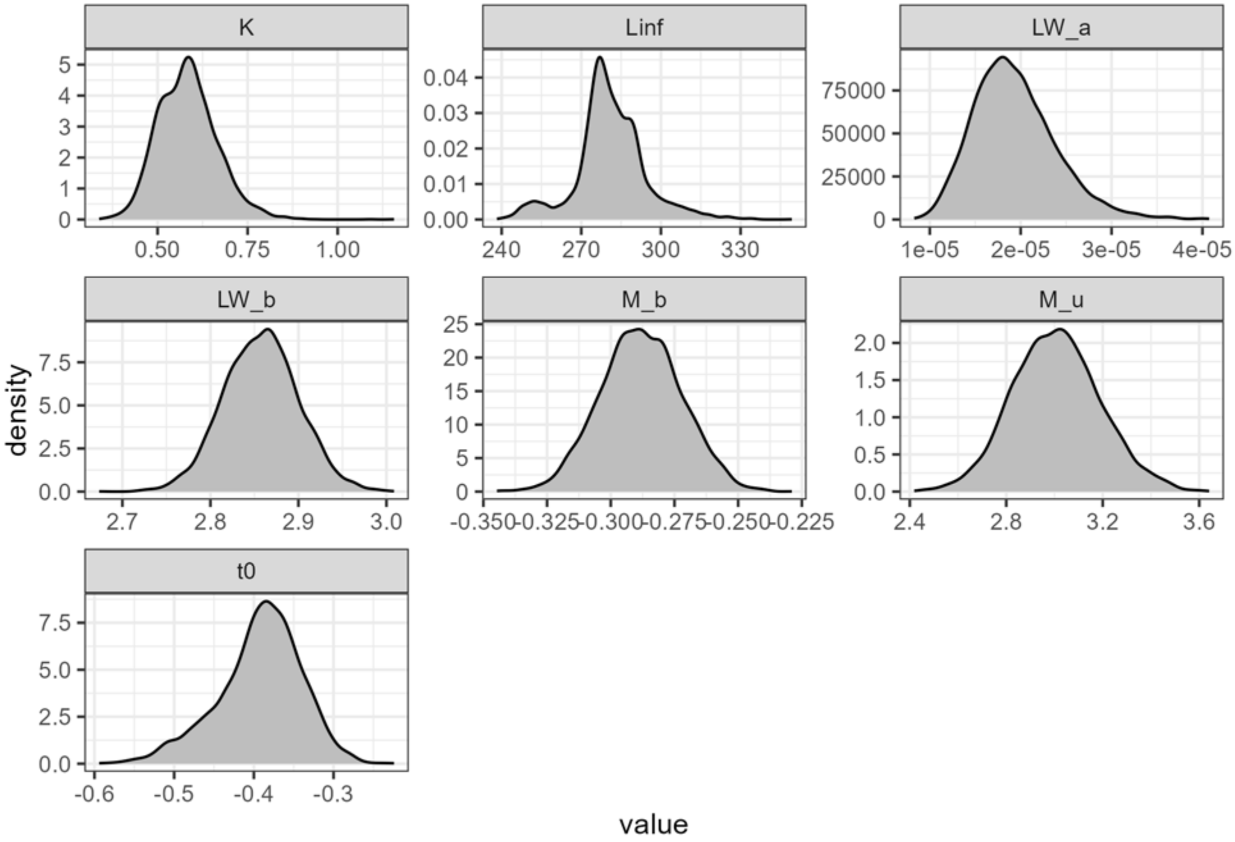


Figure 86. Density plots of drawn life history parameters from CAN-NNE Blueback Herring for the stochastic SPR.

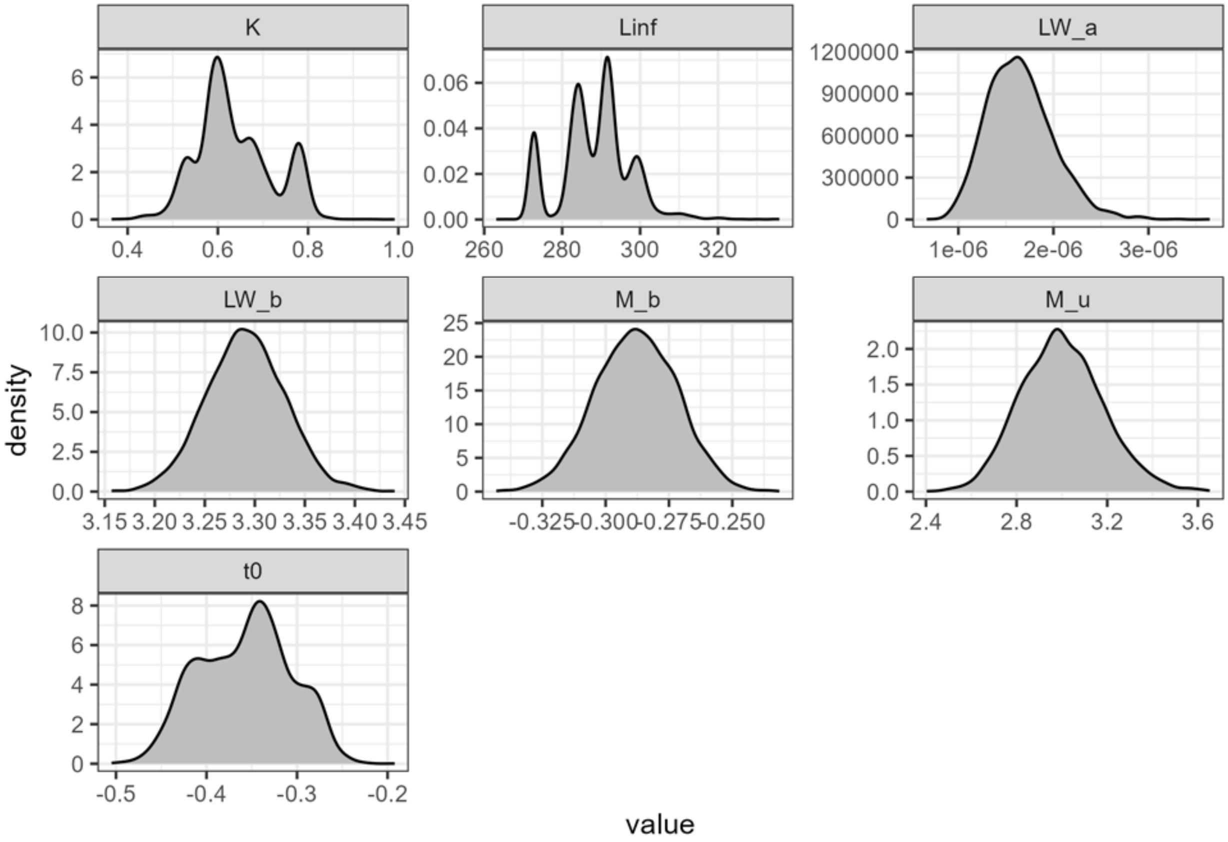


Figure 87. Density plots of drawn life history parameters from MNE Blueback Herring for the stochastic SPR.

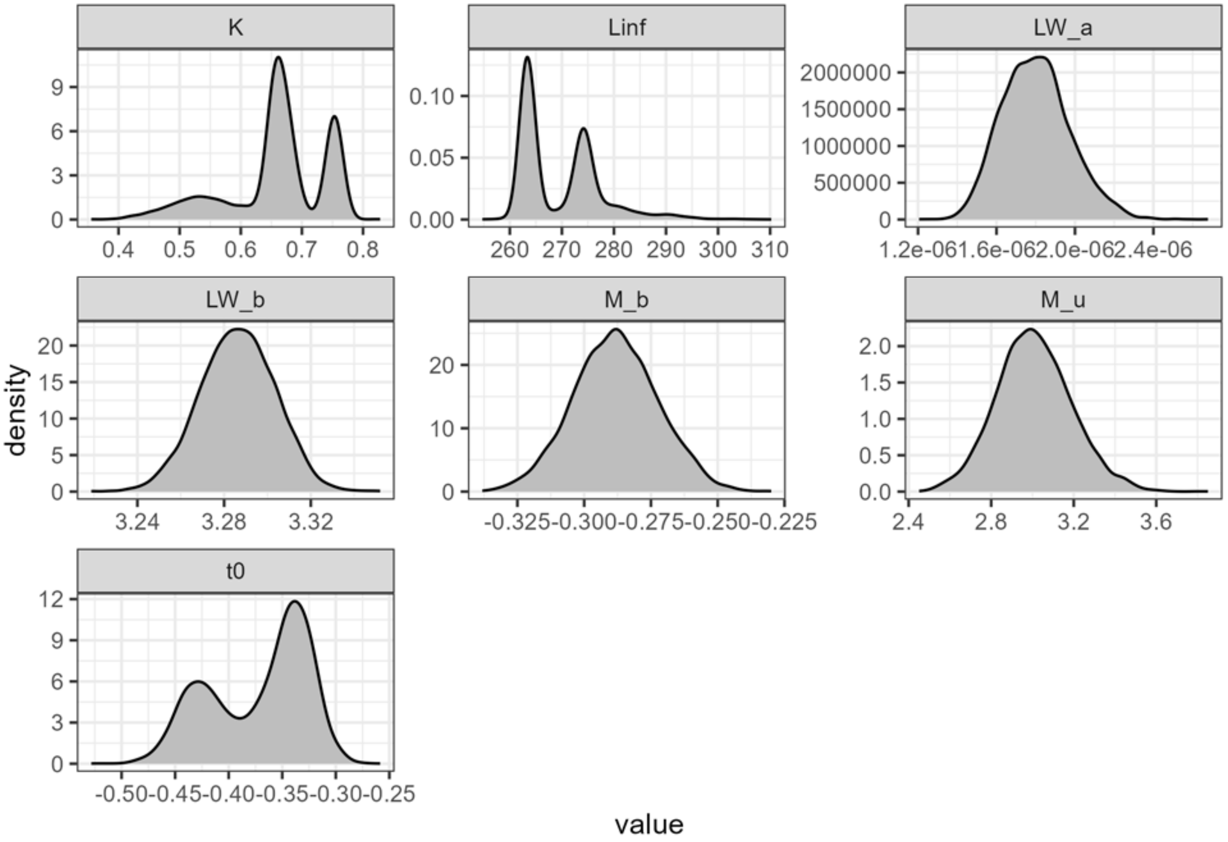


Figure 88. Density plots of drawn life history parameters from SNE Blueback Herring for the stochastic SPR.

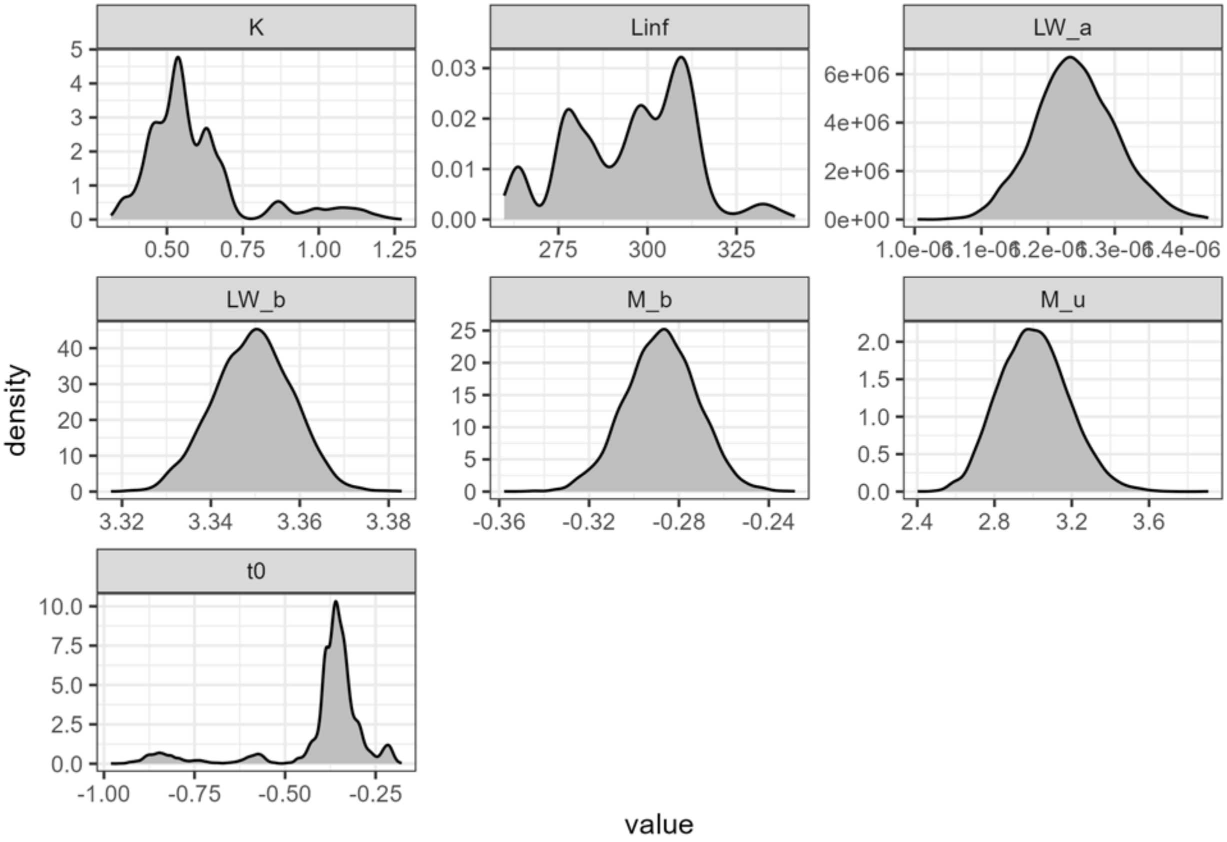


Figure 89. Density plots of drawn life history parameters from MAT Blueback Herring for the stochastic SPR.

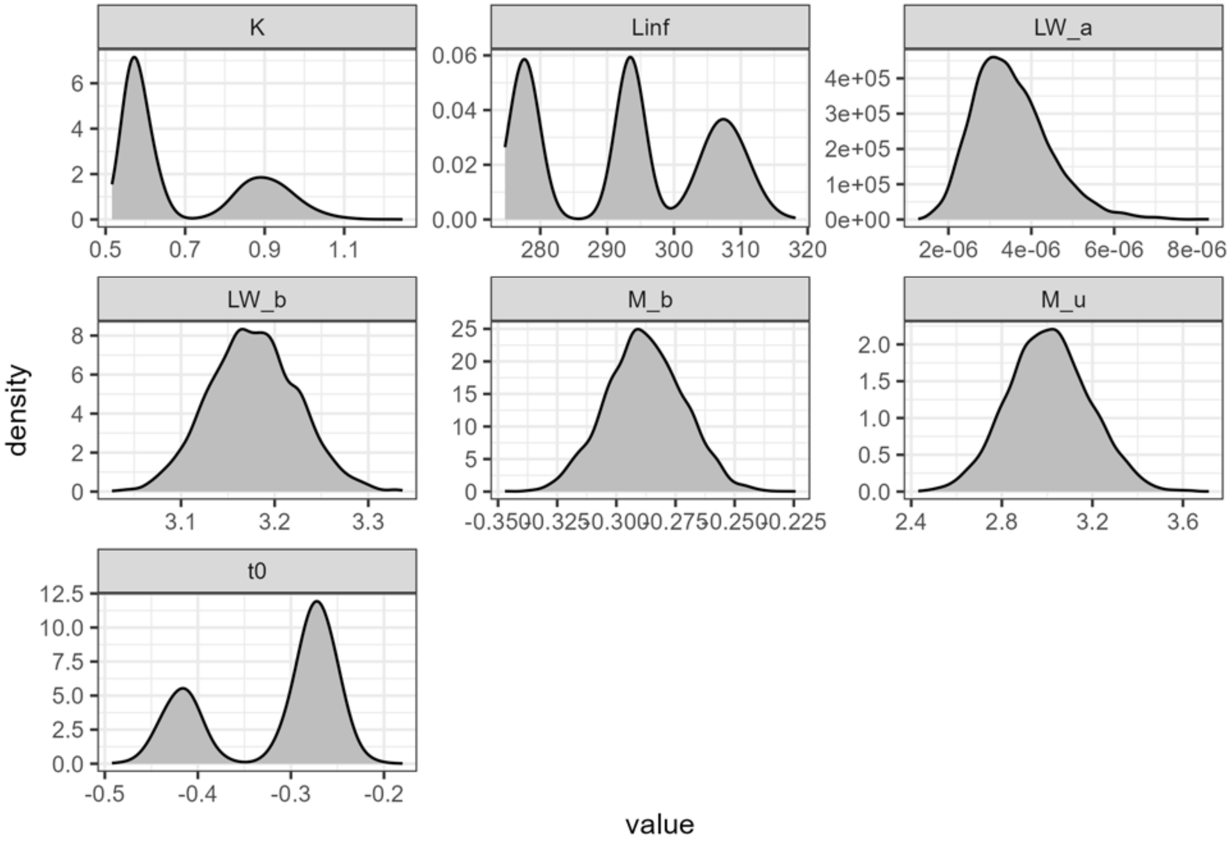


Figure 90. Density plots of drawn life history parameters from SAT Blueback Herring for the stochastic SPR.

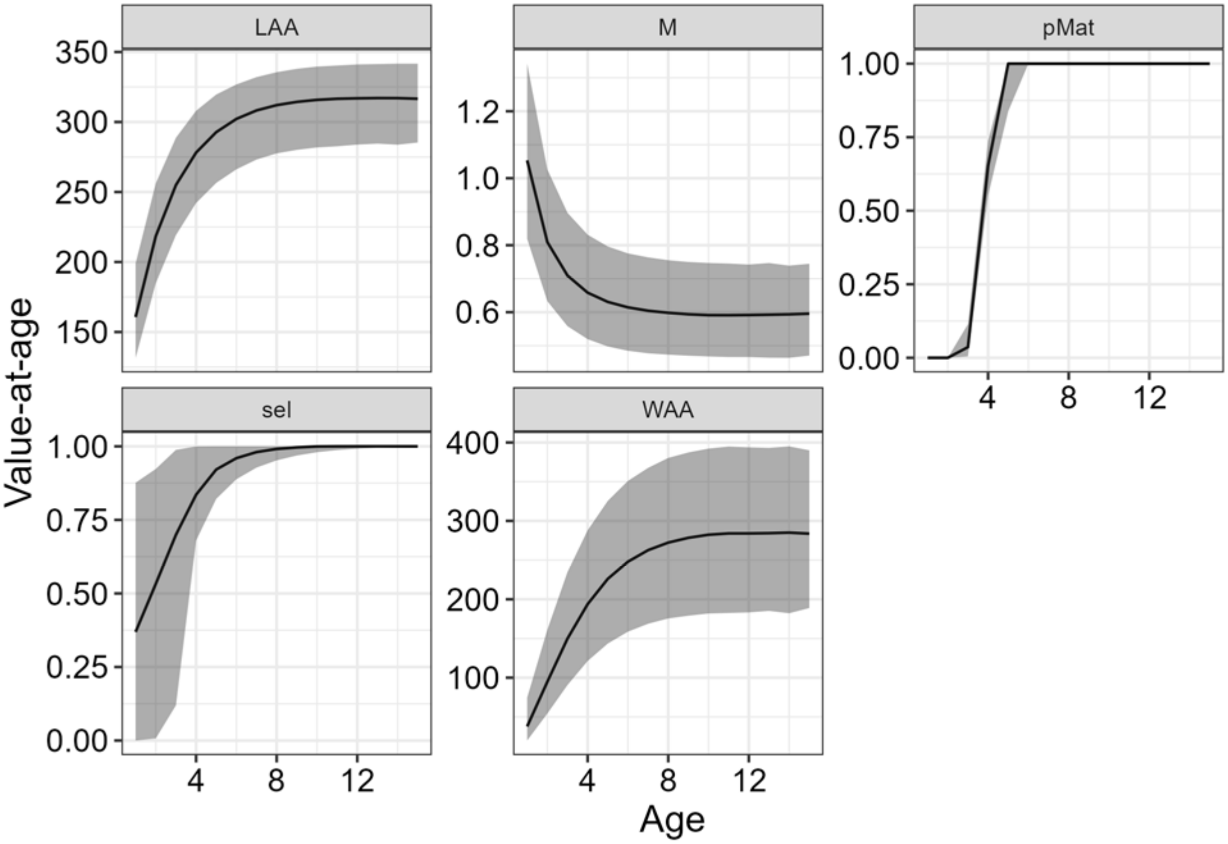


Figure 91. Median life history quantities at age from NNE Alewife for the stochastic SPR. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. LAA = length at age; M = natural mortality, pMat = probability of maturity; sel = selectivity; WAA = weight at age.

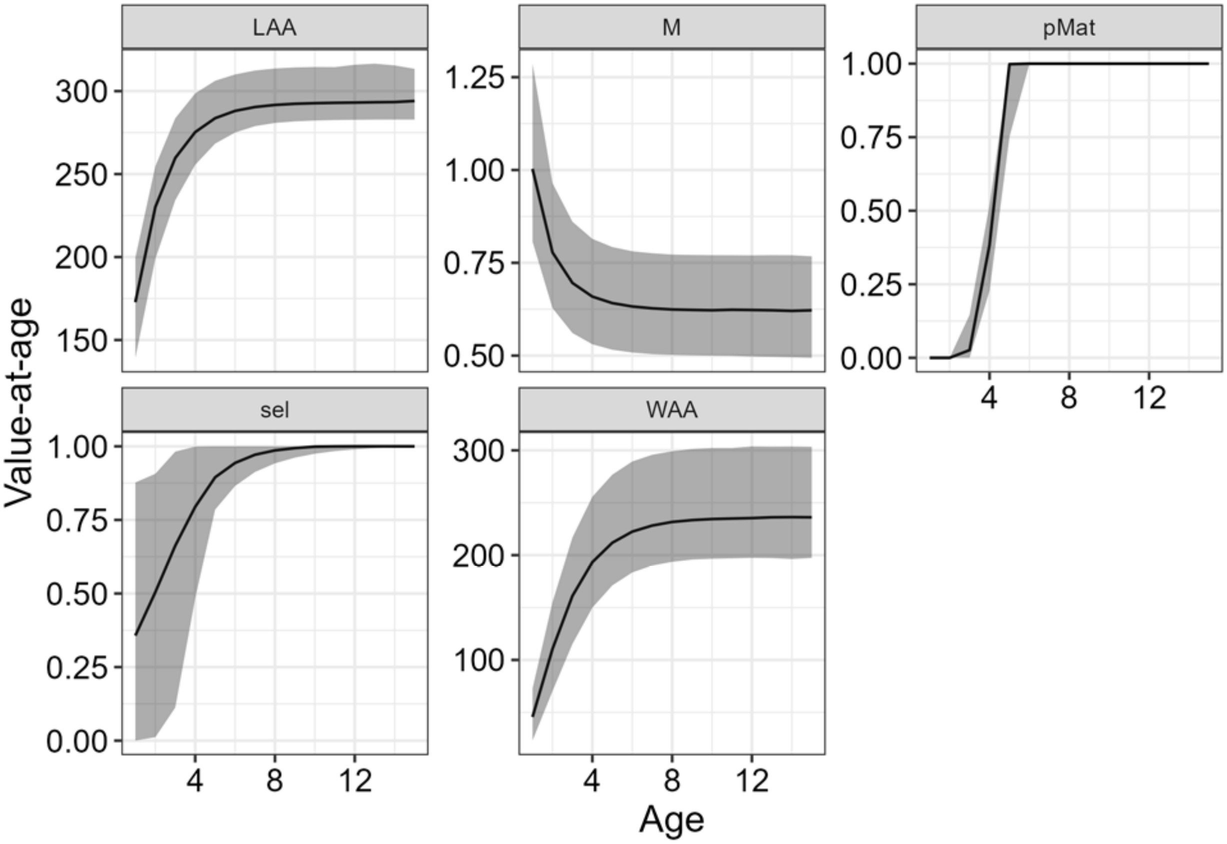


Figure 92. Median life history quantities at age from SNE Alewife for the stochastic SPR. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. LAA = length at age; M = natural mortality, pMat = probability of maturity; sel = selectivity; WAA = weight at age.

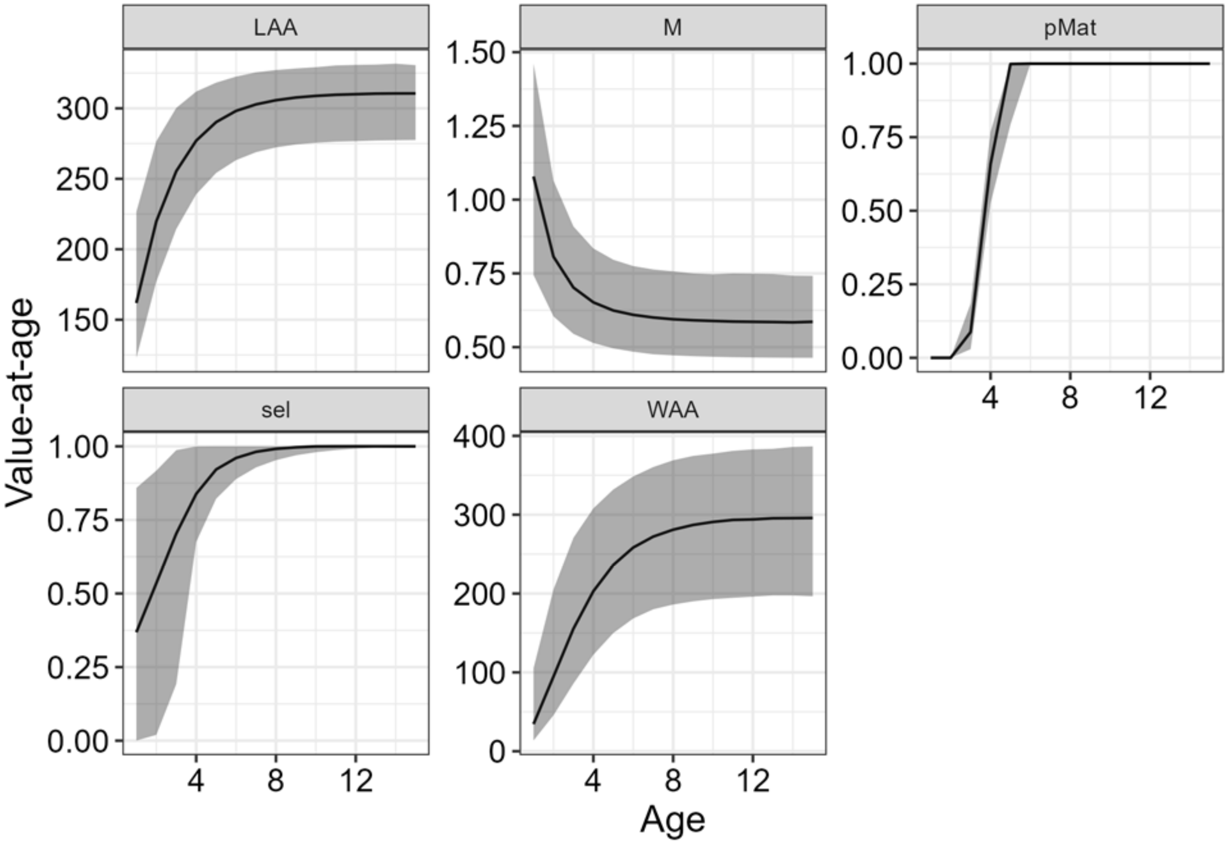


Figure 93. Median life history quantities at age from MAT Alewife for the stochastic SPR. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. LAA = length at age; M = natural mortality, pMat = probability of maturity; sel = selectivity; WAA = weight at age.

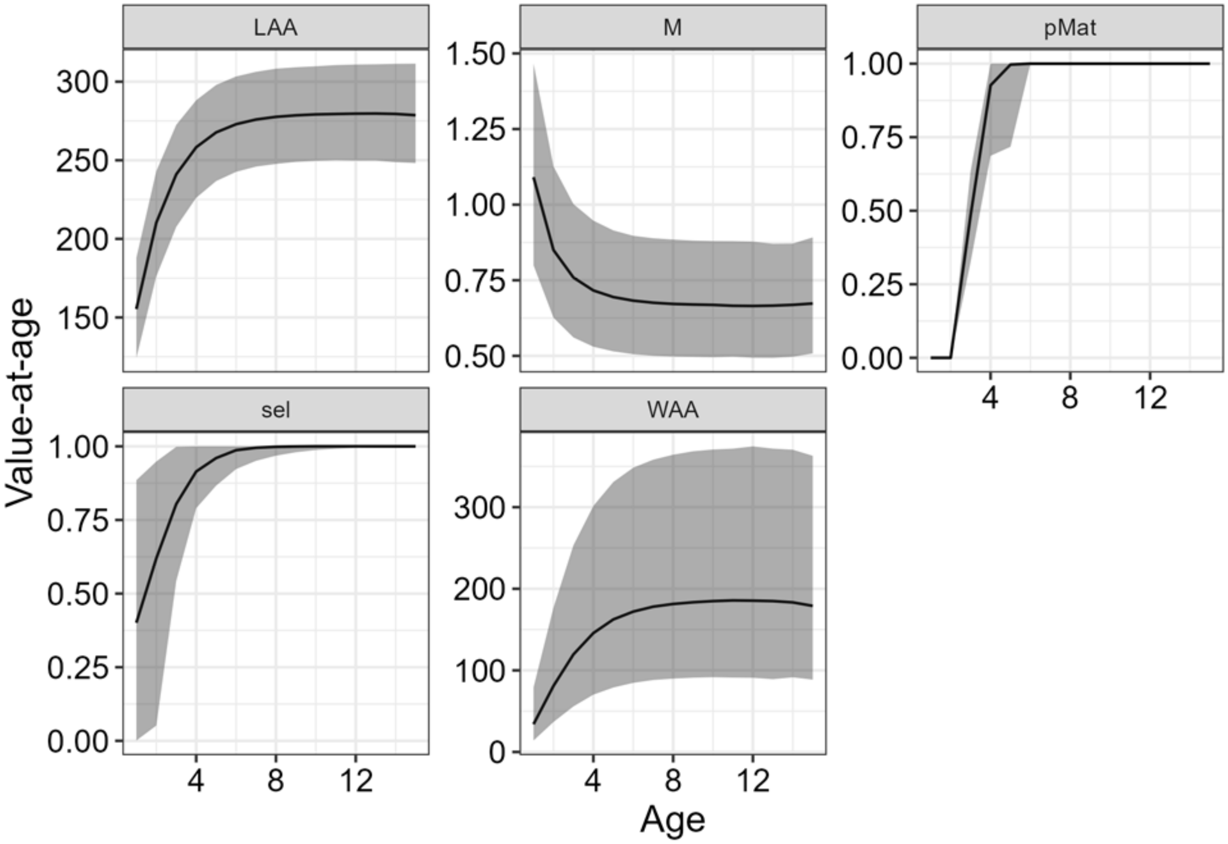


Figure 94. Median life history quantities at age from CAN-NNE blueback herring for the stochastic SPR. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. LAA = length at age; M = natural mortality, pMat = probability of maturity; sel = selectivity; WAA = weight at age.

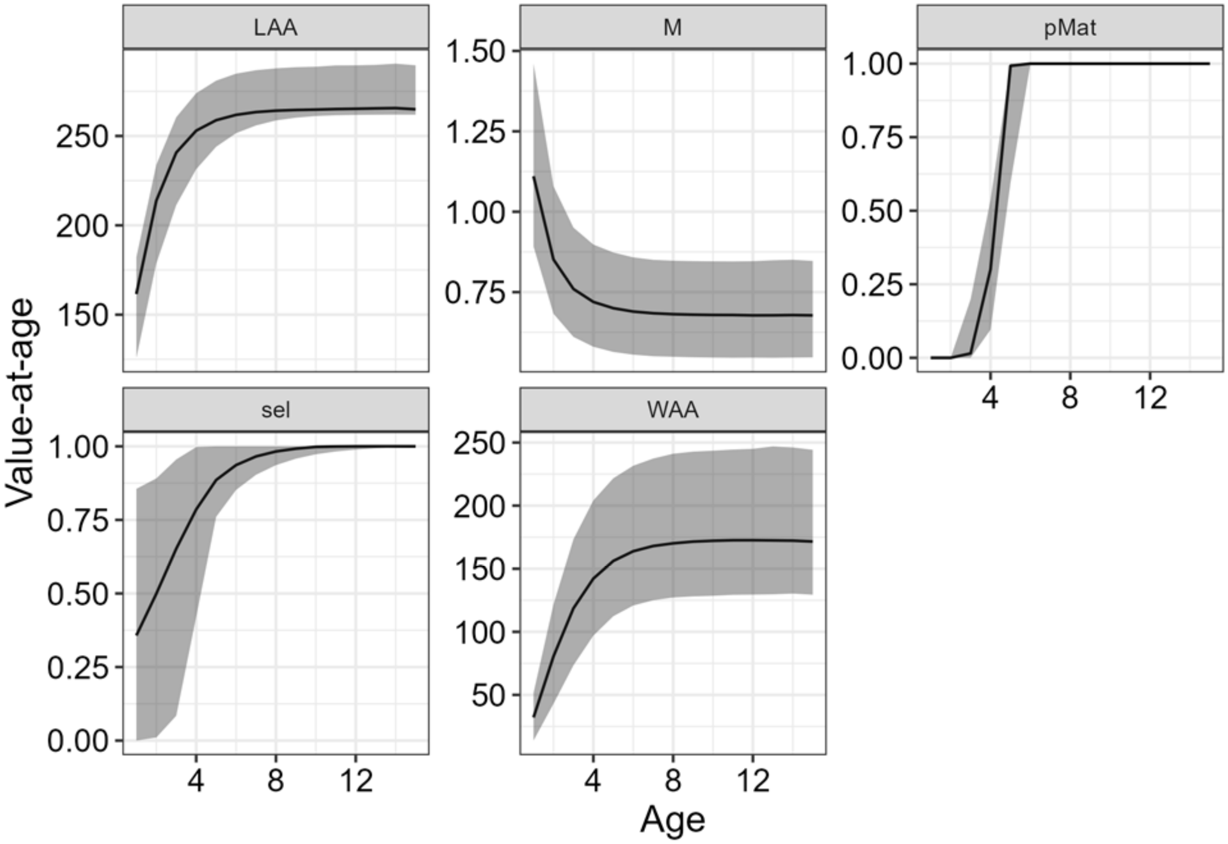


Figure 95. Median life history quantities at age from MNE blueback herring for the stochastic SPR. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. LAA = length at age; M = natural mortality, pMat = probability of maturity; sel = selectivity; WAA = weight at age.

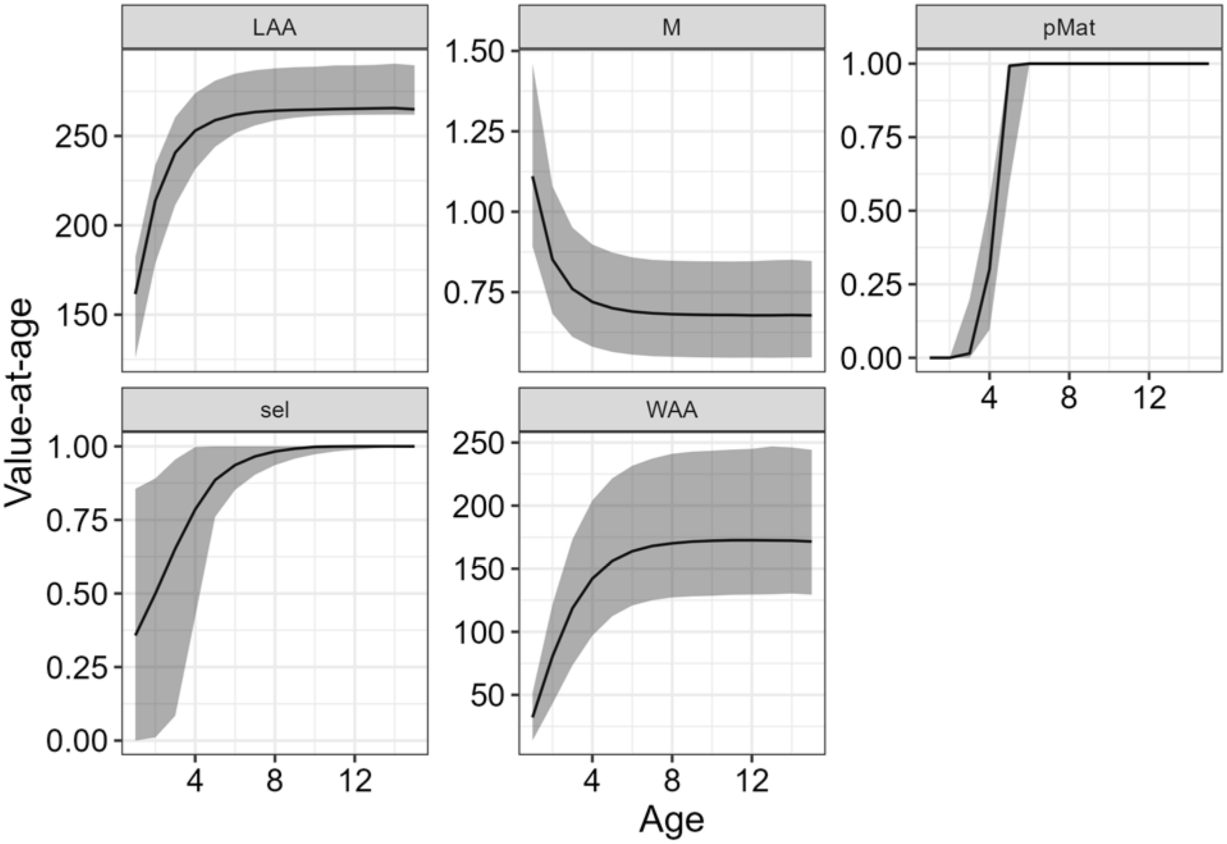


Figure 96. Median life history quantities at age from SNE blueback herring for the stochastic SPR. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. LAA = length at age; M = natural mortality, pMat = probability of maturity; sel = selectivity; WAA = weight at age.

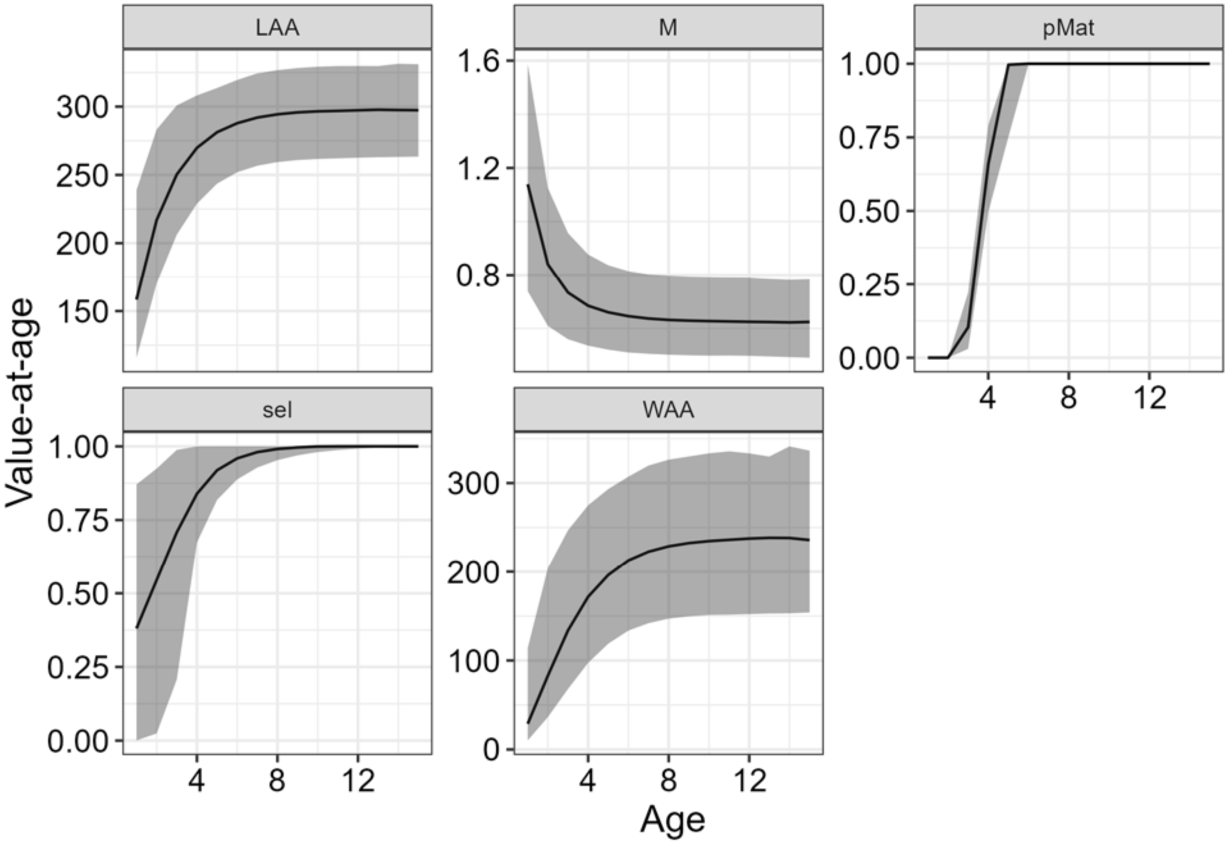


Figure 97. Median life history quantities at age from MAT blueback herring for the stochastic SPR. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. LAA = length at age; M = natural mortality, pMat = probability of maturity; sel = selectivity; WAA = weight at age.

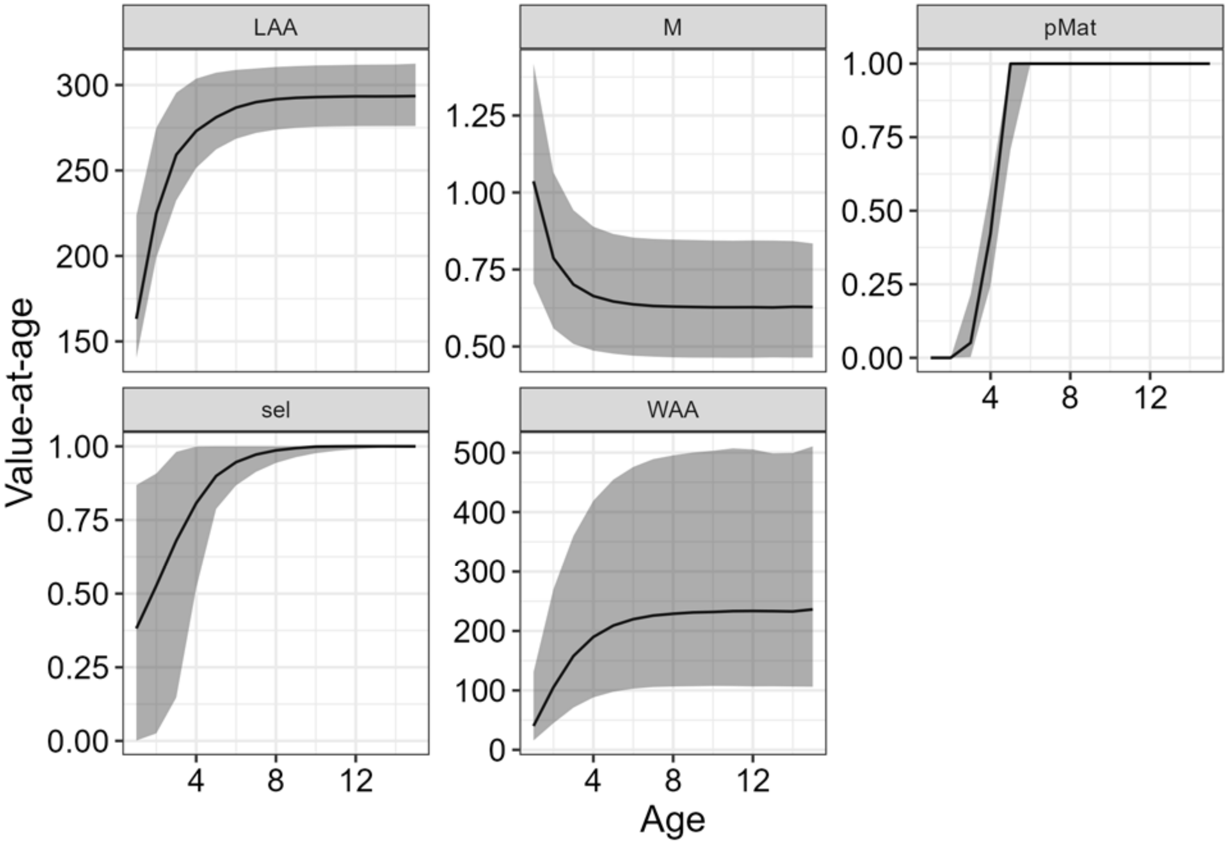


Figure 98. Median life history quantities at age from SAT blueback herring for the stochastic SPR. Shaded areas indicate the 5th and 95th percentiles of the calculated parameters. LAA = length at age; M = natural mortality, pMat = probability of maturity; sel = selectivity; WAA = weight at age.

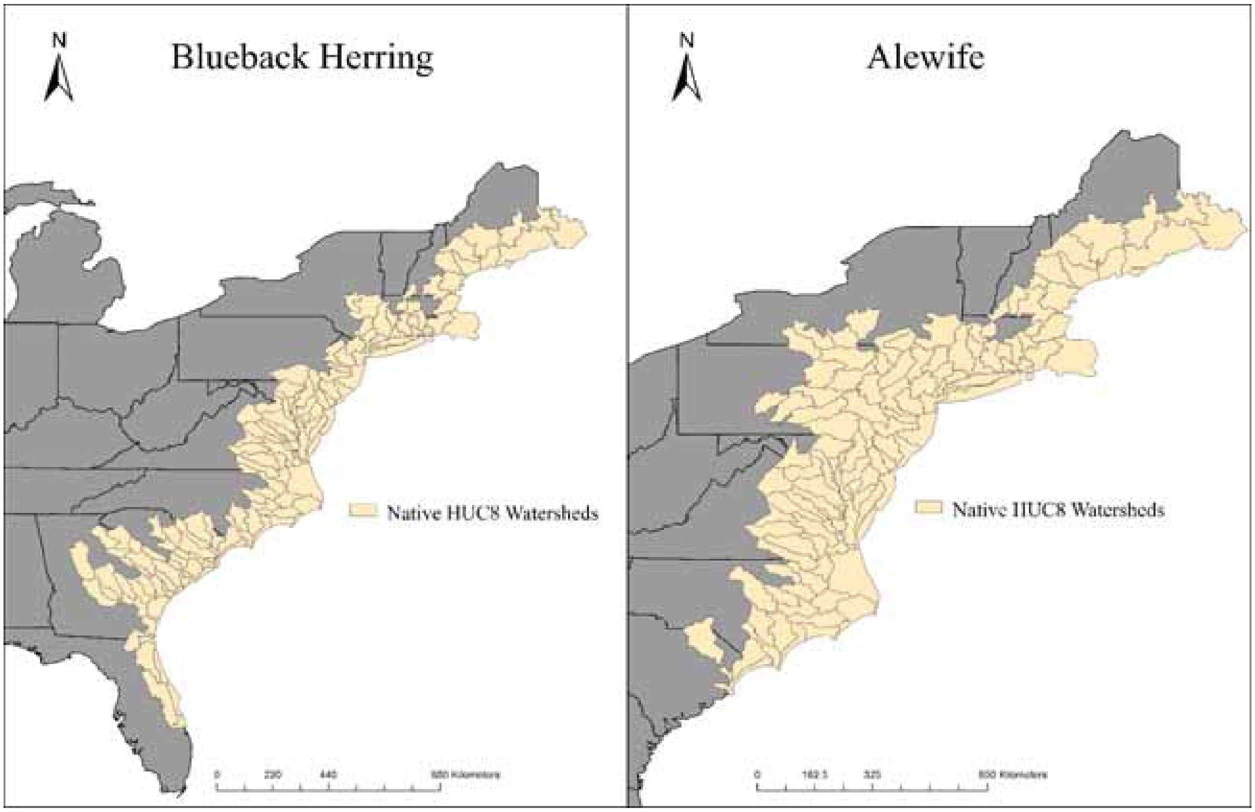


Figure 99. Historical native range for river herring in HUC8 watersheds across the Atlantic coast.

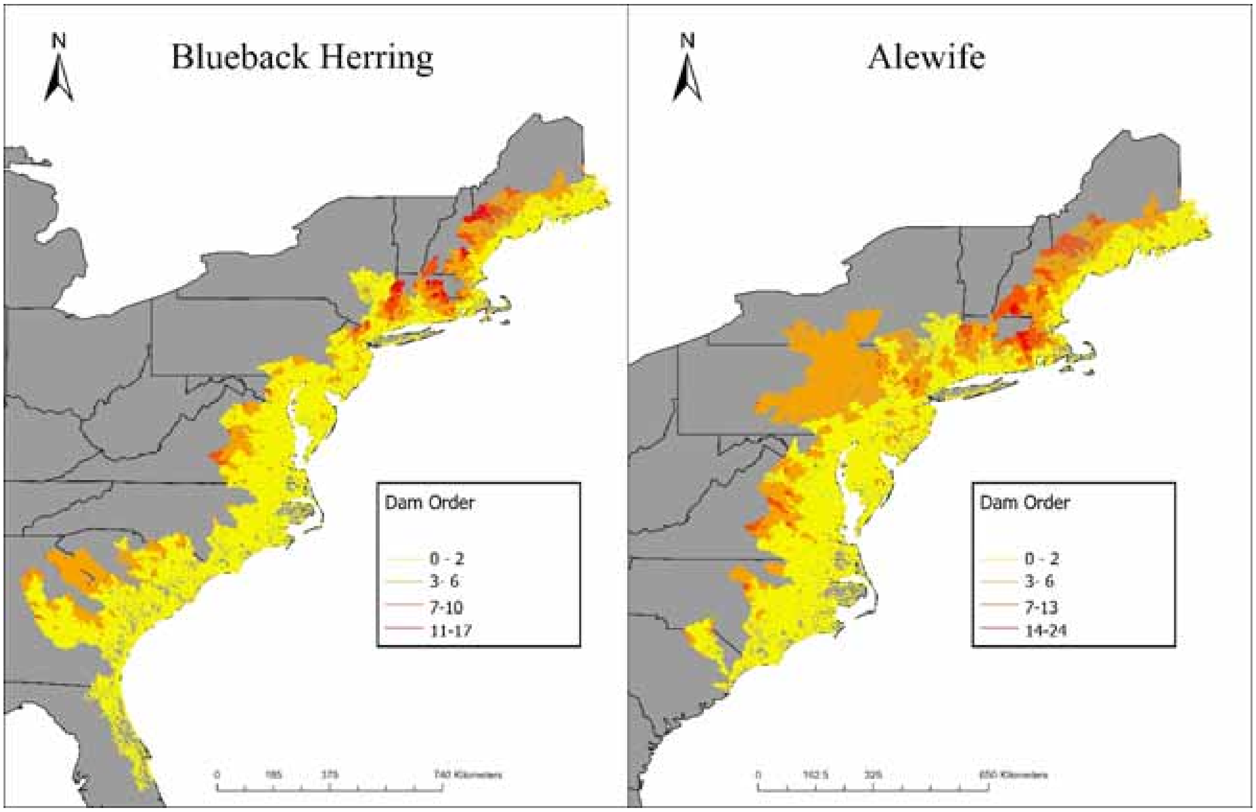


Figure 100. Number of downstream dams of each river reach segment based on the locations of dams or impoundments in the National Dam Inventory database (https://nid.sec.usace.army.mil/#/).

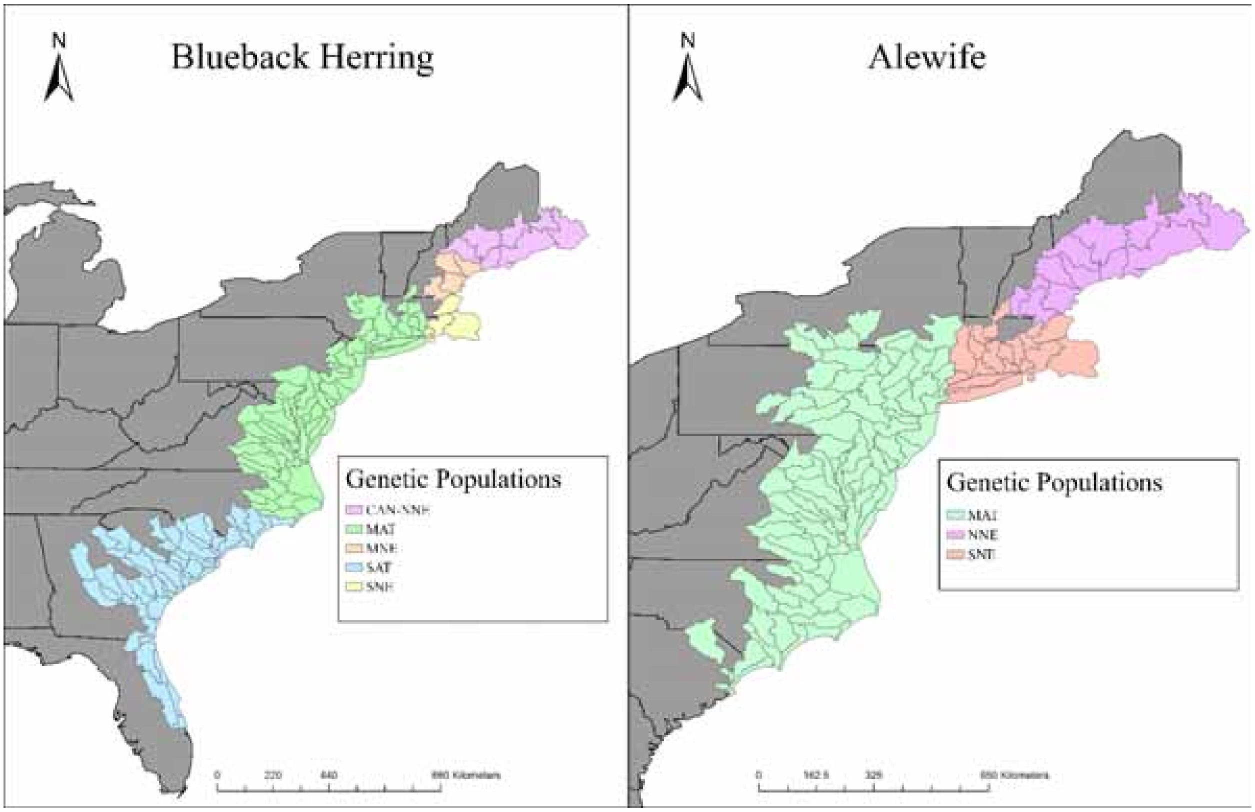


Figure 101. Genetic stock-regions of river herring within HUC8 watersheds across the Atlantic Coast extrapolated from Reid et al. (2018). Five genetic populations for blueback herring (Canada-Northern New England [CAN-NNE], Mid-New England [MNE], Southern New England [SNE], Mid-Atlantic [MAT], and South Atlantic [SAT]) and three genetic populations for alewife (Northern New England [NNE], Southern New England [SNE], and Mid- Atlantic [MAT]).

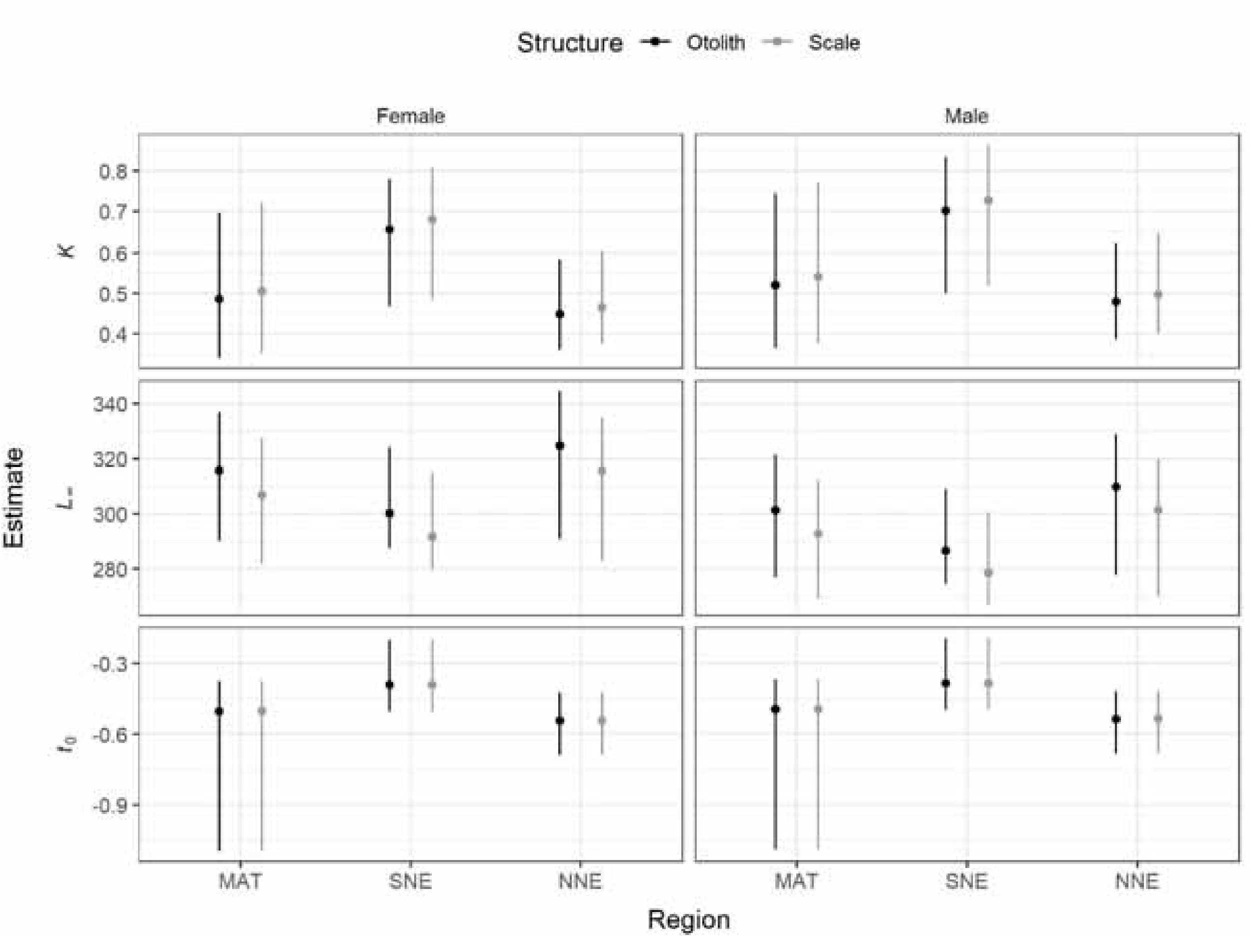


Figure 102. Estimated parameters of the von Bertalanffy growth function for alewife by regions, sex, and aging structure. Parameters include Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Points are estimated posterior means, and vertical lines are 95% credible intervals for those estimates. Regions are organized from south to north left to right: Mid-Atlantic (MAT), Southern New England (SNE), and Northern New England (NNE).

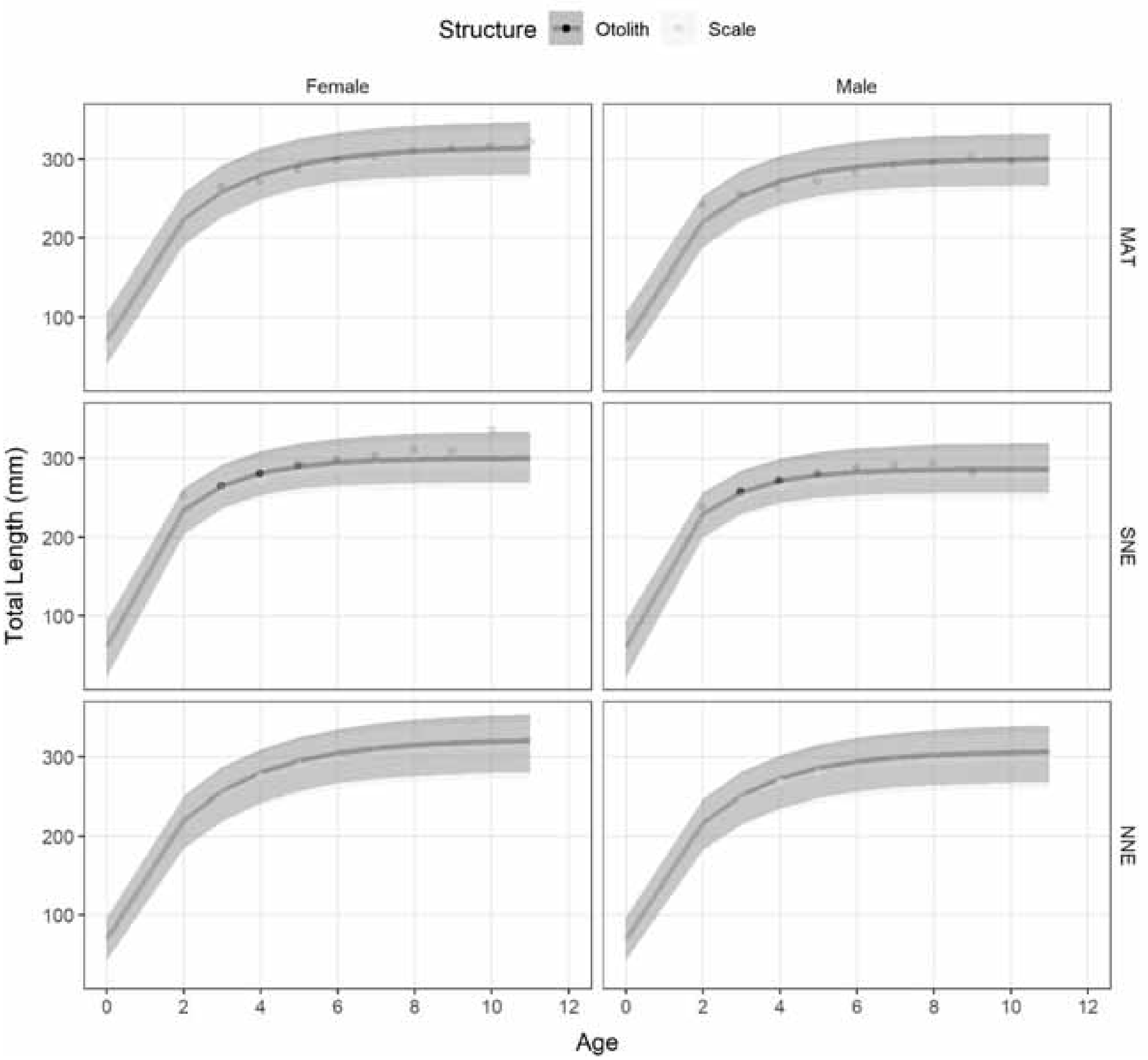


Figure 103. Regional von Bertalanffy growth function predictions and empirical mean length at age for alewife within ageing structures and sex. Points are regional mean length at age, with opacity directly proportional to sample size. Lines are mean predictions fitted growth models, and ribbons are 95% credible intervals.

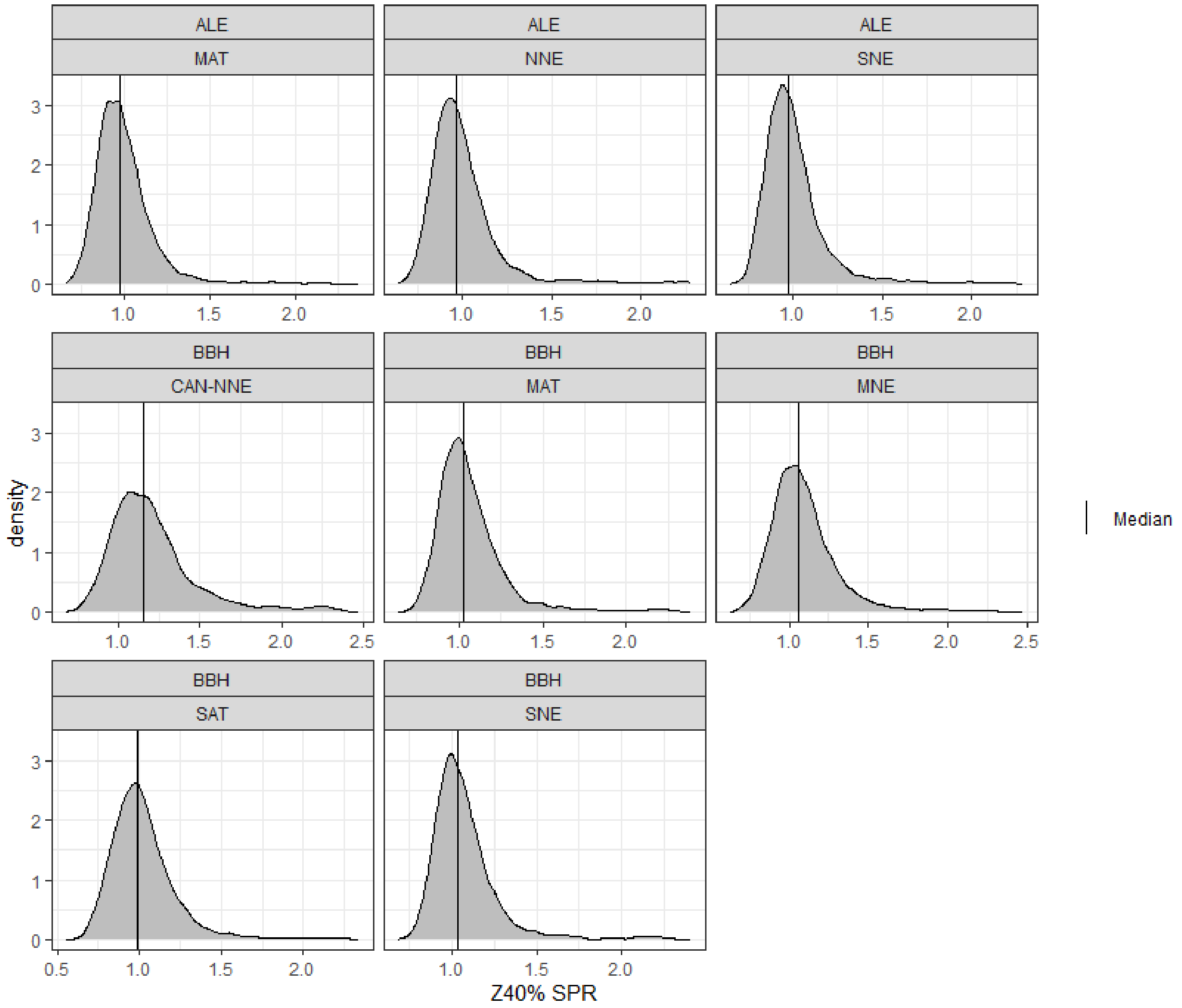


Figure 104. **Density distributions of $Z_{40\%SPR}$ estimates by species and stock region from the stochastic SPR analysis. Vertical solid lines are the median $Z_{40\%SPR}$.**

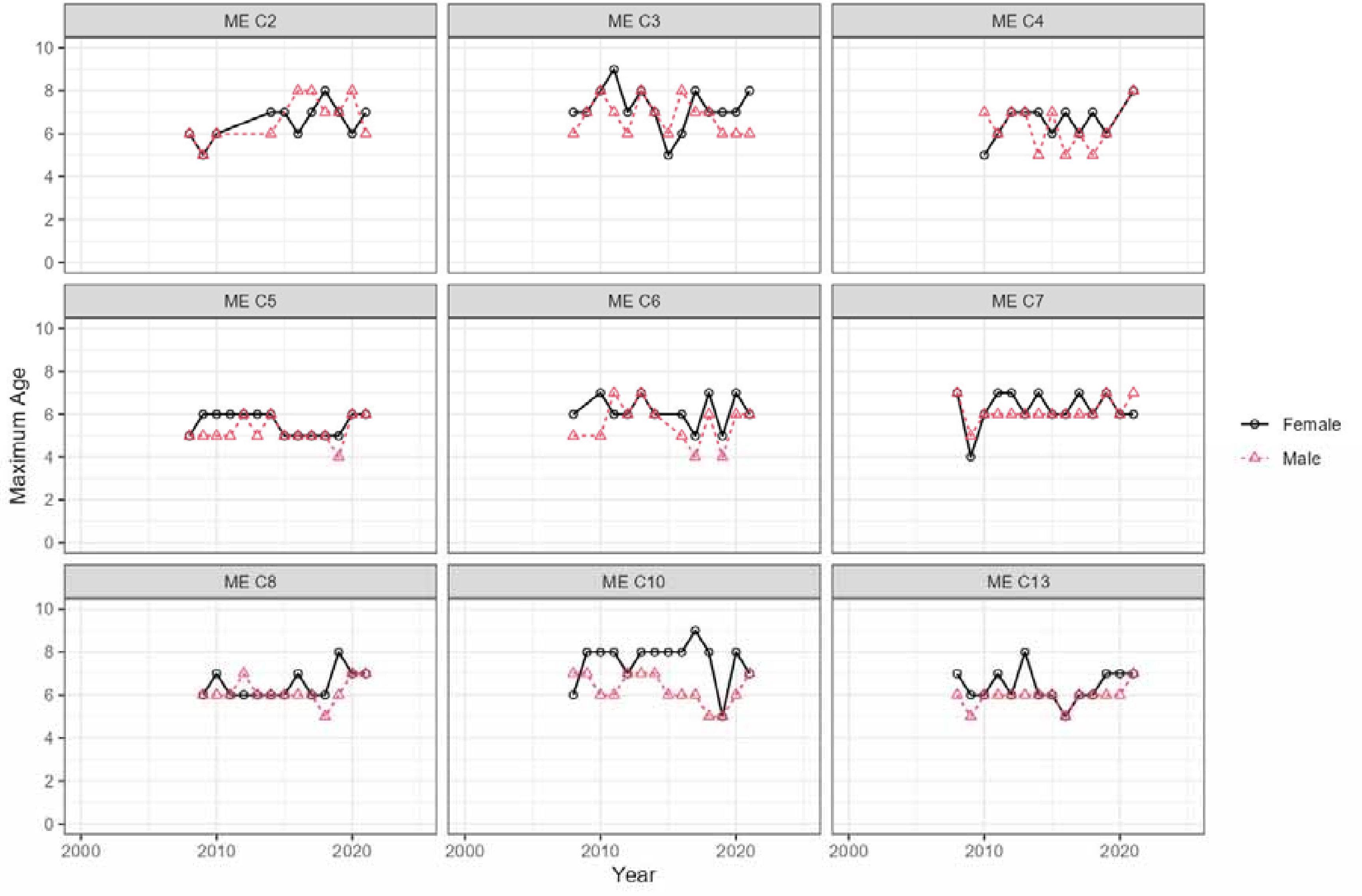


Figure 105. **Maximum scale-based ages for alewife by sex for nine Maine rivers in the NNE stock-region.**

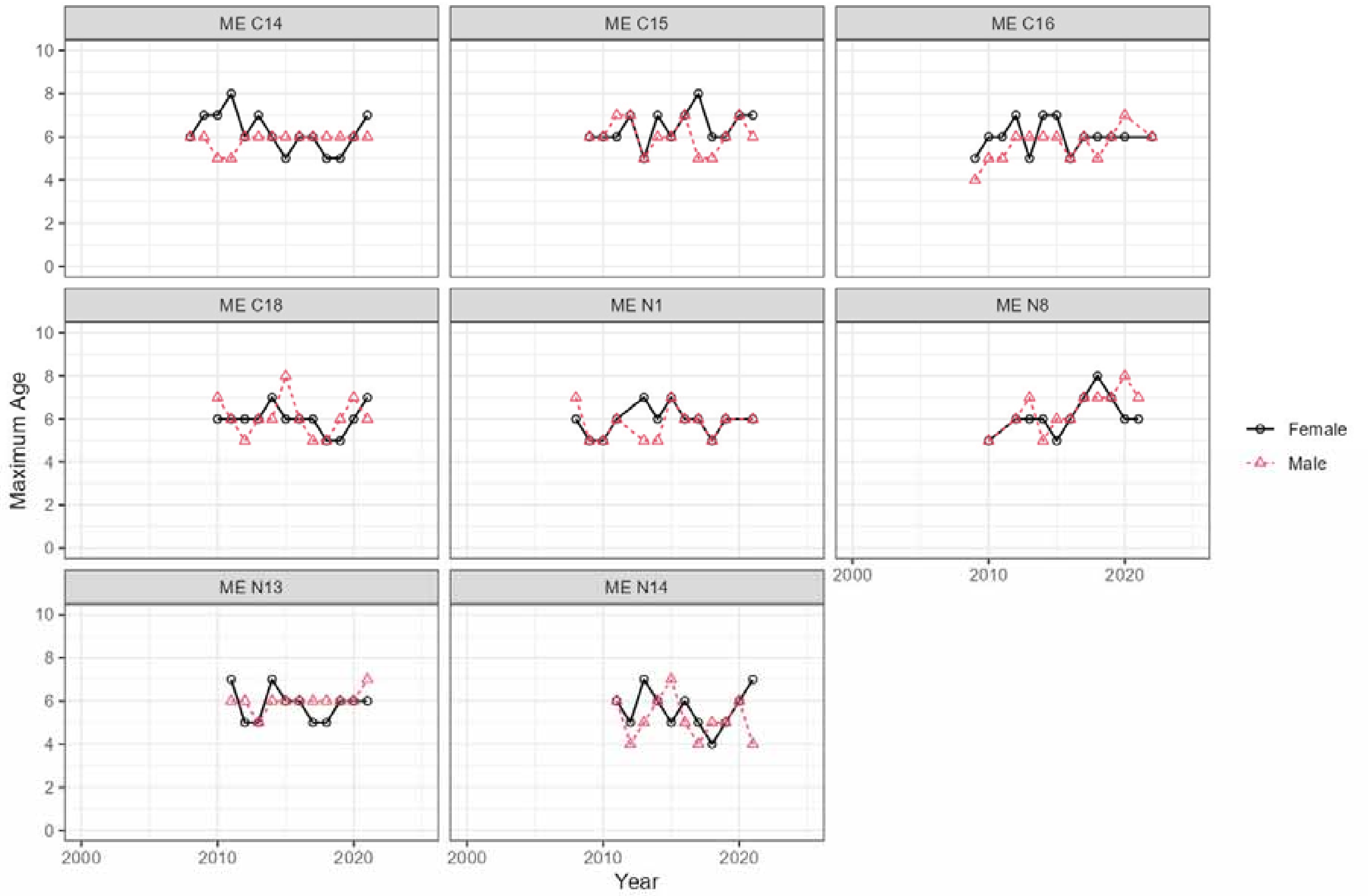


Figure 106. **Maximum scale-based ages for alewife by sex for eight Maine rivers in the NNE stock-region.**

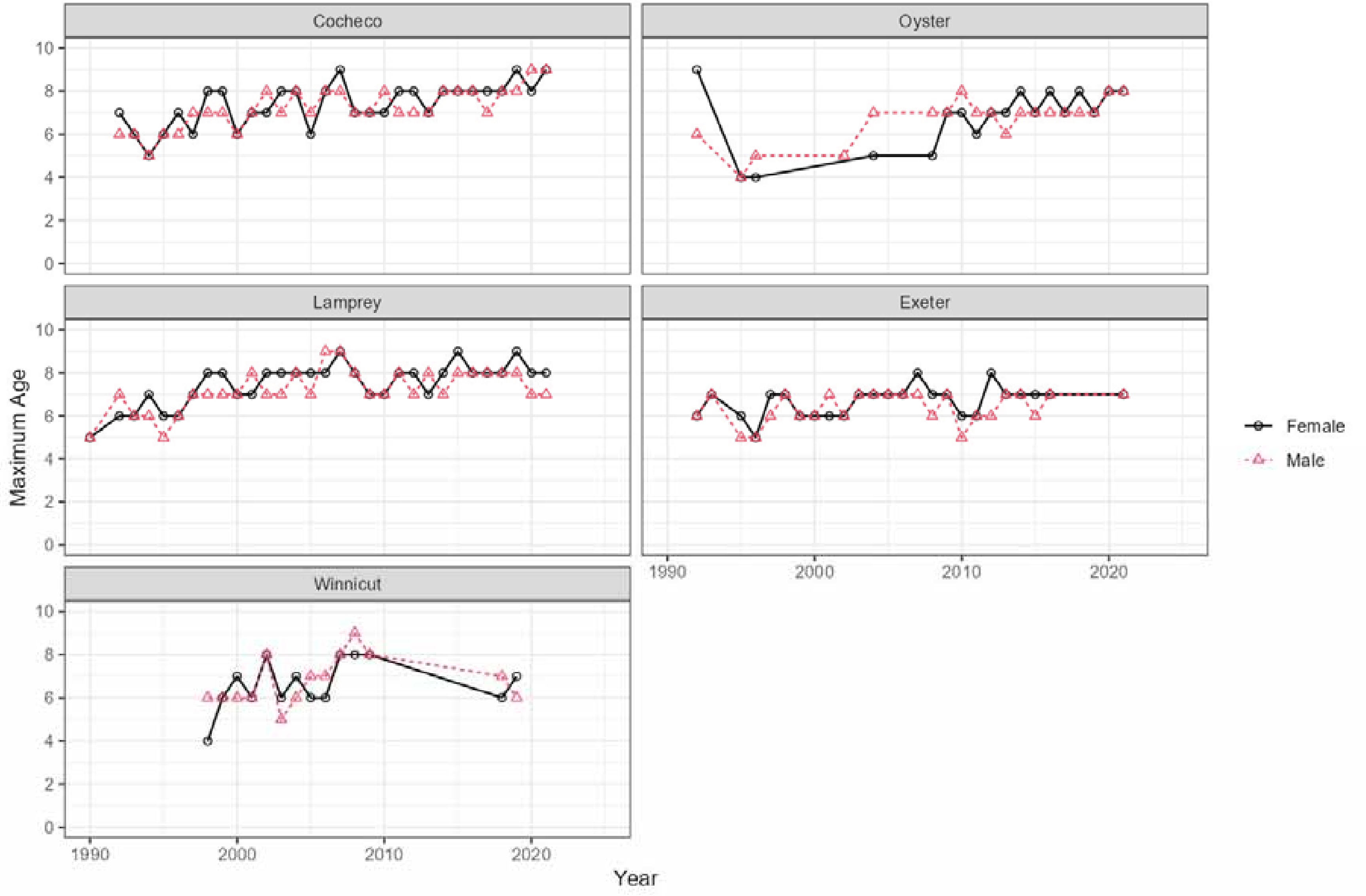


Figure 107. **Maximum scale-based ages alewife by sex for New Hampshire rivers in the NNE stock-region.**

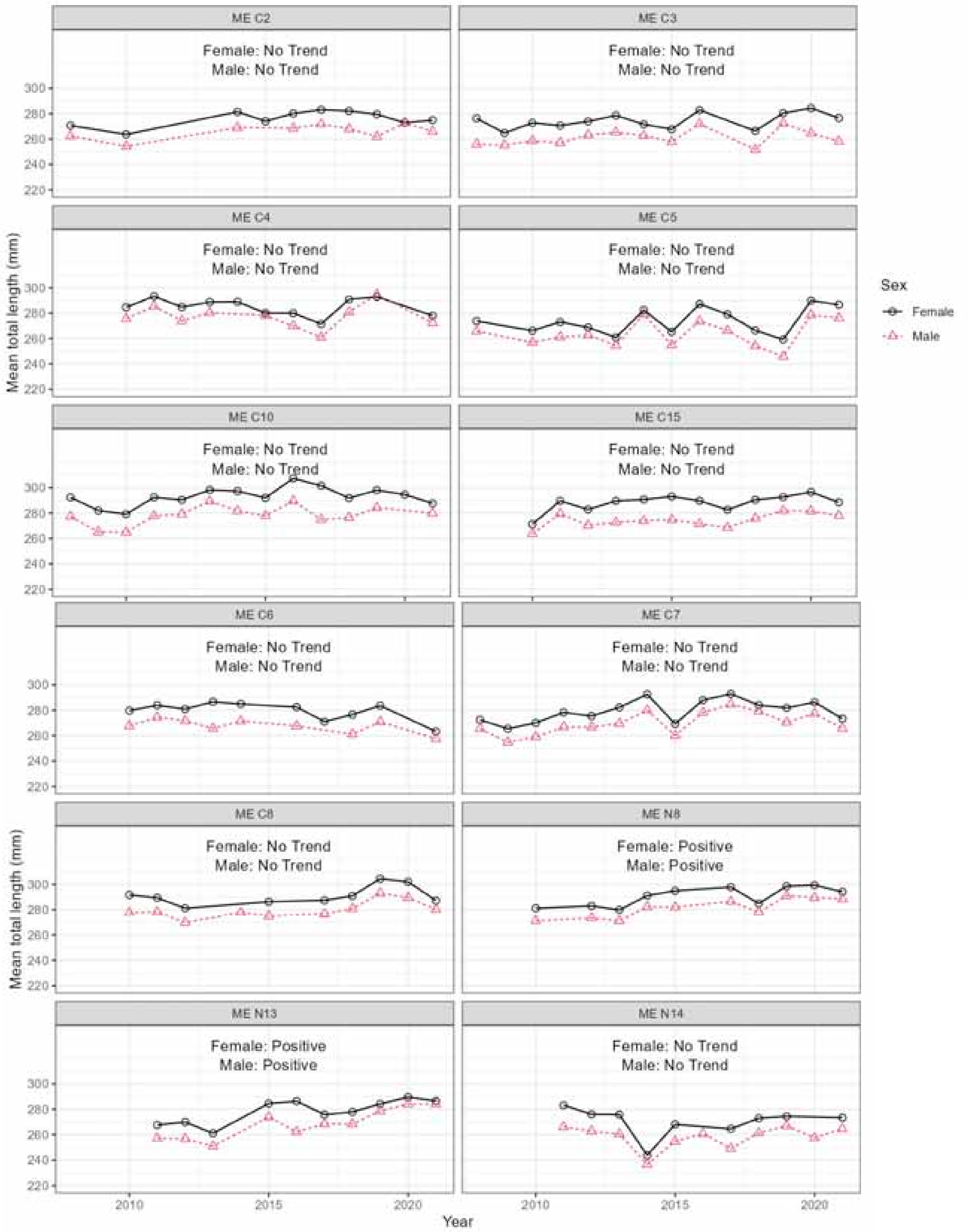


Figure 108. **Mean length over time for male and female alewife from Maine rivers in the NNE stock-region.**

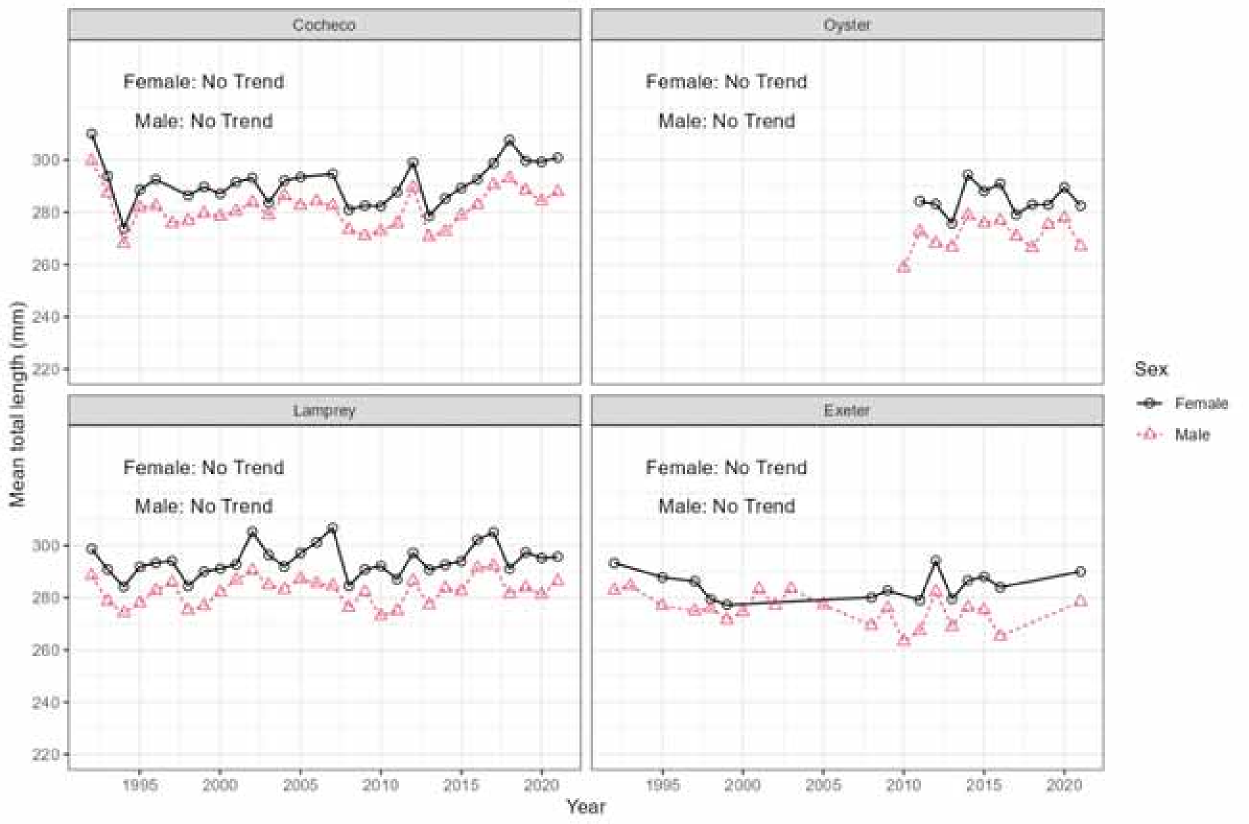


Figure 109. Mean length over time for male and female alewife from New Hampshire rivers in the NNE stock-region.

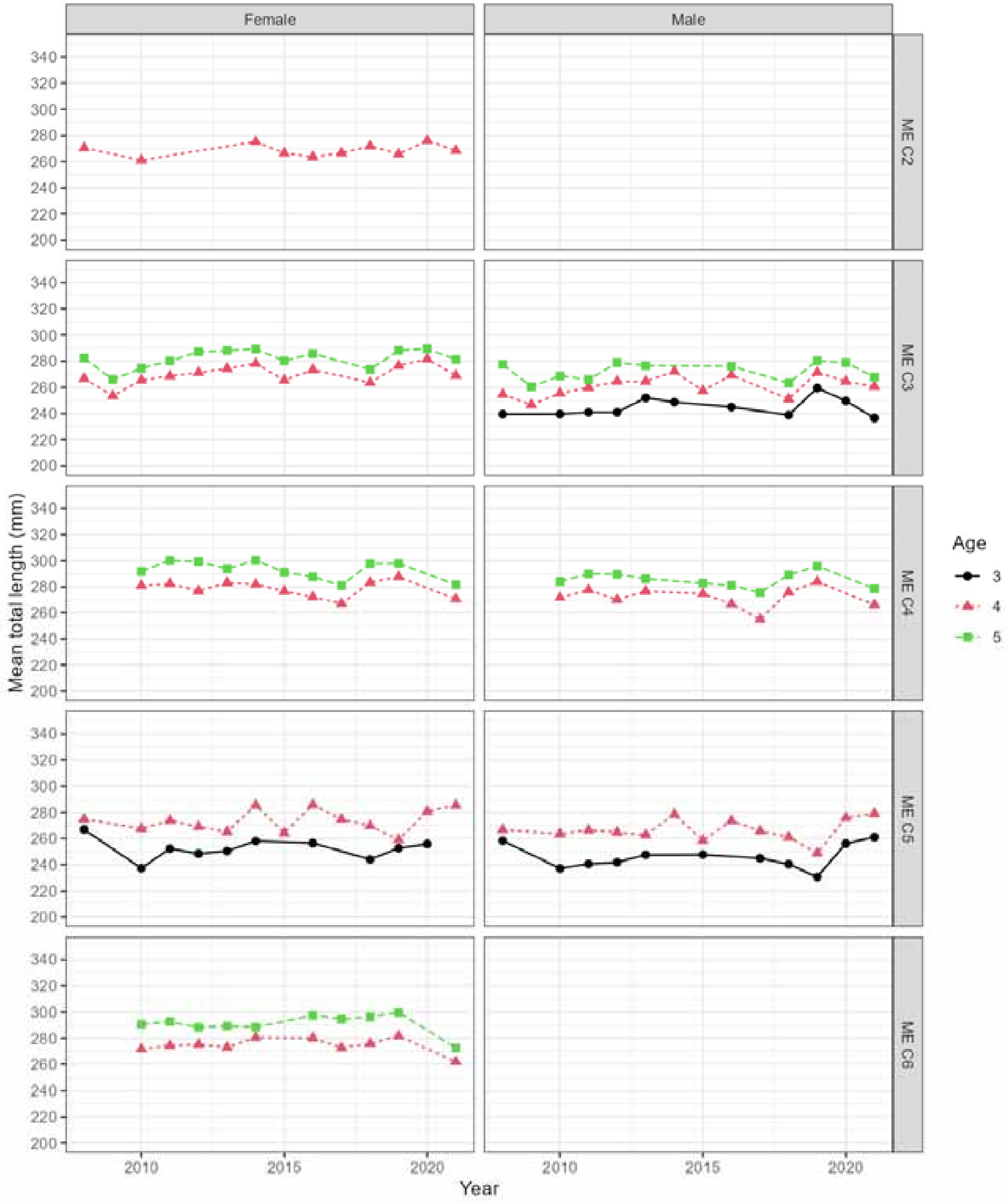


Figure 110. Mean length-at-age over time for male and female alewife from five Maine rivers in the NNE stock-region.

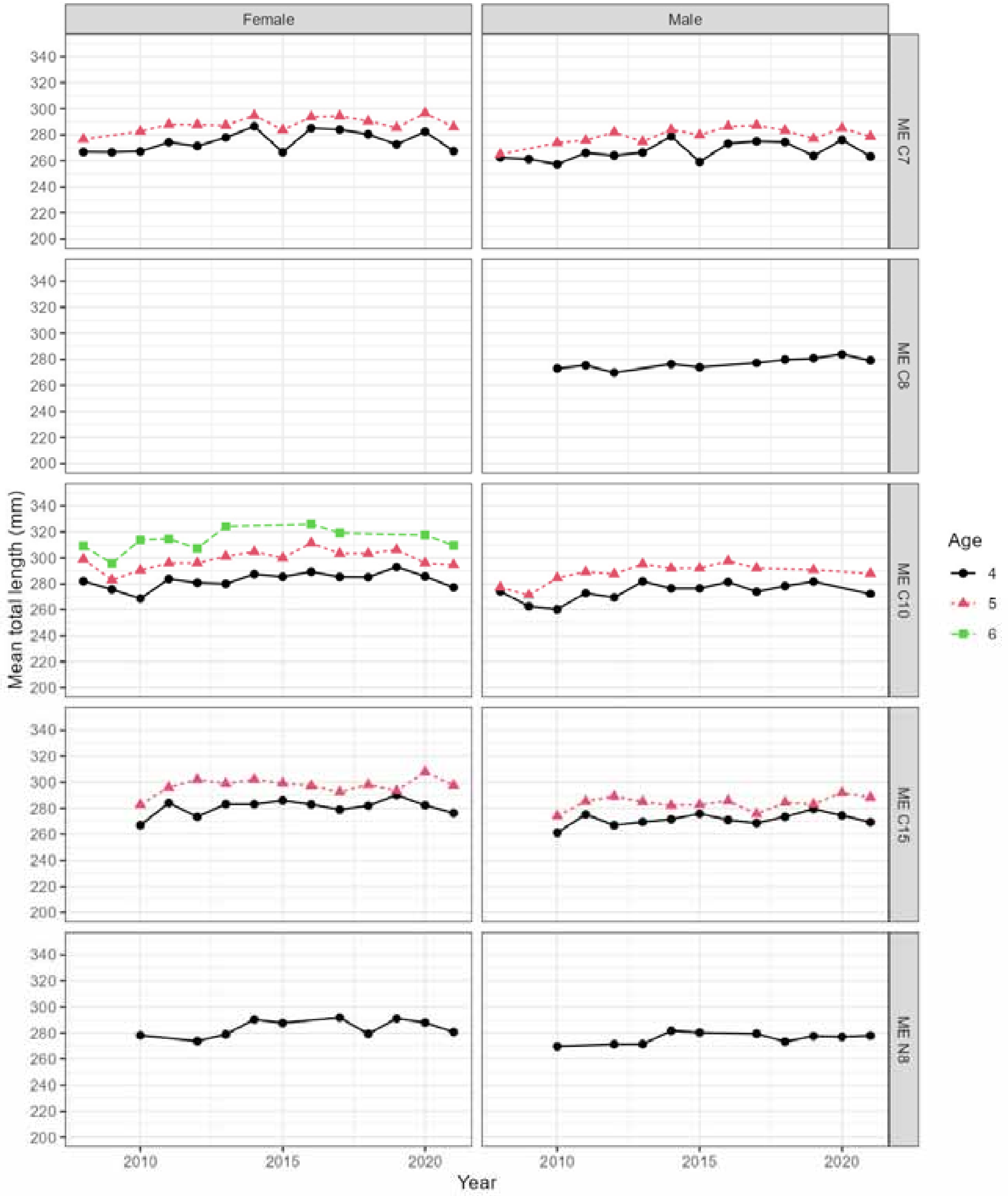


Figure 111. Mean length-at-age over time for male and female alewife from five Maine rivers in the NNE stock-region.

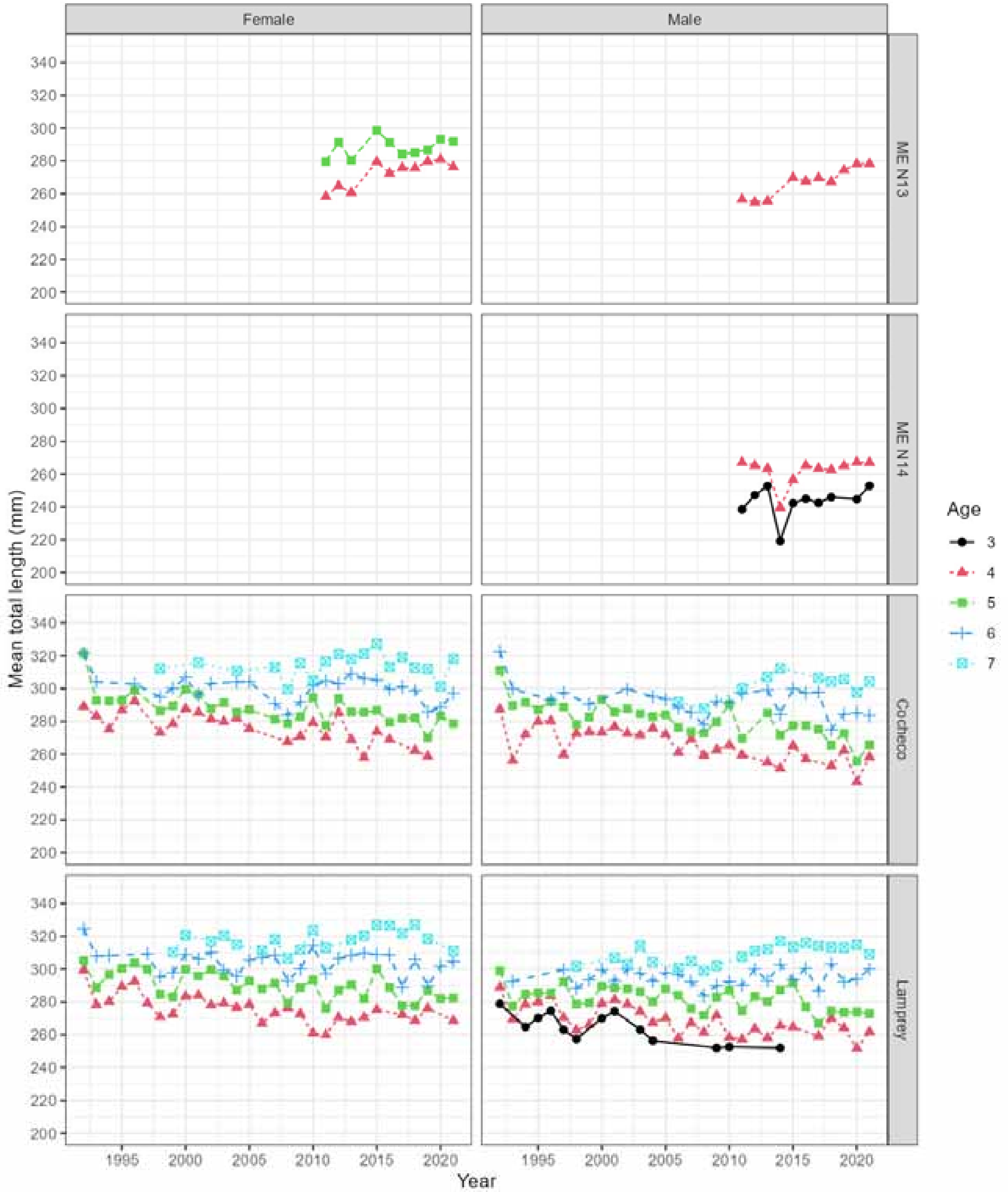


Figure 112. Mean length-at-age for male and female alewife from Maine and New Hampshire rivers in the NNE stock-region.

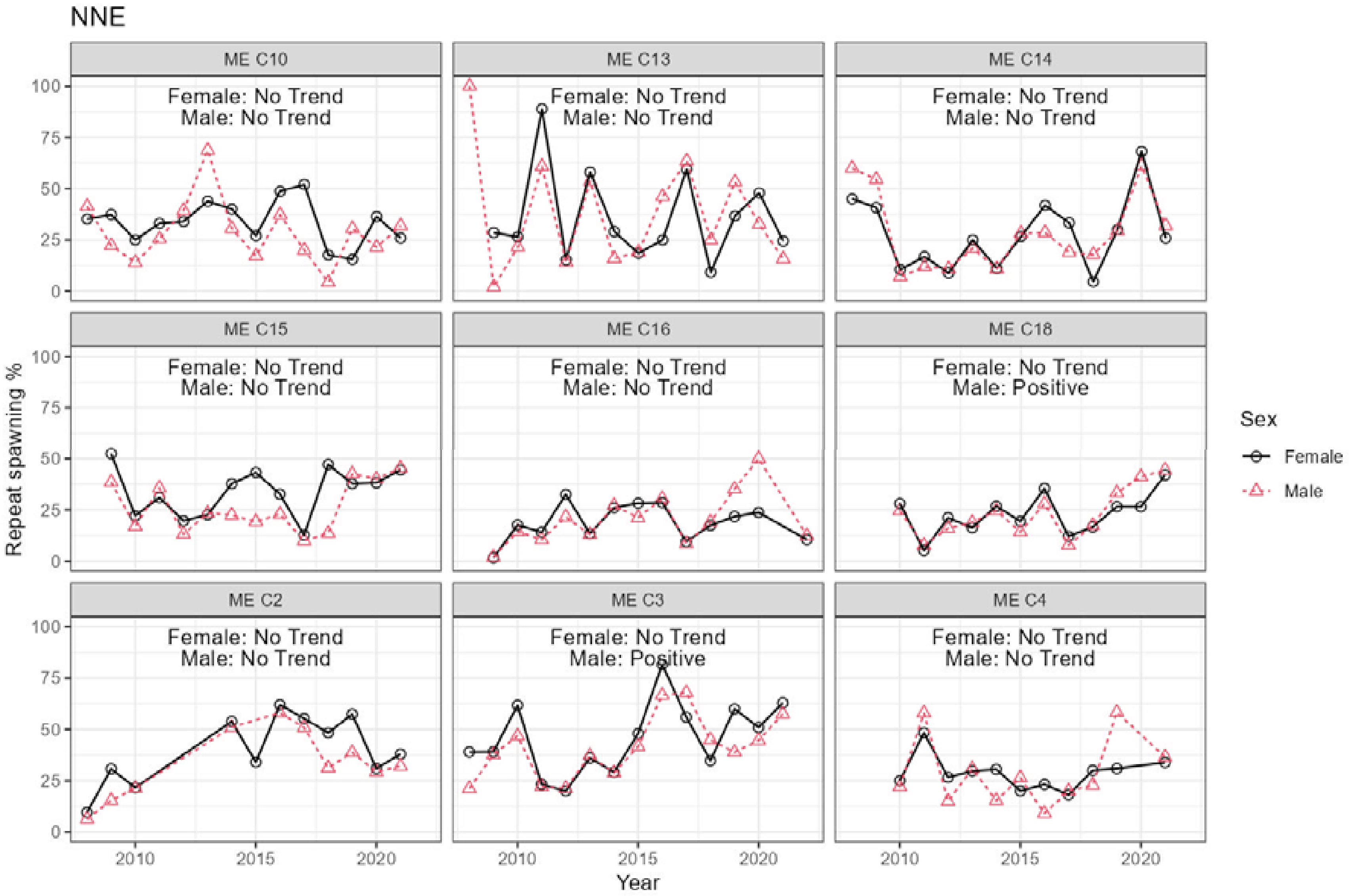


Figure 113. **Trends in percent repeat spawners for alewife by sex for ME rivers in the NNE stock-region.**

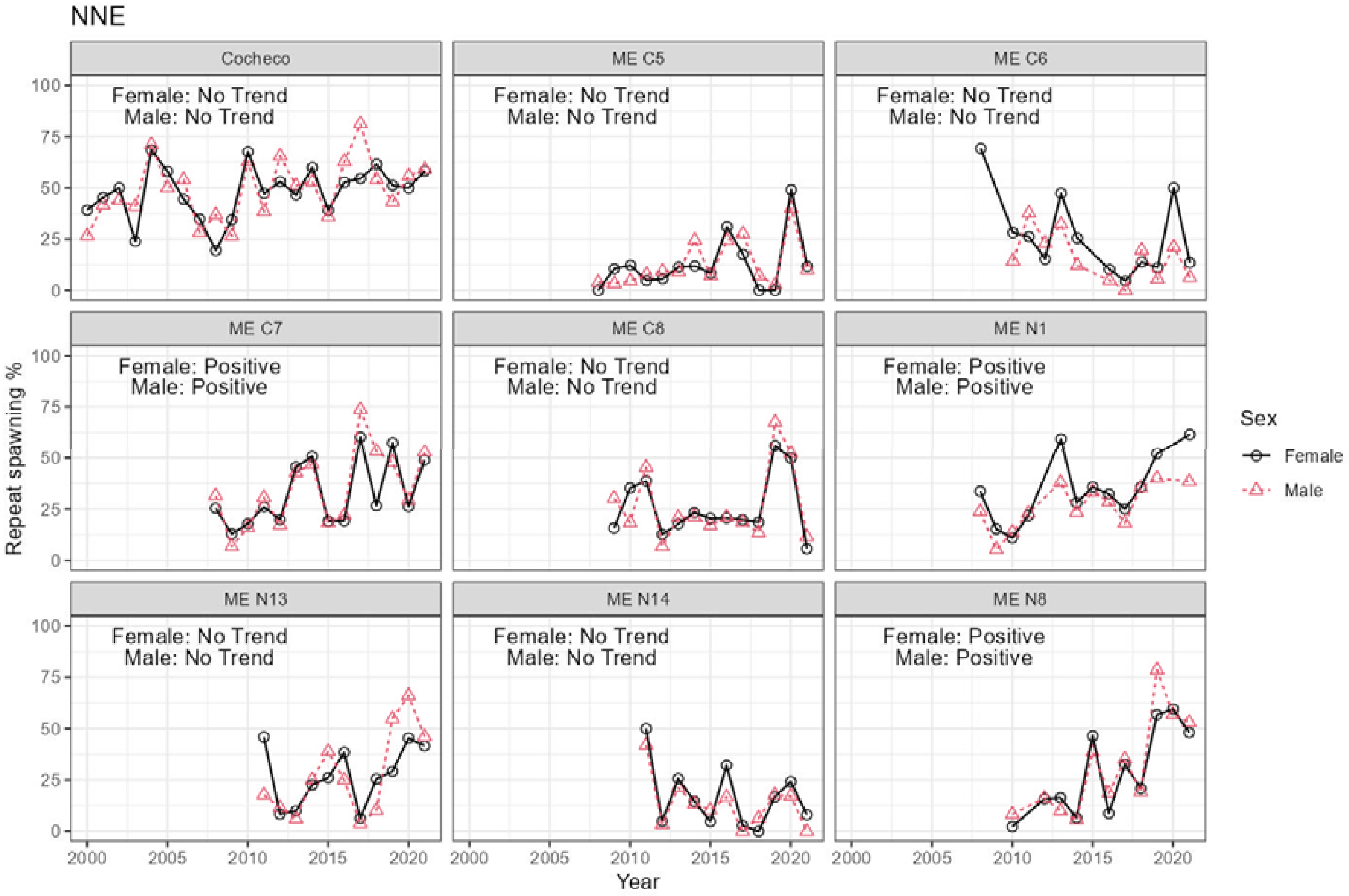


Figure 114. **Trends in percent repeat spawners for alewife by sex for 9 ME rivers in the NNE stock-region.**

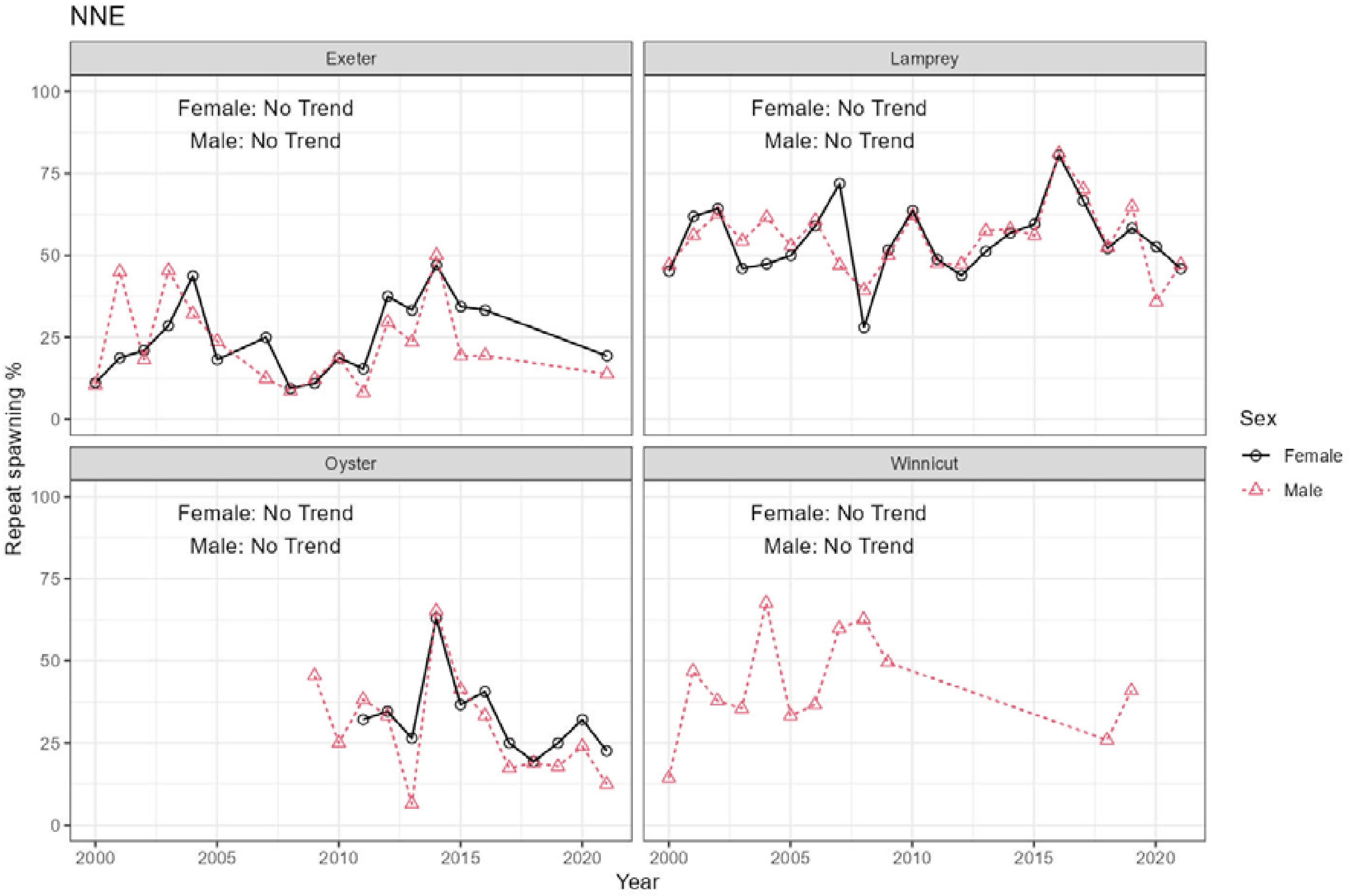


Figure 115. **Trends in percent repeat spawners for alewife by sex for 4 NH rivers in the NNE stock-region.**

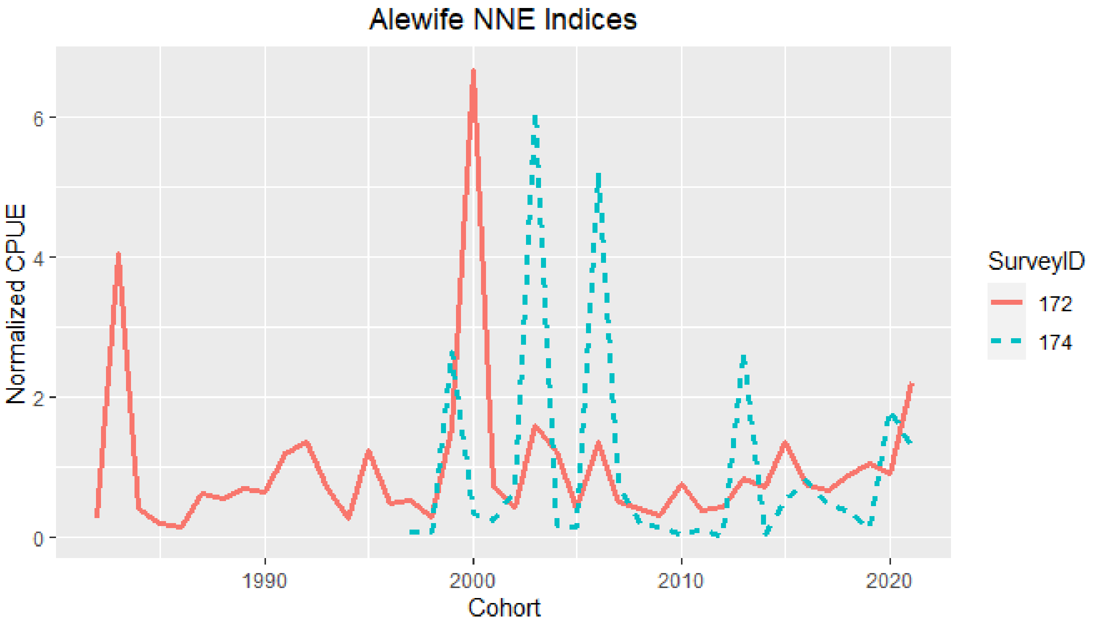
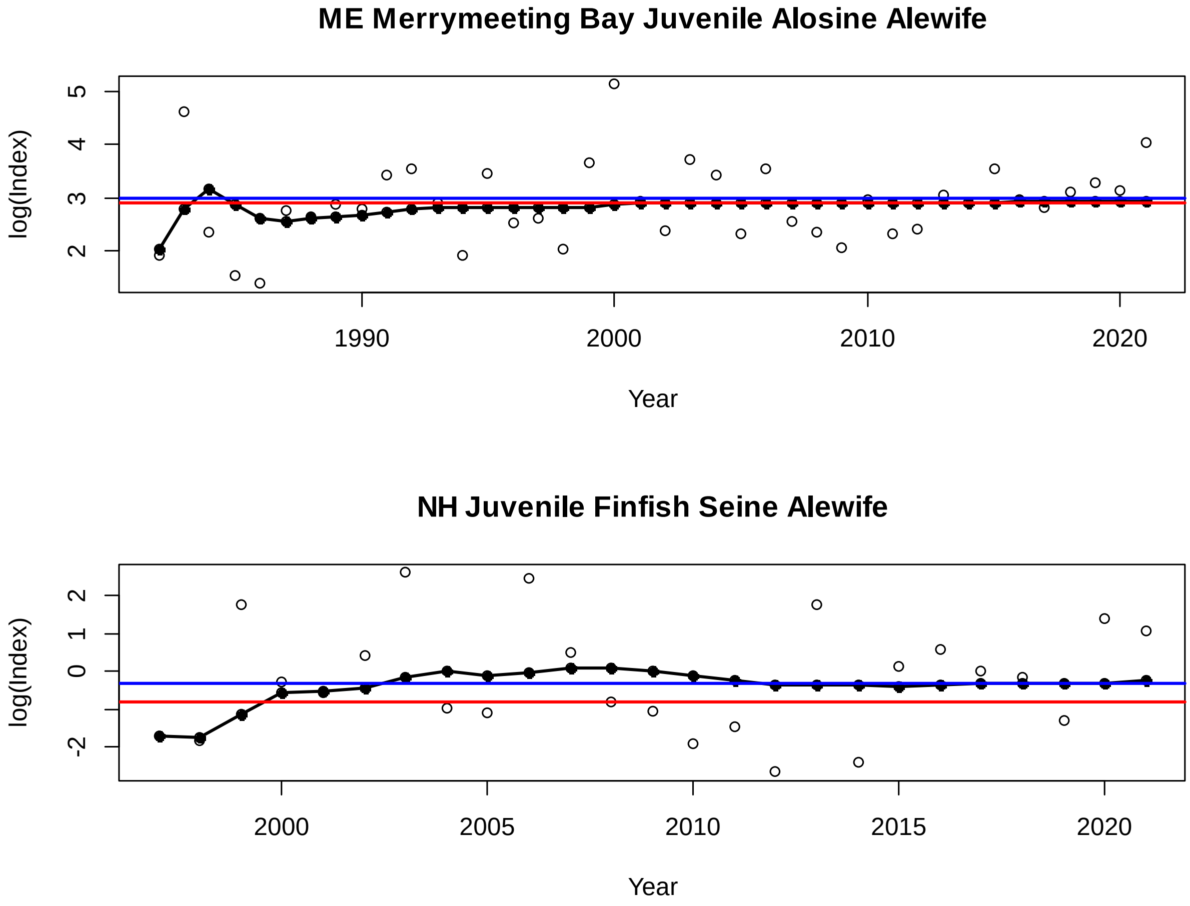


Figure 116. **Normalized fishery-independent indices for the alewife NNE stock-region by cohort year.**


ME Merrymeeting Bay Juvenile Alosine Alewife

NH Juvenile Finfish Seine Alewife

Figure 117. **ARIMA model fits to alewife survey indices from the NNE stock-region. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.**

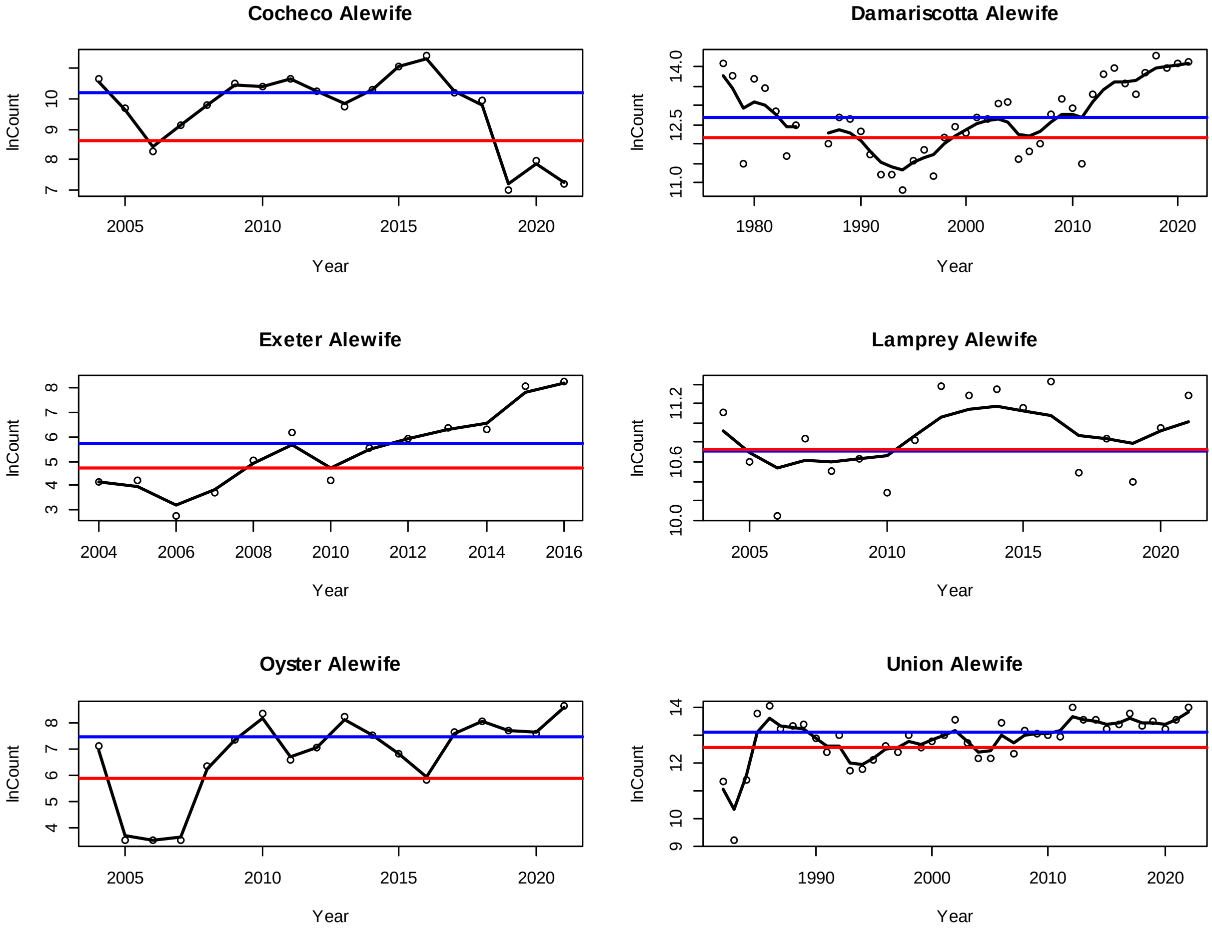


Figure 118. ARIMA model fits to alewife run counts from the NNE stock-region. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

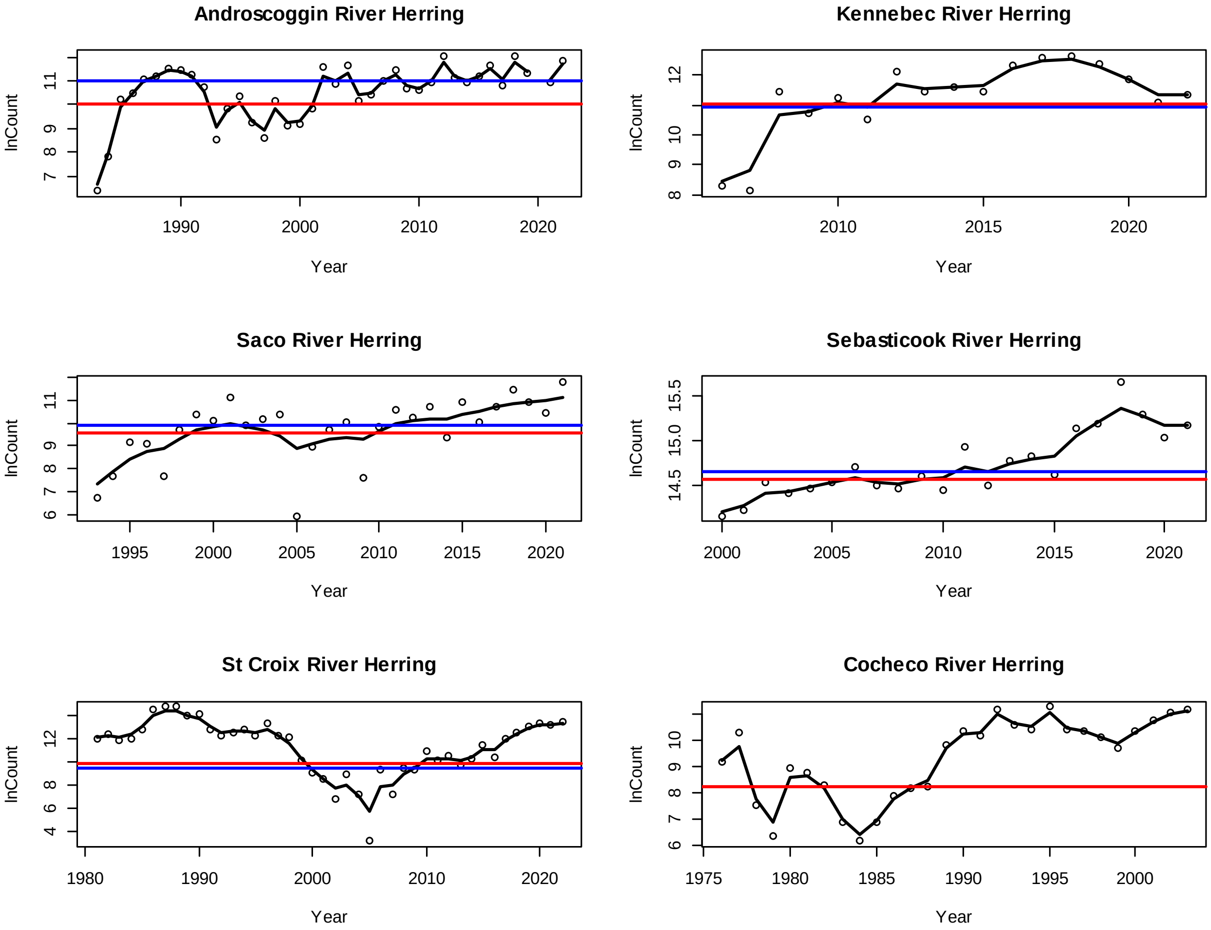


Figure 119. ARIMA model fits to river herring (combined species) run counts from Maine and New Hampshire. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

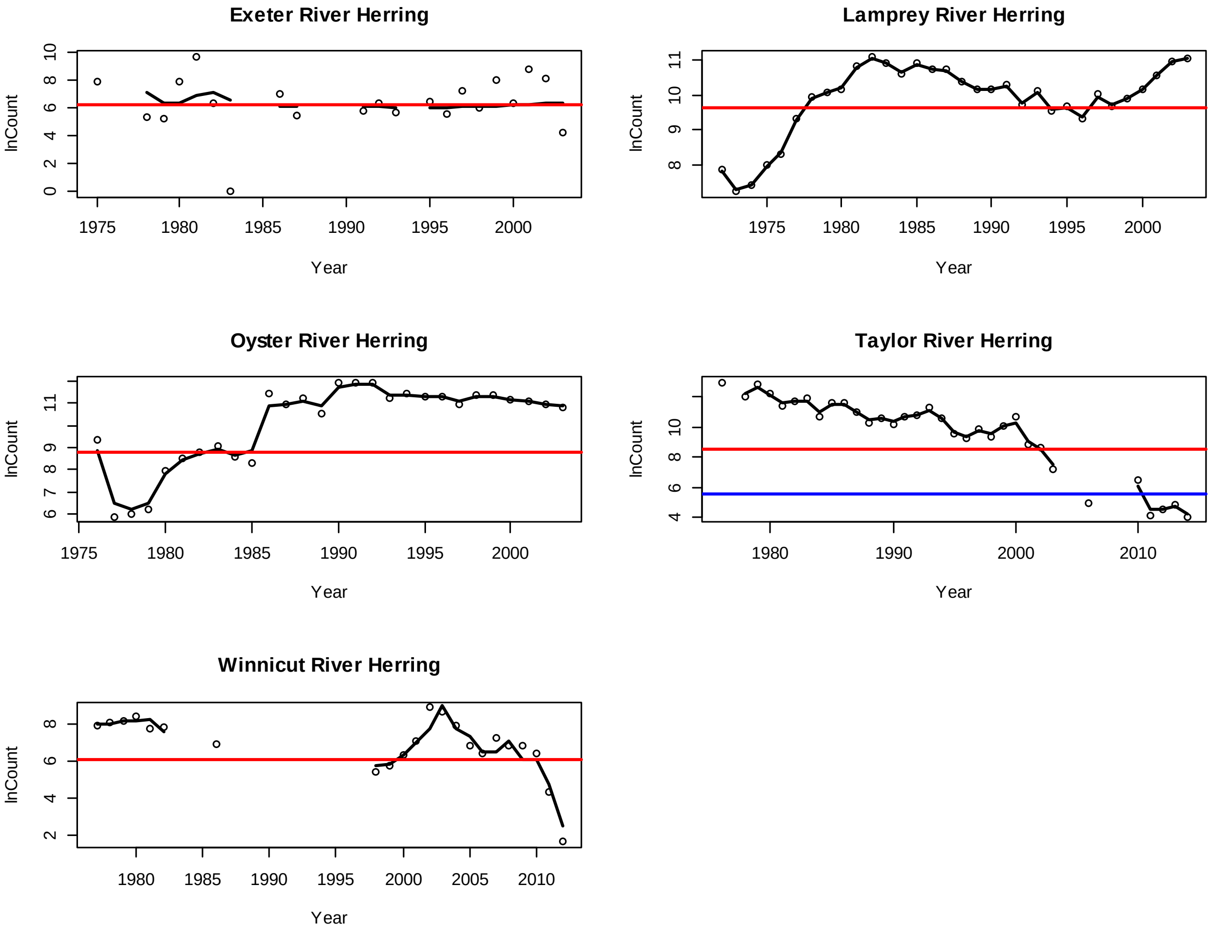


Figure 120. ARIMA model fits to river herring (combined species) run counts from New Hampshire. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

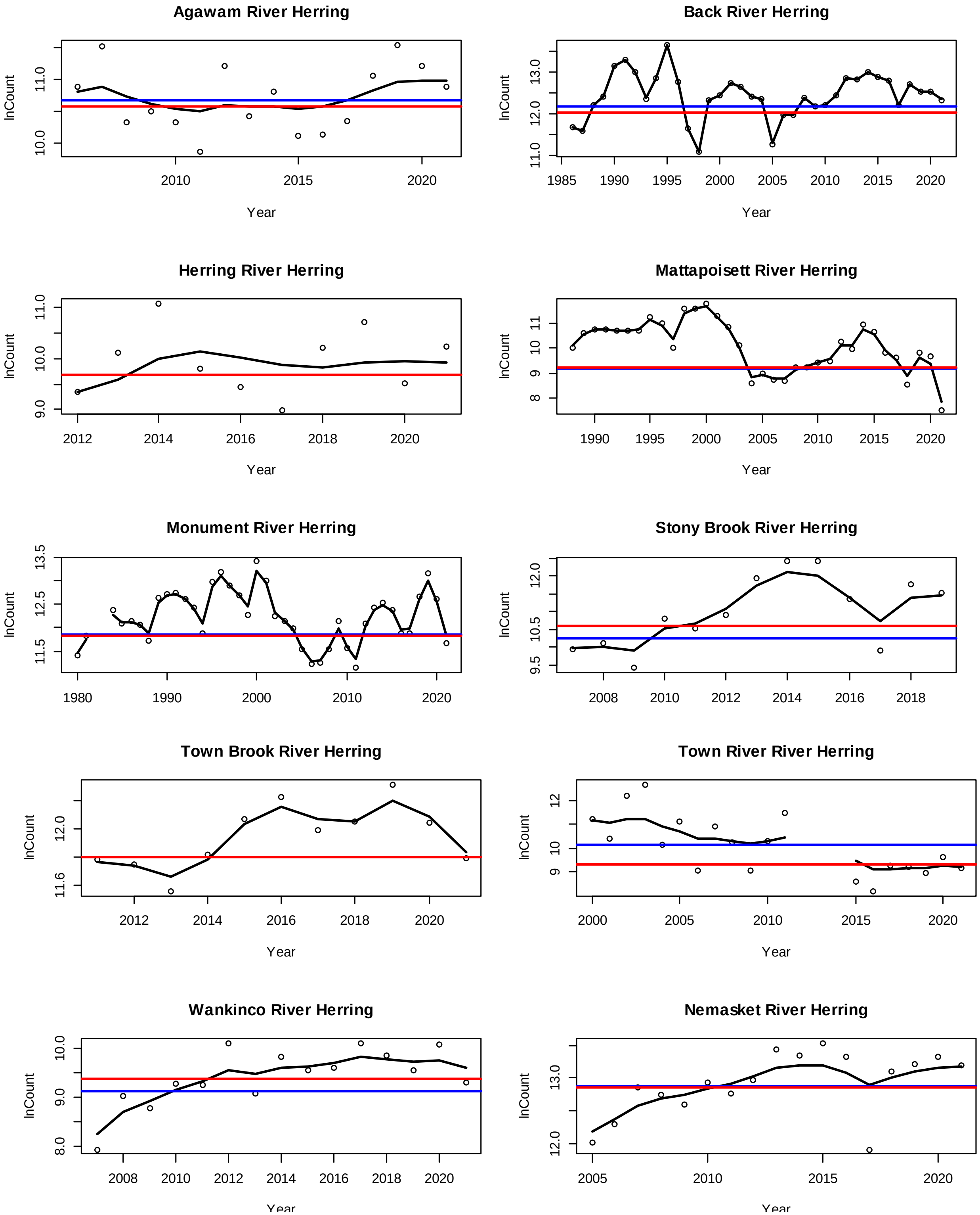


Figure 121. ARIMA model fits to river herring (combined species) run counts from Massachusetts. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

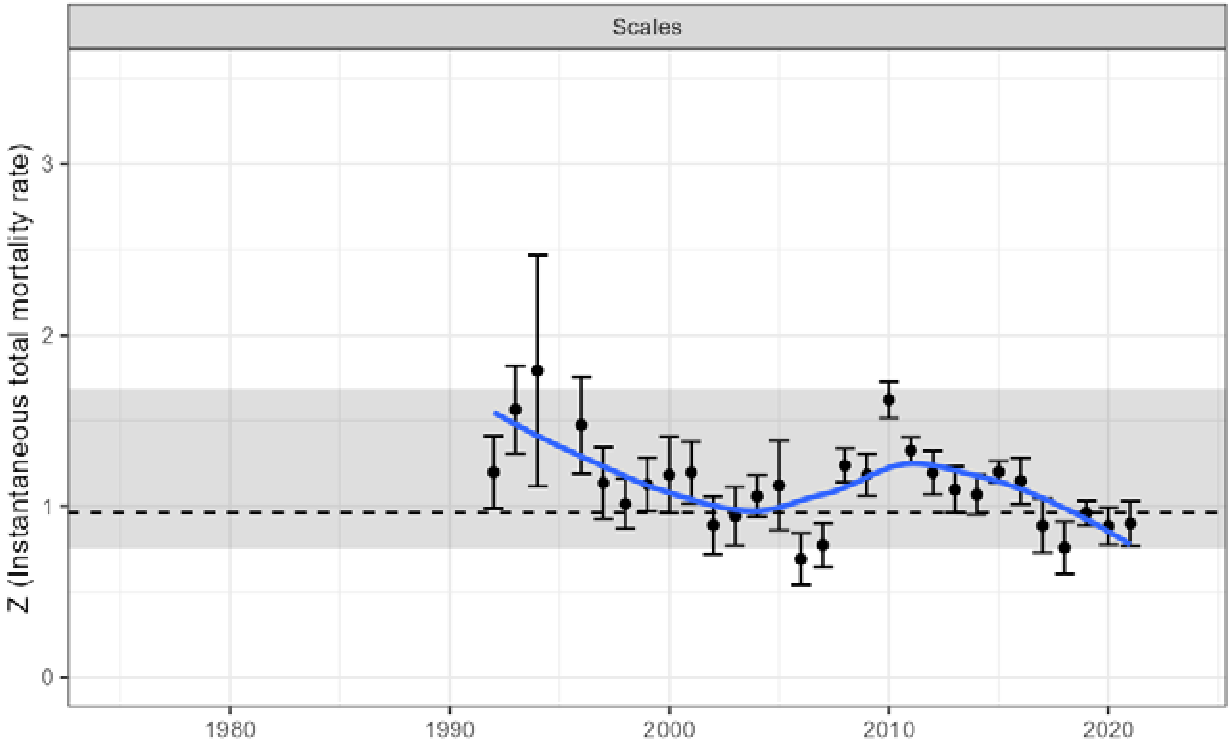


Figure 122. **Estimates of total instantaneous mortality (Z) from scales for alewife from the NNE stock-region plotted with the $Z_{40\%SPR}$ reference points. Blues lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the NNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.**

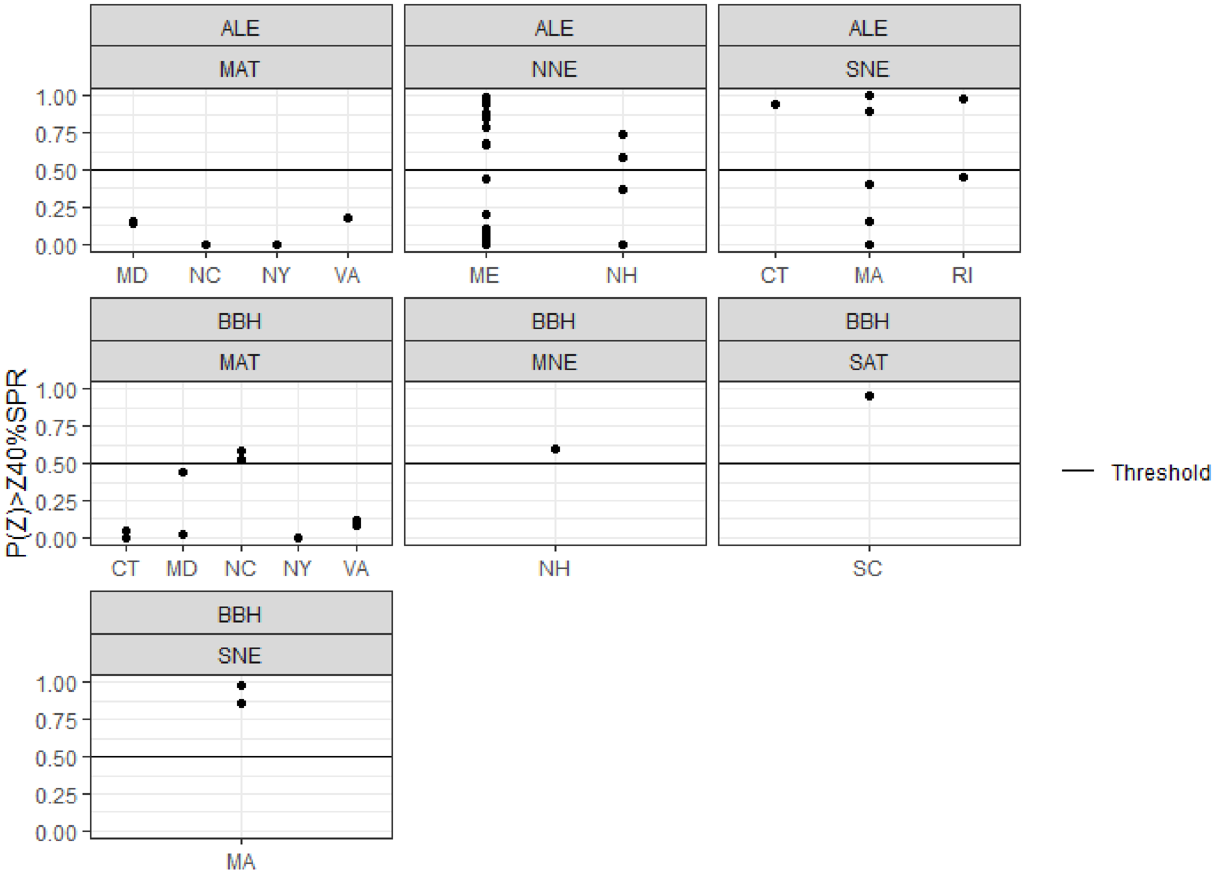


Figure 123. River-specific probabilities of terminal year Z estimates (solid dots) being above $Z_{40\%SPR}$ by species and stock region since the previous assessment. The solid line is the 50% credible threshold.

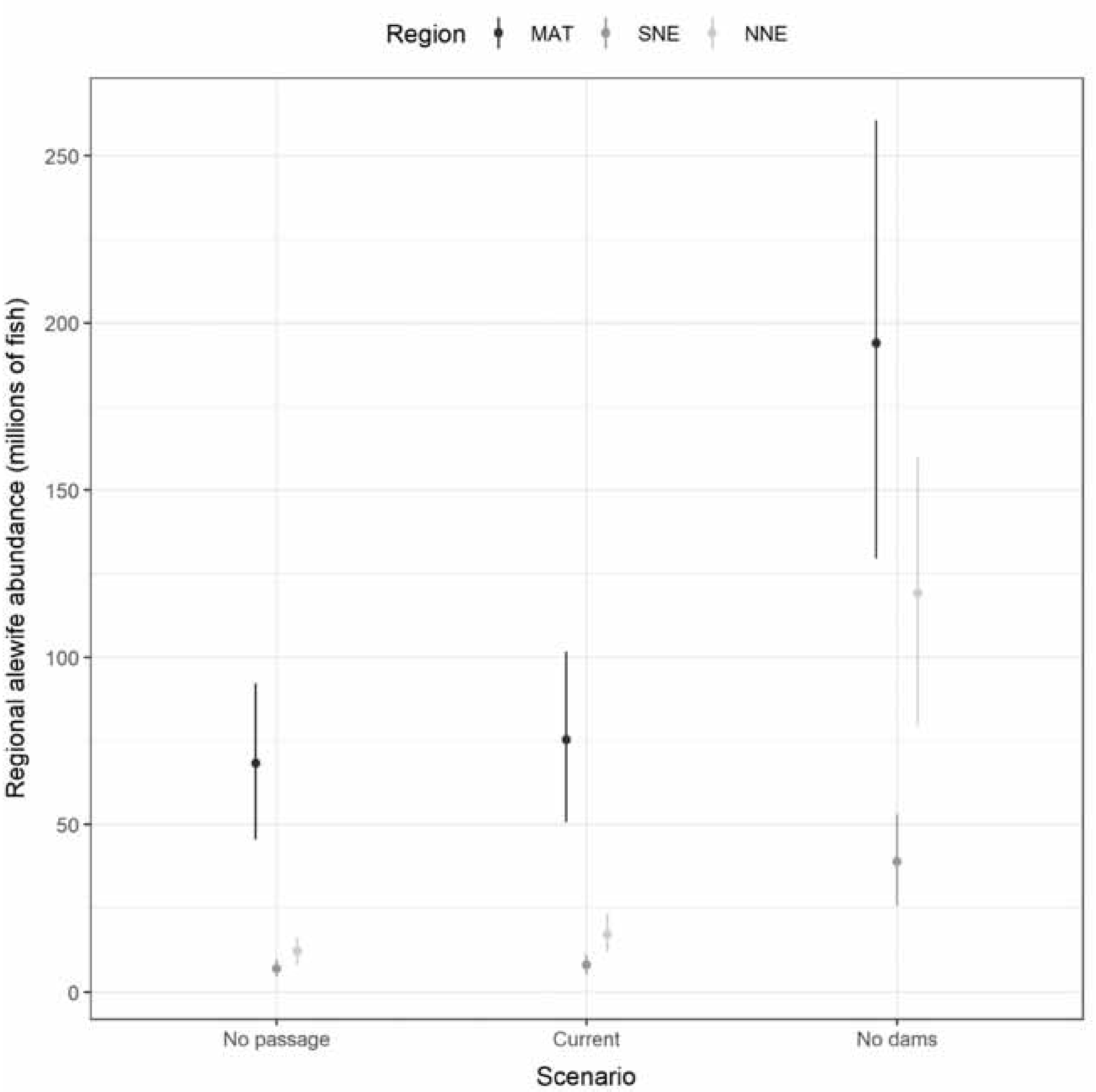


Figure 124. **Predicted regional abundance of spawning alewife in watersheds on the east coast of the United States under "no passage", "current conditions", and "no dams" scenarios. Points are mean of simulated abundance, and vertical lines are 95% confidence intervals.**

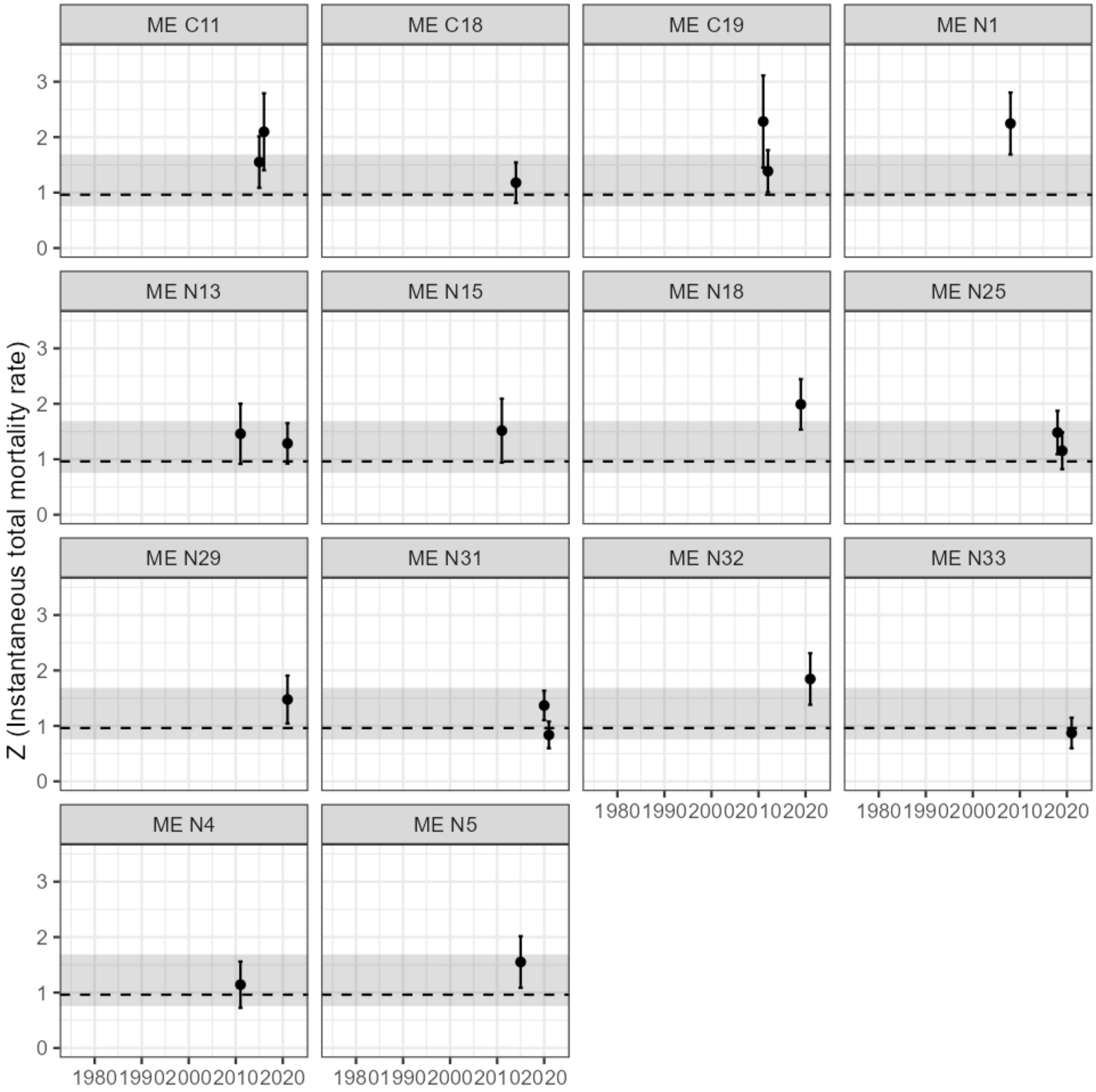


Figure 125. **Age-based estimates of total instantaneous mortality for alewife (from scale data) in Maine by river and year, for rivers that each had only one or two total estimates. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the NNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.**

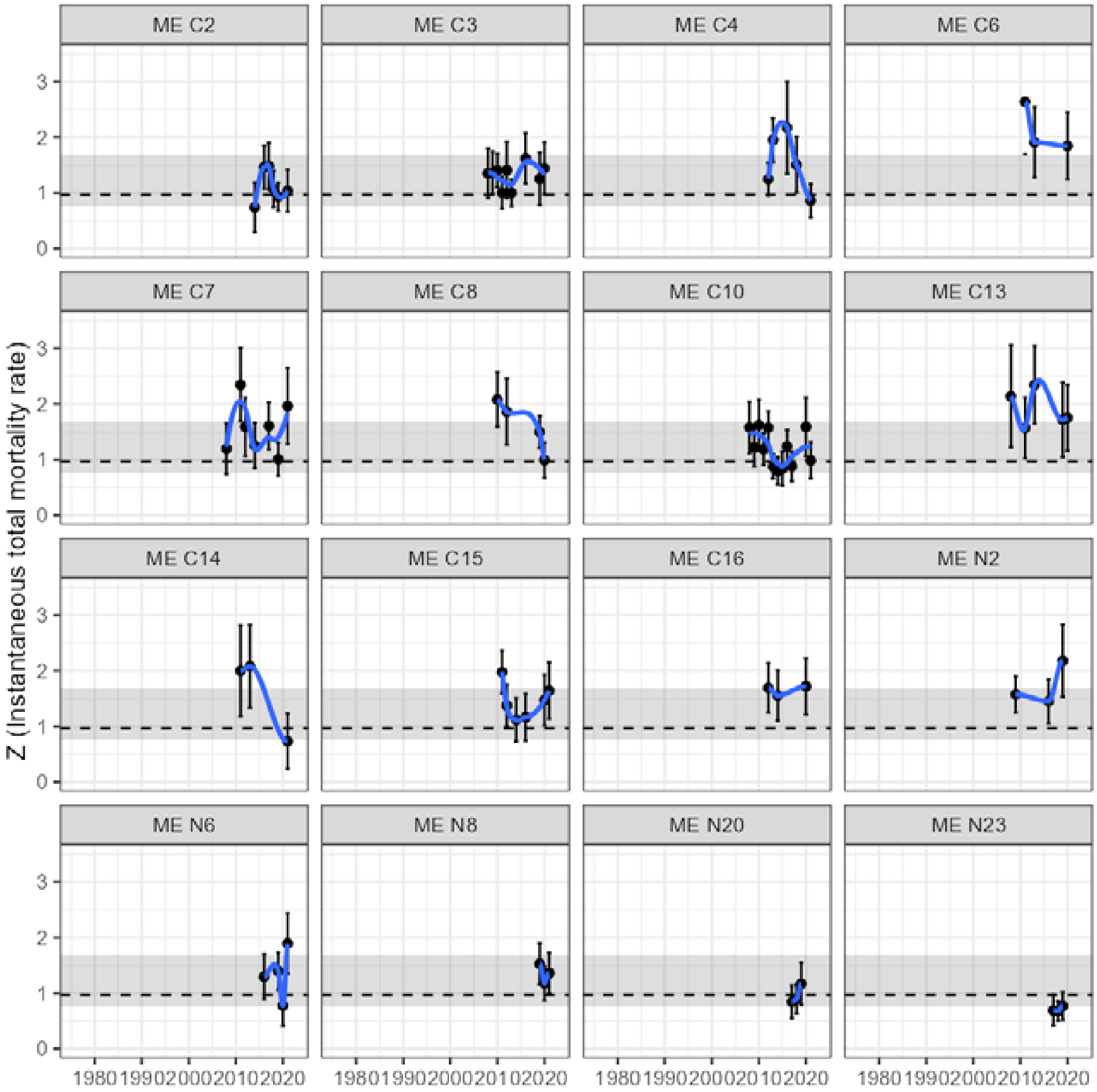


Figure 126. **Age-based estimates of total instantaneous mortality for alewife (from scale data) in Maine by river and year, for rivers that each had more than two total estimates. Blues lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the NNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.**

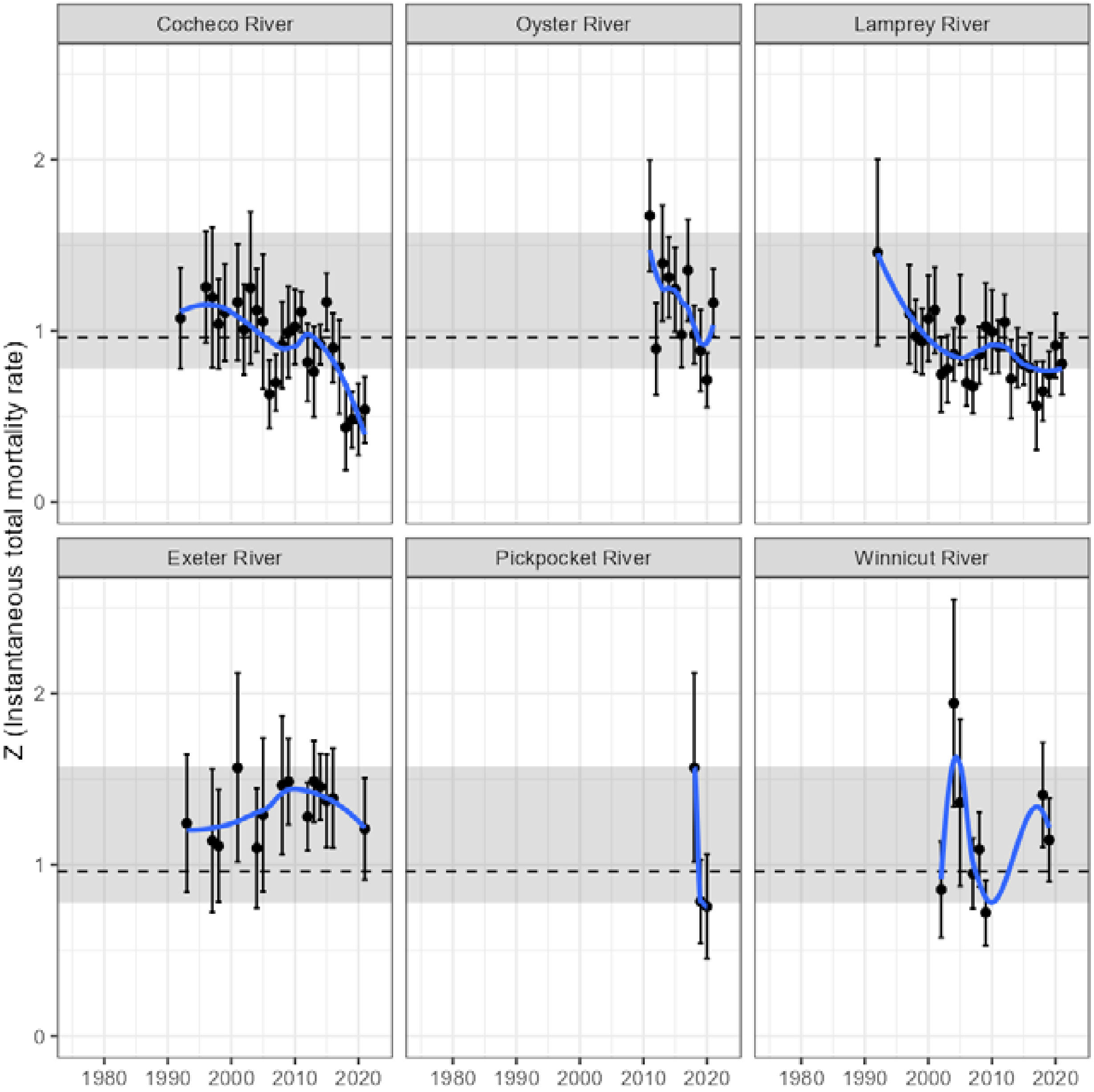


Figure 127. Age-based estimates of total instantaneous mortality for alewife (from scale data) in New Hampshire by river and year. Blues lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the NNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

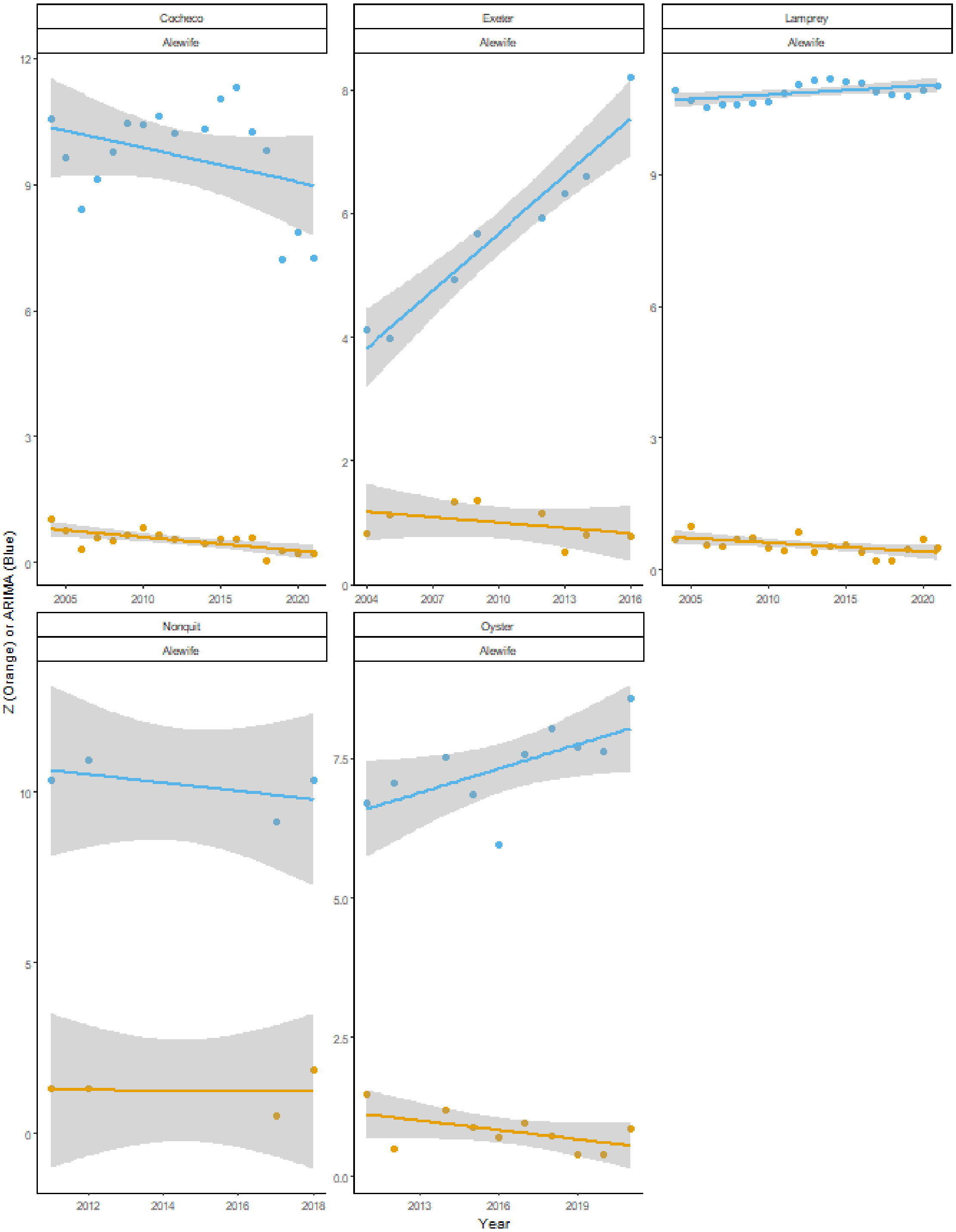


Figure 128. Comparison of Z (orange lines/points) and ARIMA indices of alewife run counts (blue lines/points) for the NNE stock-region for systems where both metrics are available.

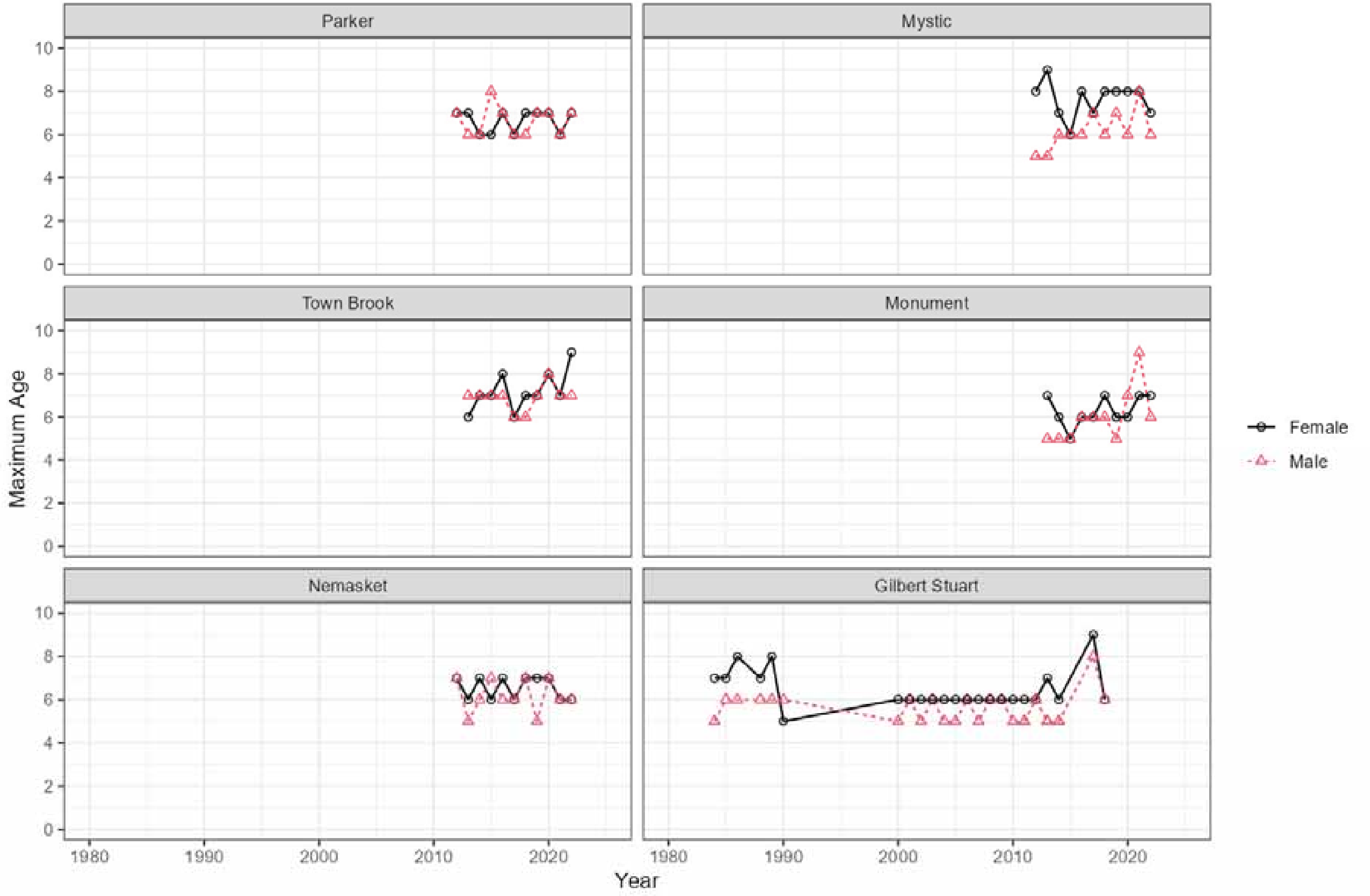


Figure 129. Maximum scale-based ages for female and male alewife by river in the SNE stock-region.

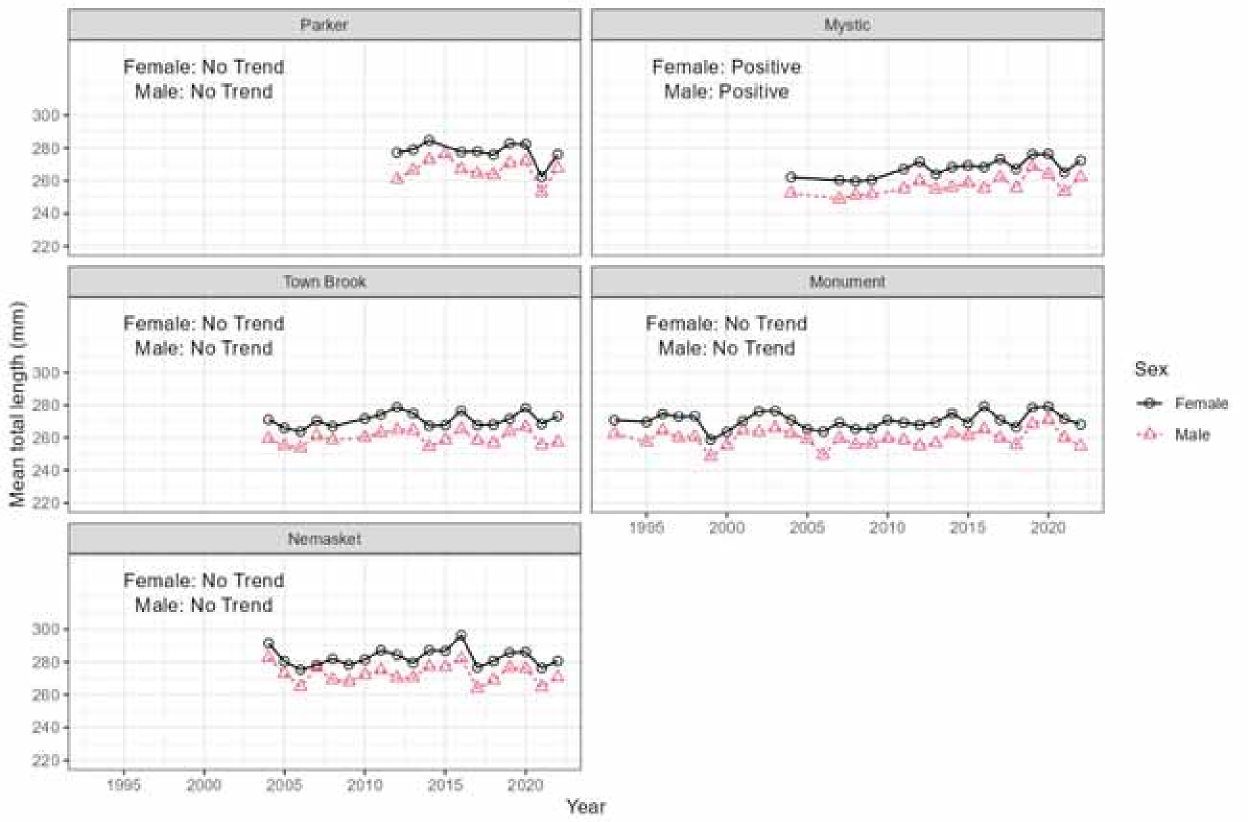


Figure 130. **Mean length by year for female and male alewife in five river systems the SNE stock-region region.**

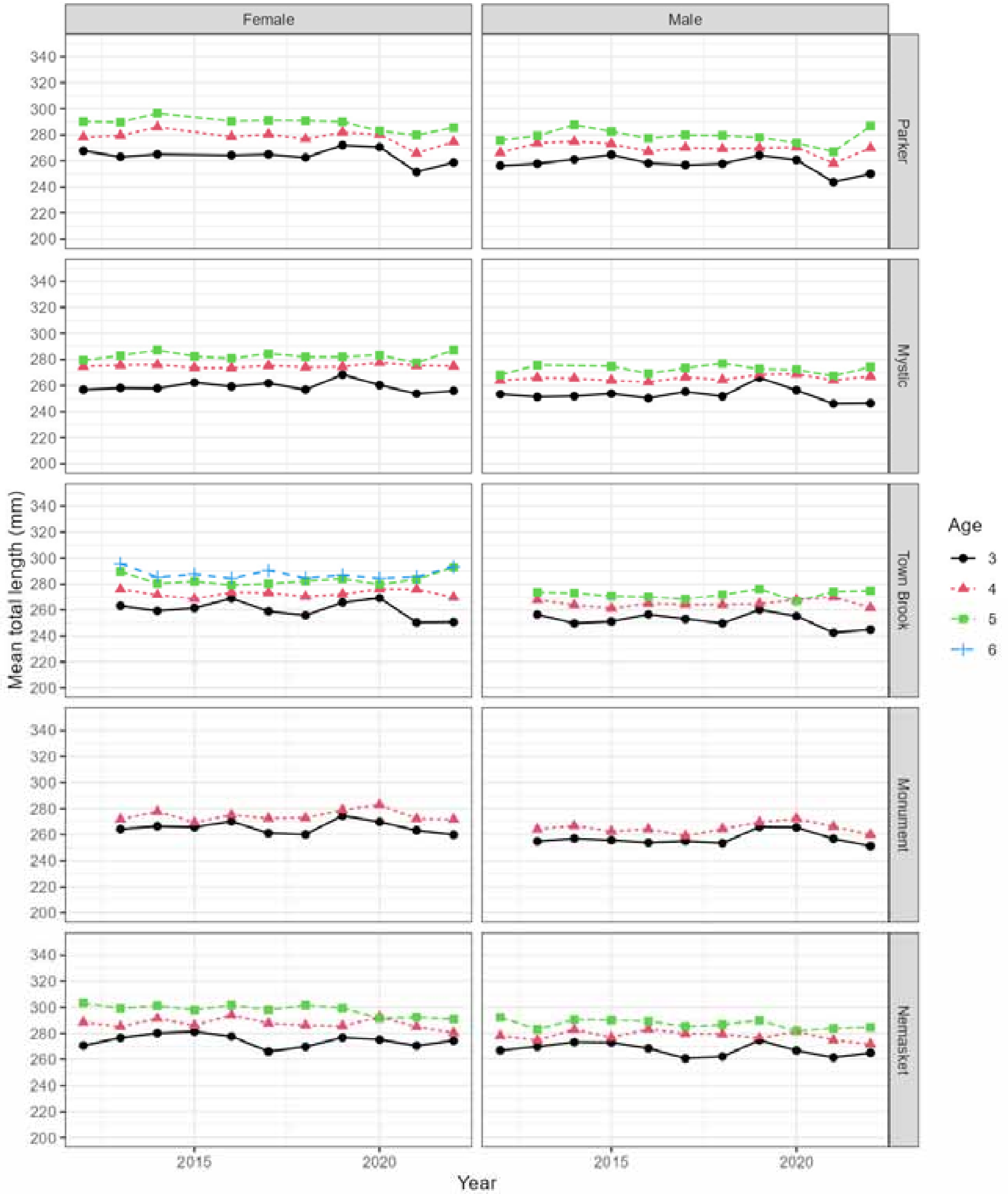


Figure 131. **Mean length-at-age by year for female and male alewife in five river systems the SNE stock-region region.**

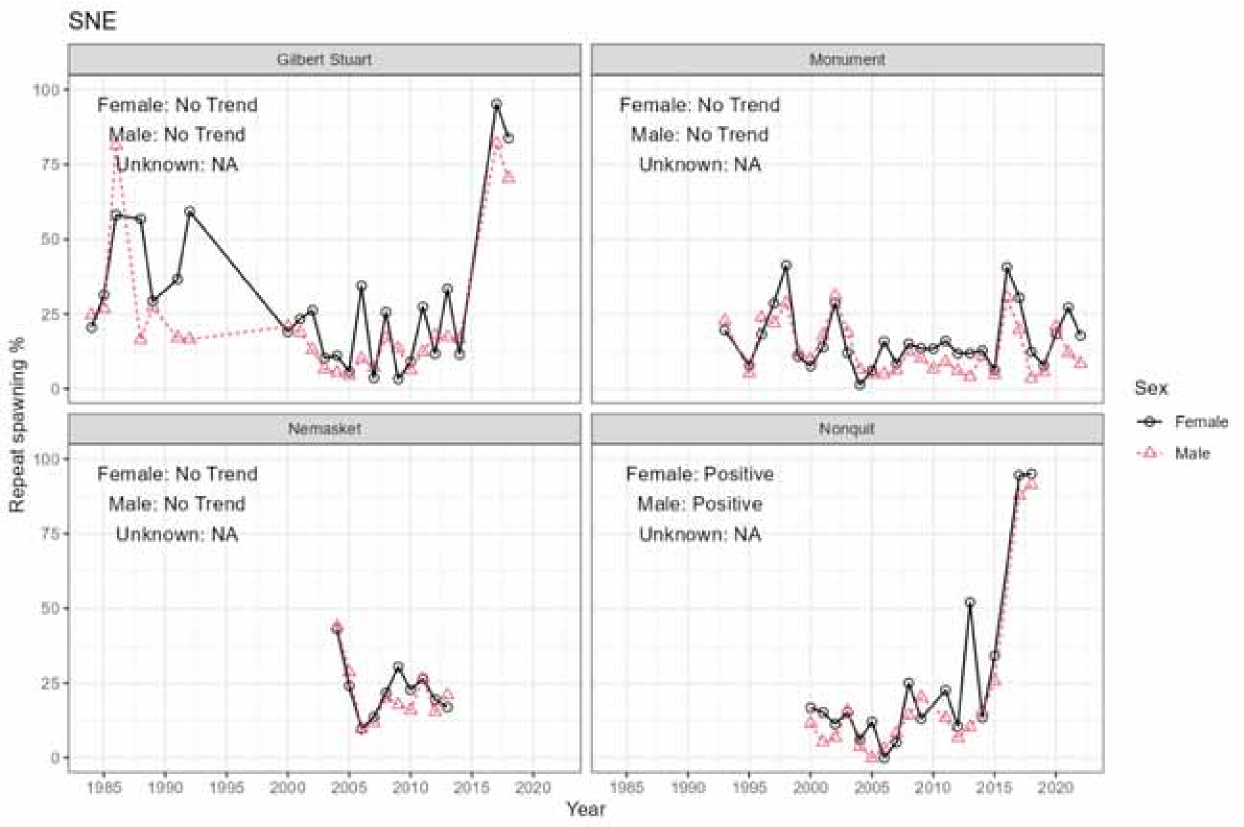


Figure 132. **Trends in repeat spawner percentage for alewife from rivers in the SNE stock-region.**

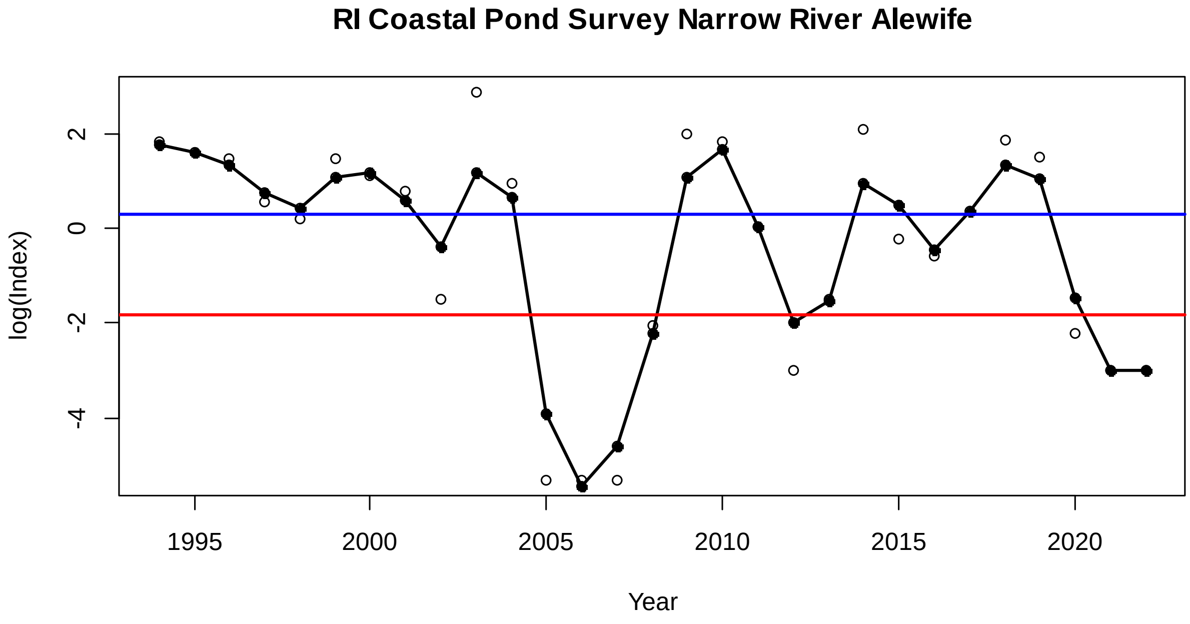


Figure 133. **ARIMA model fits to the Rhode Island Coastal Pond Survey for the Narrow River (the only alewife survey for the SNE stock-region). Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.**

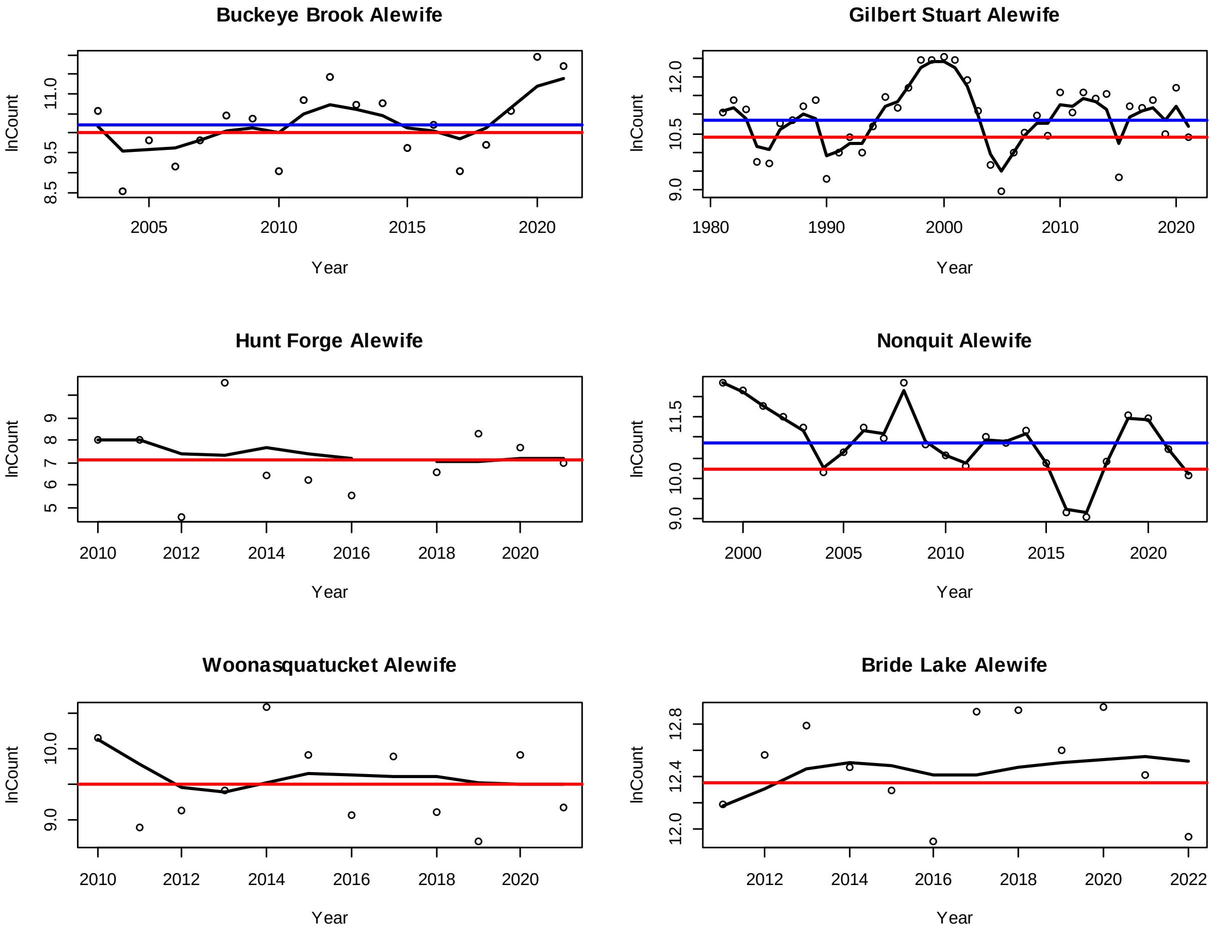


Figure 134. ARIMA model fits to alewife run counts from the SNE stock-region. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

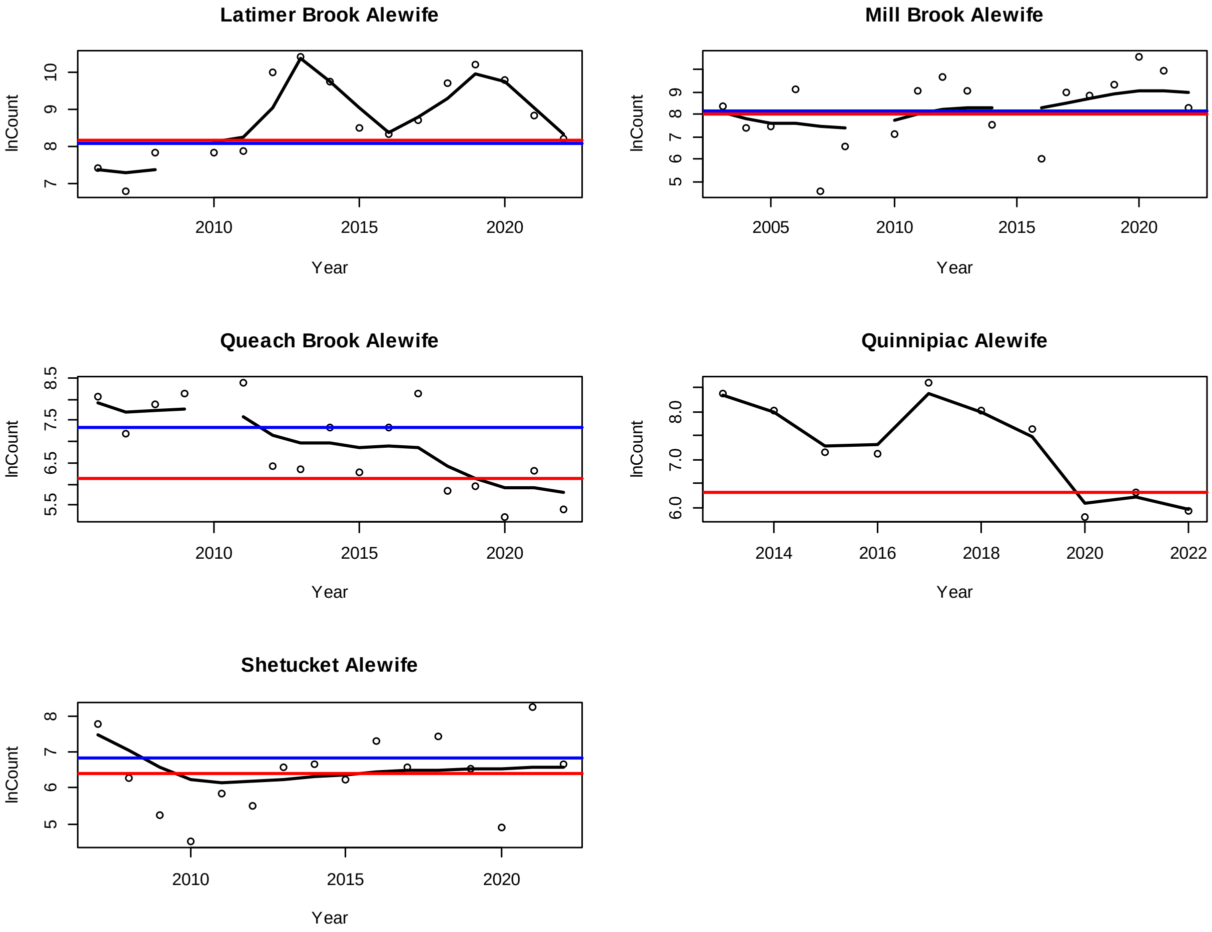


Figure 134 (cont.)

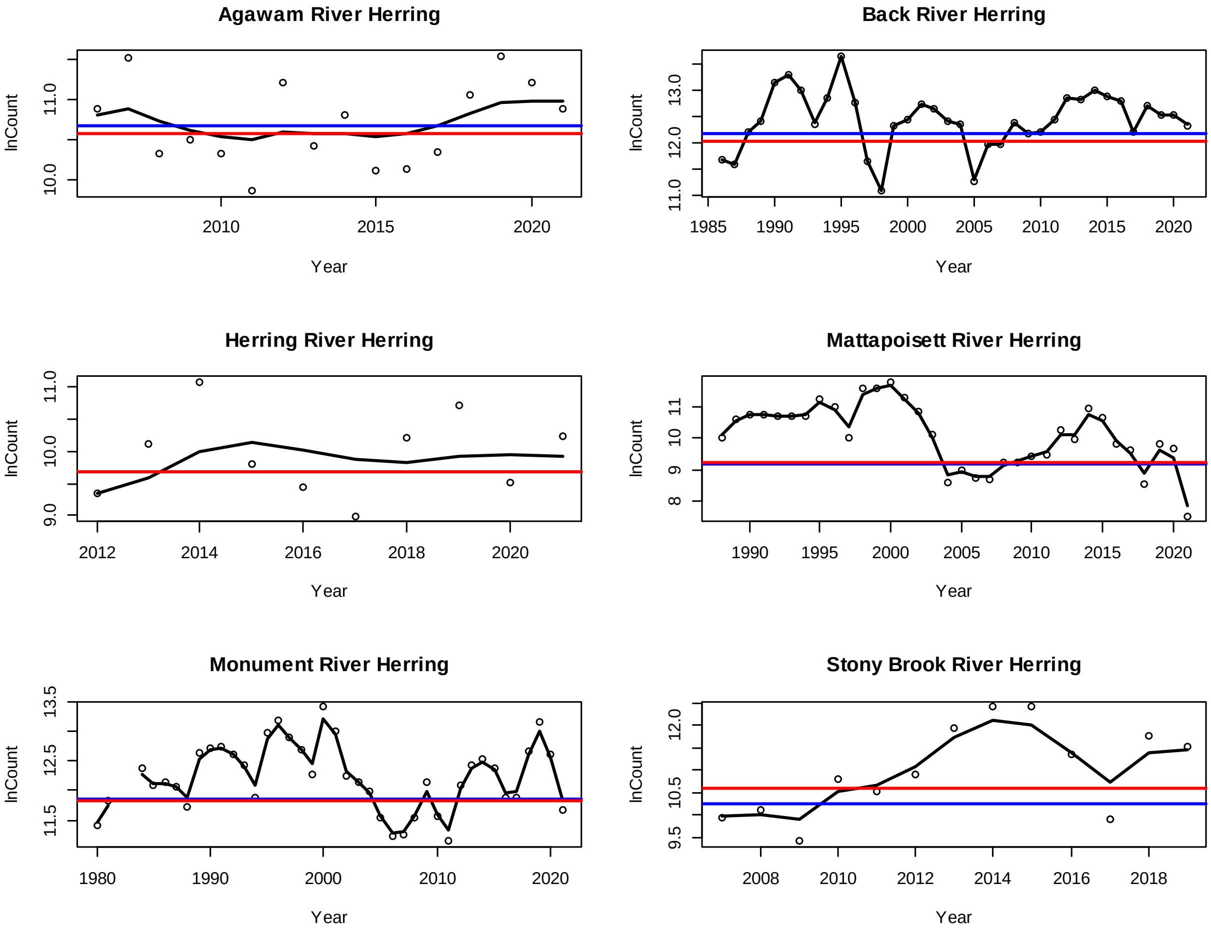


Figure 135. ARIMA model fits to river herring (combined species) run counts from Massachusetts. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

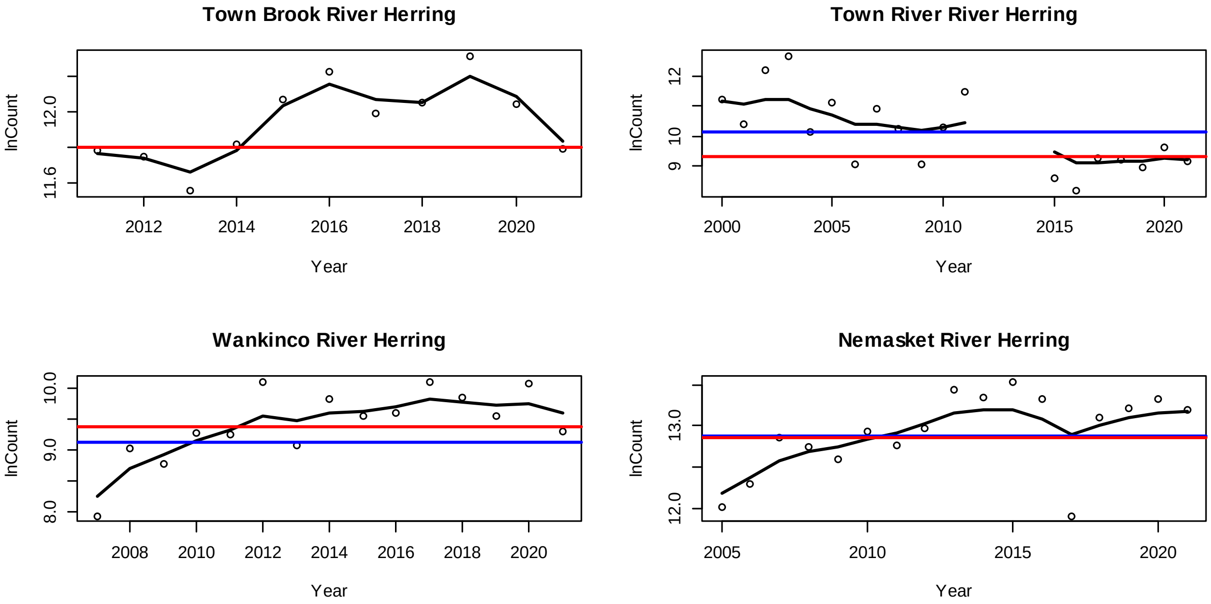


Figure 136. ARIMA model fits to river herring (combined species) run counts from Massachusetts Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

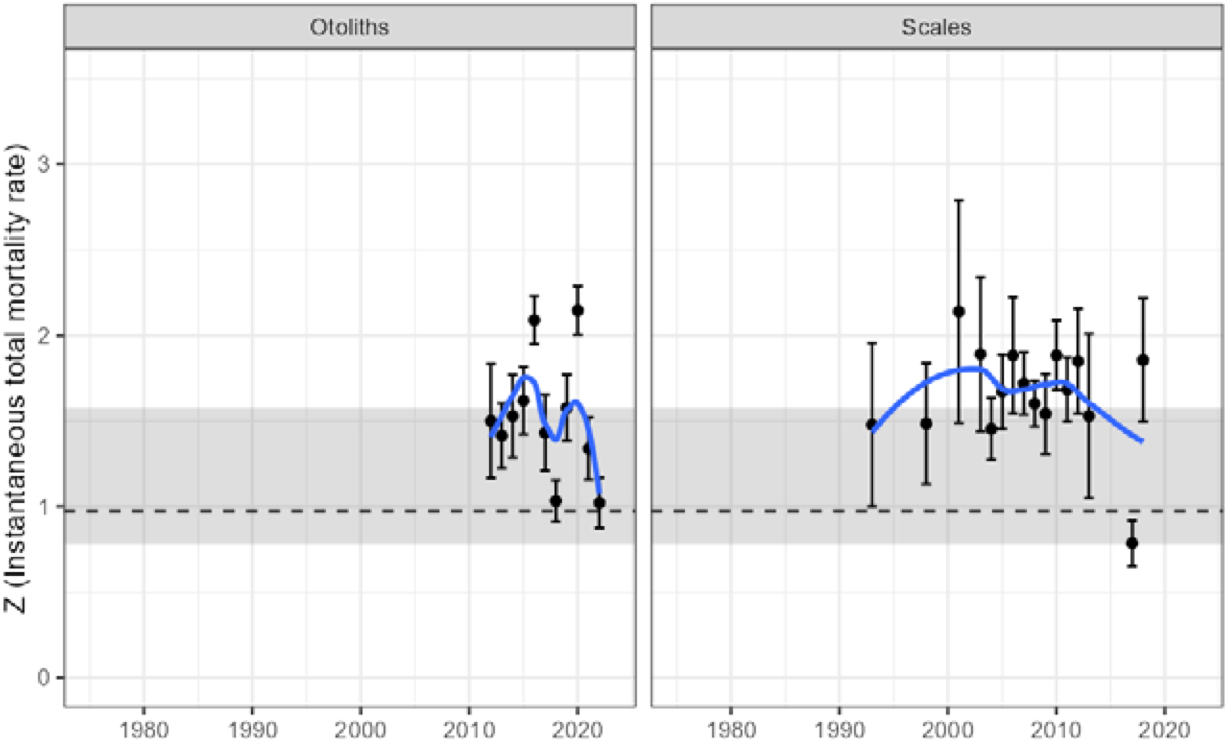


Figure 137. Estimates of total instantaneous mortality (Z) for alewife from the SNE stock-region by ageing structure, plotted with the $Z_{40\%SPR}$ reference point for the SNE stock-region. Blues lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the SNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

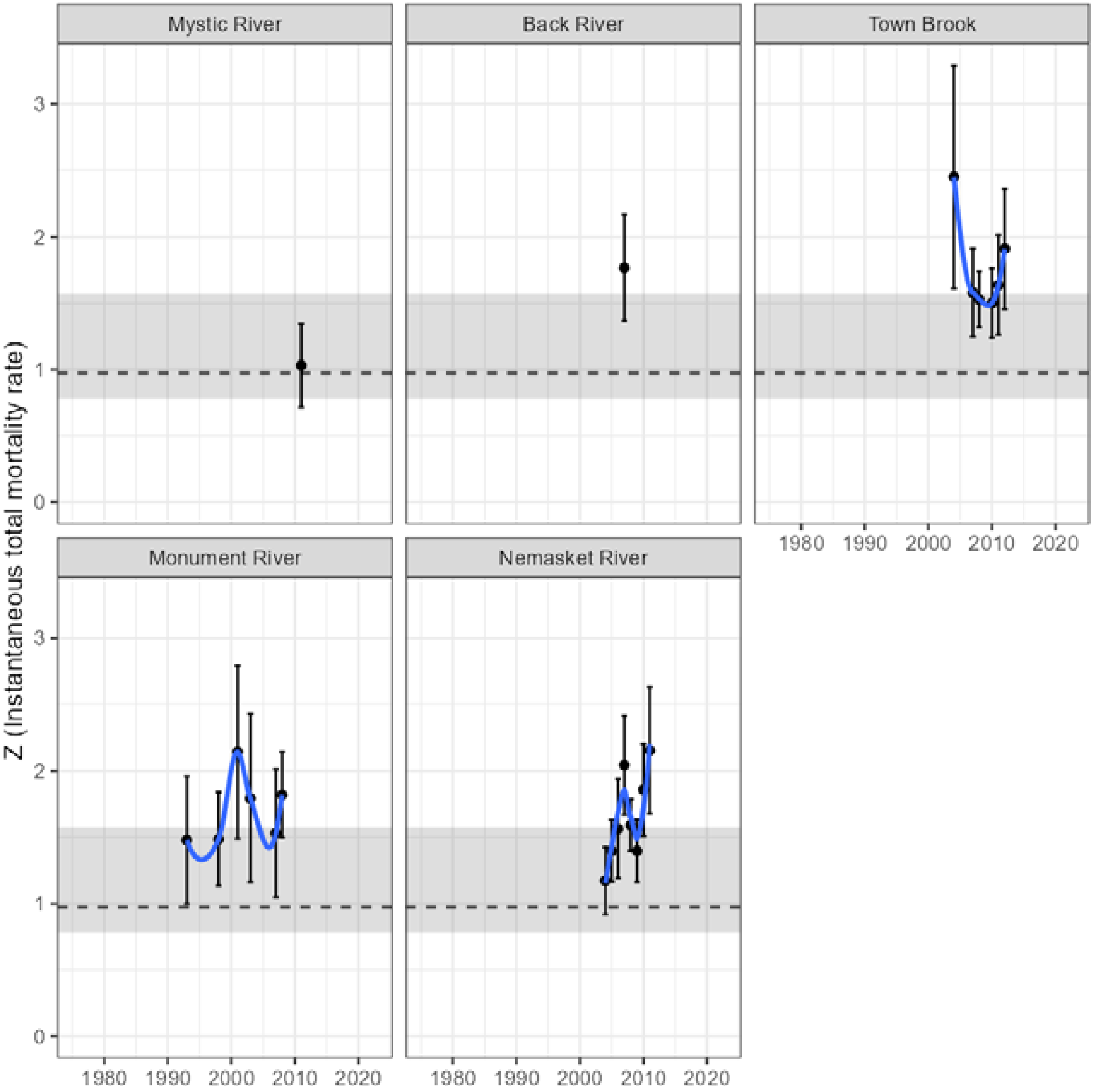


Figure 138. Age-based estimates of total instantaneous mortality for alewife (from scale data) in Massachusetts by river and year. Blues lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the SNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

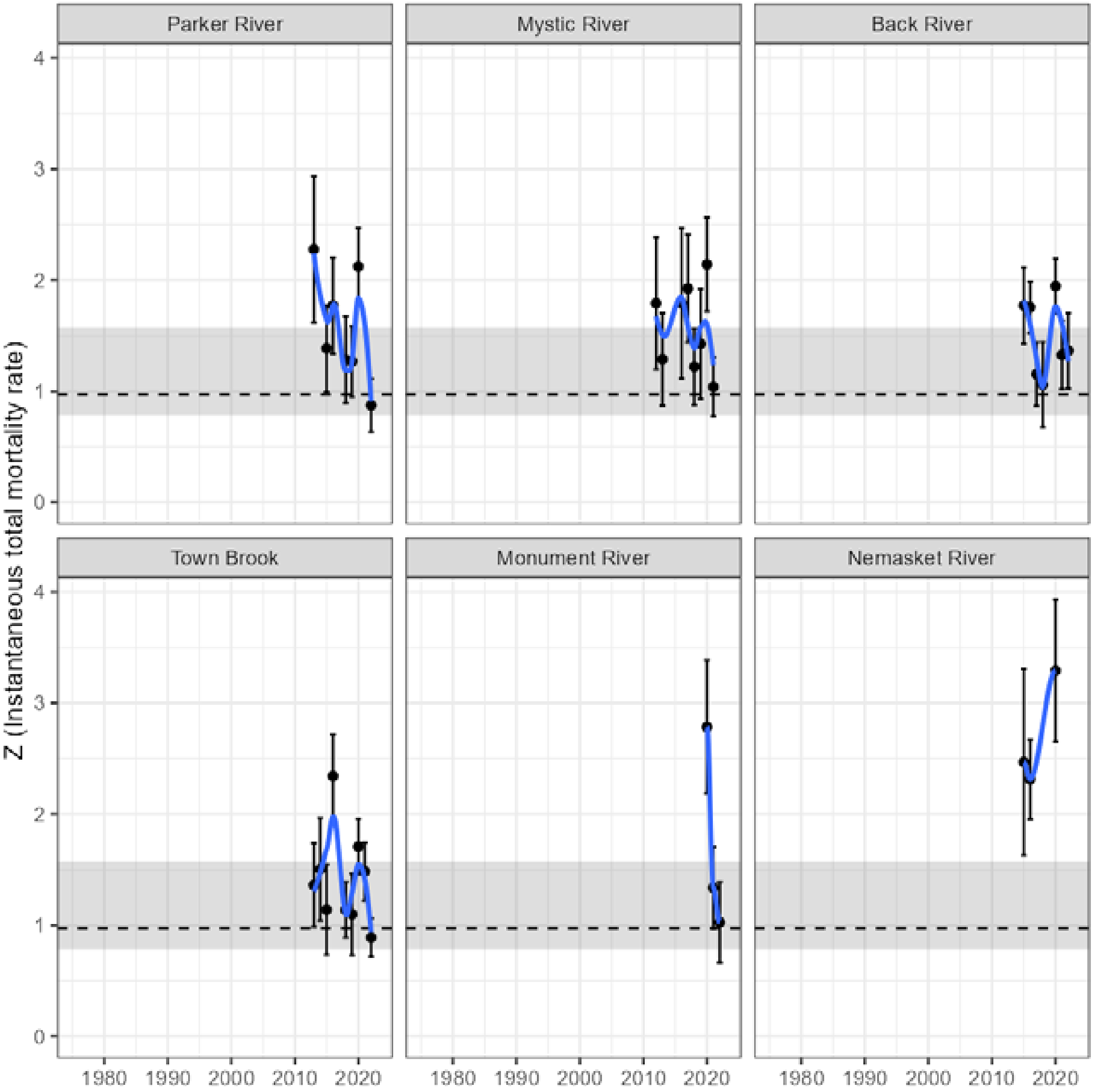


Figure 139. Age-based estimates of total instantaneous mortality for alewife (from otolith data) in Massachusetts by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the SNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

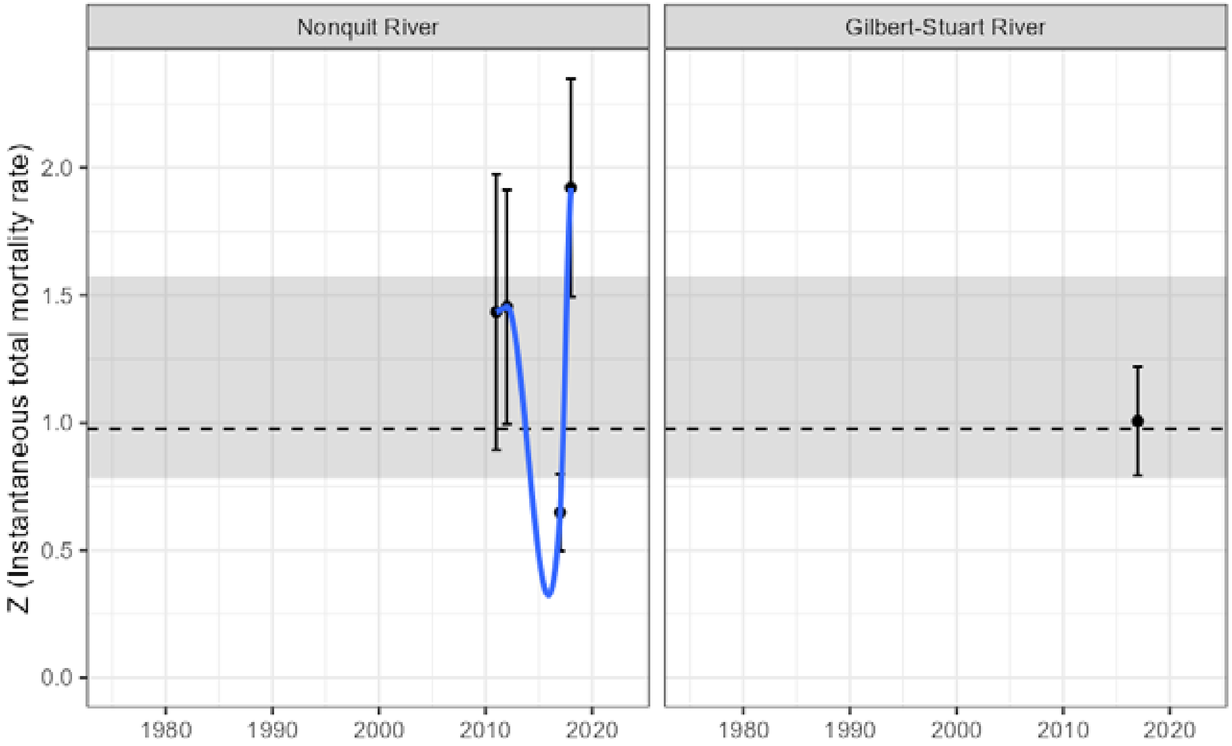


Figure 140. Age-based estimates of total instantaneous mortality for alewife (from scale data) in Rhode Island by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the SNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

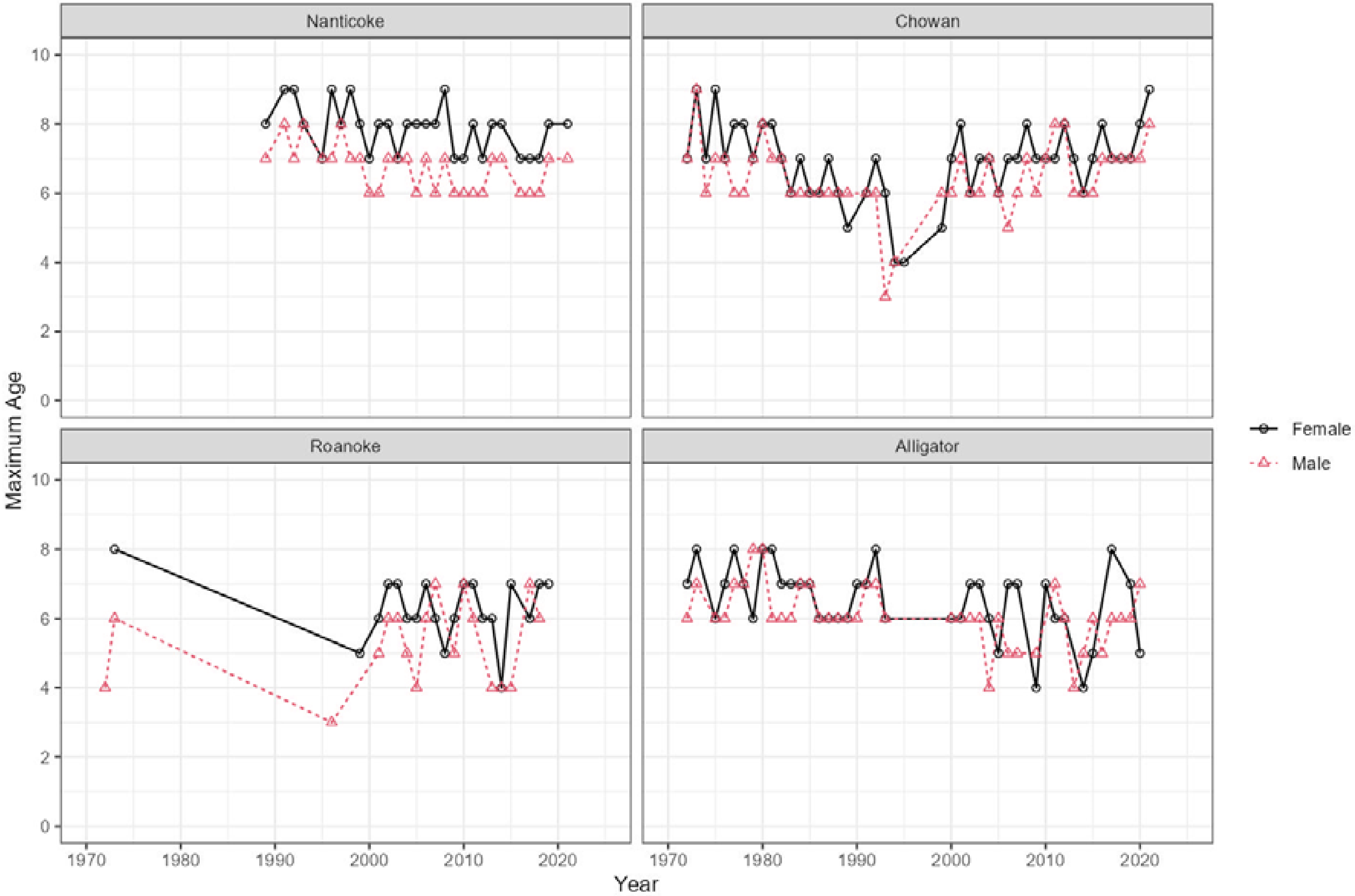


Figure 141. **Maximum scale-based ages for alewife by sex for four rivers in the MAT stock-region.**

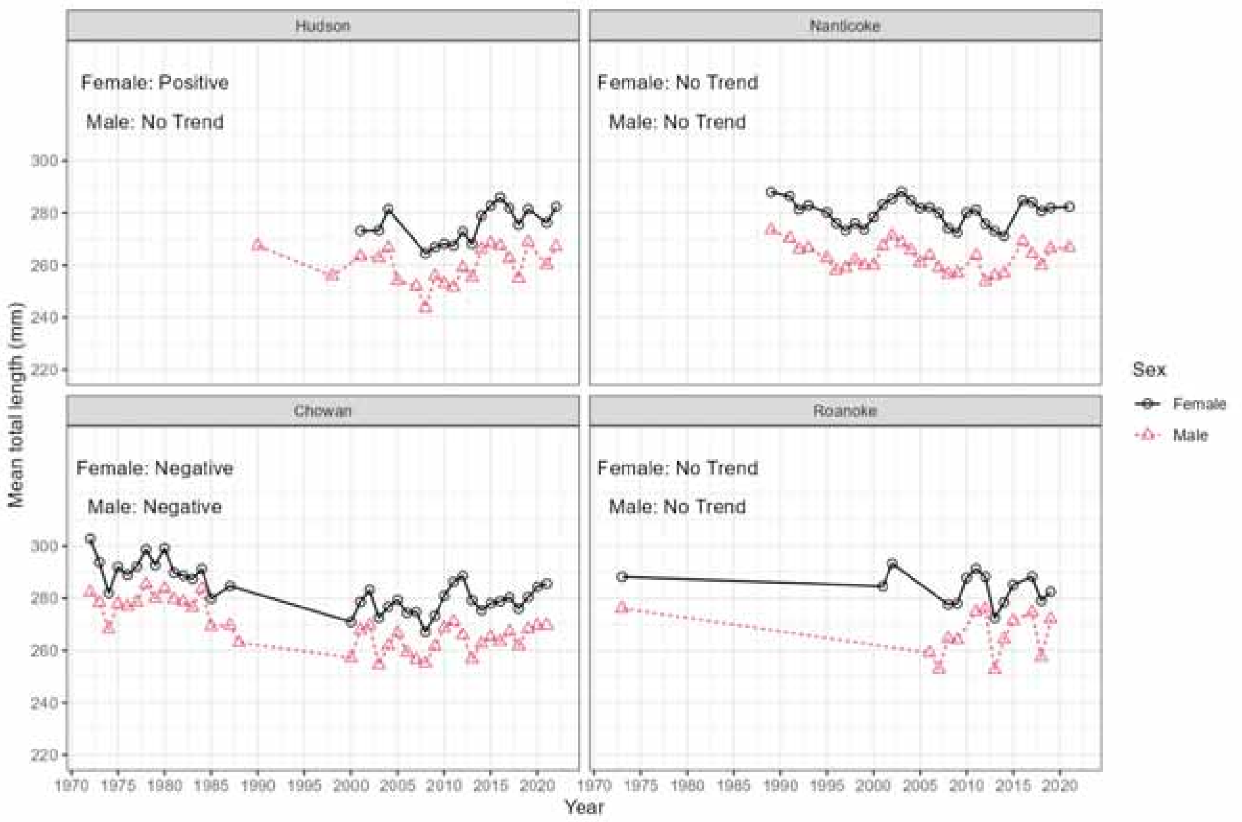


Figure 142. Mean length by year for female and male alewife from four river systems from the MAT stock-region.

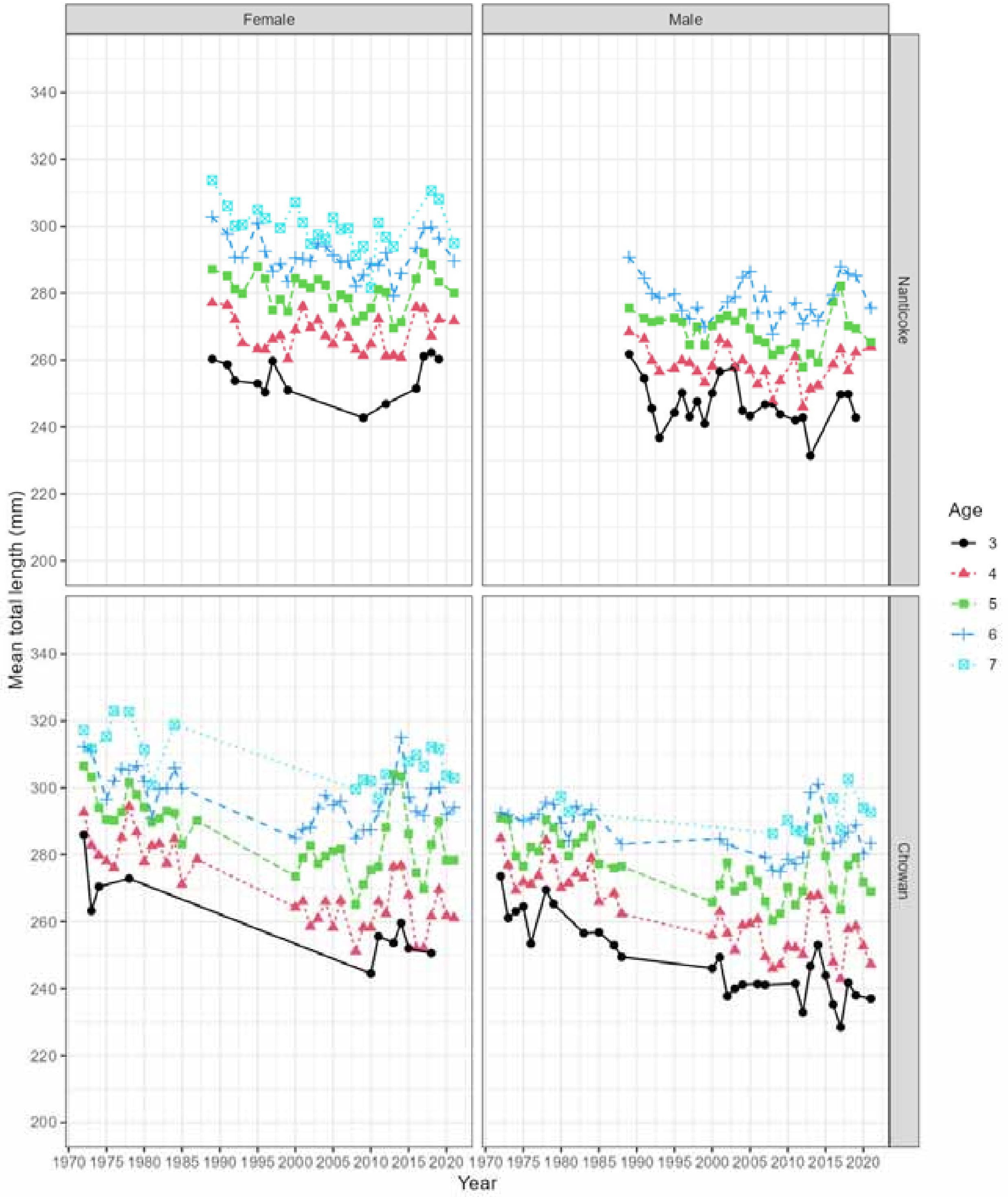


Figure 143. **Mean length-at-age by year for female and male alewife from four river systems from the MAT stock-region.**

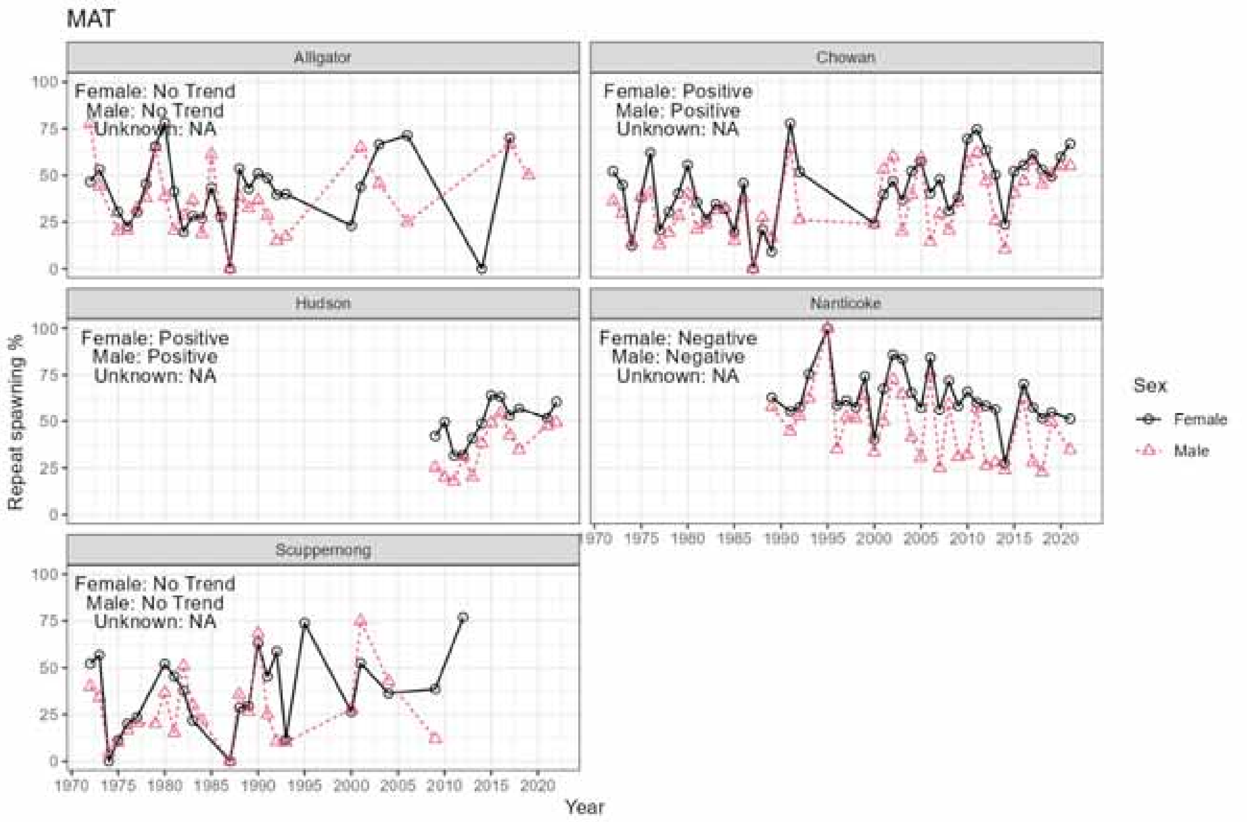


Figure 144. Trends in repeat spawner percentage for alewife from rivers in the MAT stock-region.

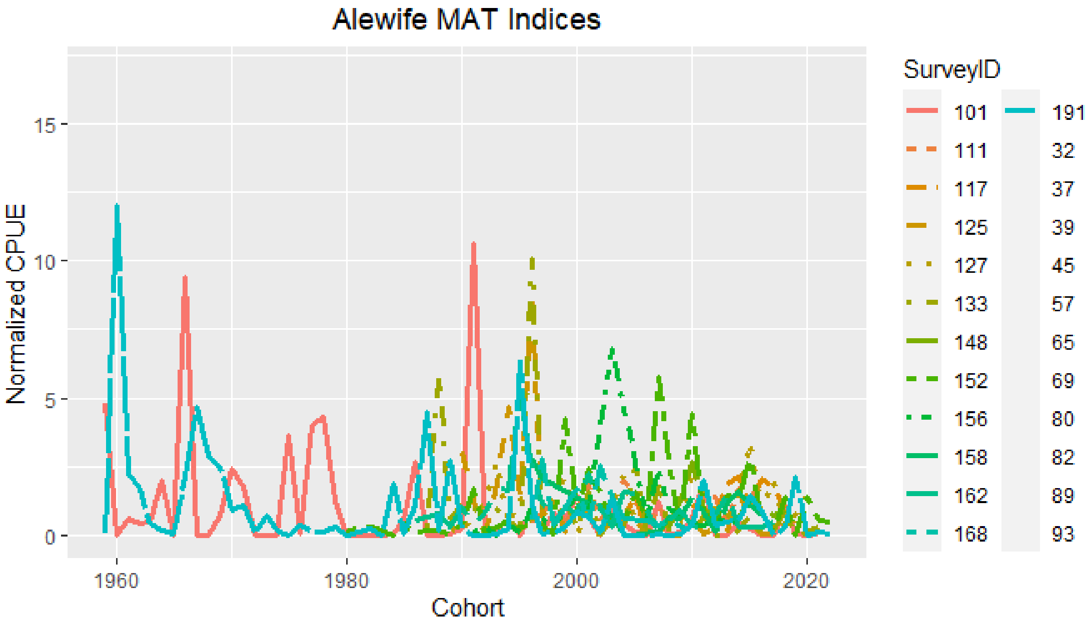


Figure 145. **Normalized fishery-independent indices for the alewife MAT stock-region plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.**

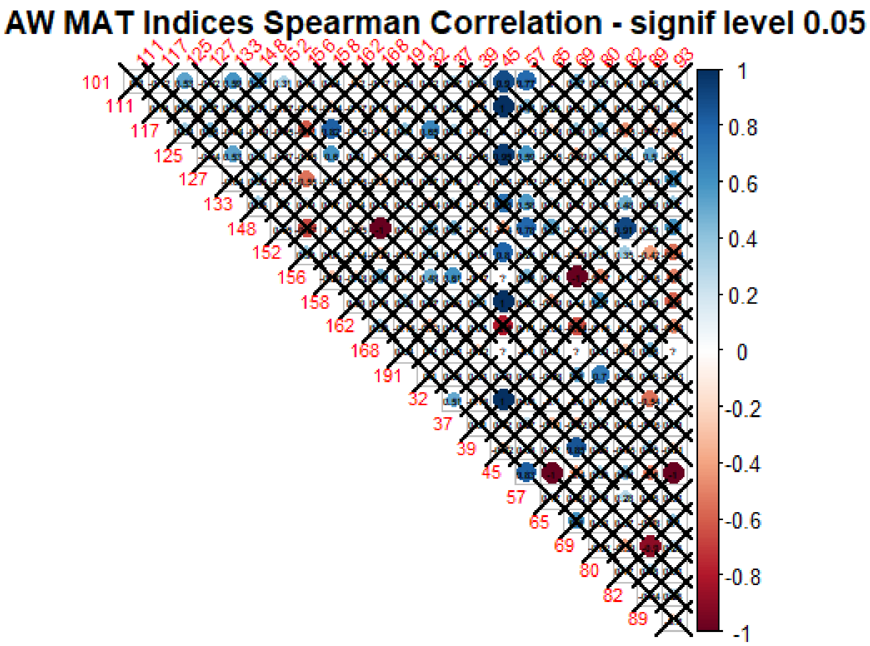


Figure 146. Spearman correlations among fishery-independent indices in the alewife MAT region. Crossed-out cells indicate no significant correlation at the p<0.05 level. See Appendix 6 for survey names corresponding to SurveyID.

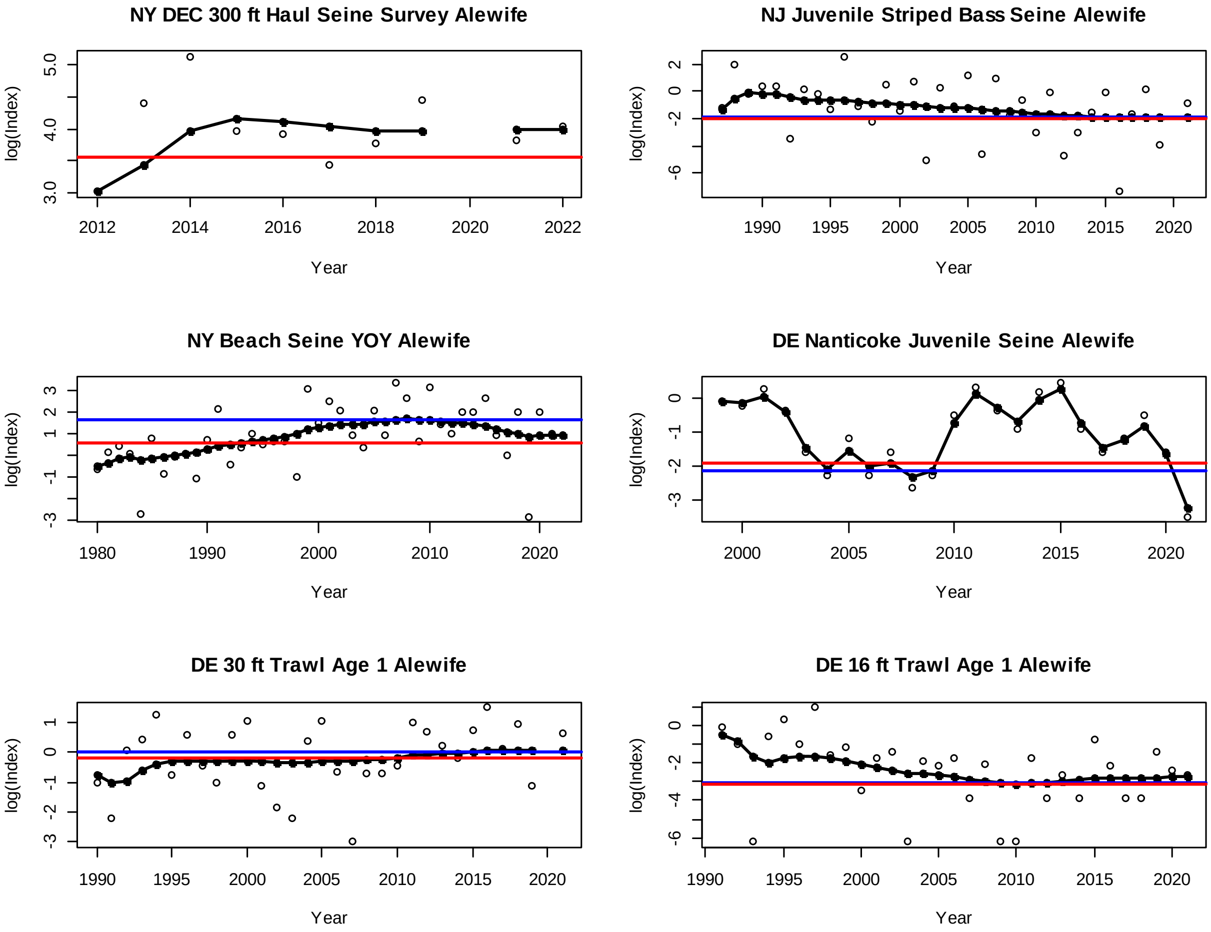
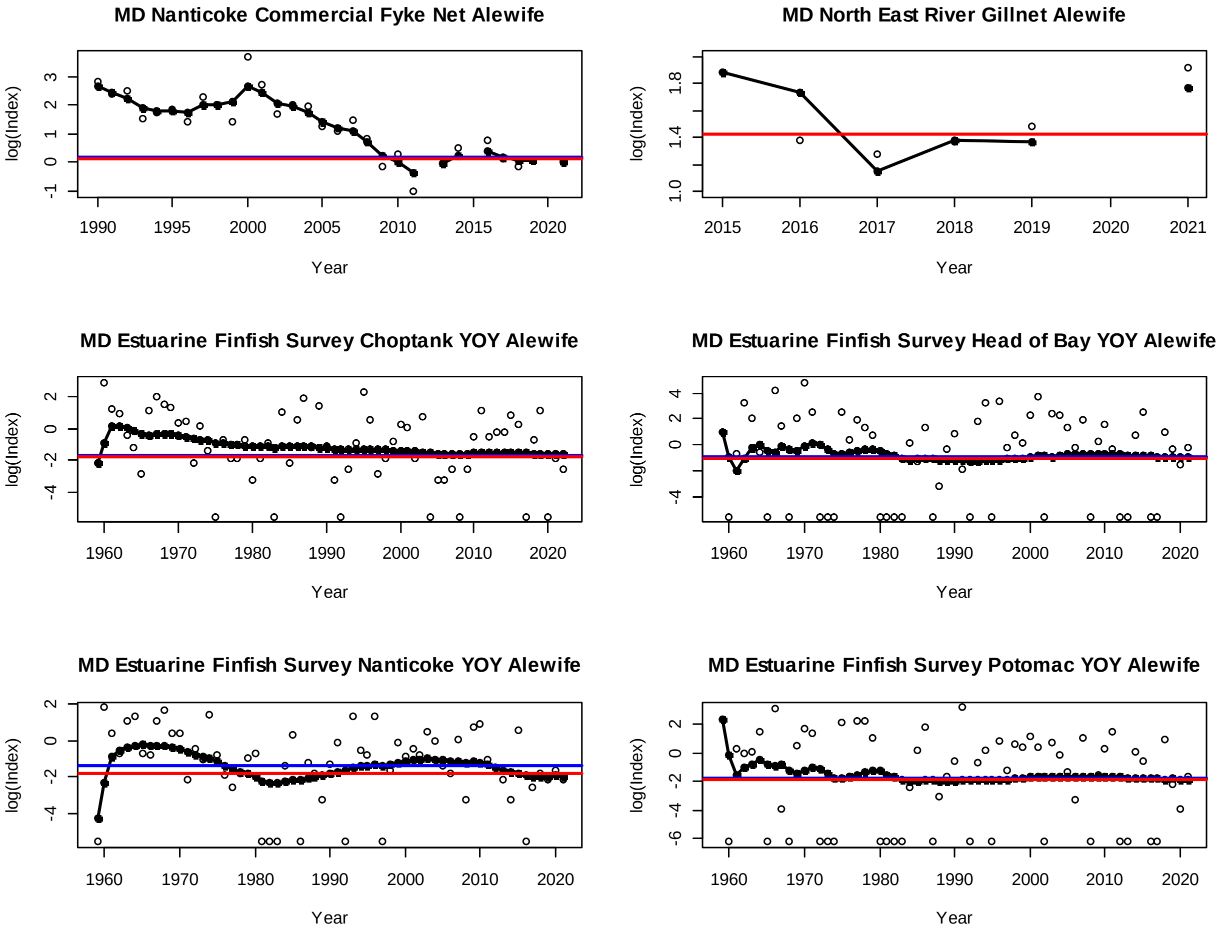


Figure 147. ARIMA model fits to alewife survey indices from the MAT stock-region. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.


MD Nanticoke Commercial Fyke Net Alewife

MD North East River Gillnet Alewife

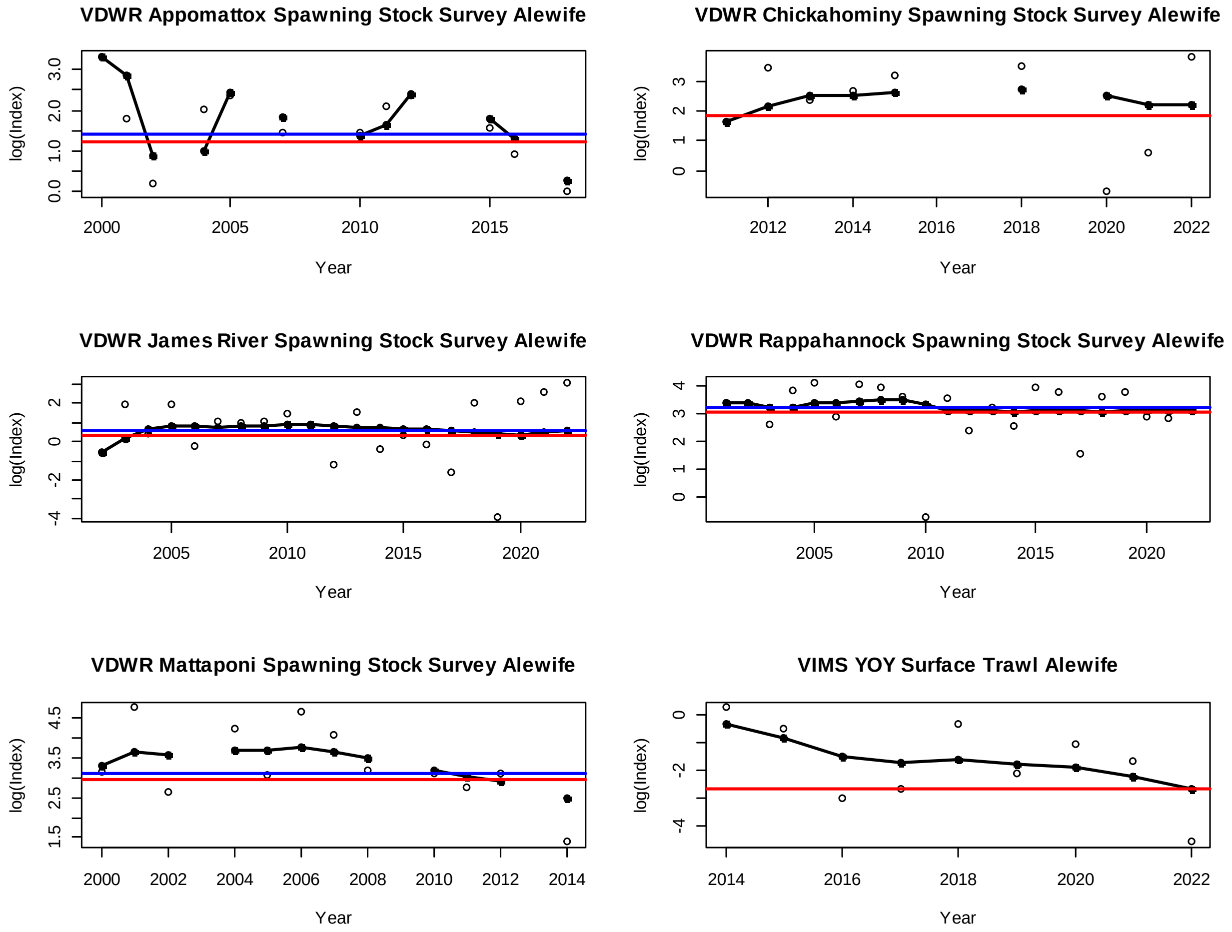
MD Estuarine Finfish Survey Choptank YOY Alewife

MD Estuarine Finfish Survey Head of Bay YOY Alewife

MD Estuarine Finfish Survey Nanticoke YOY Alewife

MD Estuarine Finfish Survey Potomac YOY Alewife

Figure 147 (cont.)



VDWR Appomattox Spawning Stock Survey Alewife

VDWR Chickahominy Spawning Stock Survey Alewife

VDWR James River Spawning Stock Survey Alewife

VDWR Rappahannock Spawning Stock Survey Alewife

VDWR Mattaponi Spawning Stock Survey Alewife

VIMS YOY Surface Trawl Alewife

Figure 147 (cont.)

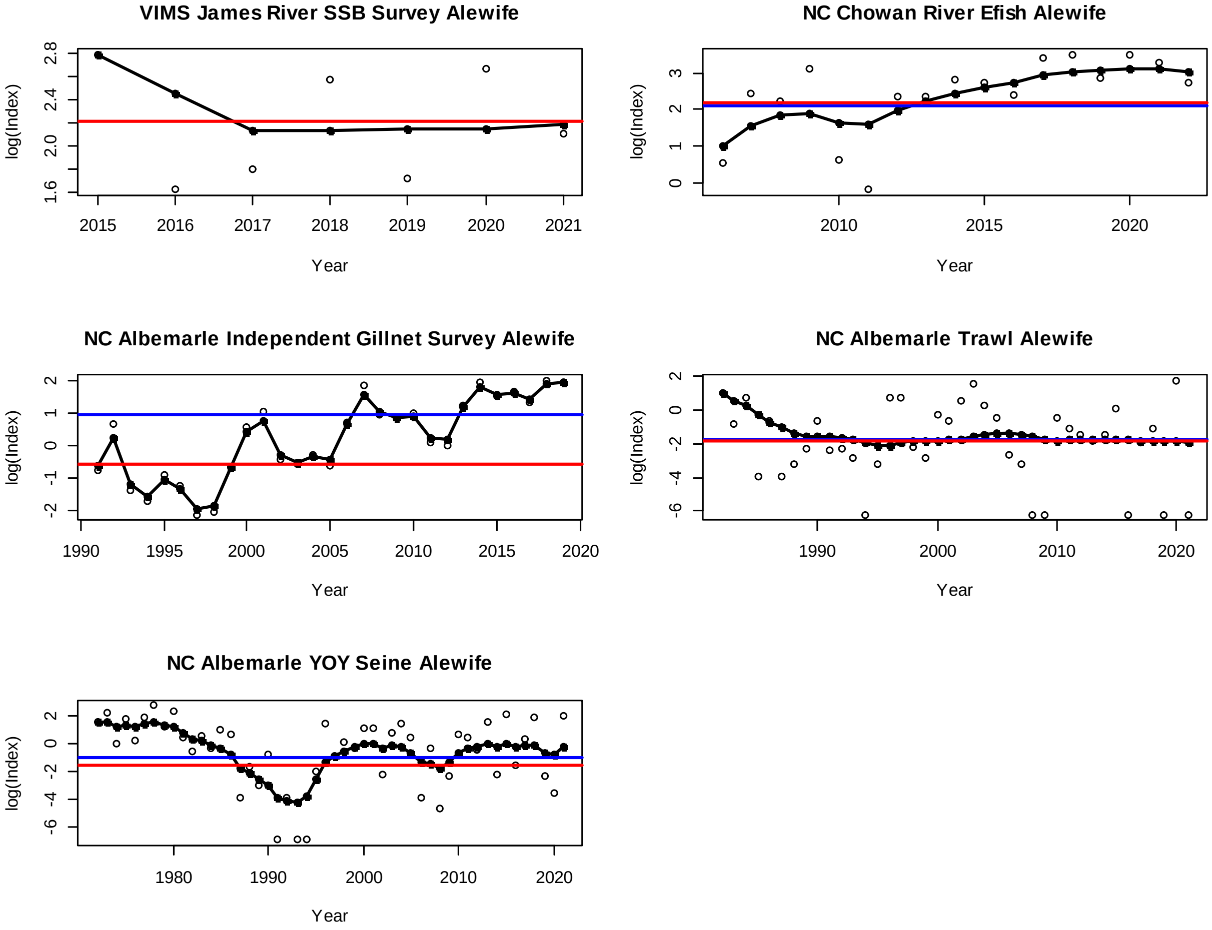


Figure 147 (cont.)

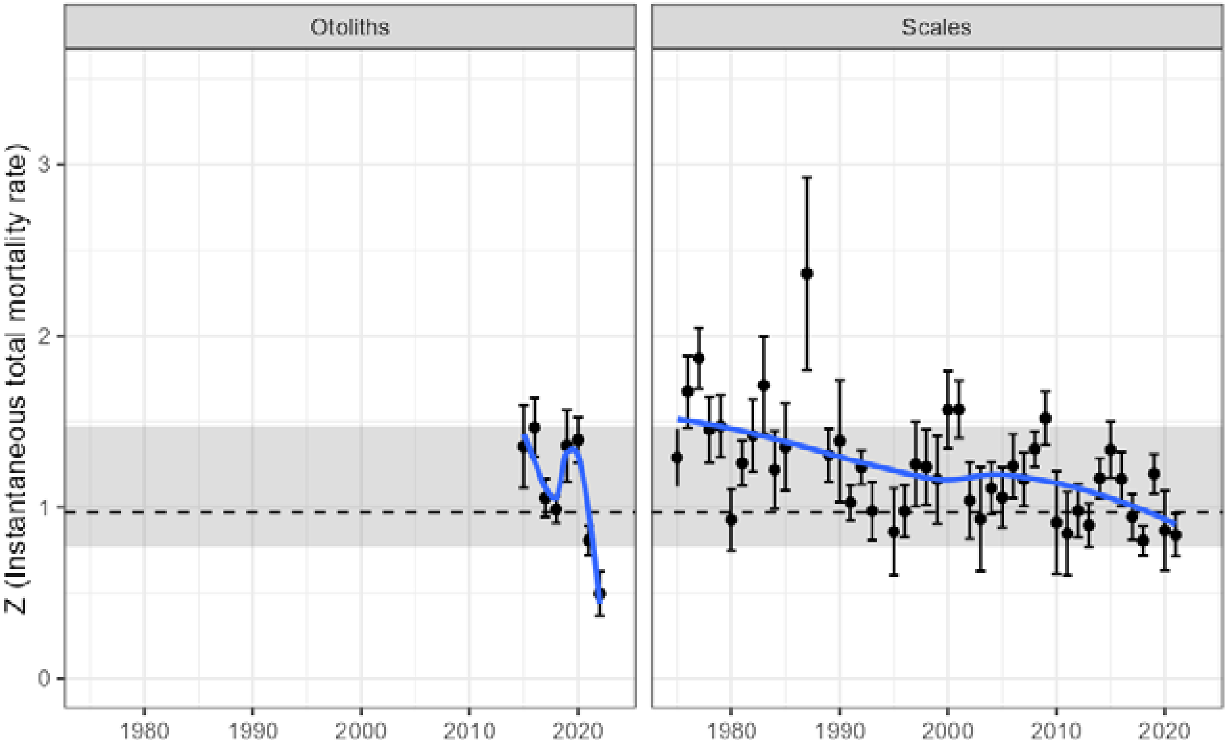


Figure 148. **Estimates of total instantaneous mortality (Z) for alewife from the MAT stock-region by ageing structure, plotted with the $Z_{40\%SPR}$ reference point for the MAT stock-region. Blues lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the Z40% reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.**

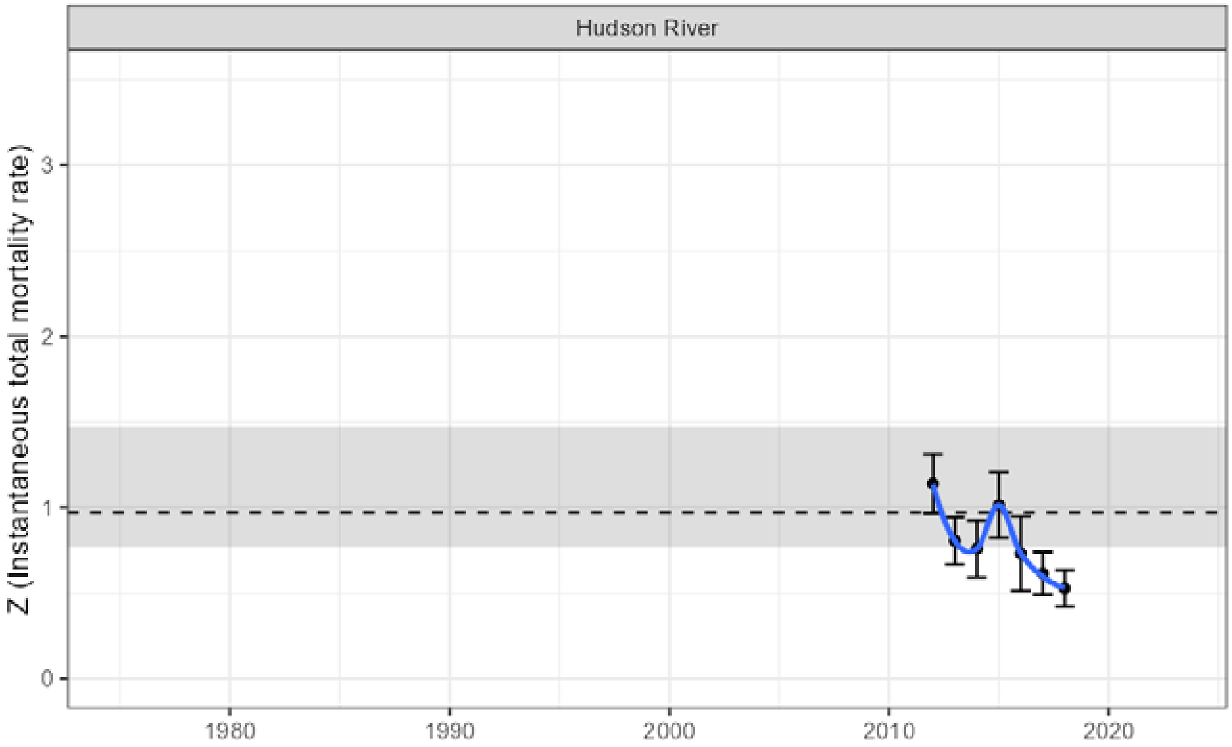


Figure 149. Age-based estimates of total instantaneous mortality for alewife (from scale data) in New York by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

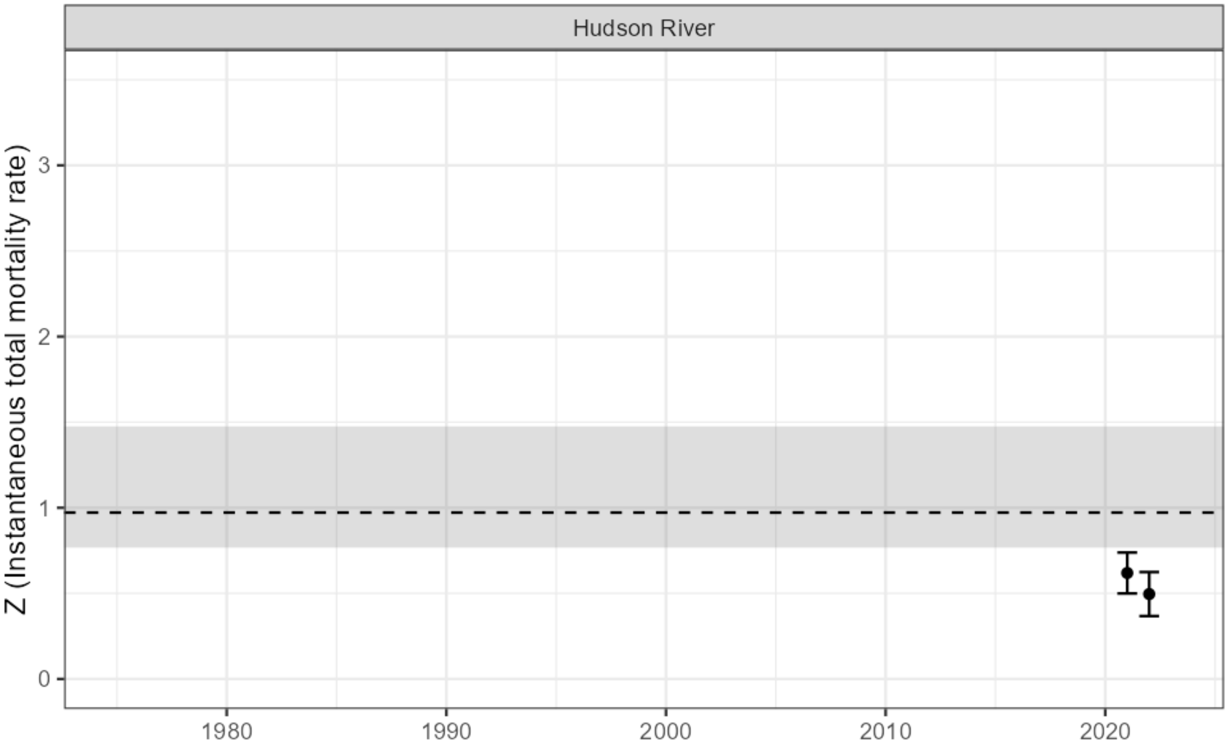


Figure 150. Age-based estimates of total instantaneous mortality for alewife (from otolith data) in New York by river and year. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

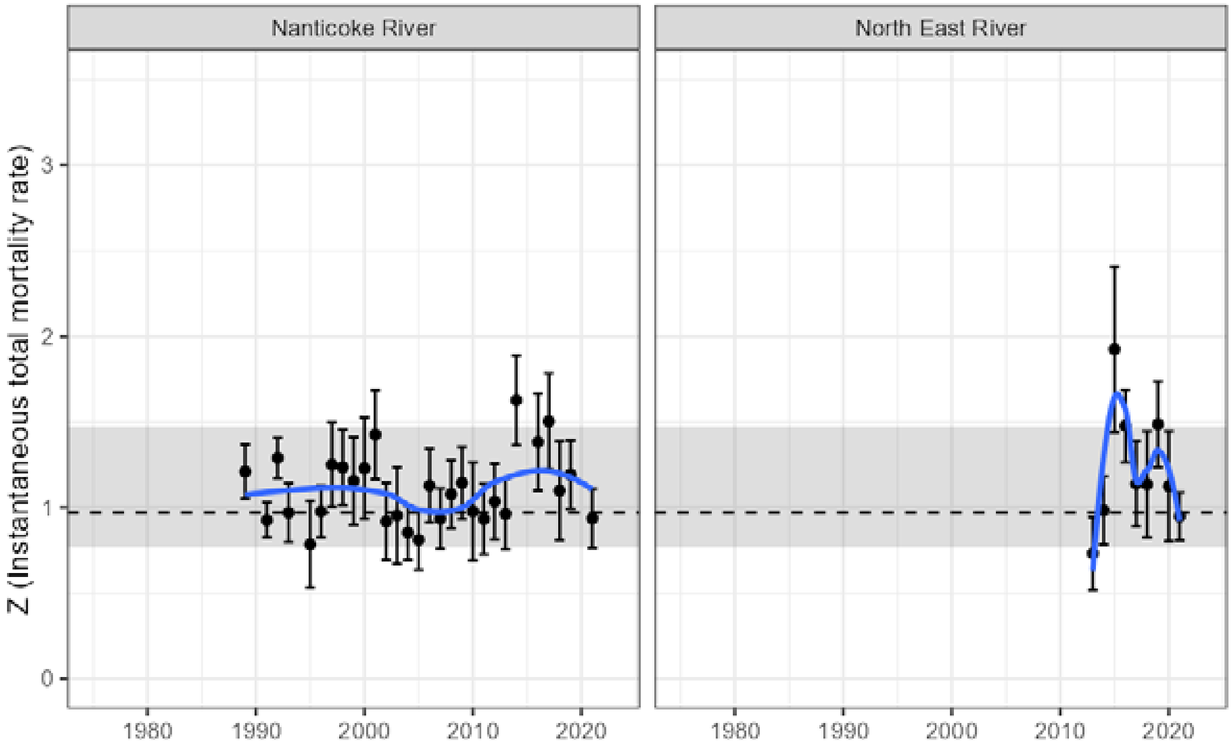


Figure 151. **Age-based estimates of total instantaneous mortality for alewife (from scale data) in Maryland by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.**

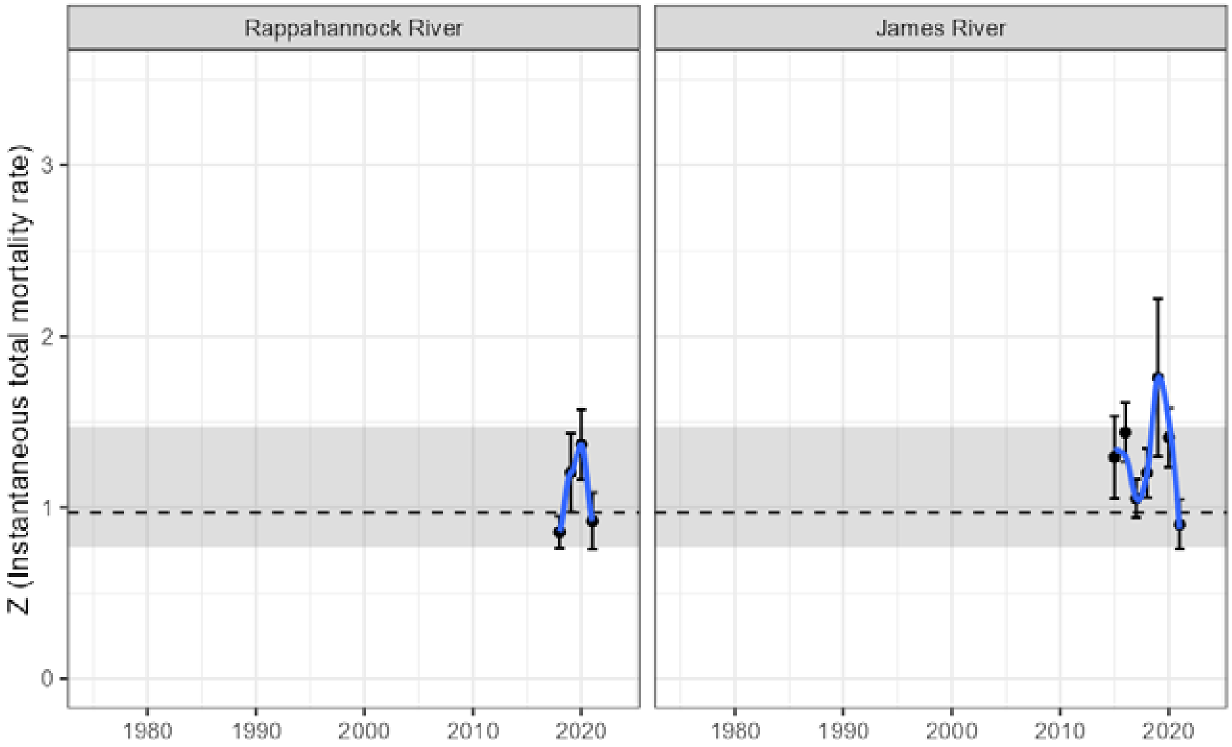


Figure 152. **Age-based estimates of total instantaneous mortality for alewife (from otolith data) in Virginia by river and year.Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.**

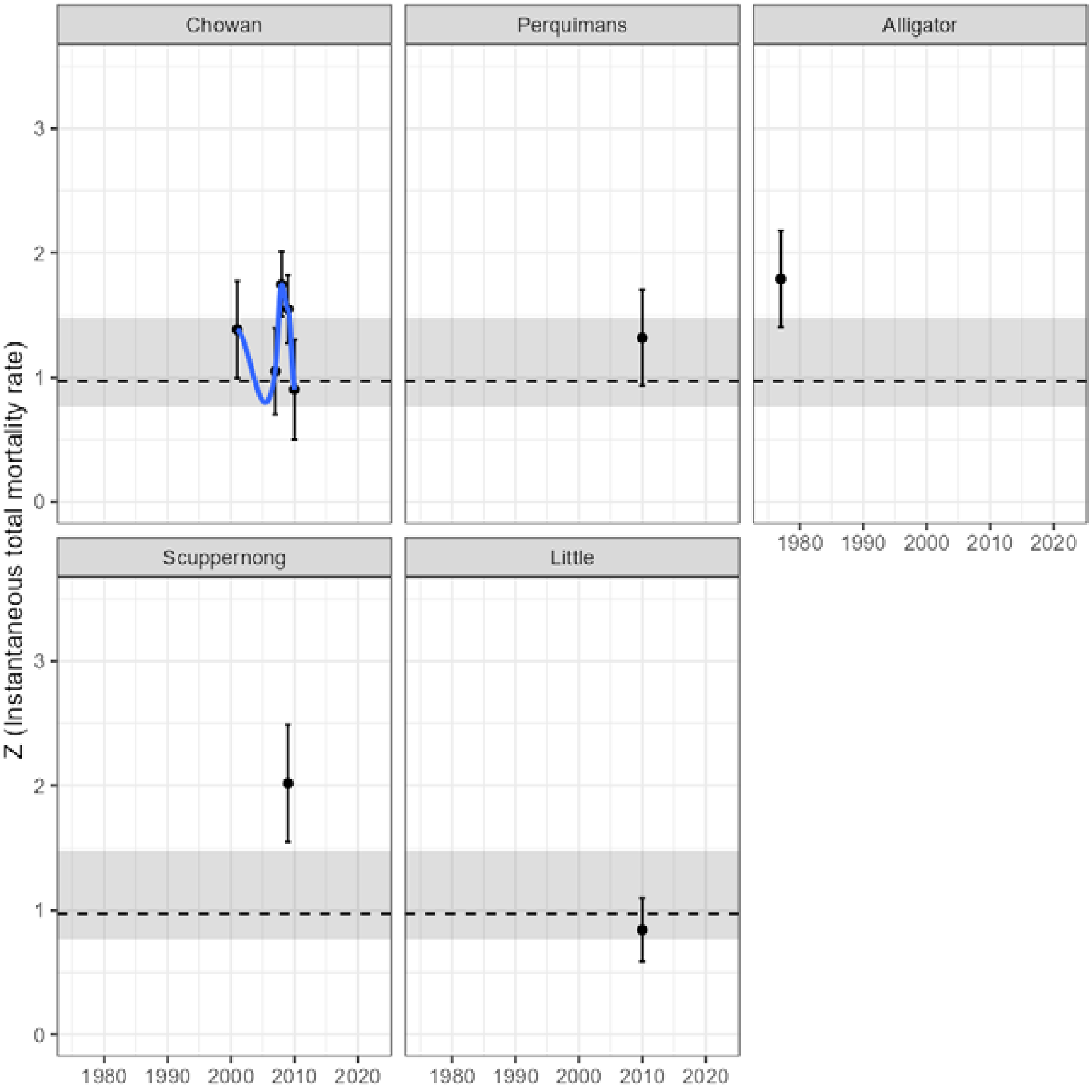


Figure 153. Age-based estimates of total instantaneous mortality for alewife (from fishery independent scale data) in North Carolina by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

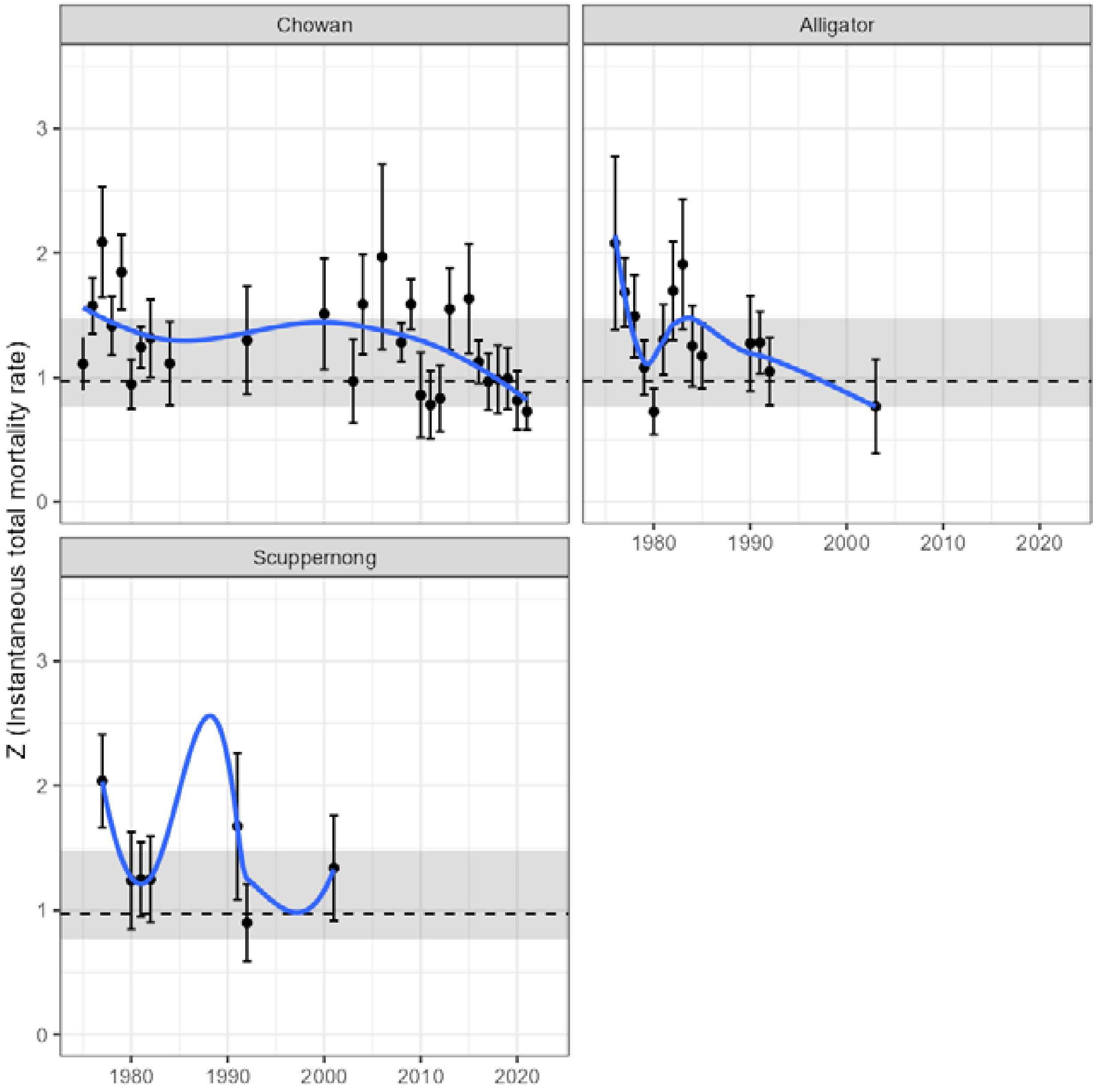


Figure 154. Age-based estimates of total instantaneous mortality for alewife (from fishery dependent scale data) in North Carolina by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

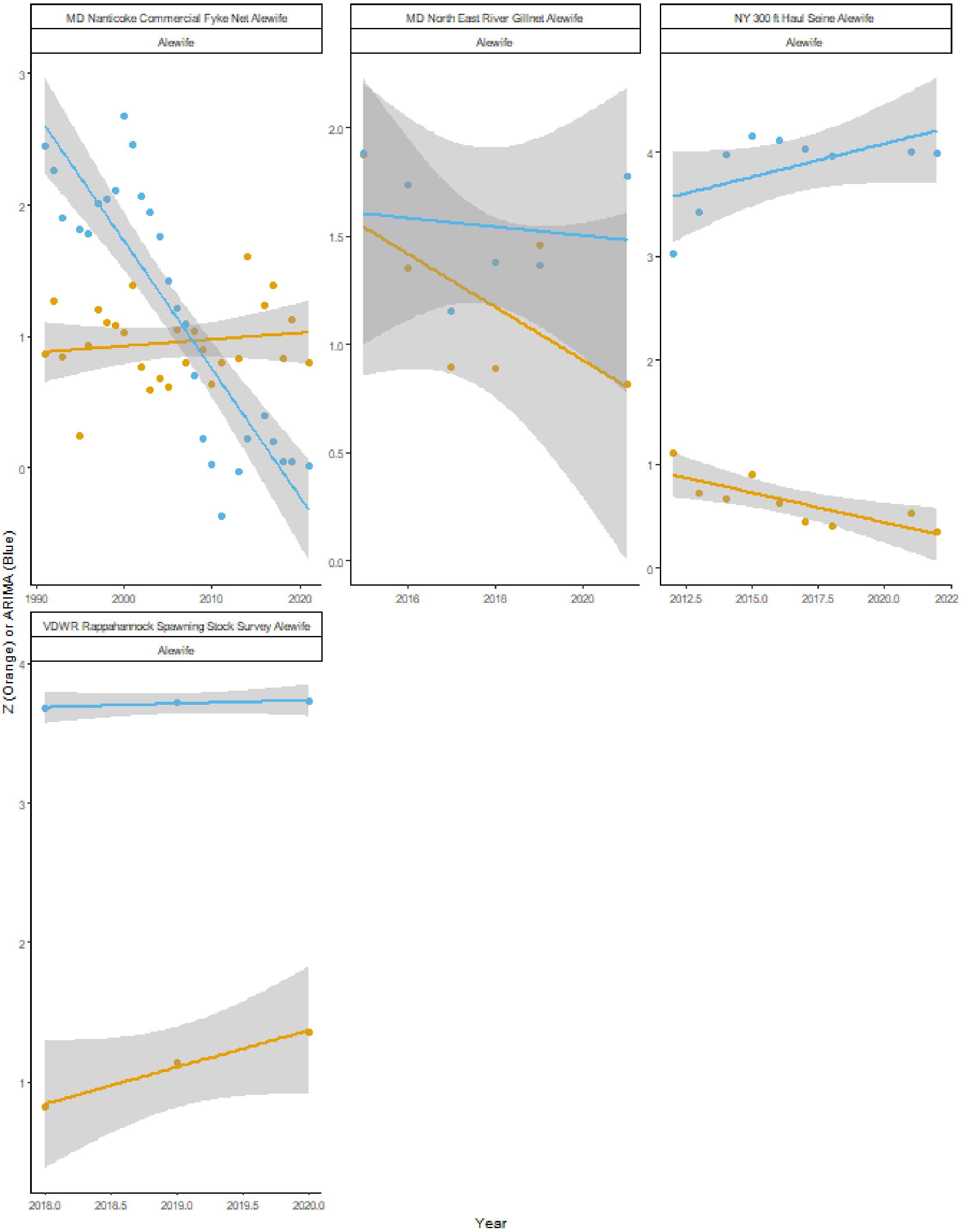


Figure 155. Comparison of Z (orange lines/points) and ARIMA indices of adult alewife (blue lines/points) for the MAT stock-region for systems where both metrics are available.

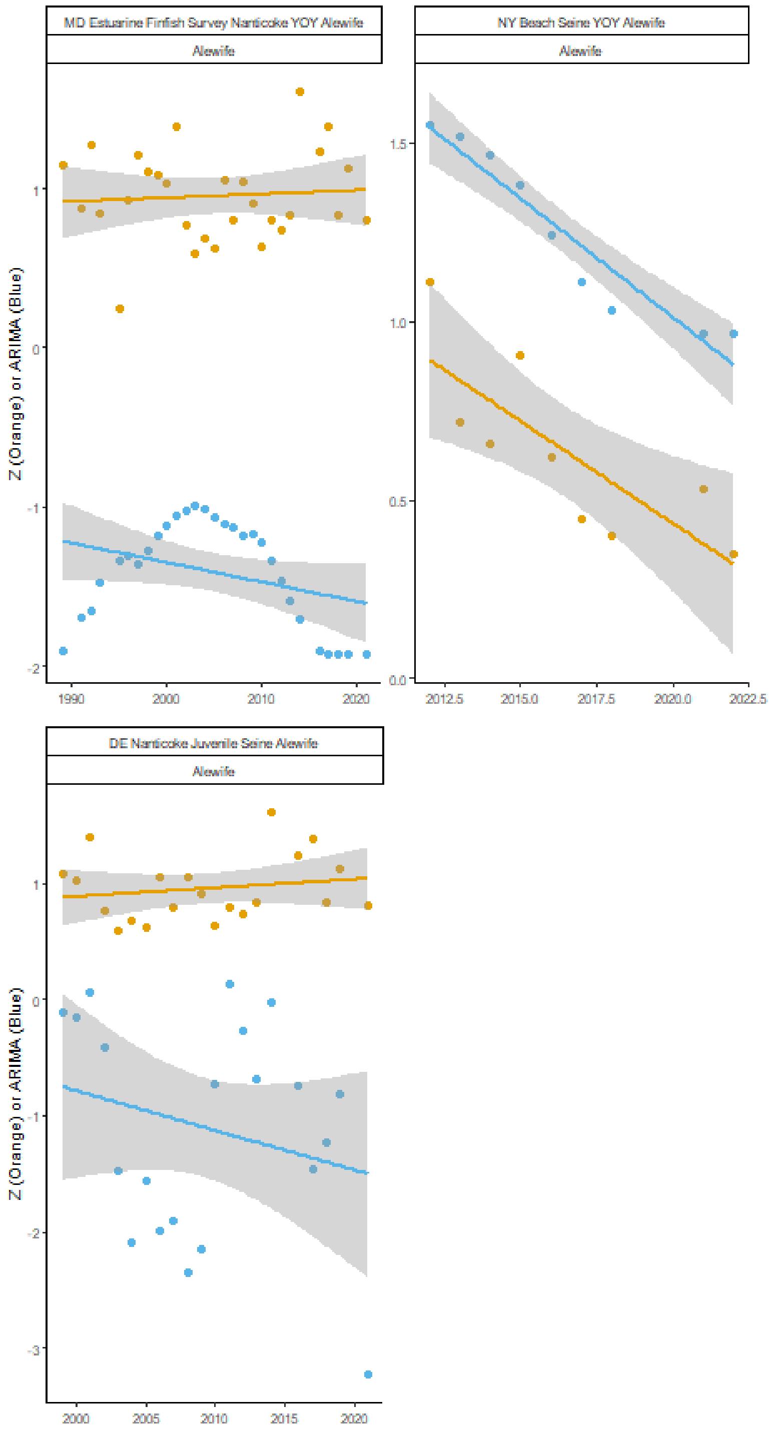


Figure 156. Comparison of Z (orange lines/points) and ARIMA indices of juvenile or YOY alewife (blue lines/points) for the MAT stock-region for systems where both metrics are available

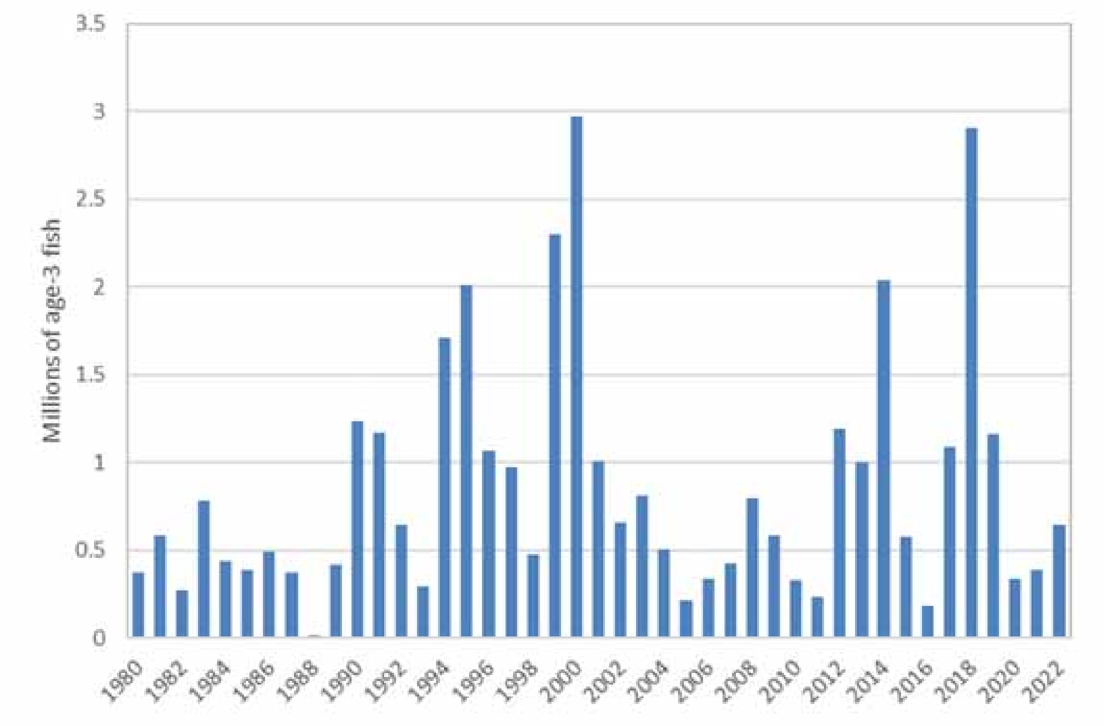


Figure 157. Estimates of recruitment (age-3 fish) for Monument River alewife from the Monument River SCA model.

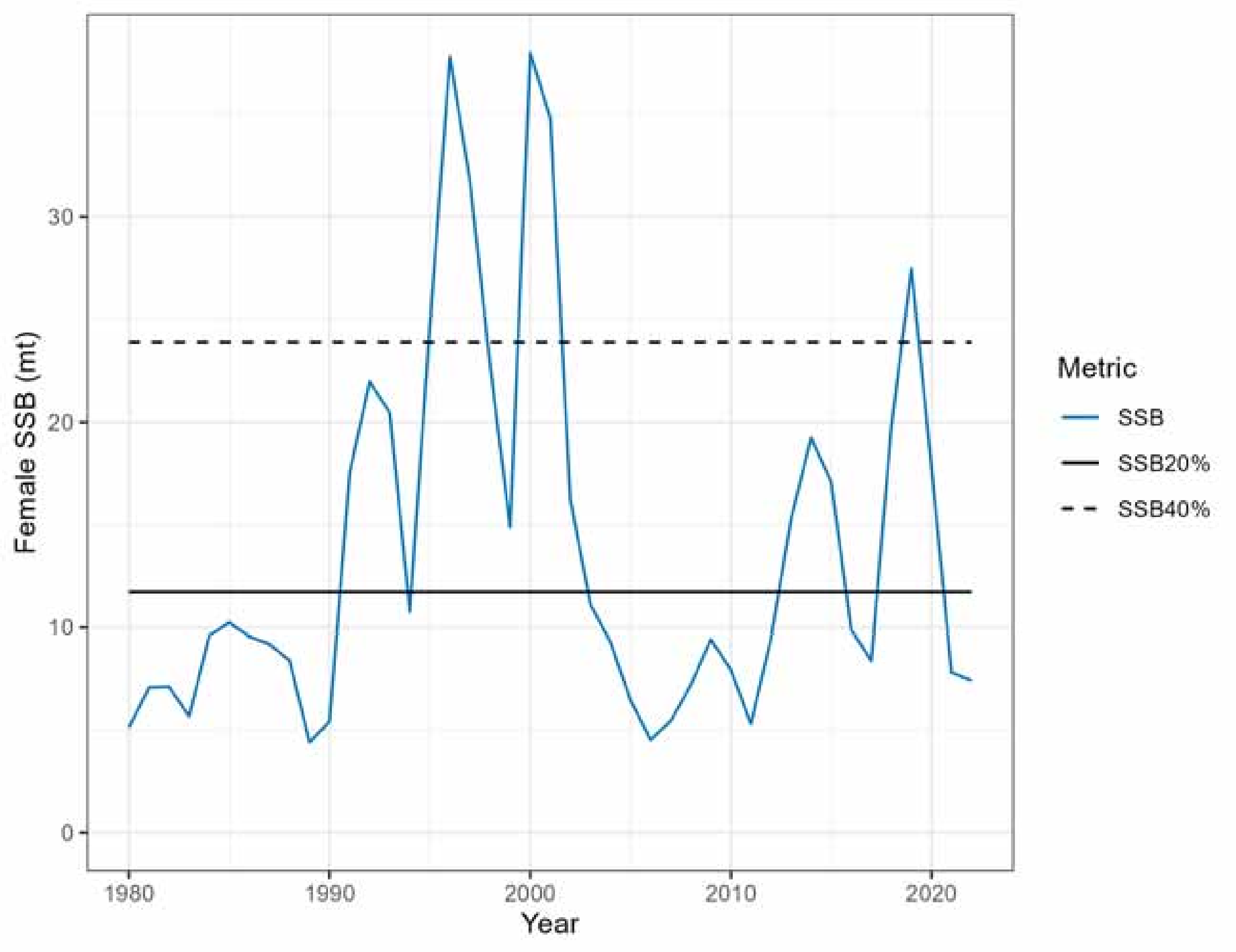


Figure 158. Estimates of female spawning stock biomass (mt) for Monument River alewife from the Monument River SCA model plotted with the SSB 40% and 20% reference points.

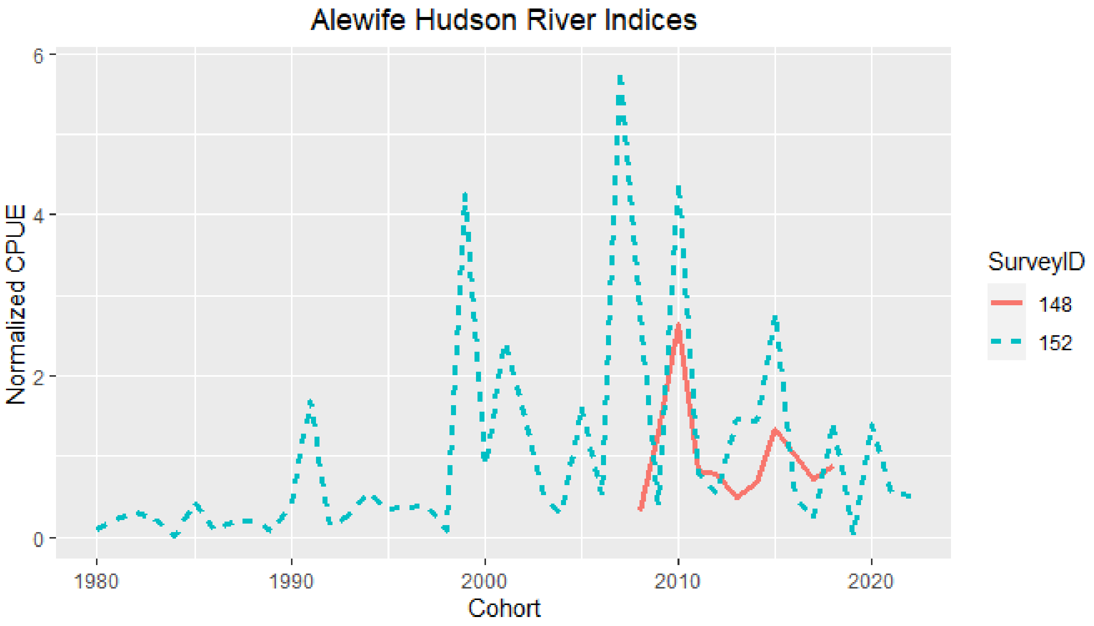


Figure 159. **Normalized fishery-independent indices for Hudson River alewife plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.**

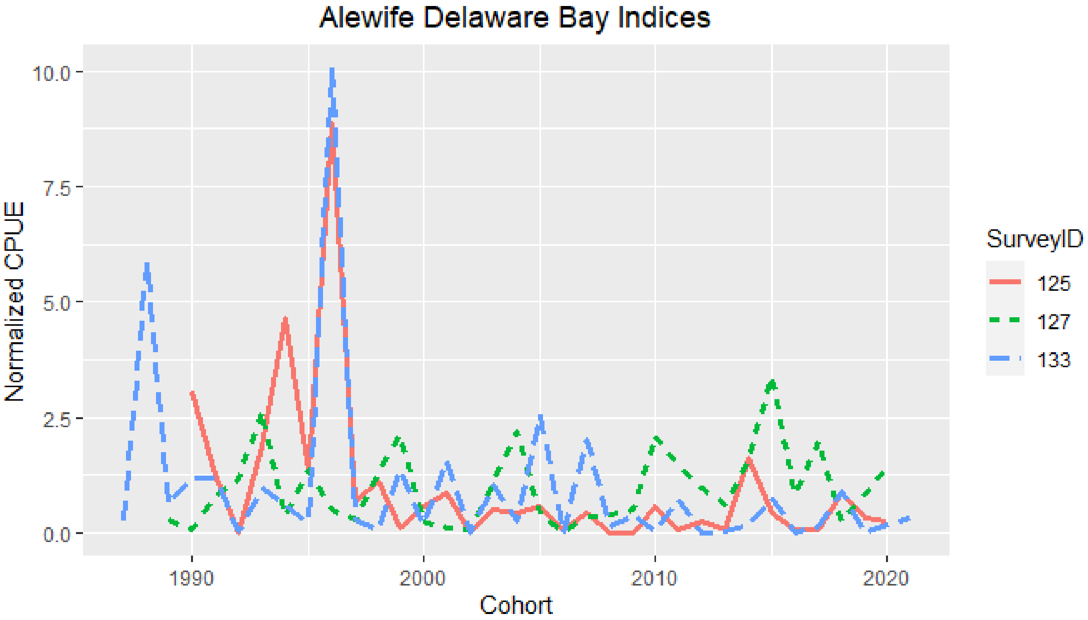


Figure 160. Normalized fishery-independent indices for Delaware Bay alewife plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.

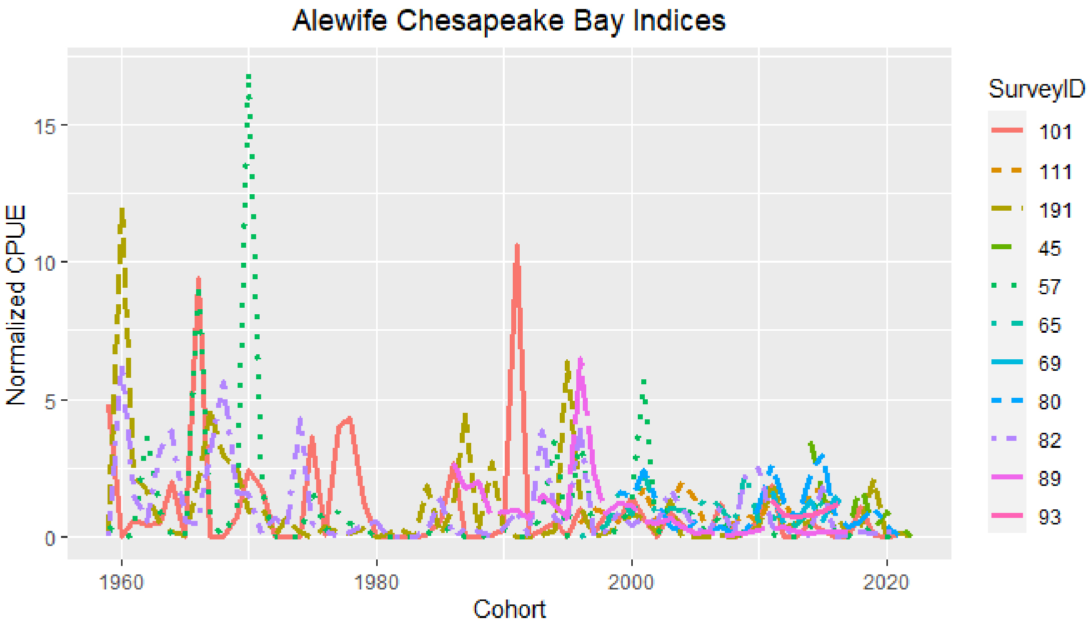


Figure 161. **Normalized fishery-independent indices for Chesapeake Bay alewife plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.**

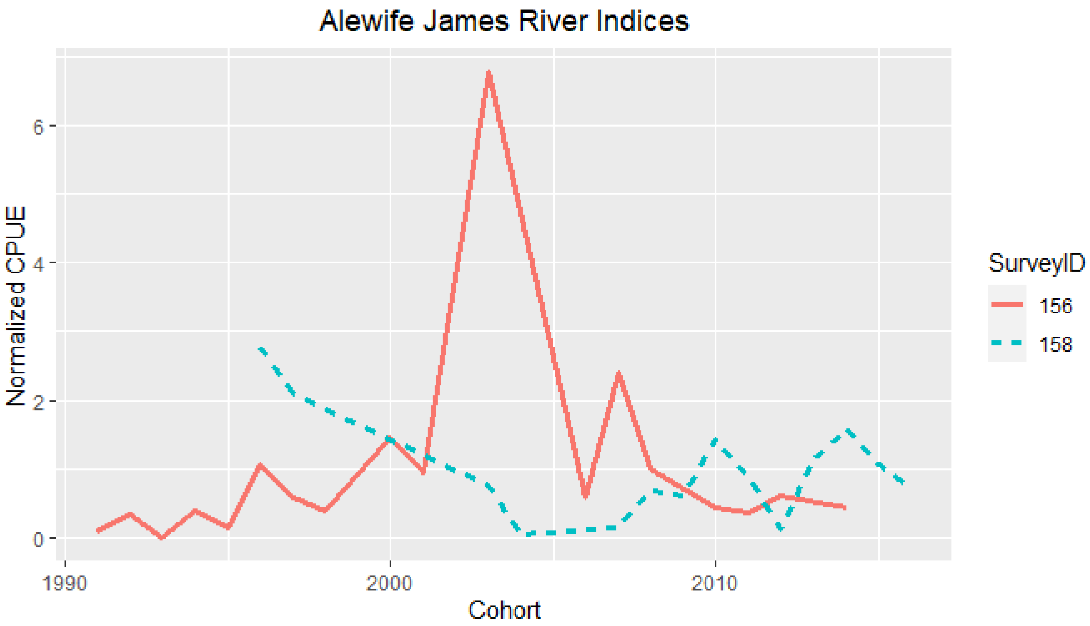


Figure 162. Normalized fishery-independent indices for James River alewife plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.

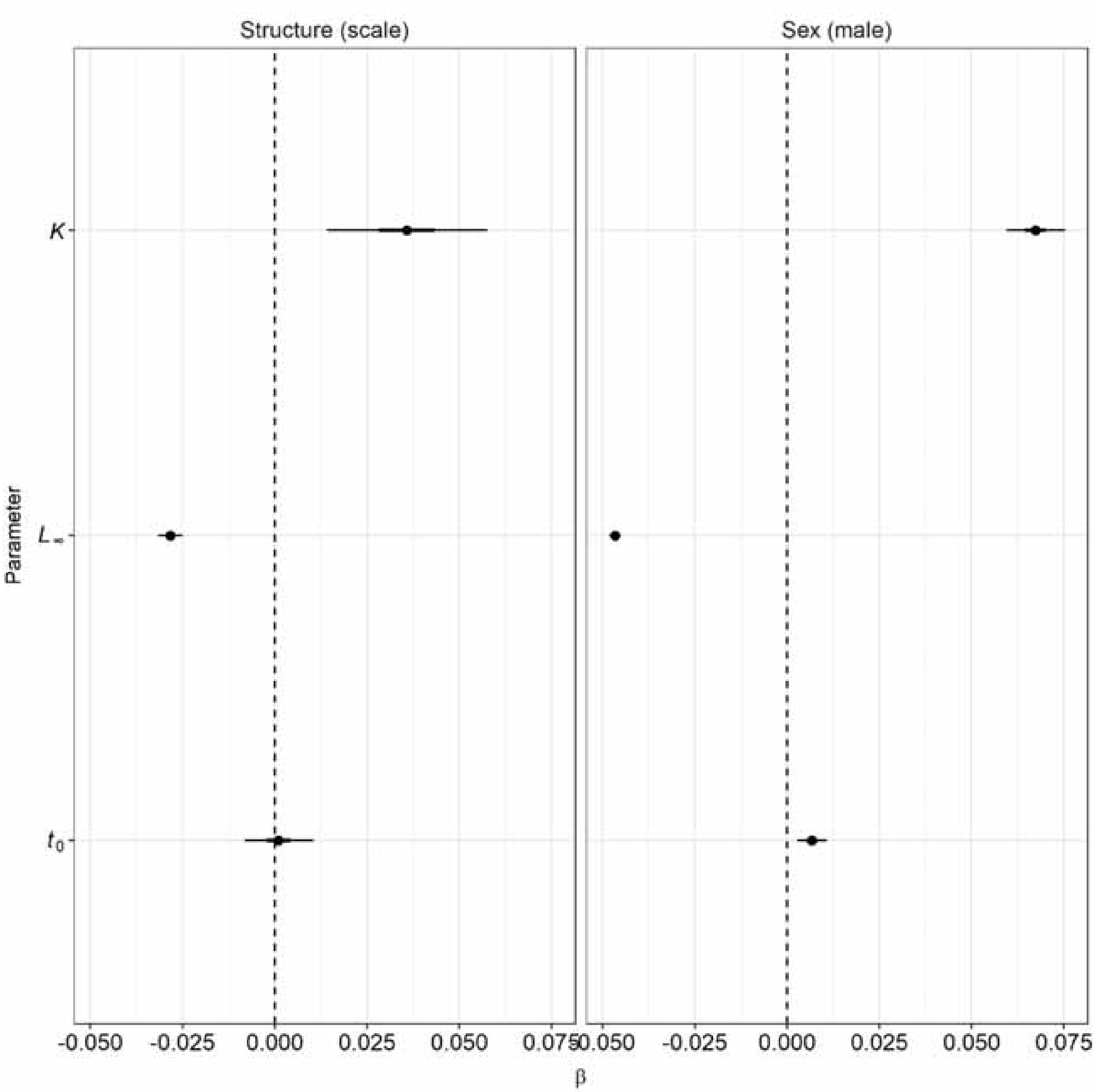


Figure 163. Estimated regression coefficients (β) for additive effects of aging structure (left) and sex (right) on parameters of the sex-specific von Bertalanffy growth function for alewife across rivers.

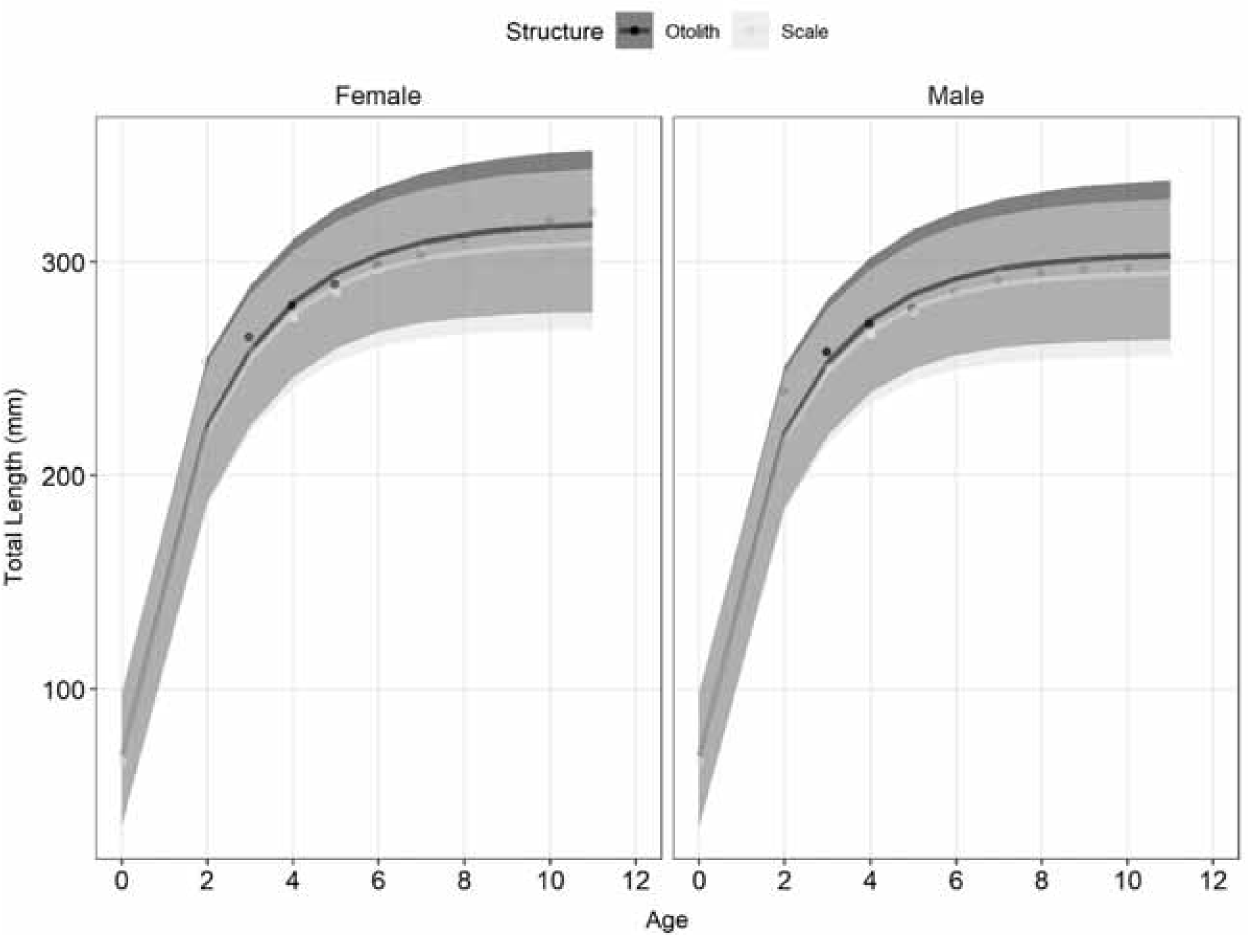


Figure 164. Coastwide growth of female (left) and male (right) alewife by ageing structure from the sex-specific von Bertalanffy growth function. Points represent coastwide mean length at age from the raw data for otoliths (dark gray) and scales (light gray). More opaque points indicate larger sample sizes. Lines represent posterior predicted median length at age and ribbons represent 95% credible intervals.

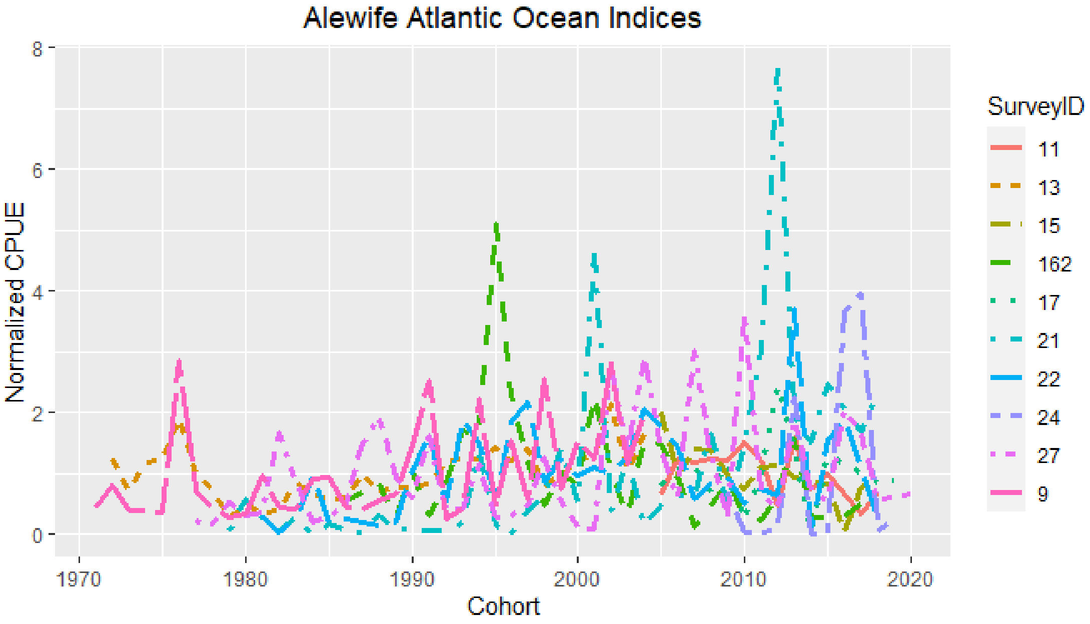


Figure 165. **Normalized fishery-independent indices for the ocean/mixed stock alewife plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.**

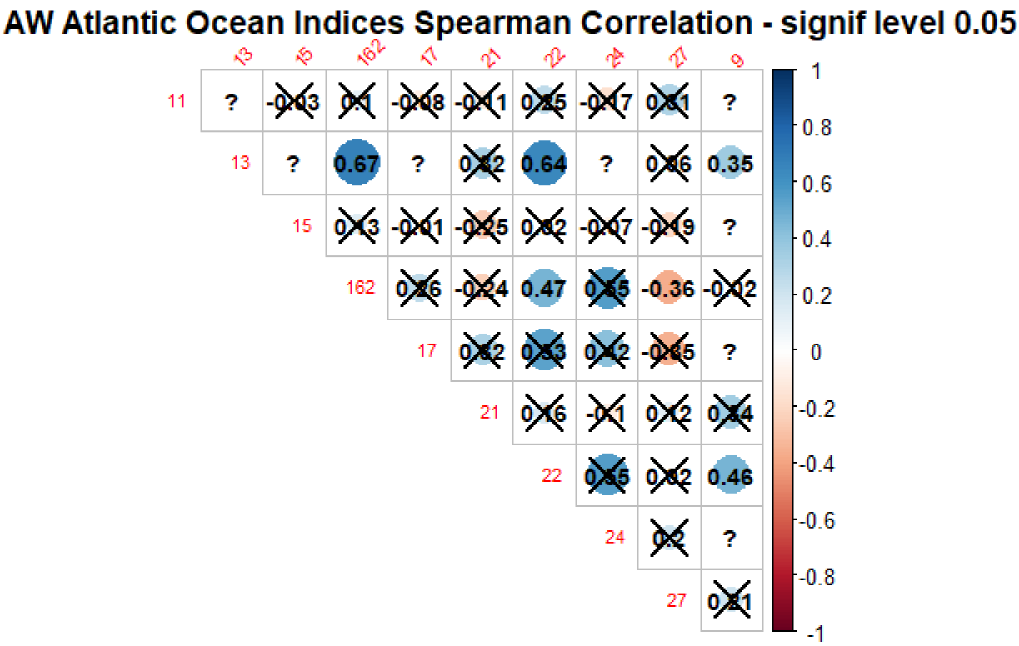


Figure 166. Spearman correlations among fishery-independent indices for ocean/mixed stock alewife. Cross-out cells indicate no significant correlation. See Appendix 6 for survey names corresponding to SurveyID.

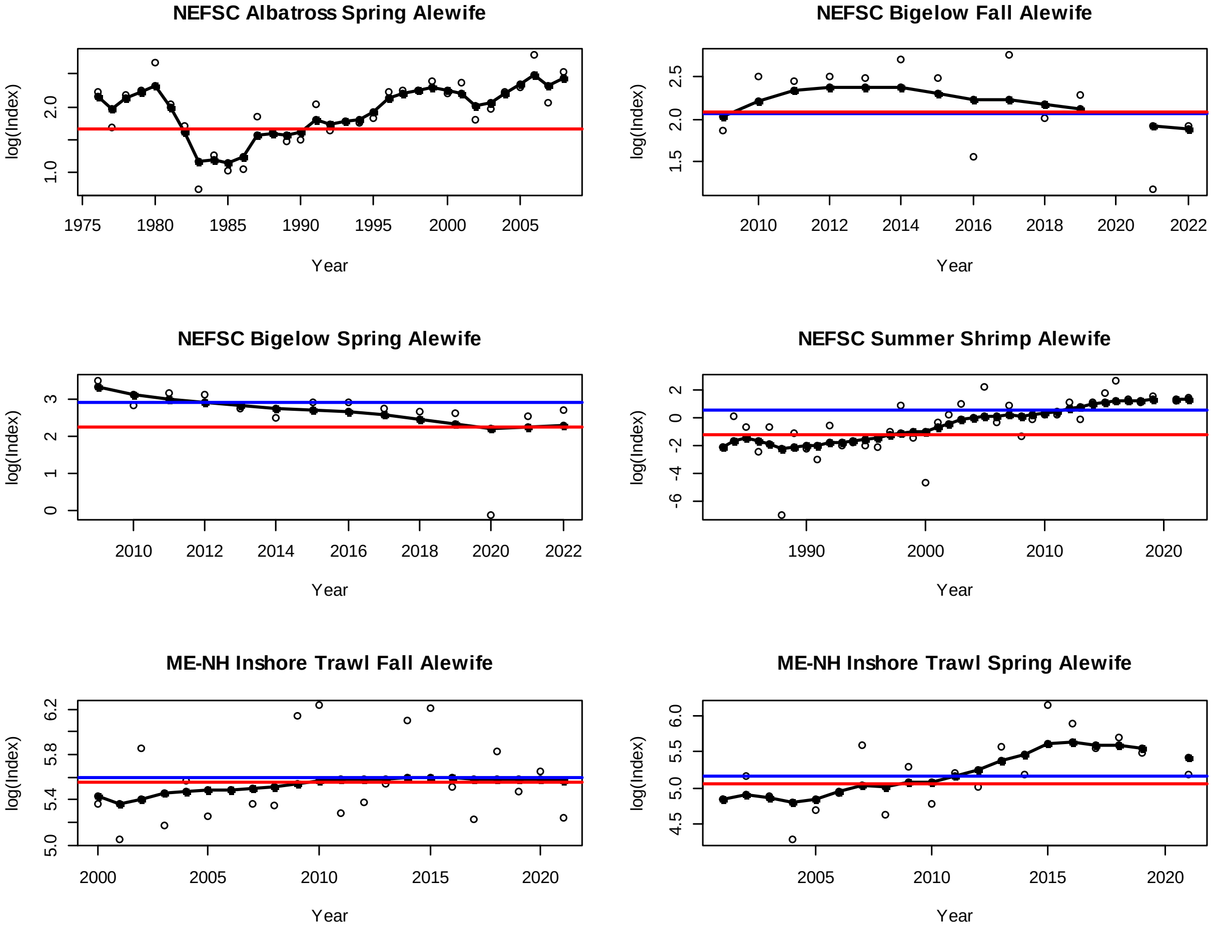


Figure 167. ARIMA model fits to mixed-stock alewife survey indices from the ocean. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

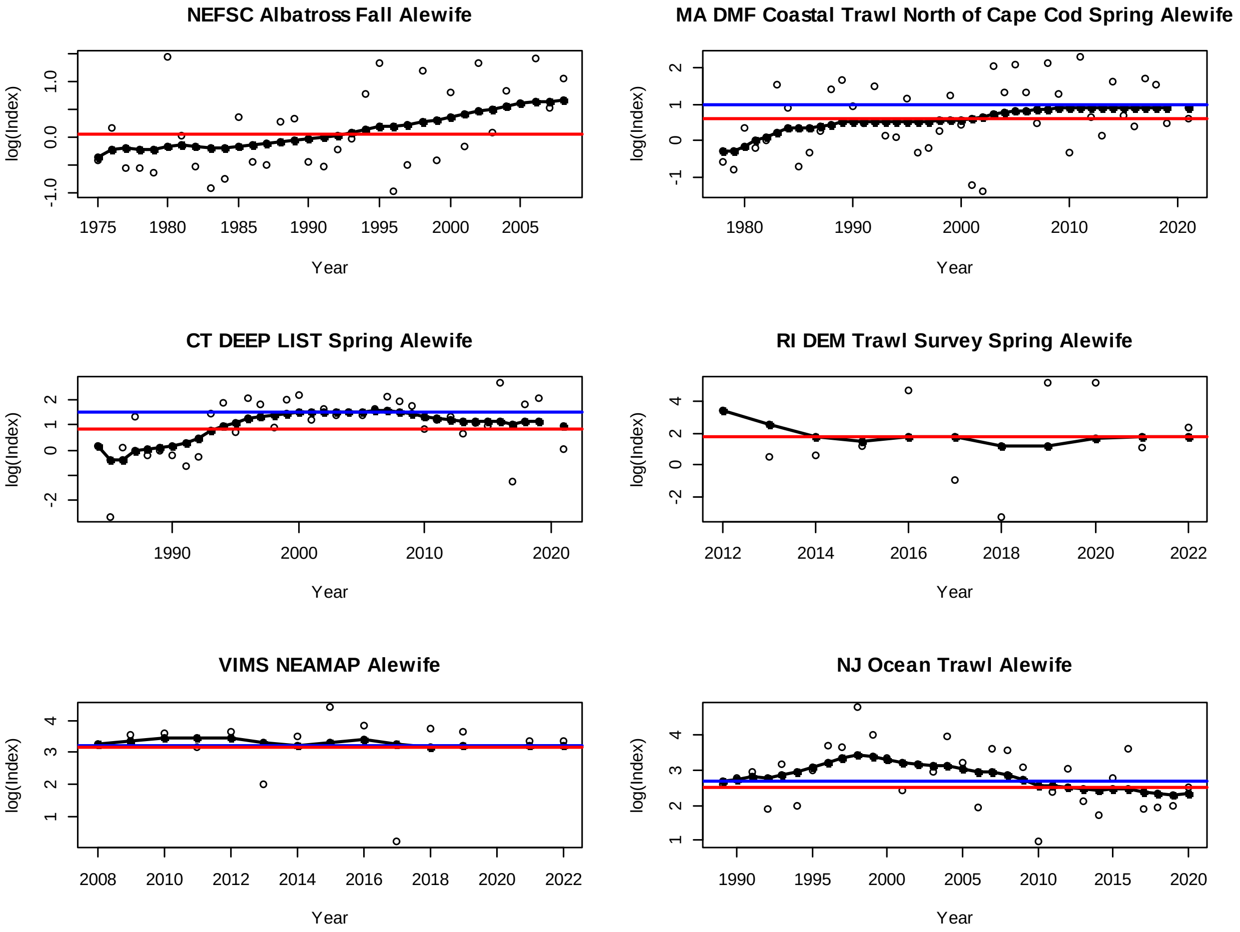


Figure 167 (cont.)

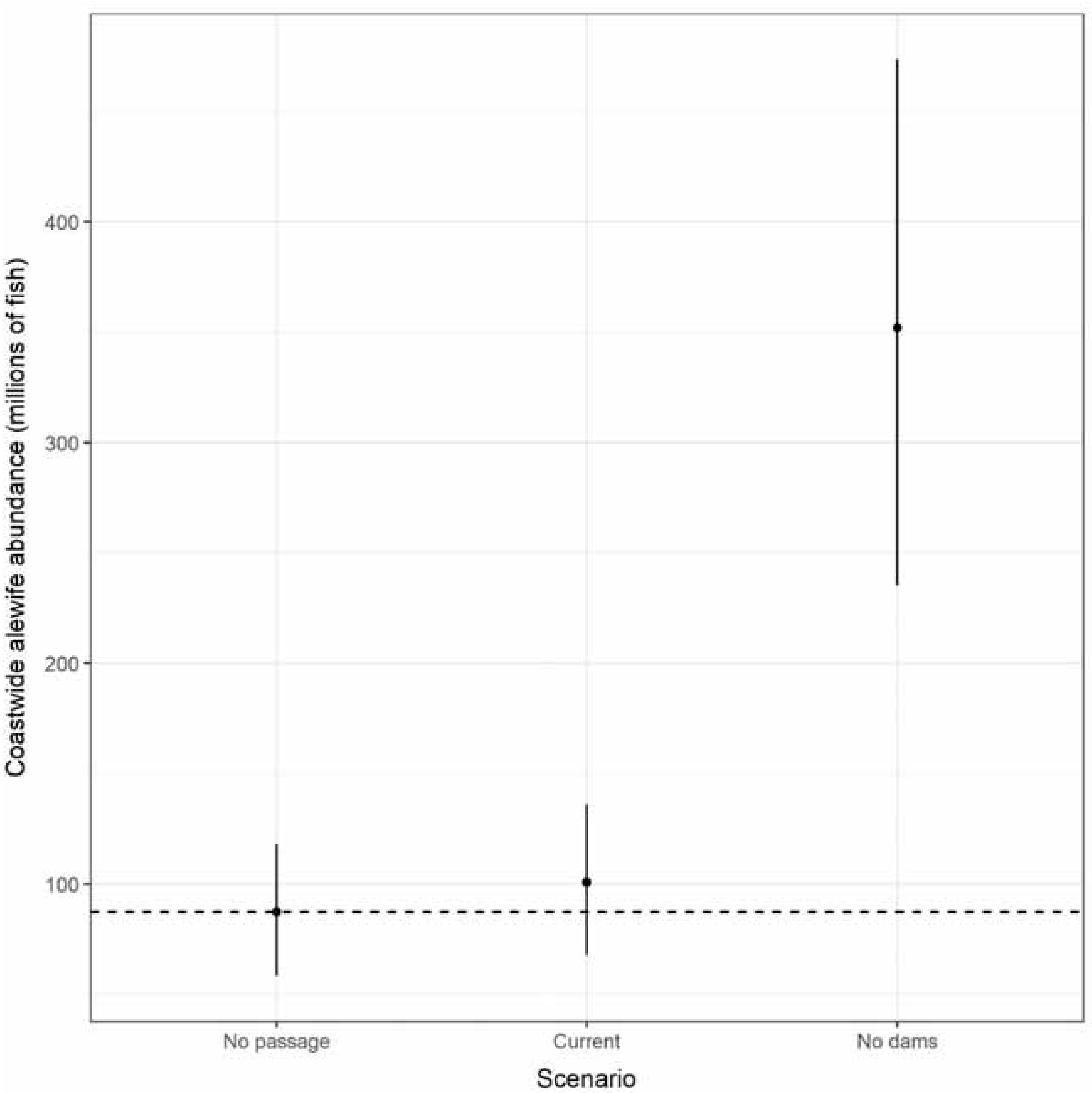


Figure 168. Predicted regional abundance of spawning alewife in watersheds on the east coast of the United States under "no passage", "current conditions", and "no dams" scenarios. Points are mean of simulated abundance, and vertical lines are 95% confidence intervals.

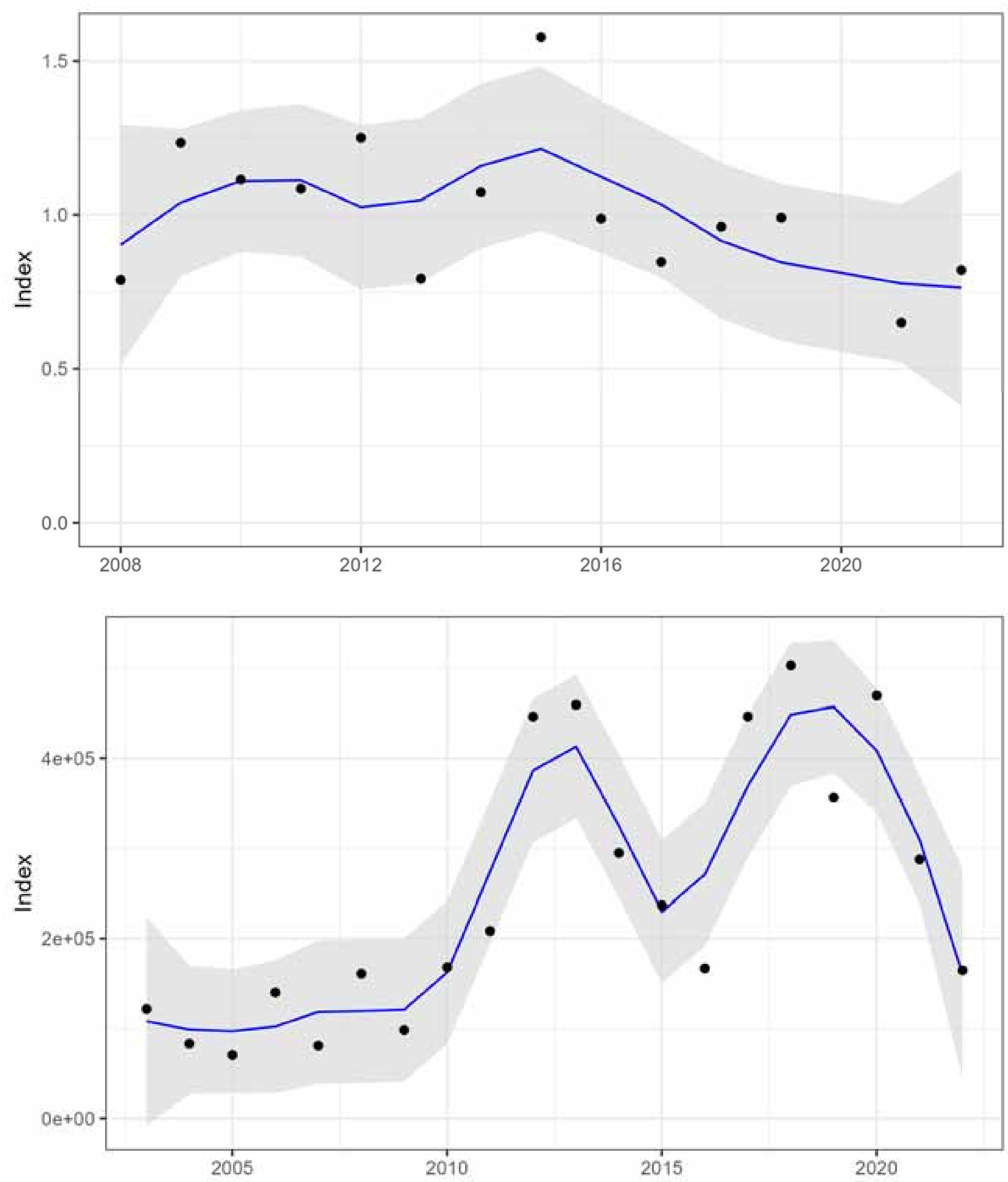


Figure 169. Indices used in the data limited catch cap approaches for alewife developed from fishery independent indices (top) and run counts for the SNE stock region, with the loess smoother (blue line) and its confidence intervals (grey area) for the iSmooth approach.

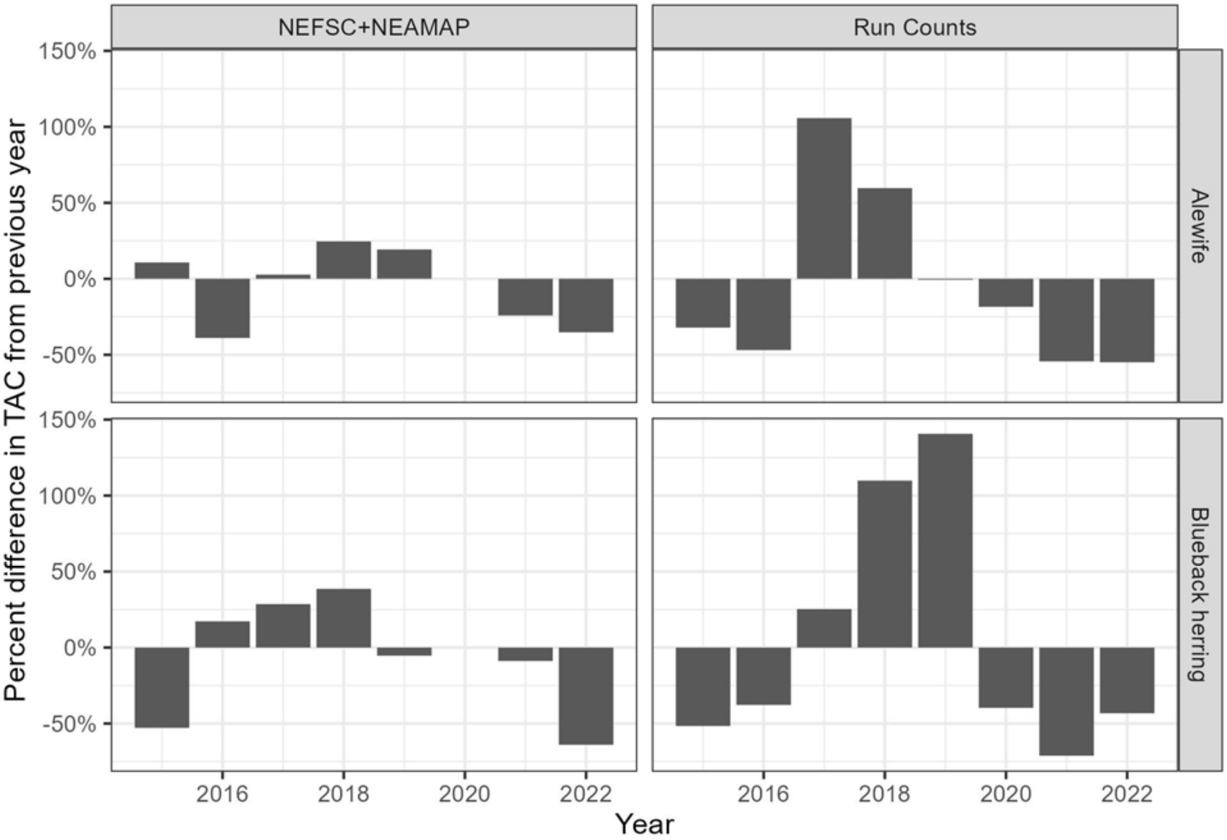


Figure 170. Percent difference from year-to-year in the TAC recommended by the iSmooth approach by species and type of input.

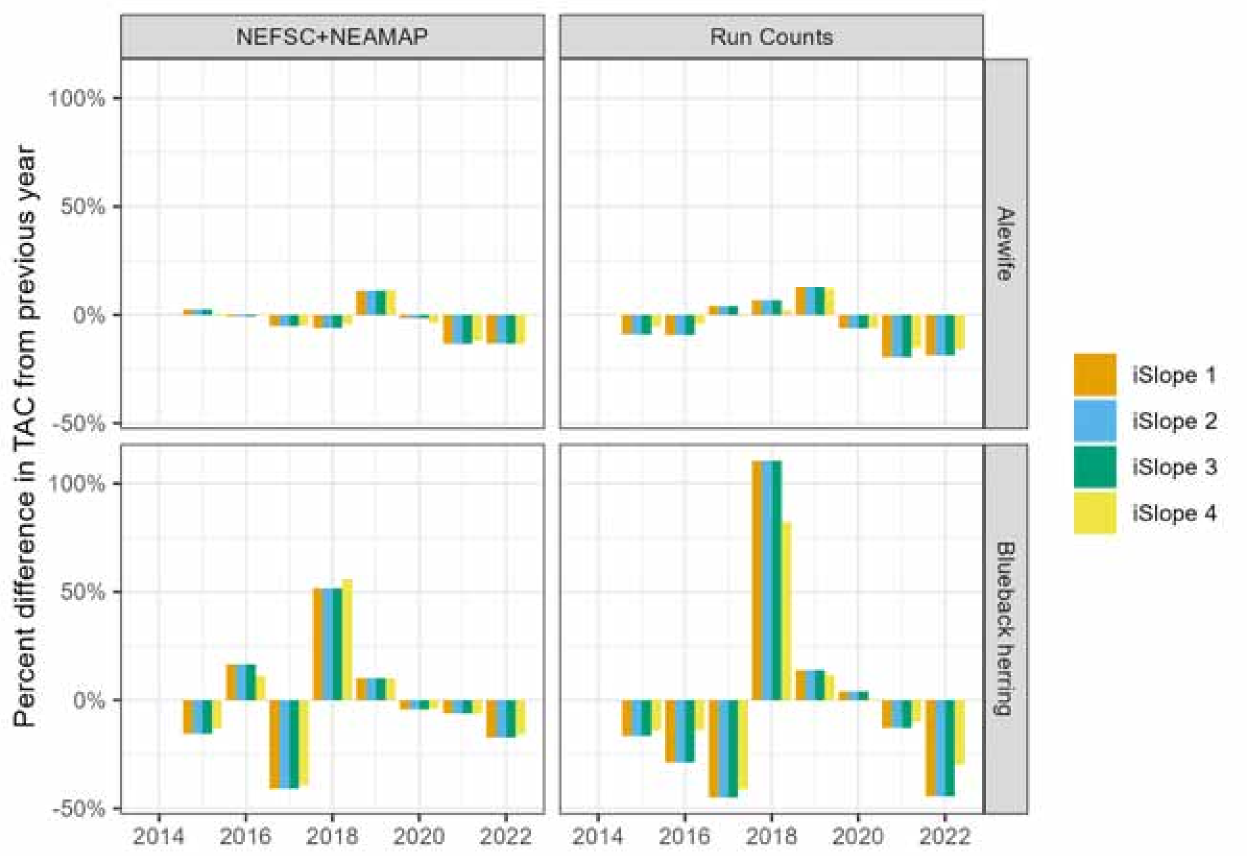


Figure 171. Percent difference from year-to-year in the TAC recommended by the iSlope approaches by species and type of input.

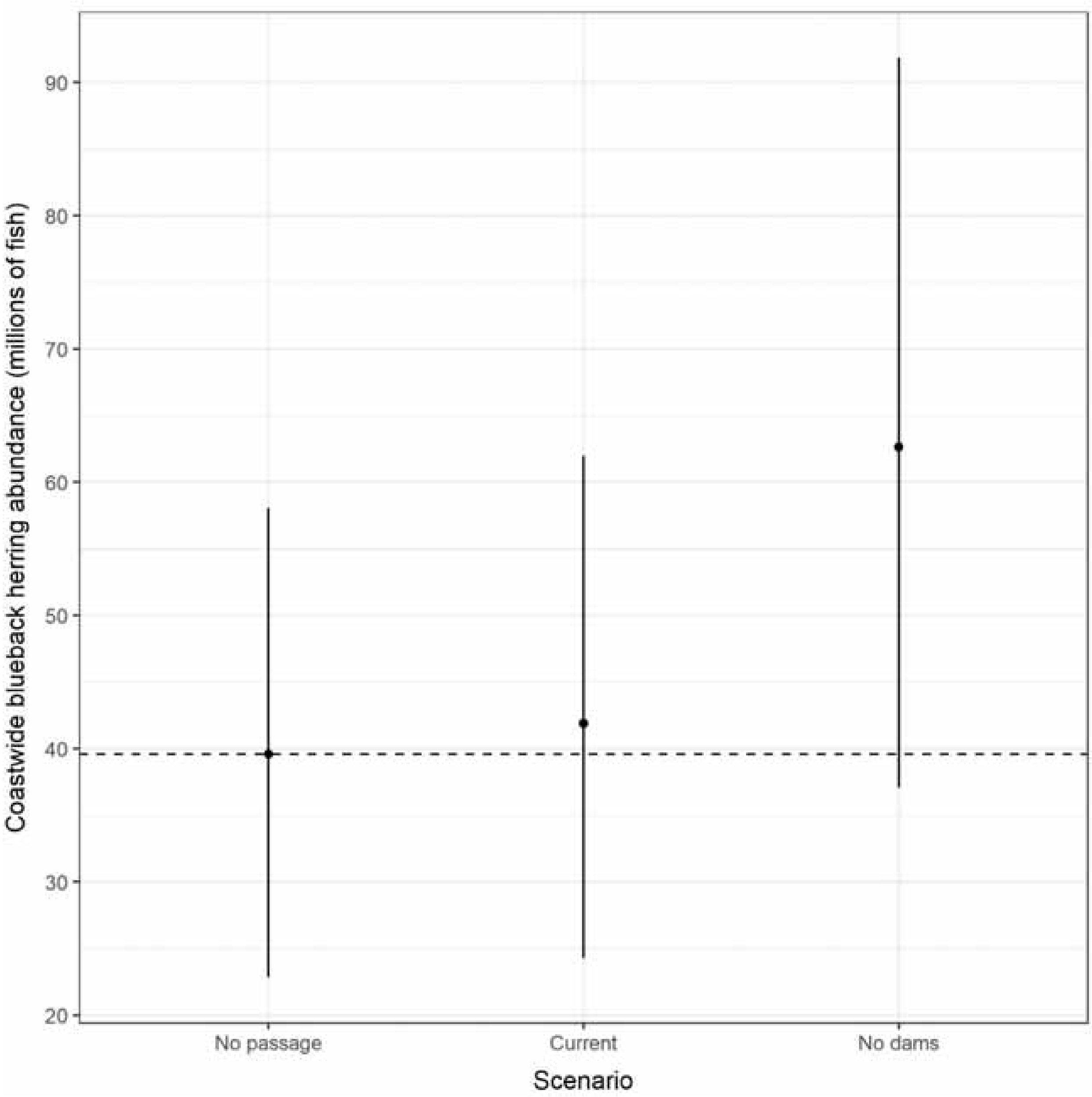


Figure 172. **Predicted coast-wide abundance of spawning blueback herring in watersheds on the east coast of the United States under "no passage", "current conditions", and "no dams" scenarios. Points are mean of simulated abundance, vertical lines are 95% confidence intervals, and the dashed horizonal line is abundance under the no-passage scenario.**

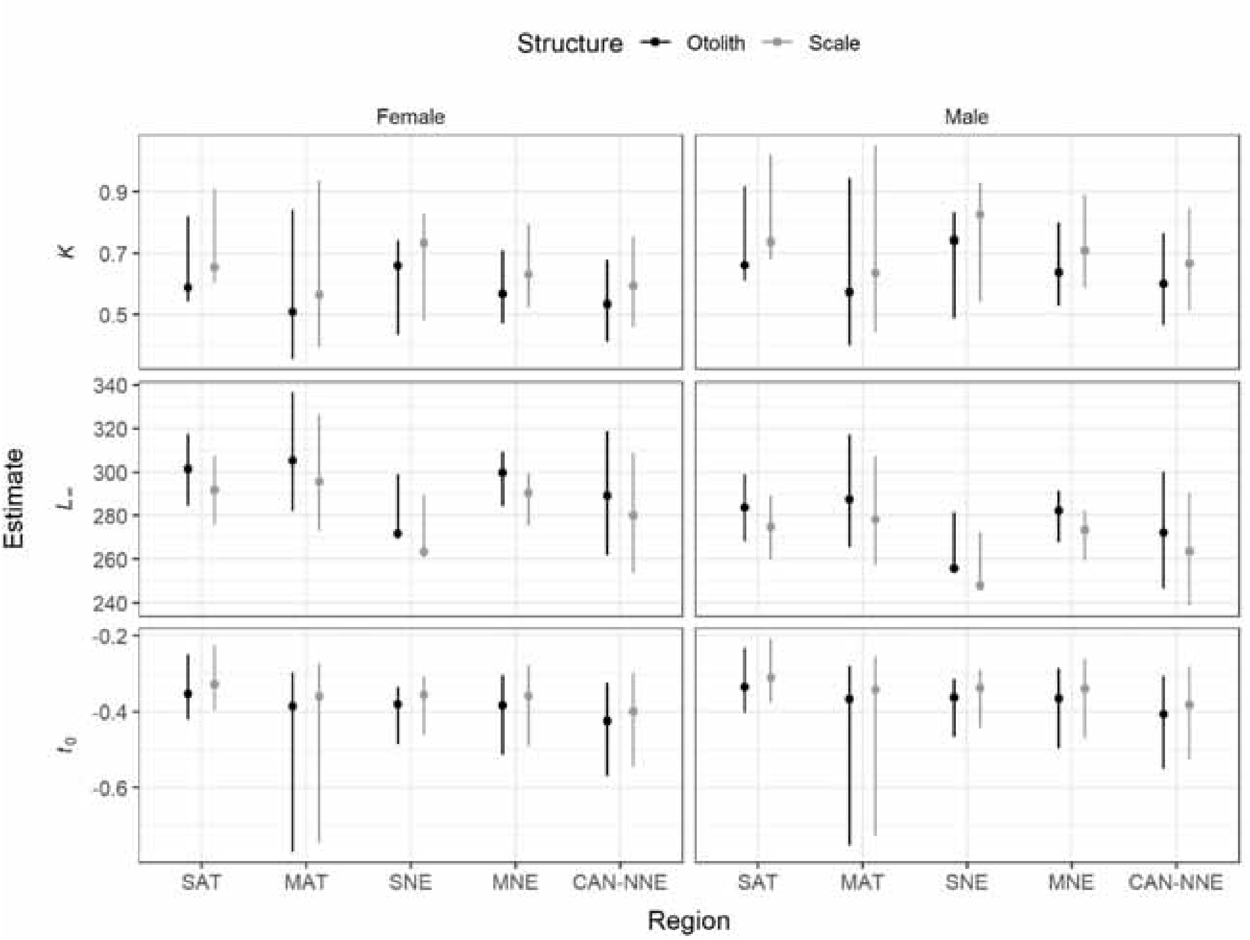


Figure 173. Estimated parameters of the von Bertalanffy growth function for blueback herring within regions, sex, and ageing structure. Parameters include Brody growth coefficient (*K*), mean asymptotic total length (L_∞) in mm, and estimated age at which length was zero (t_0). Points are estimated posterior means, and vertical lines are 95% credible intervals for those estimates. Regions are organized from south to north left to right: South Atlantic (SAT), Mid-Atlantic (MAT), Southern New England (SNE), Middle New England (MNE) and Canada-Northern New England (CAN-NNE).

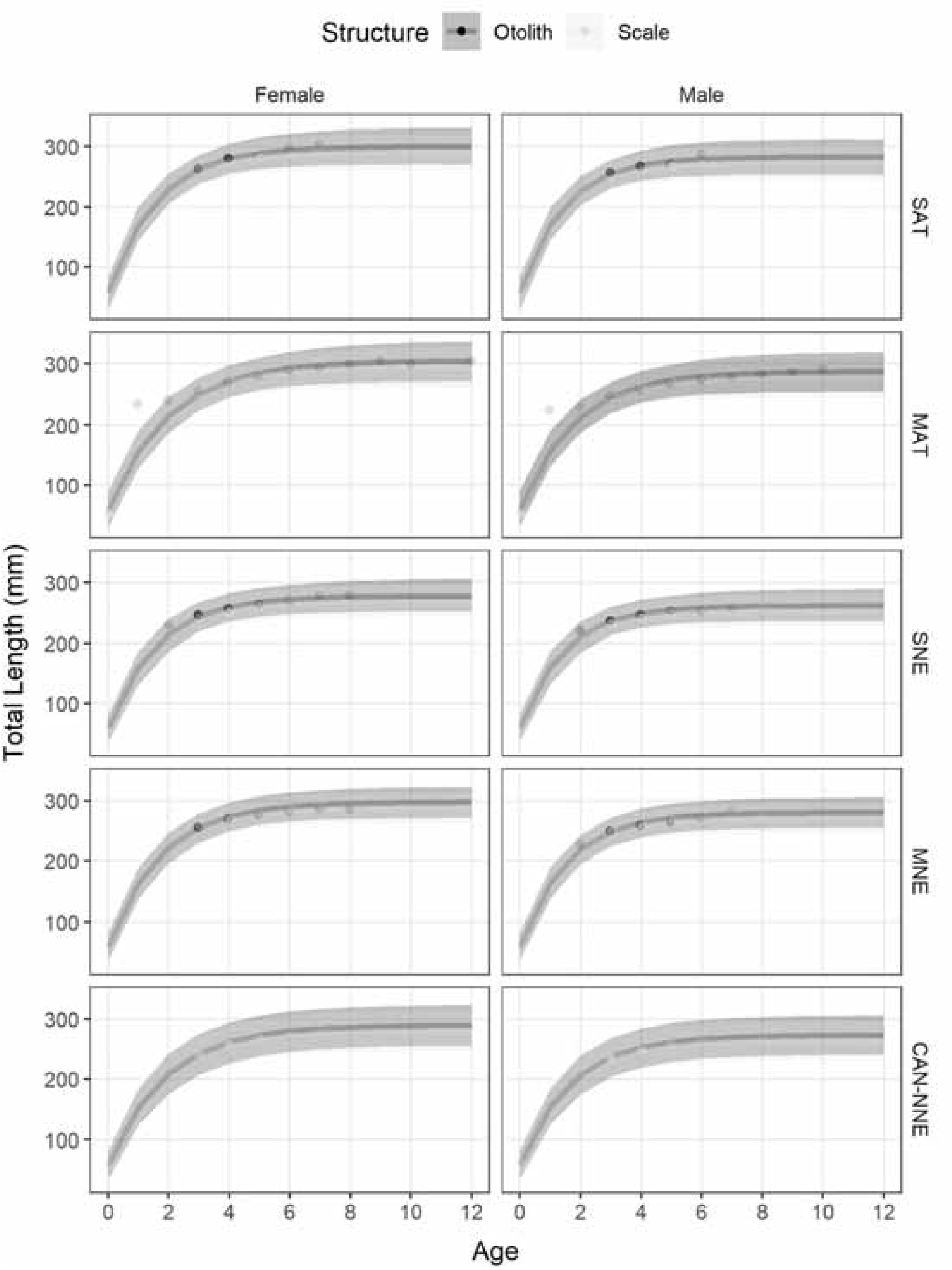


Figure 174. Regional von Bertalanffy growth function predictions and empirical mean length at age for blueback herring within aging structures and sex. Points are regional mean length at age, with opacity directly proportional to sample size. Lines are mean predictions fitted growth models, and ribbons are 95% credible intervals. Regions are organized from south to north from top to bottom: South Atlantic (SAT), Mid-Atlantic (MAT), Southern New England (SNE), Middle New England (MNE) and Canada-Northern New England (CAN-NNE).

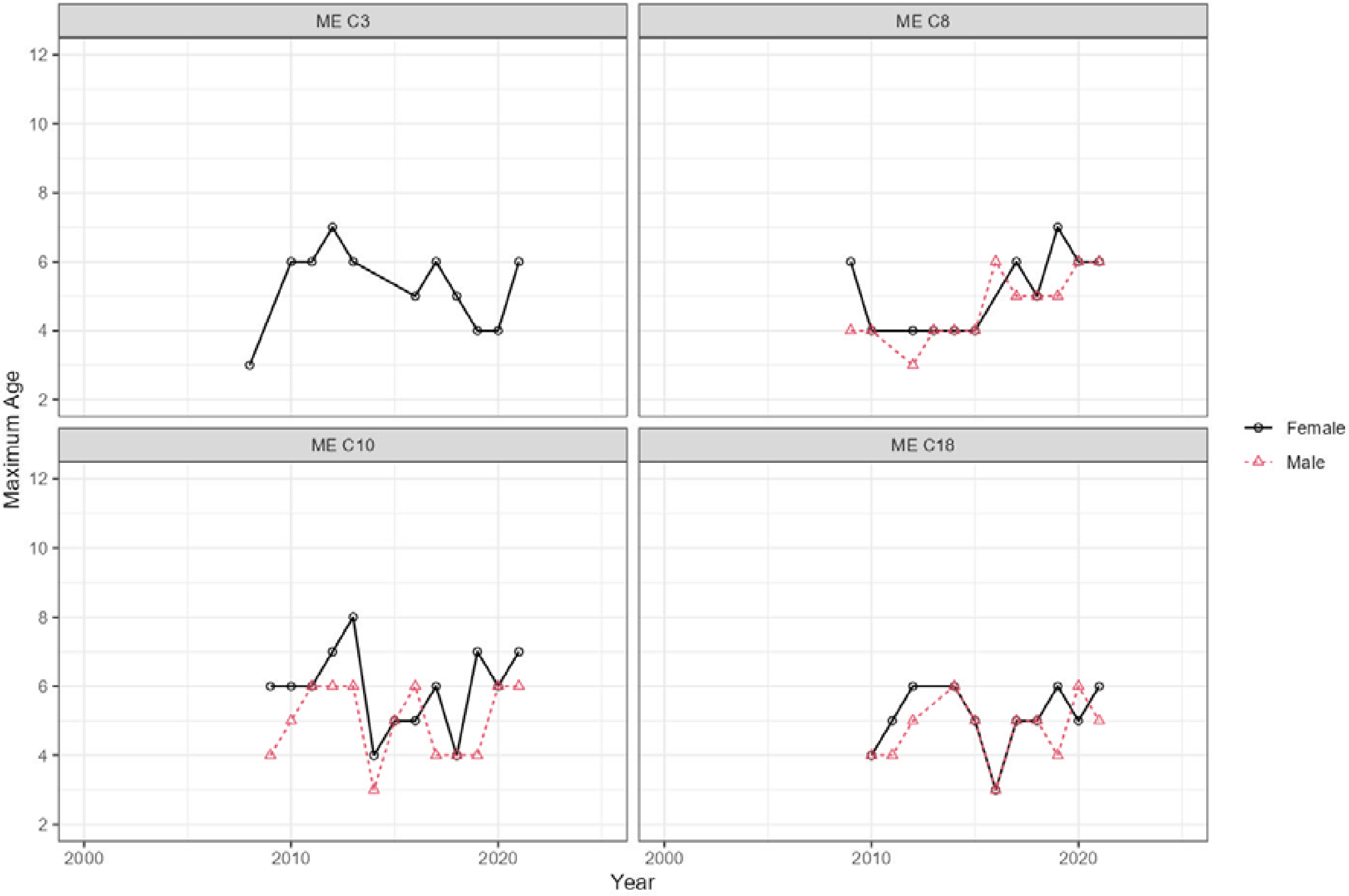


Figure 175. **Maximum scale-based ages for blueback herring by sex for rivers in the CAN-NNE stock-region.**

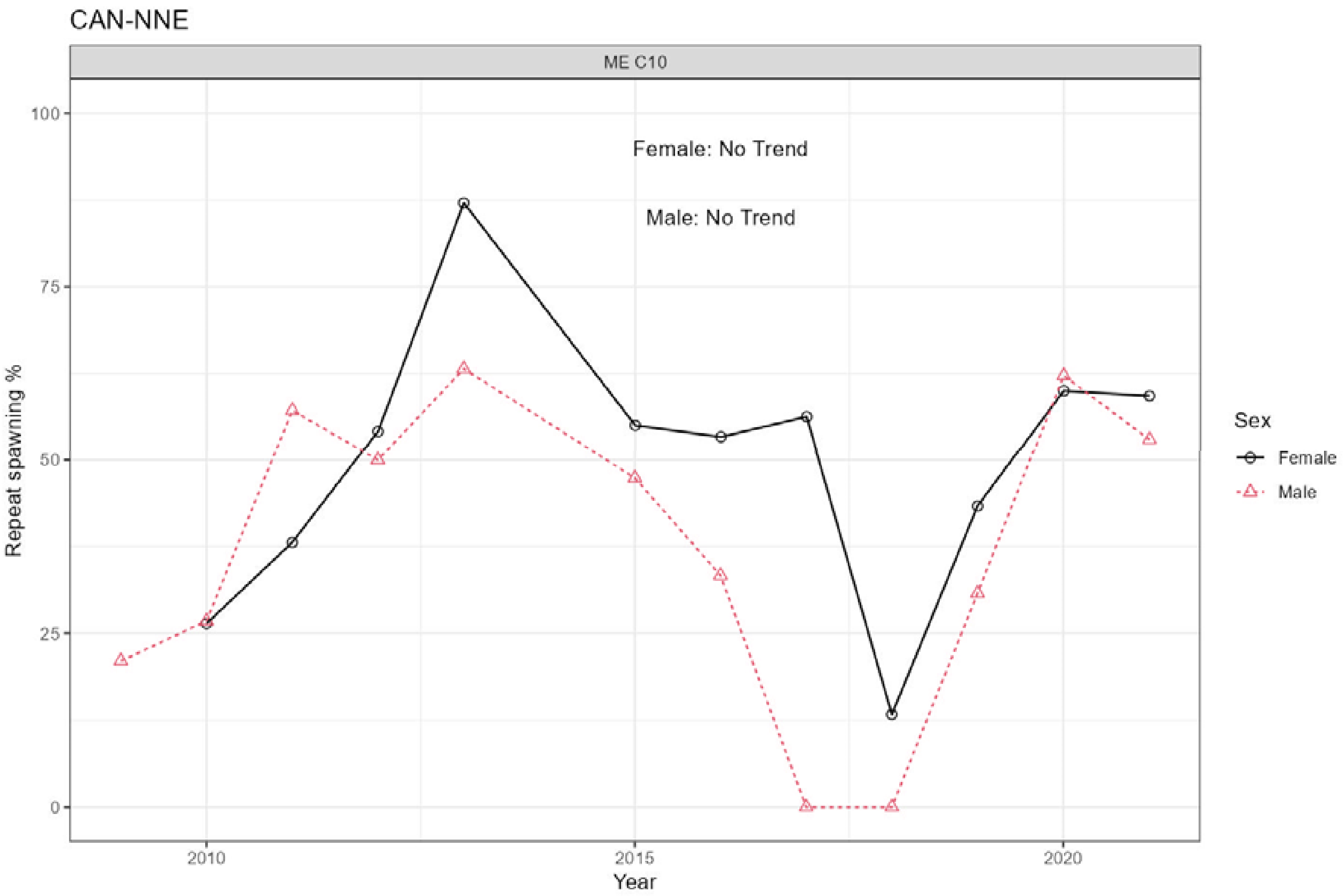


Figure 176. **Trends in repeat spawner percentage for blueback herring from rivers in the CAN-NNE stock-region.**

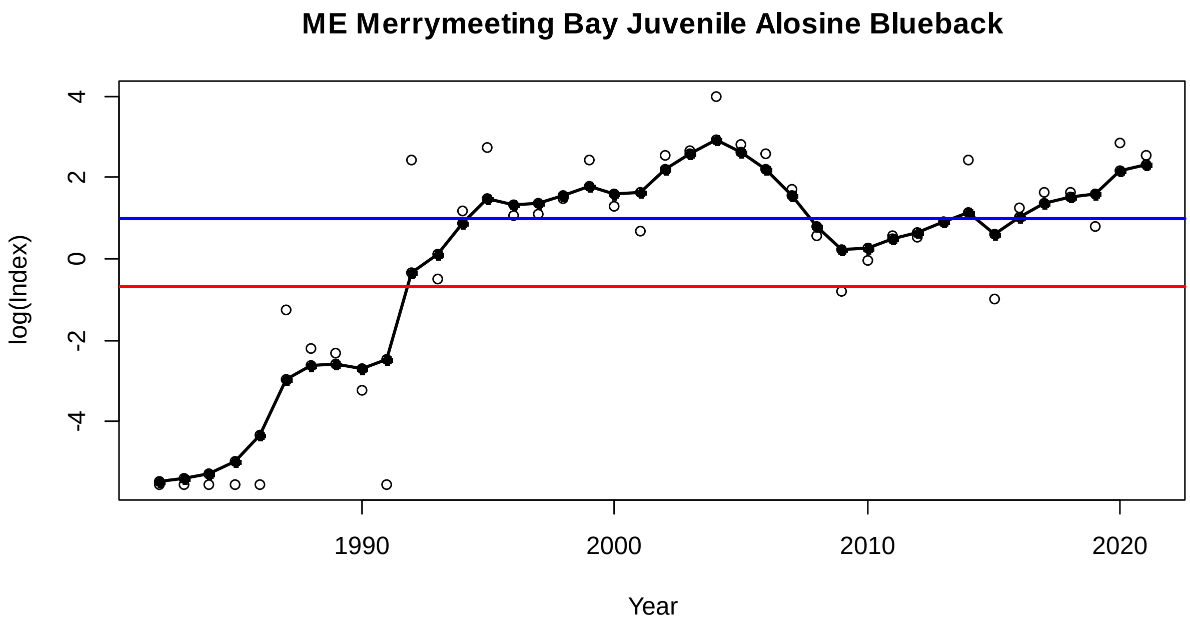


Figure 177. ARIMA model fits to the Merrymeeting Bay Juvenile Alosine Survey for blueback herring (the only blueback herring survey for the CAN-NNE stock-region) Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

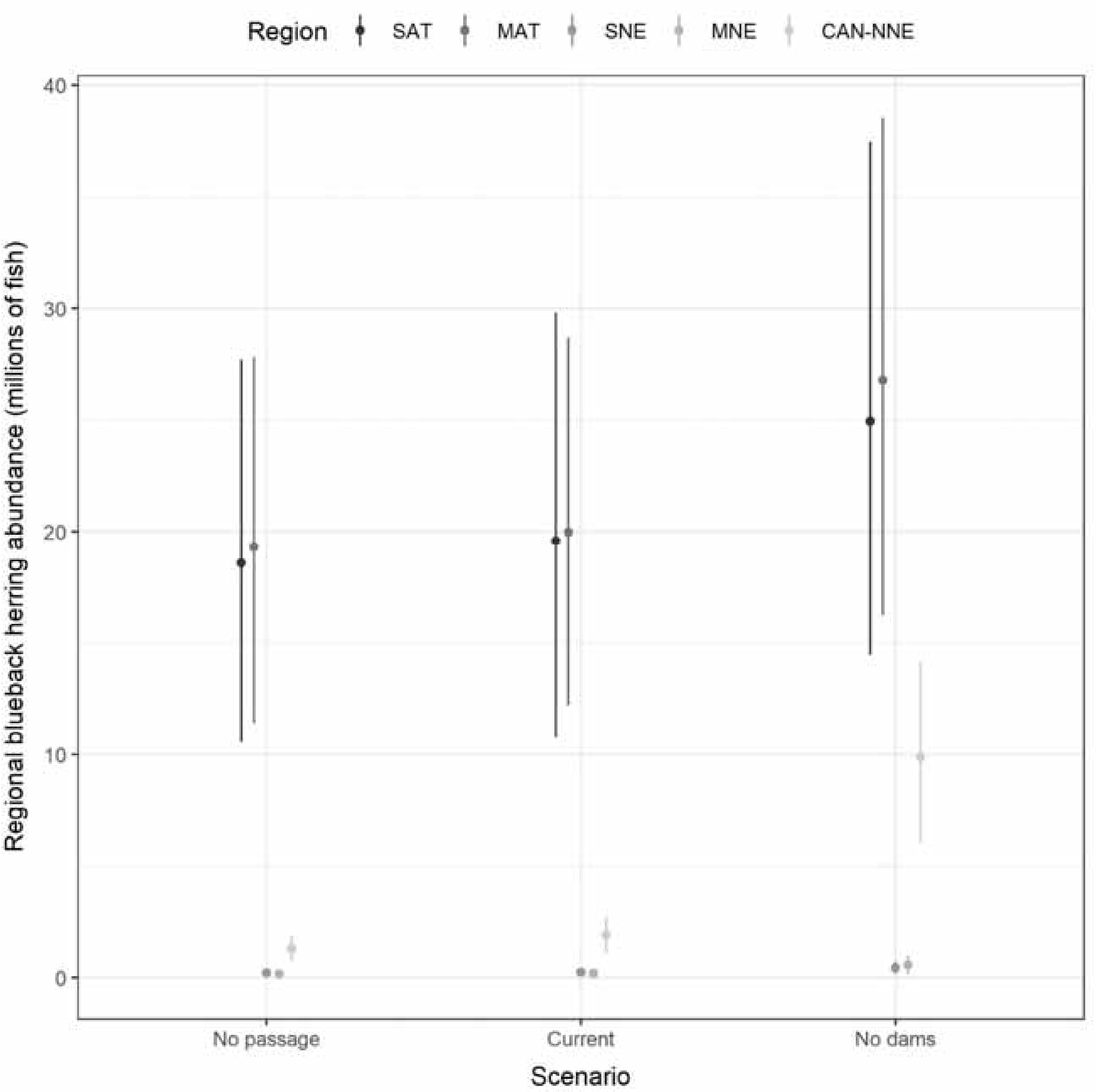


Figure 178. **Predicted coast-wide abundance of spawning blueback herring in watersheds on the east coast of the United States under varying upstream passage through dams, and downstream survival of juveniles and adults through dams. Points are mean of simulated abundance, vertical lines are 95% confidence intervals, and the dashed horizontal line is abundance under the no-passage scenario.**

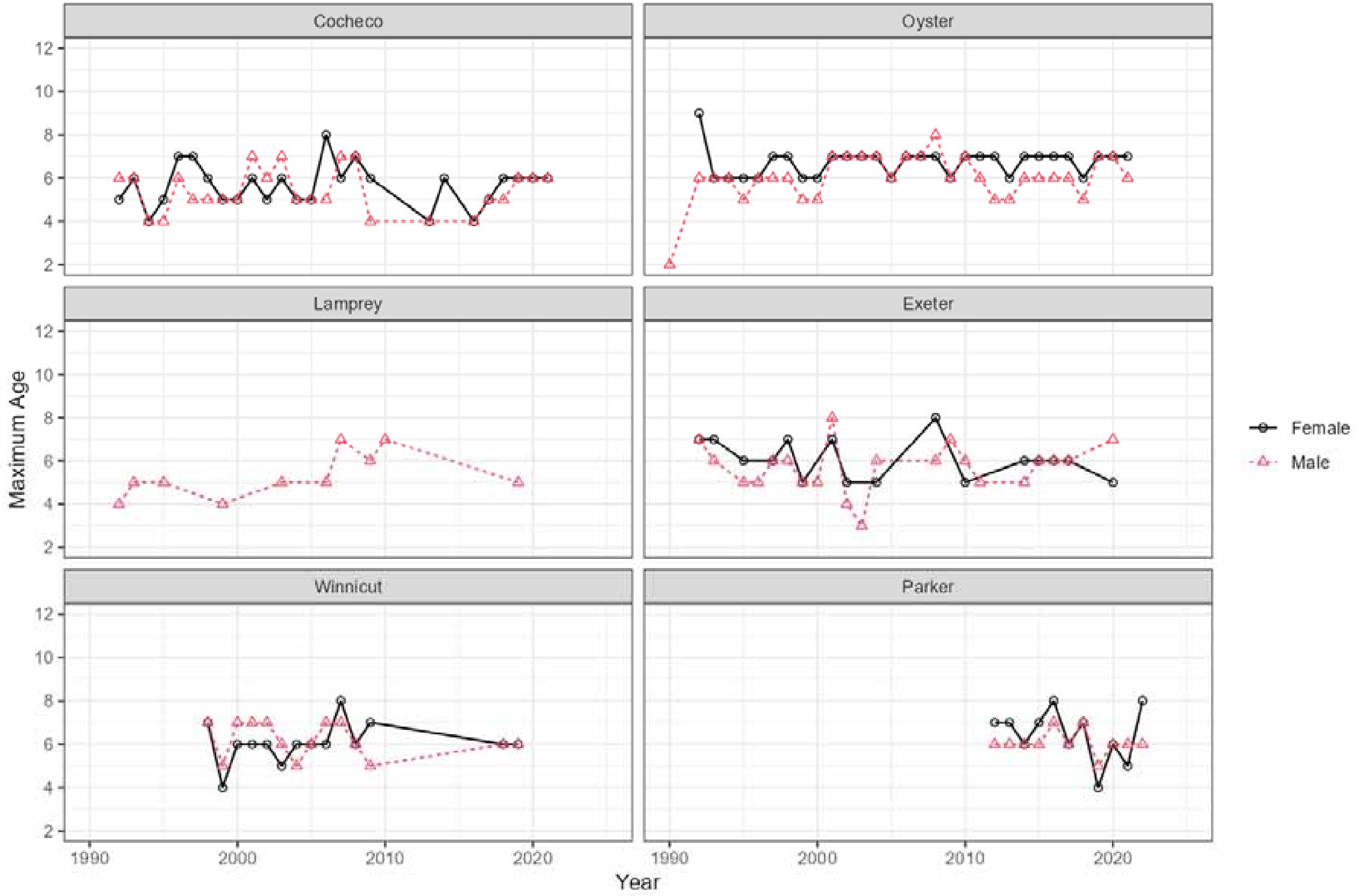


Figure 179. Maximum scale-based ages for blueback herring by sex and river in the MNE stock-region

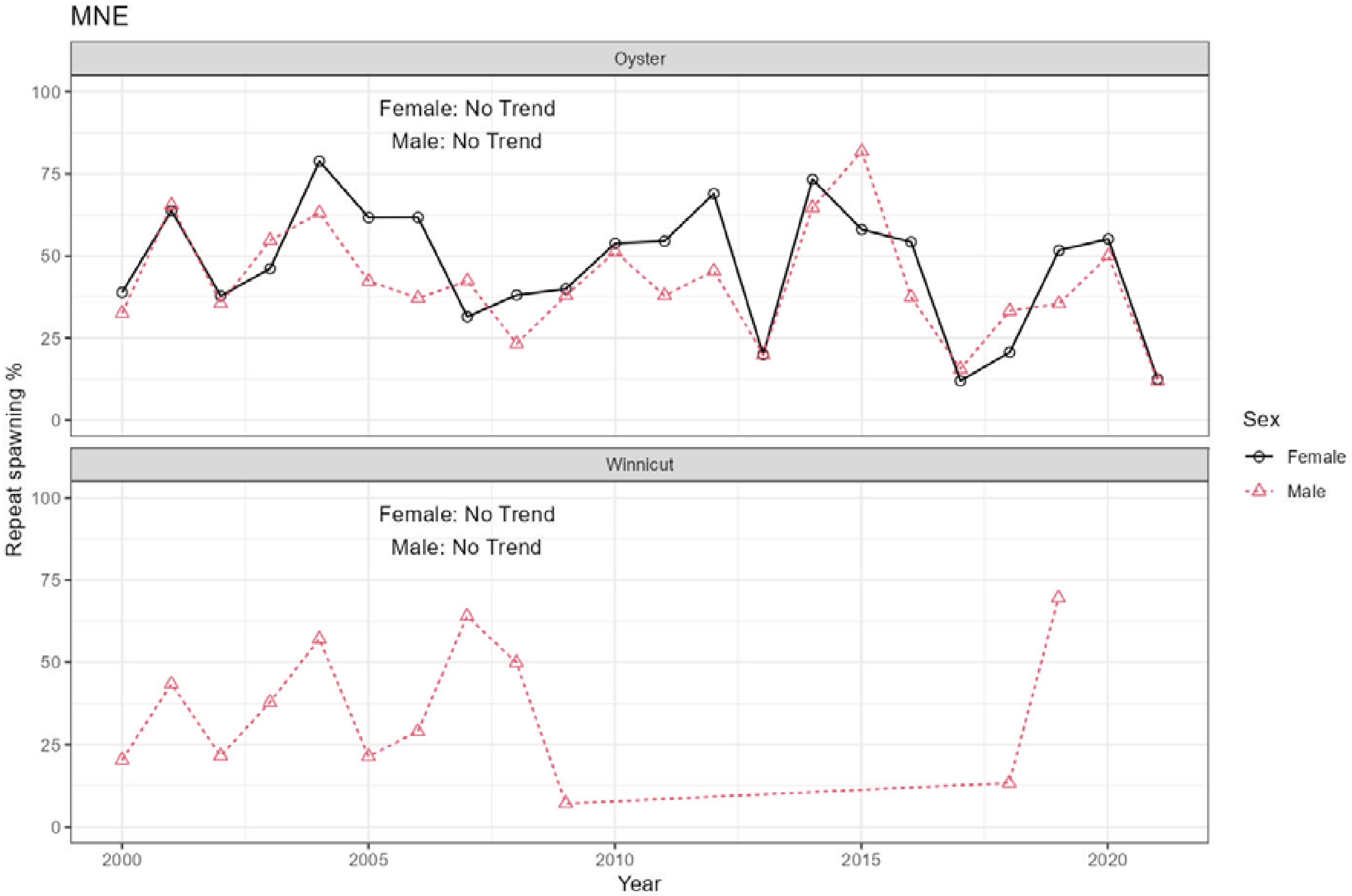


Figure 180. Repeat spawner percentages for blueback herring by river and sex for the MNE stock-region.

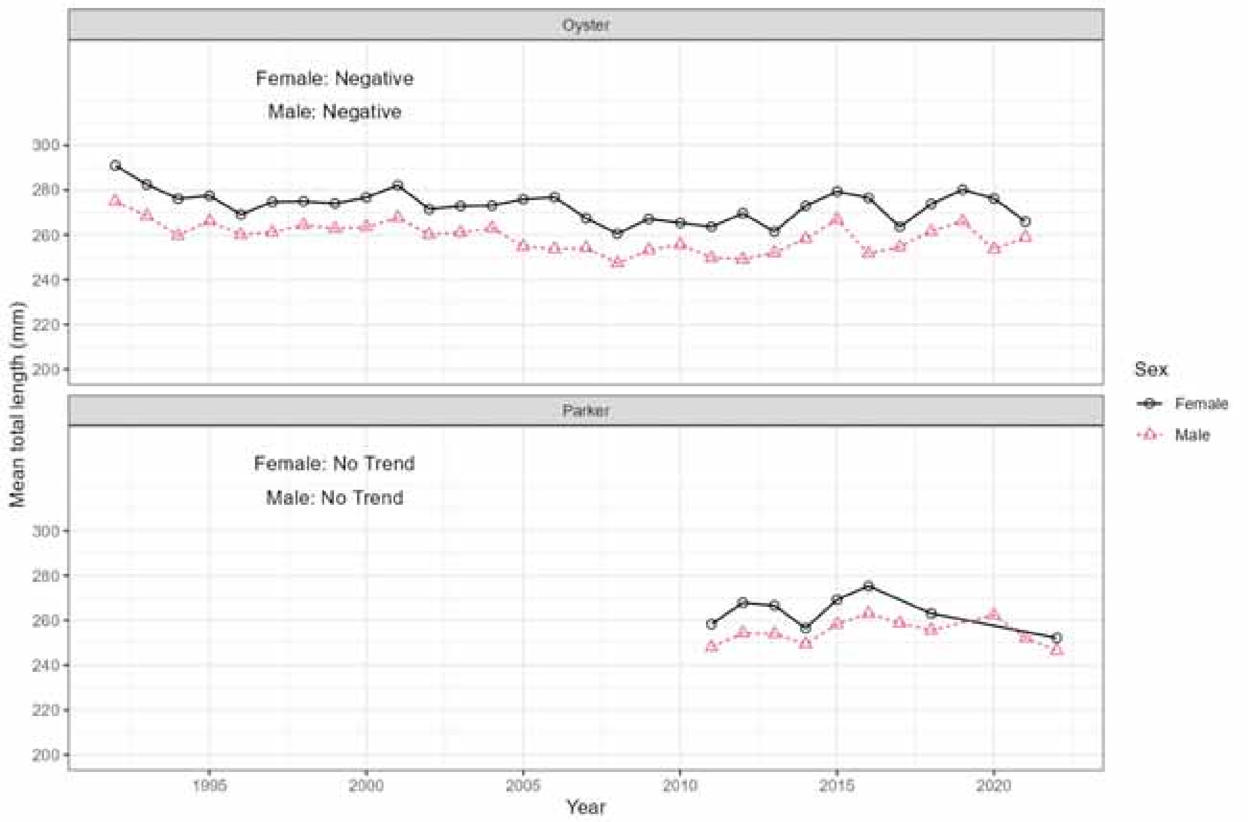


Figure 181. **Mean length by year for female and male blueback herring from two river systems in the MNE stock-region.**

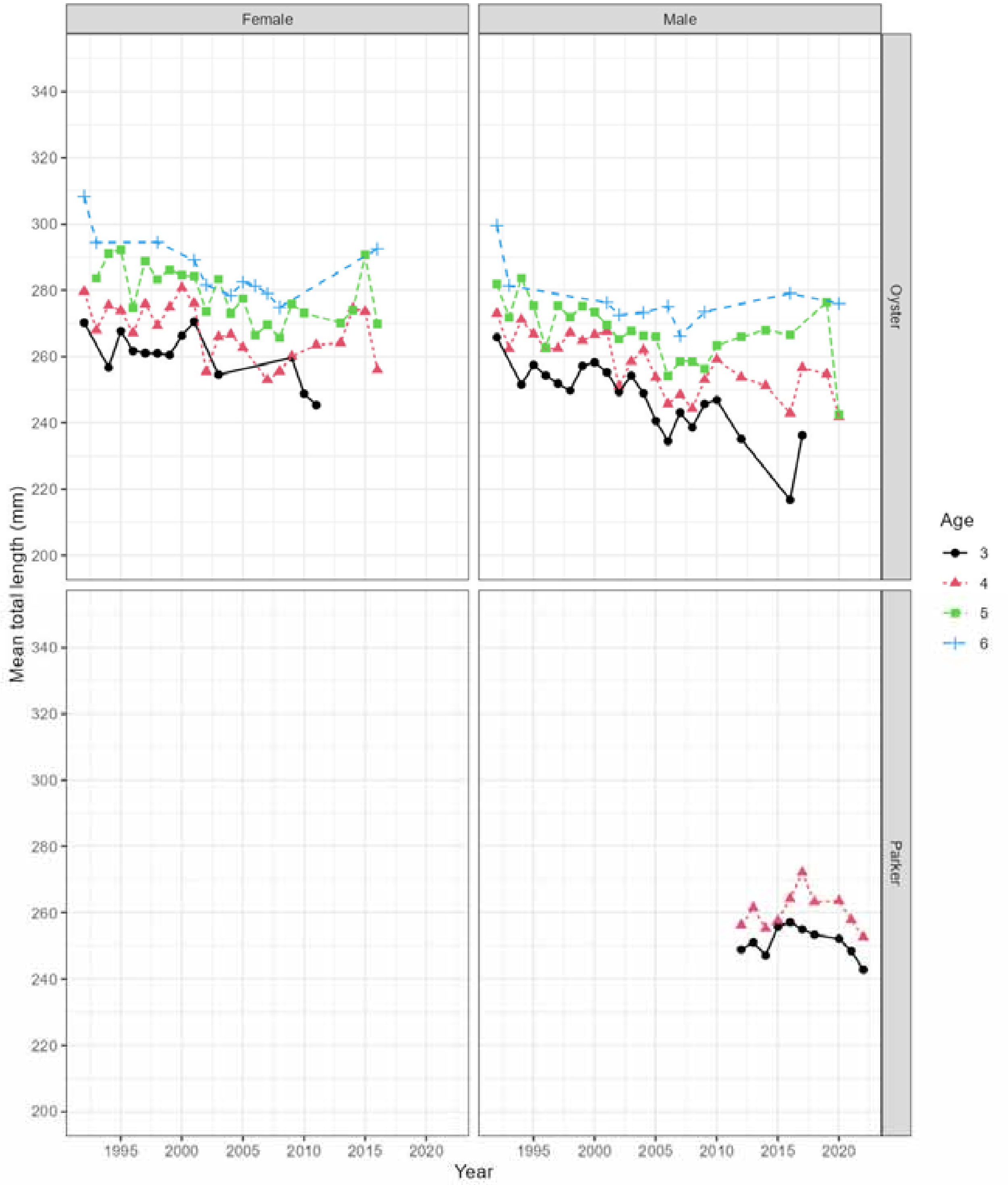


Figure 182. **Mean lengths-at-age of male and female blueback herring from two rivers in the MNE stock-region by sex, river, age, and year. Oyster River ages are derived from scales and Parker River ages are from otoliths.**

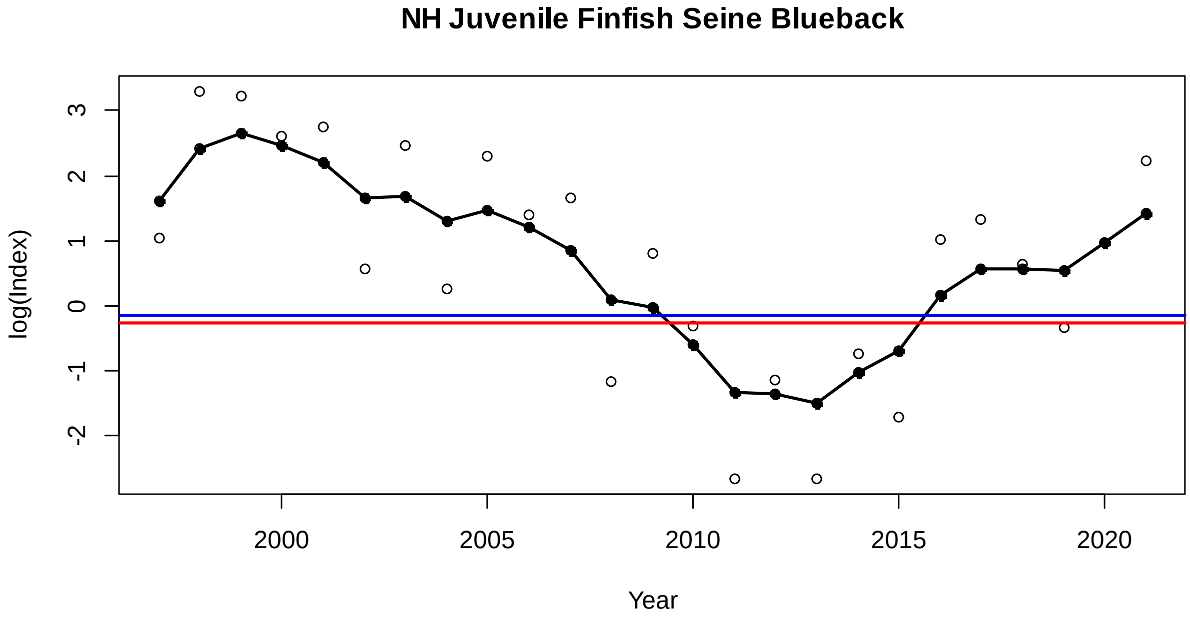


Figure 183. ARIMA model fits to the New Hampshire Juvenile Finfish Seine Survey for blueback herring (the only blueback herring survey for the MNE stock-region). Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

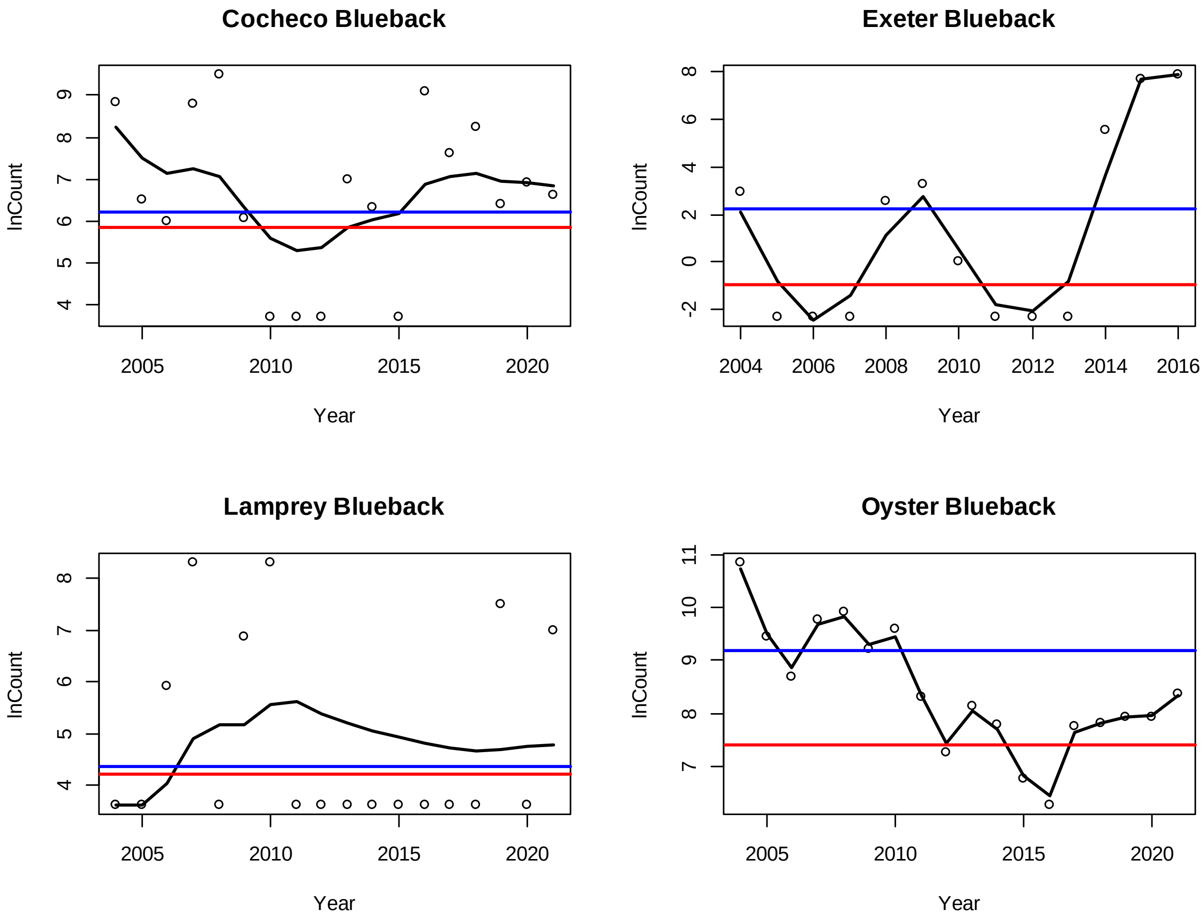


Figure 184. **ARIMA model fits to blueback herring run counts from the MNE stock-region. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.**

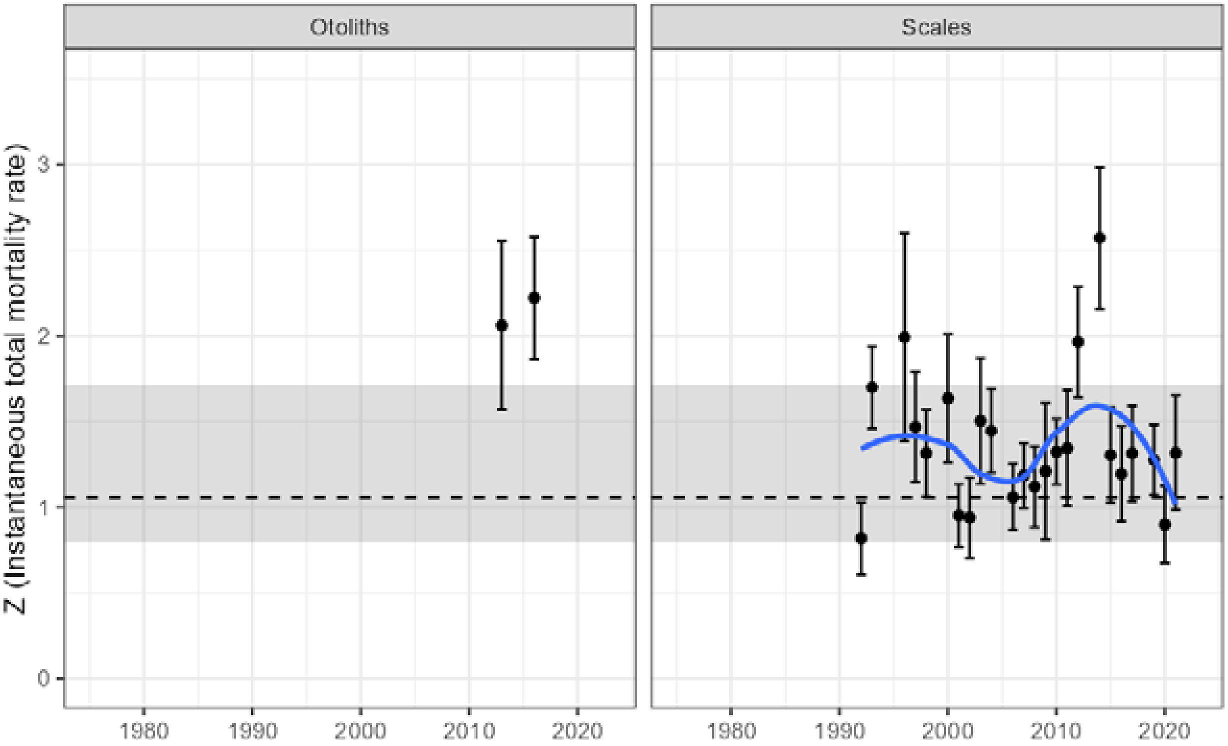


Figure 185. Estimates of total instantaneous mortality (Z) for blueback herring from the MNE stock-region by ageing structure, plotted with the $Z_{40\%SPR}$ reference points for the MNE stock-region. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

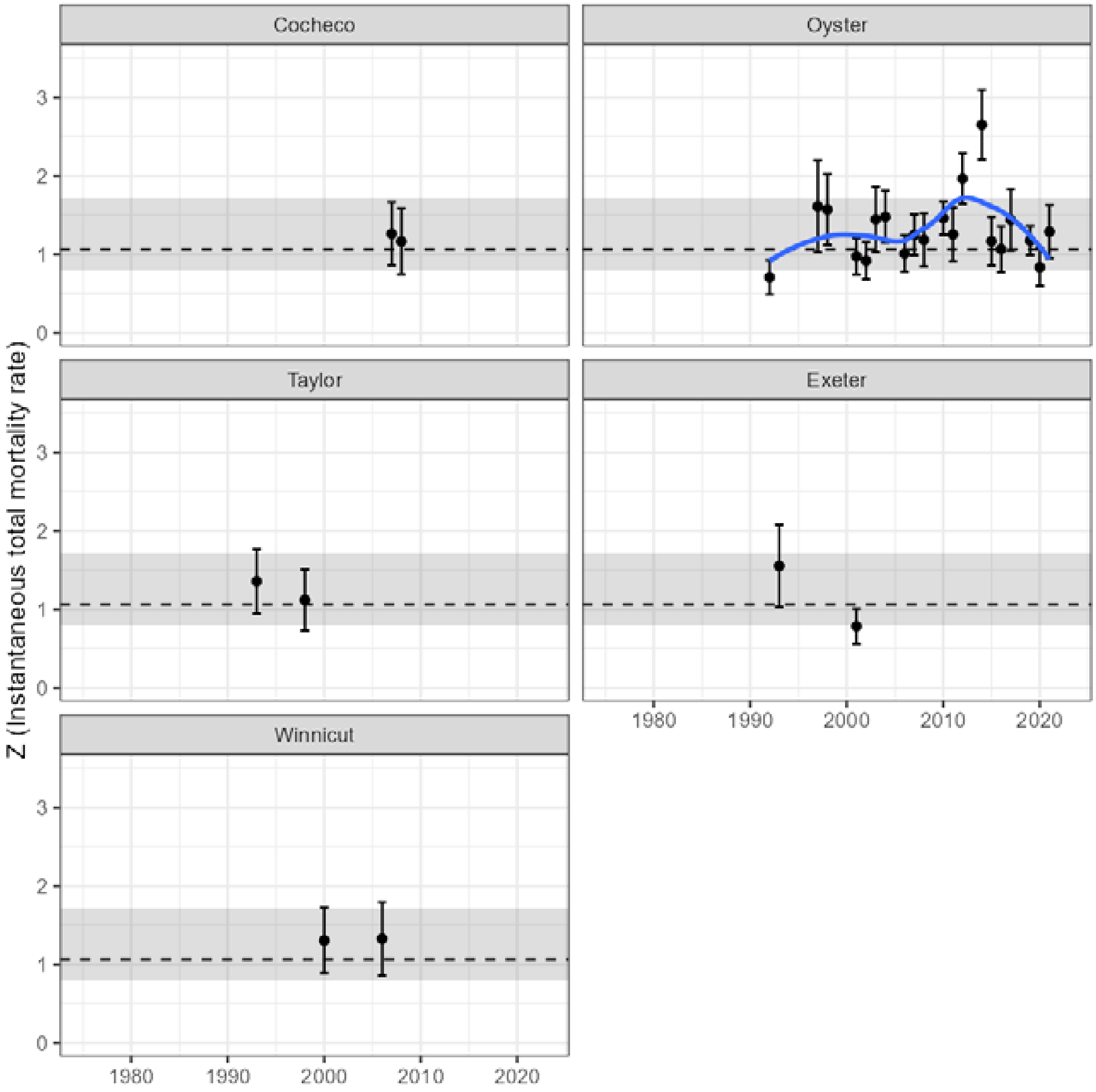


Figure 186. **Age-based estimates of total instantaneous mortality for MNE blueback herring (from scale data) in New Hampshire by river and year. Blues lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.**

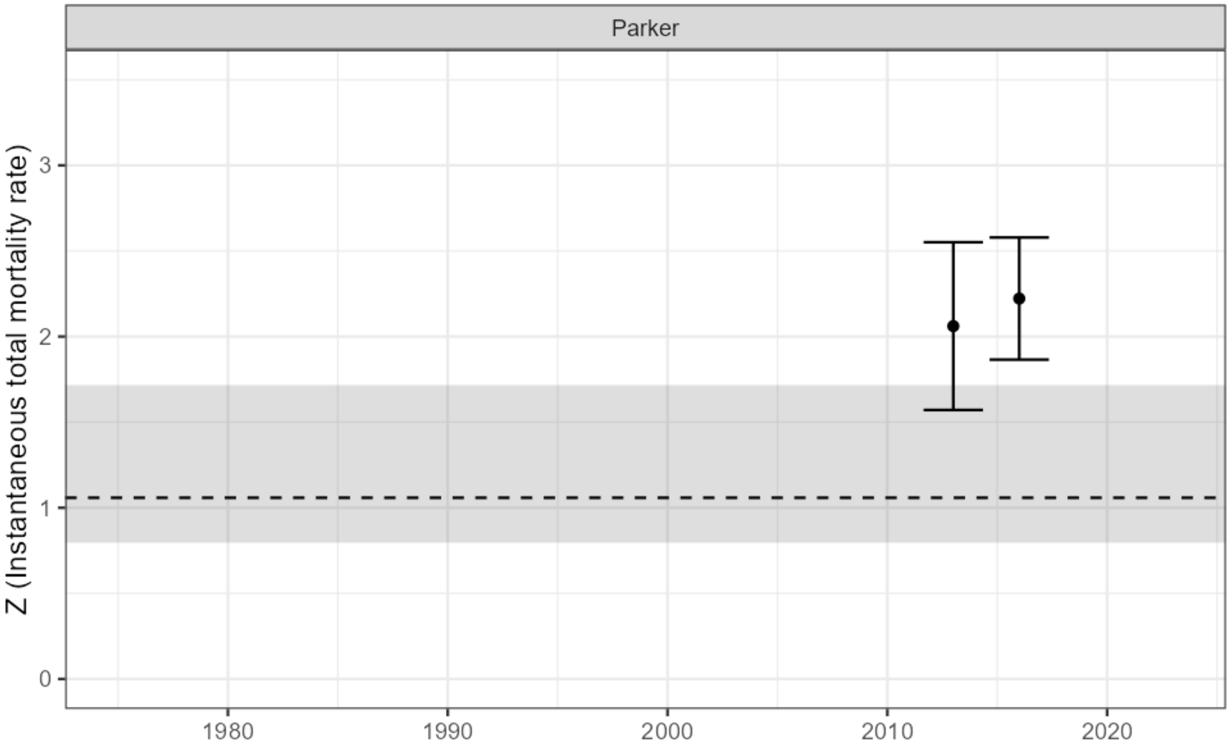


Figure 187. Age-based estimates of total instantaneous mortality for MNE blueback herring (from otolith data) in Massachusetts by river and year. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

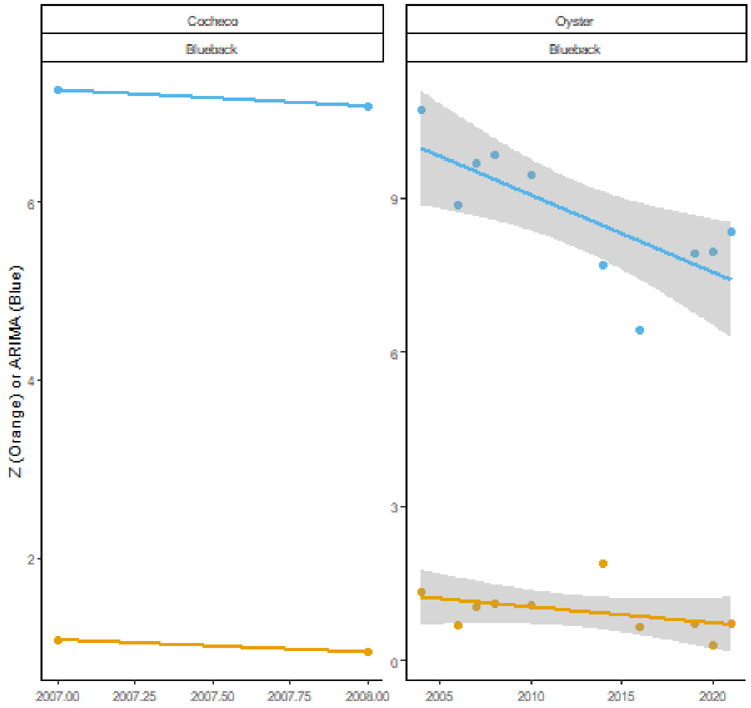


Figure 188. **Comparison of Z (orange lines/points) and ARIMA indices of blueback herring run counts (blue lines/points) for the MNE stock-region for systems where both metrics are available.**

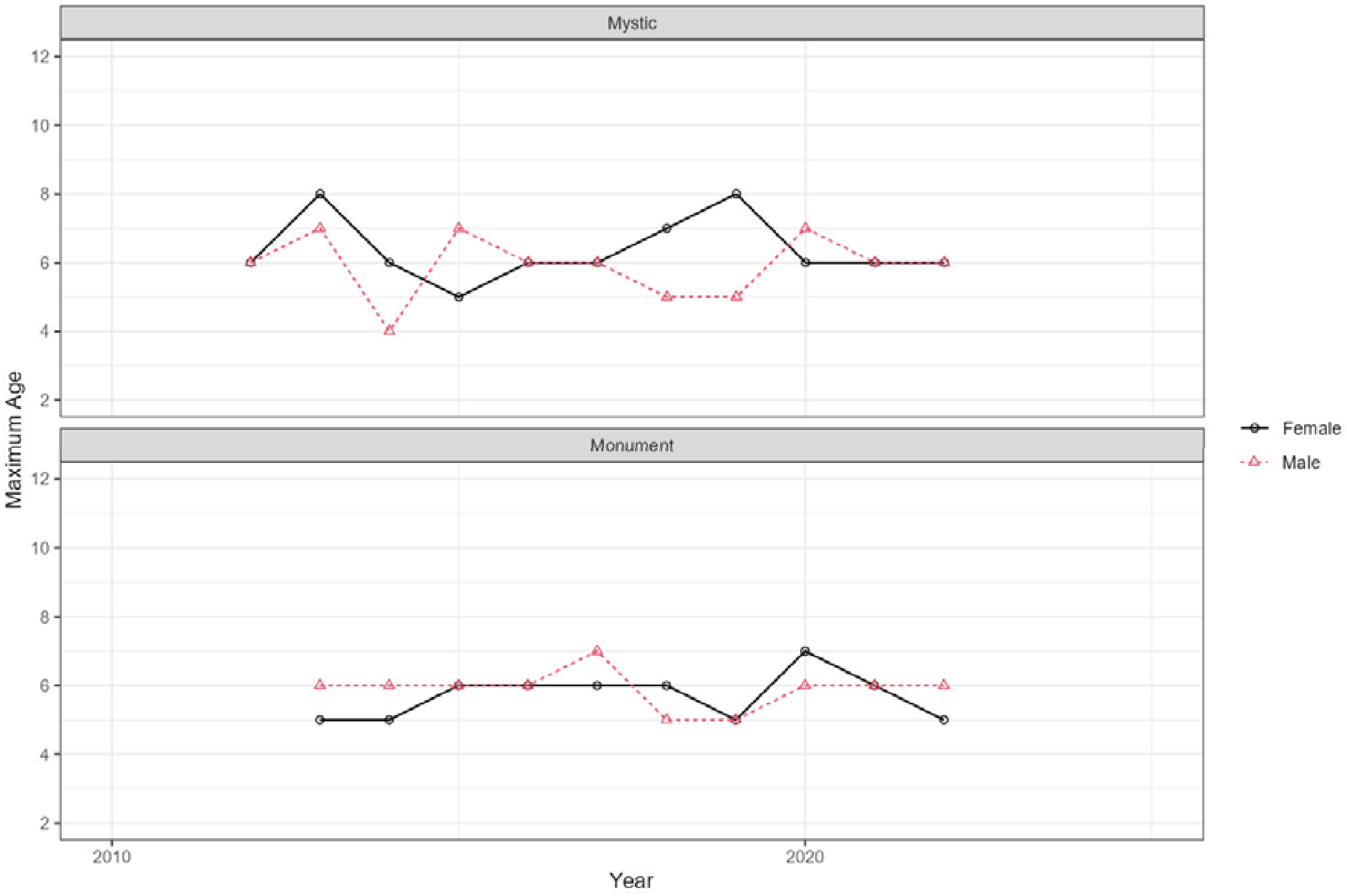


Figure 189. **Maximum scale-based ages for blueback herring by sex for rivers in the SNE stock-region.**

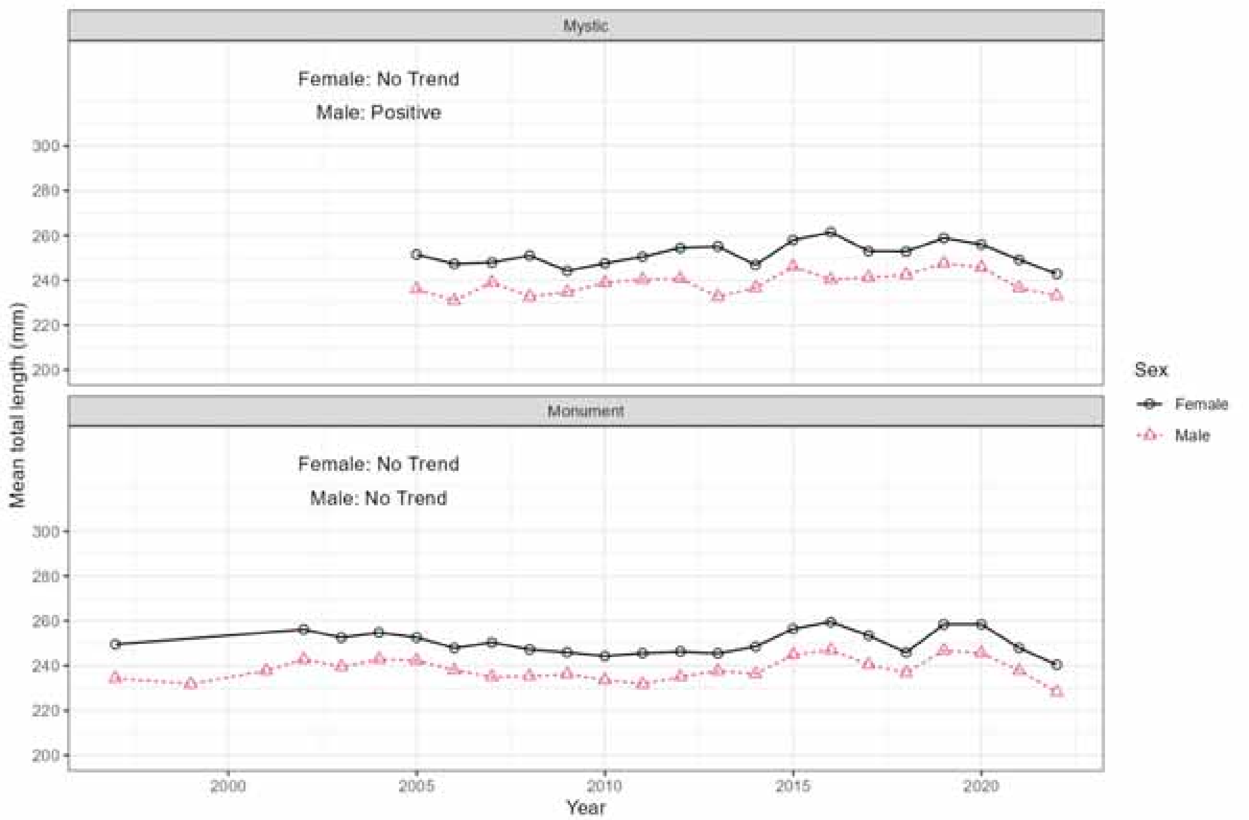


Figure 190. Mean length by year for female and male blueback herring in two river systems from the SNE stock-region.

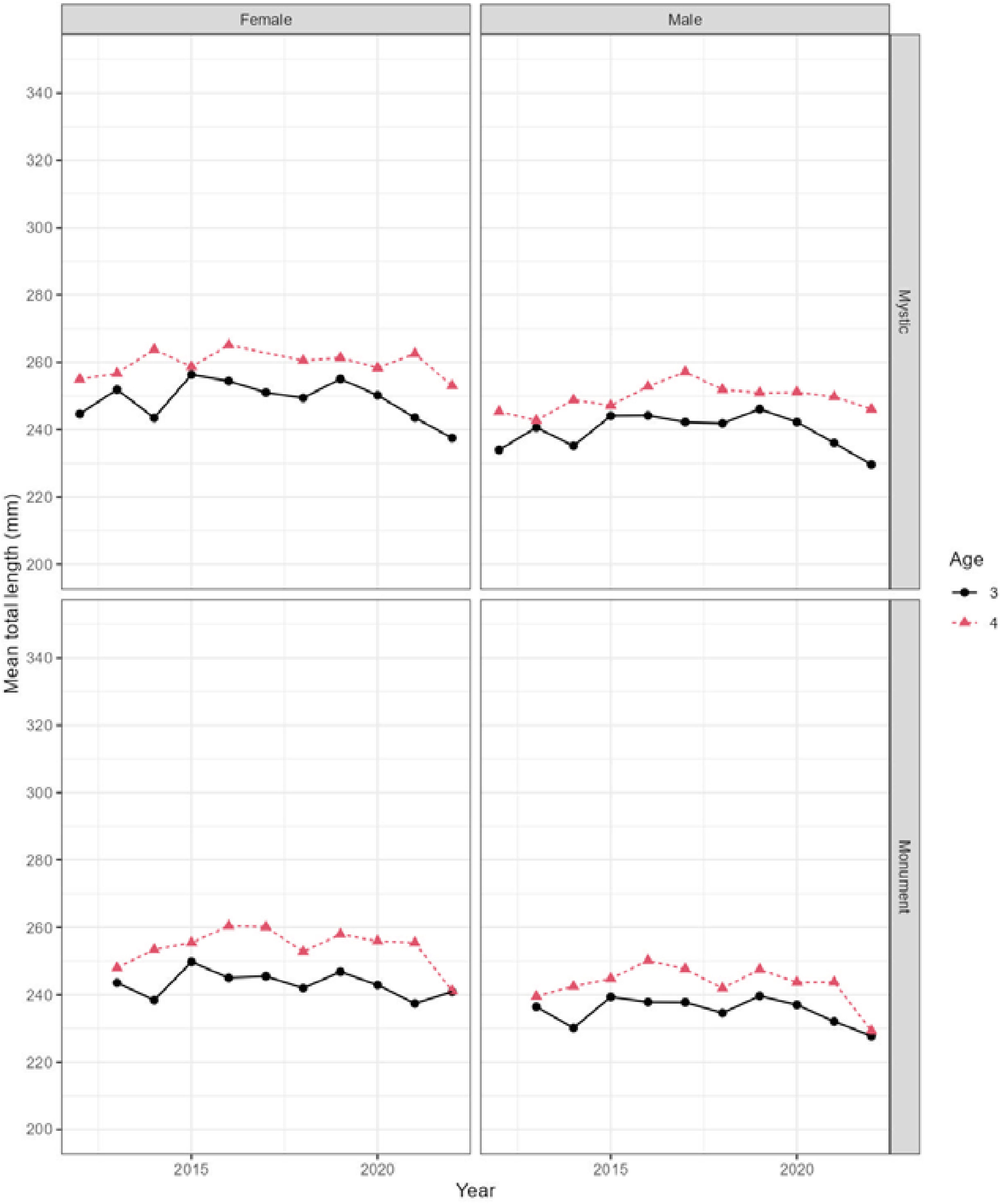


Figure 191. **Mean lengths-at-age of male and female blueback herring from two rivers in the SNE stock-region by sex, river, age, and year.**

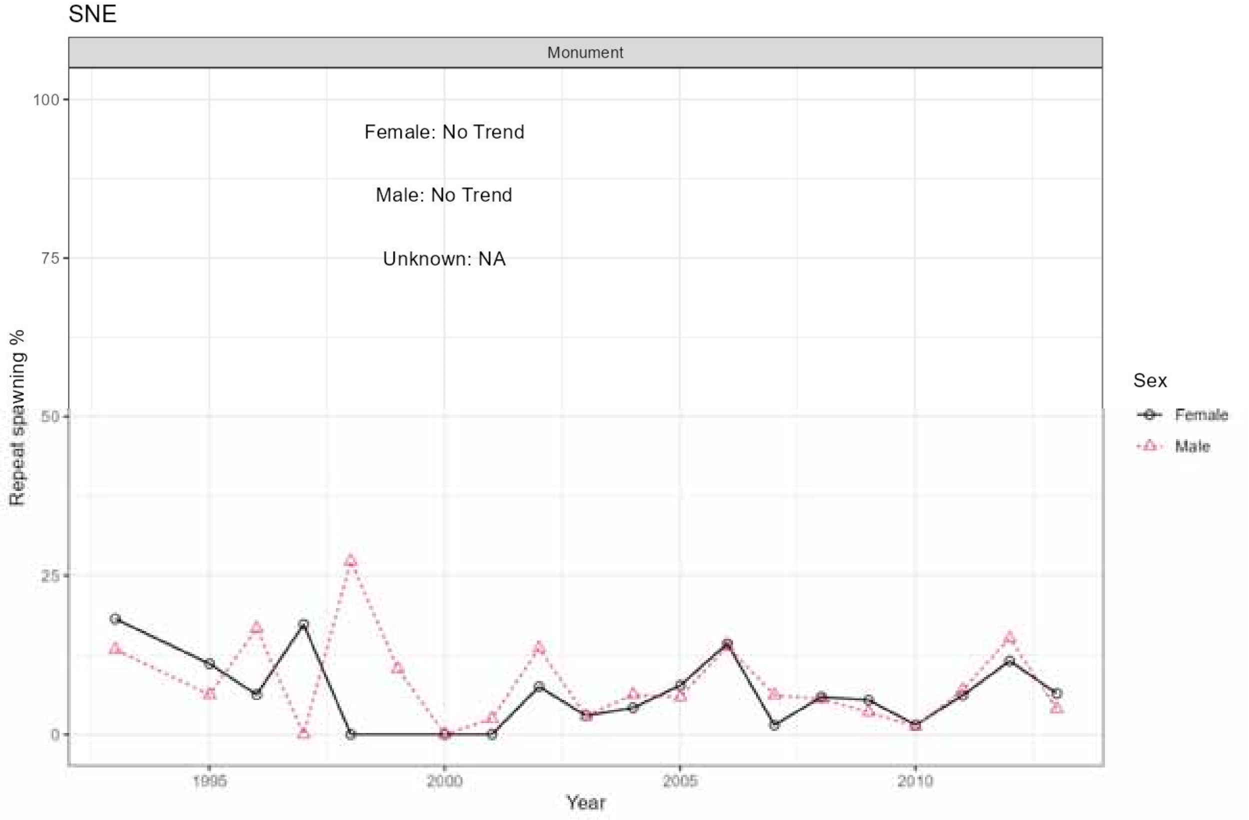


Figure 192. **Trends in repeat spawner percentage for blueback herring from rivers in the SNE stock-region.**

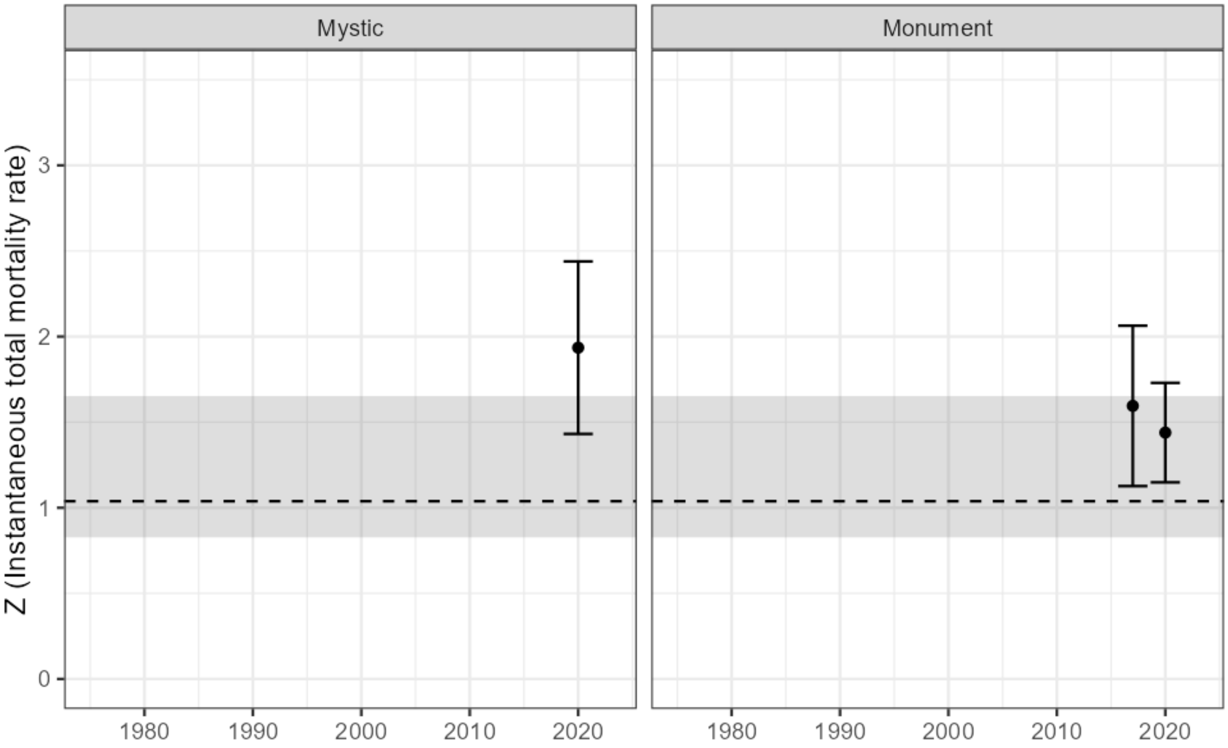


Figure 193. Age-based estimates of total instantaneous mortality for SNE blueback herring (from otolith data) in Massachusetts by river and year. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the SNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

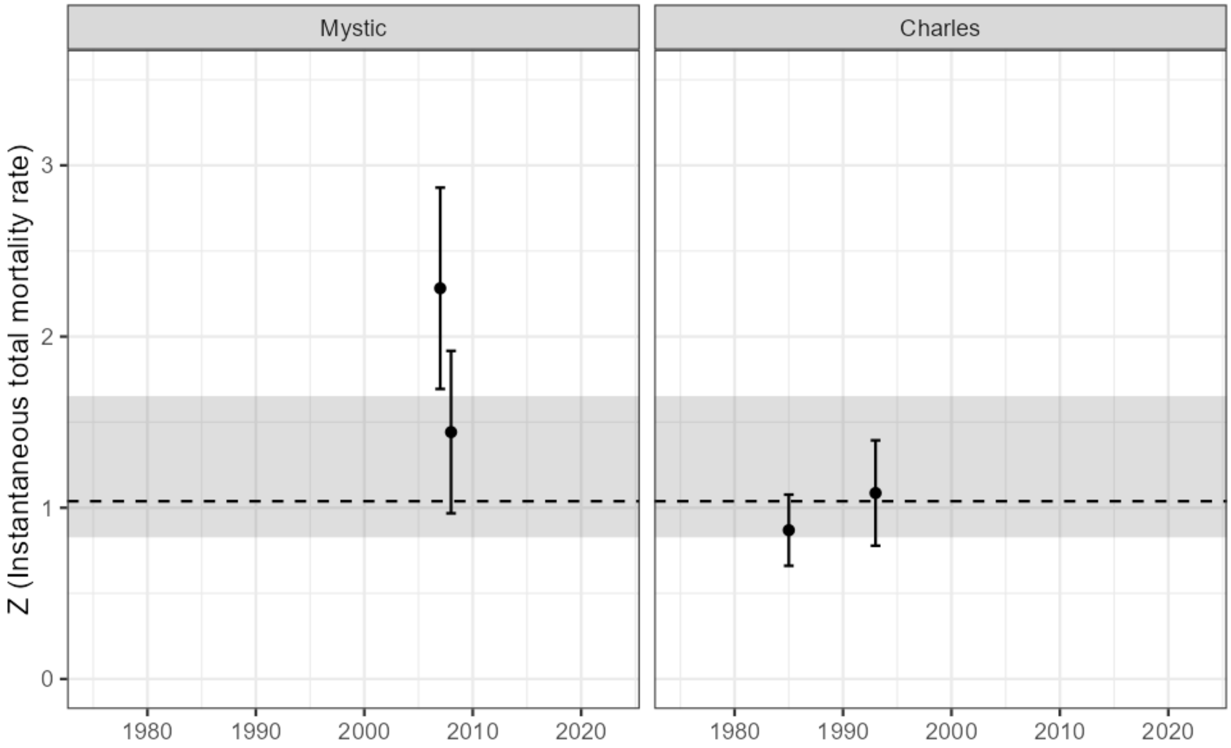


Figure 194. Age-based estimates of total instantaneous mortality for SNE blueback herring (from scale data) in Massachusetts by river and year. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the SNE stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

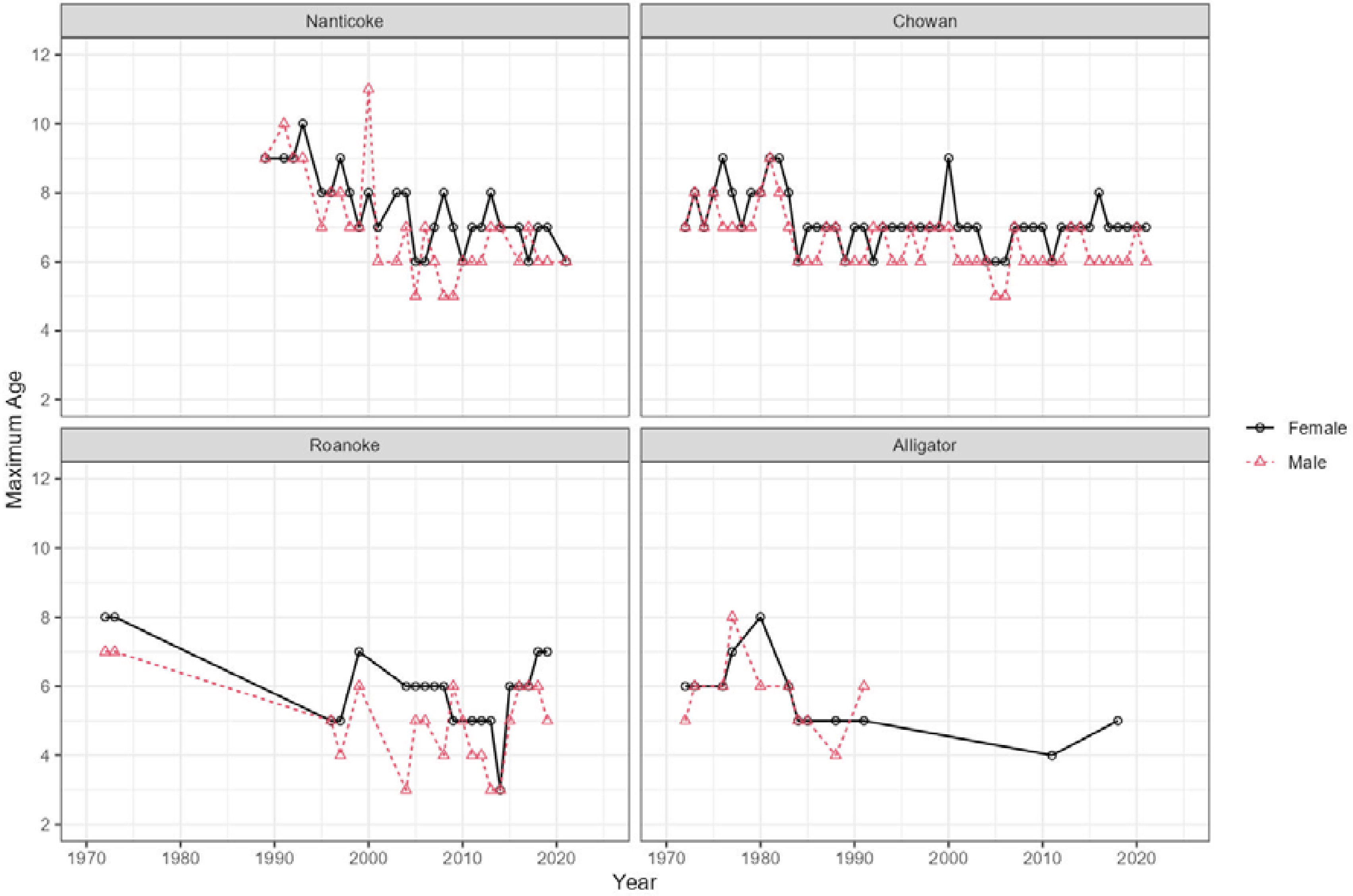


Figure 195. **Maximum scale-based ages for female and male blueback herring by river in the MAT stock-region.**

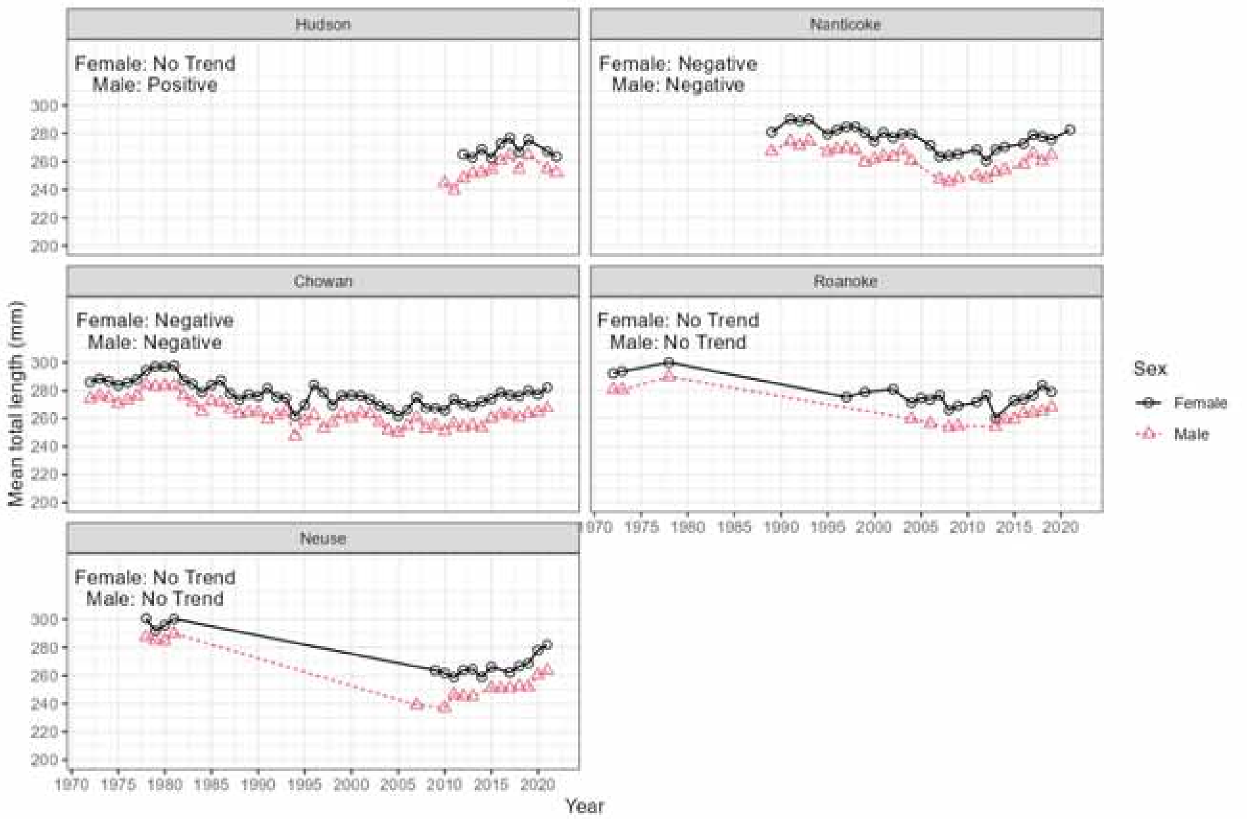


Figure 196. Mean length by year for female and male blueback herring in 5 river systems from the MAT stock-region.

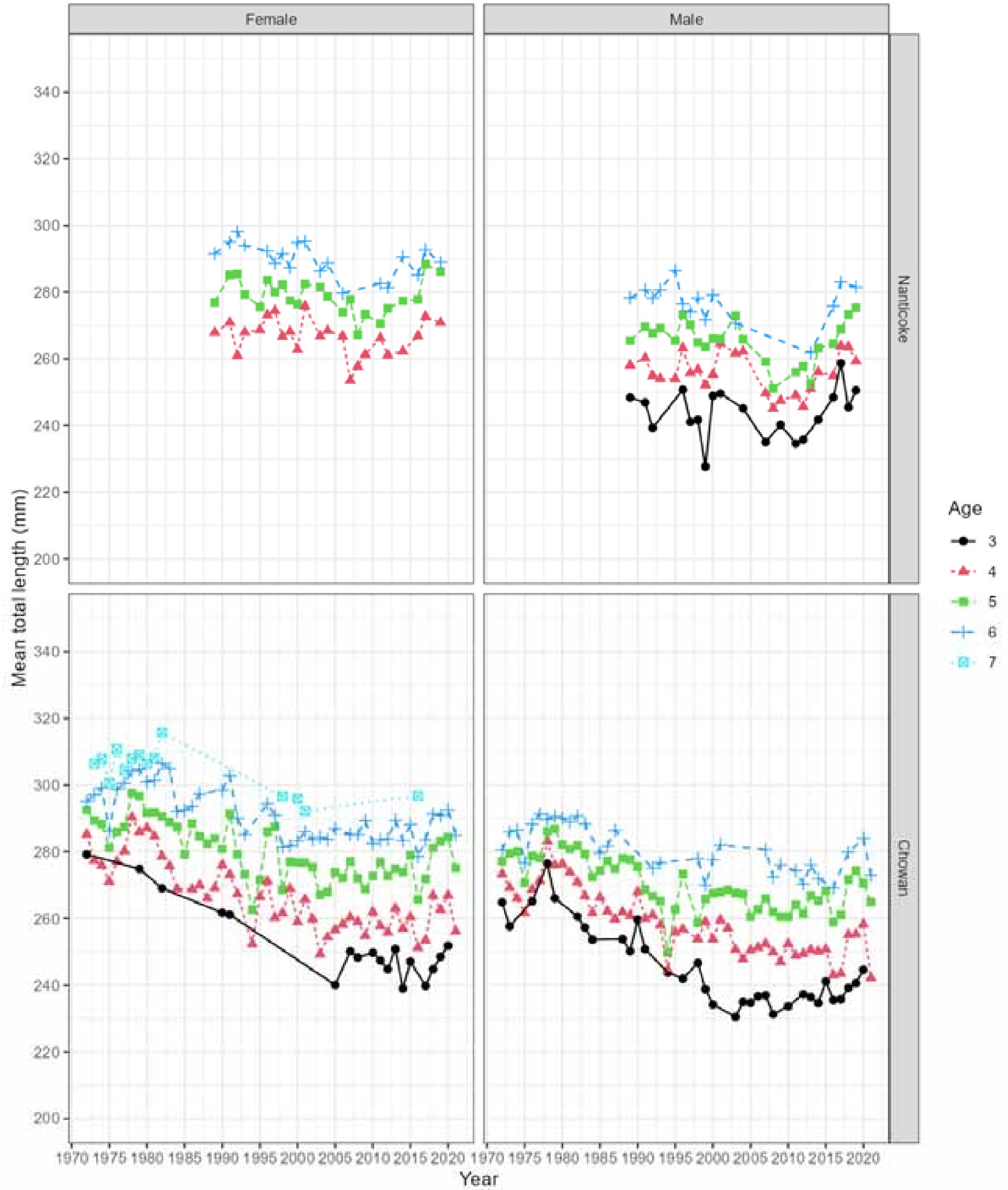


Figure 197. **Mean lengths-at-age of male and female blueback herring from two rivers in the MAT stock-region by sex, river, age, and year.**

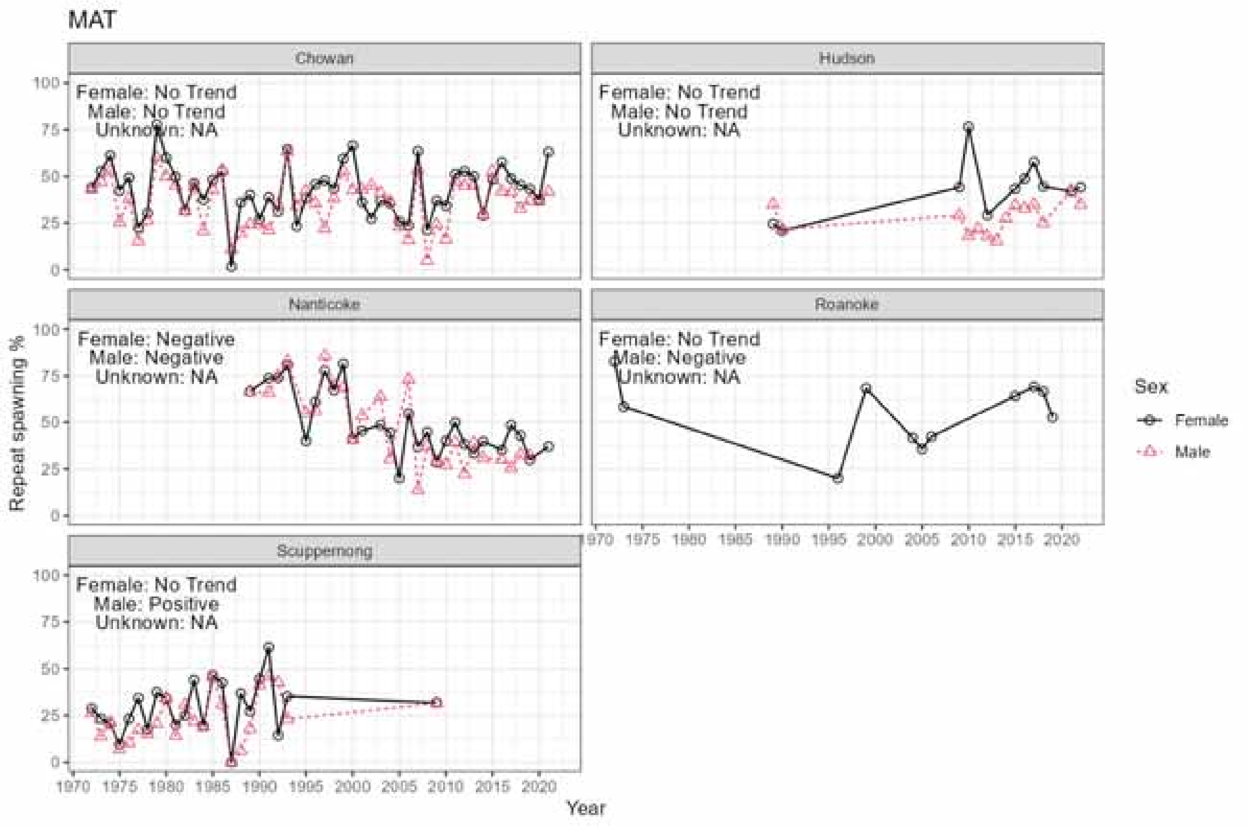


Figure 198. Trends in repeat spawner percentages for blueback herring from rivers in the MAT stock-region.

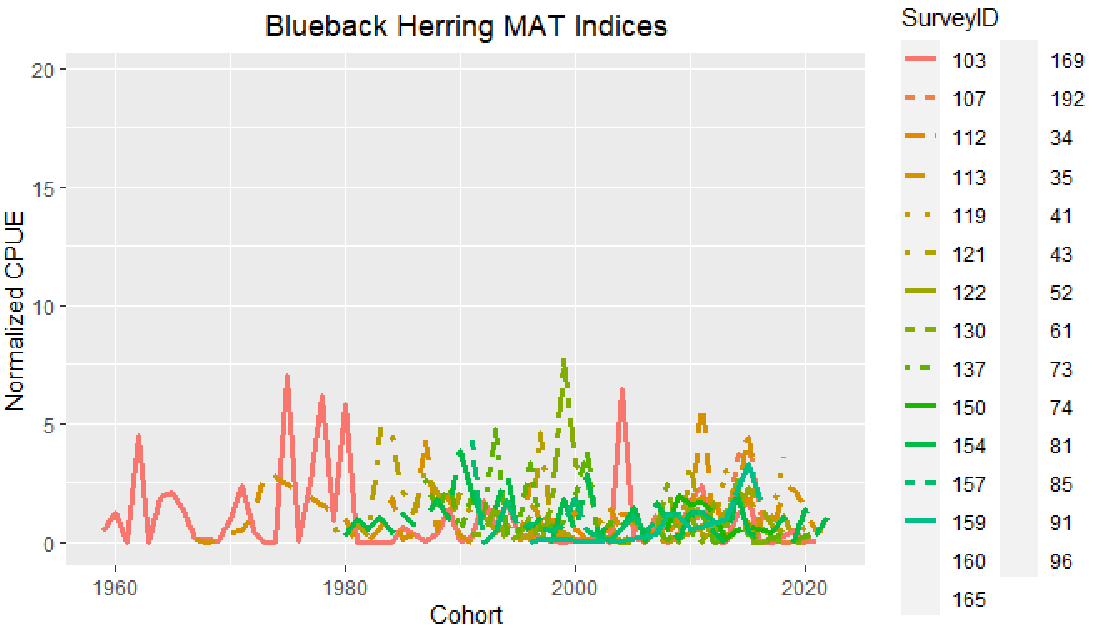


Figure 199. Normalized fishery-independent indices for the blueback herring MAT stock-region plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.

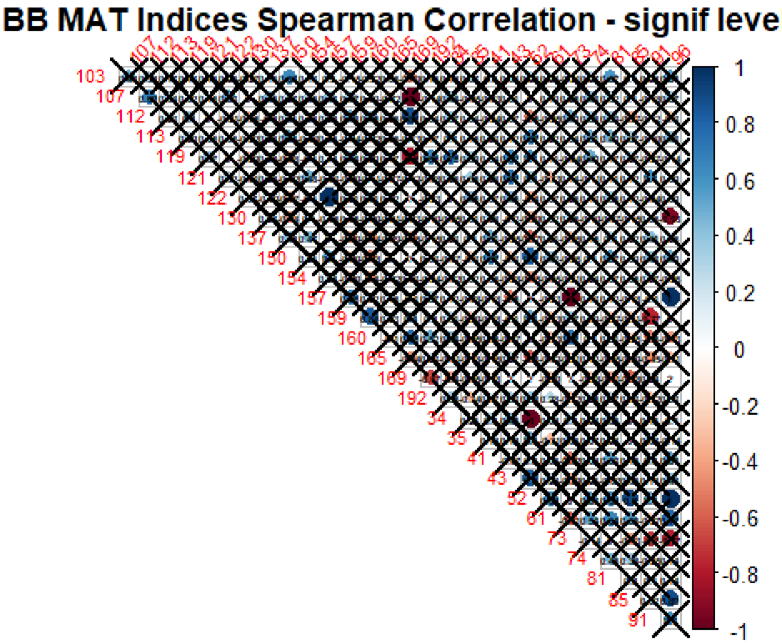


Figure 200. Spearman correlations among fishery-independent indices in the blueback herring MAT stock-region. Crossed-out cells indicate no significant correlation at the $p<0.05$ level. See Appendix 6 for survey names corresponding to SurveyID.

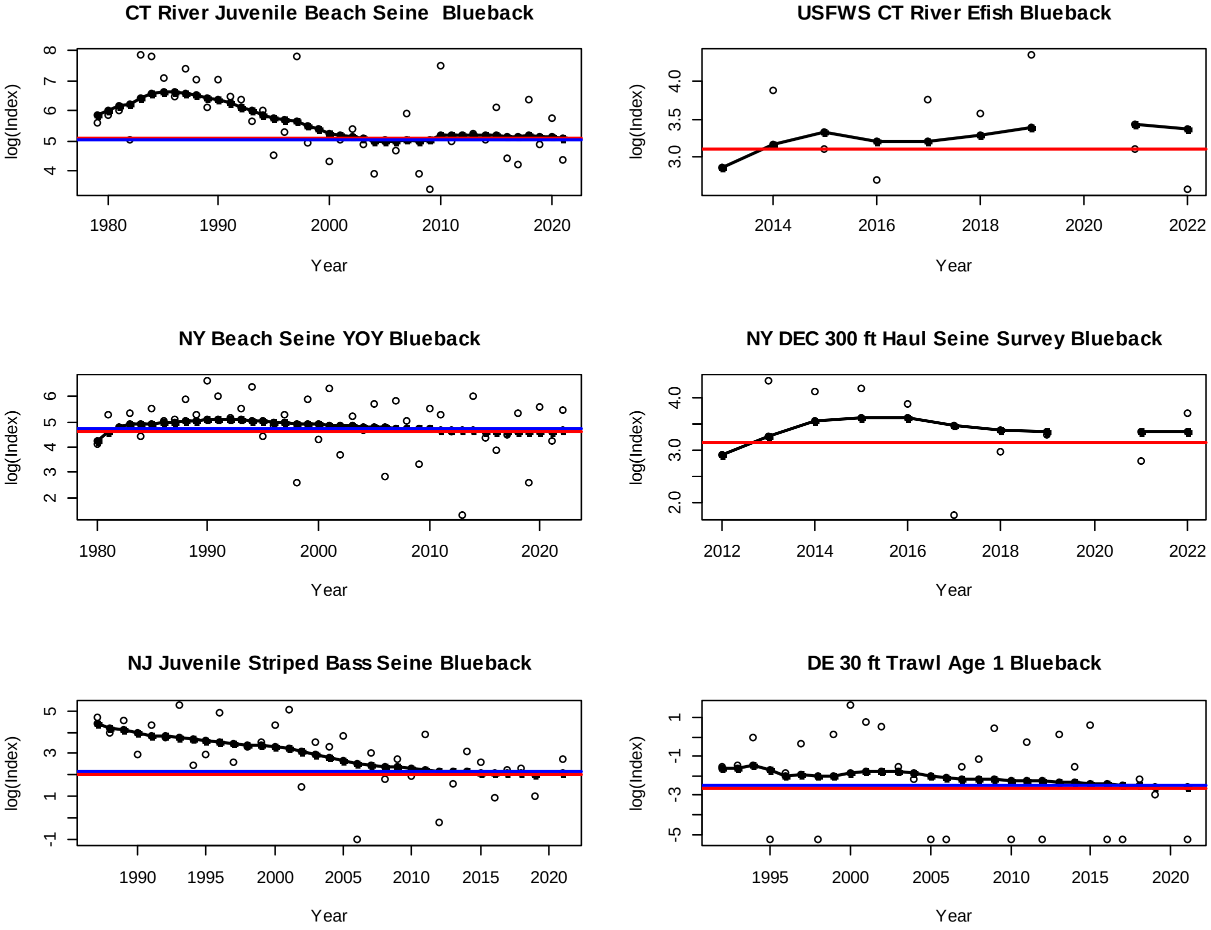


Figure 201. ARIMA model fits to blueback herring survey indices from the MAT stock-region. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

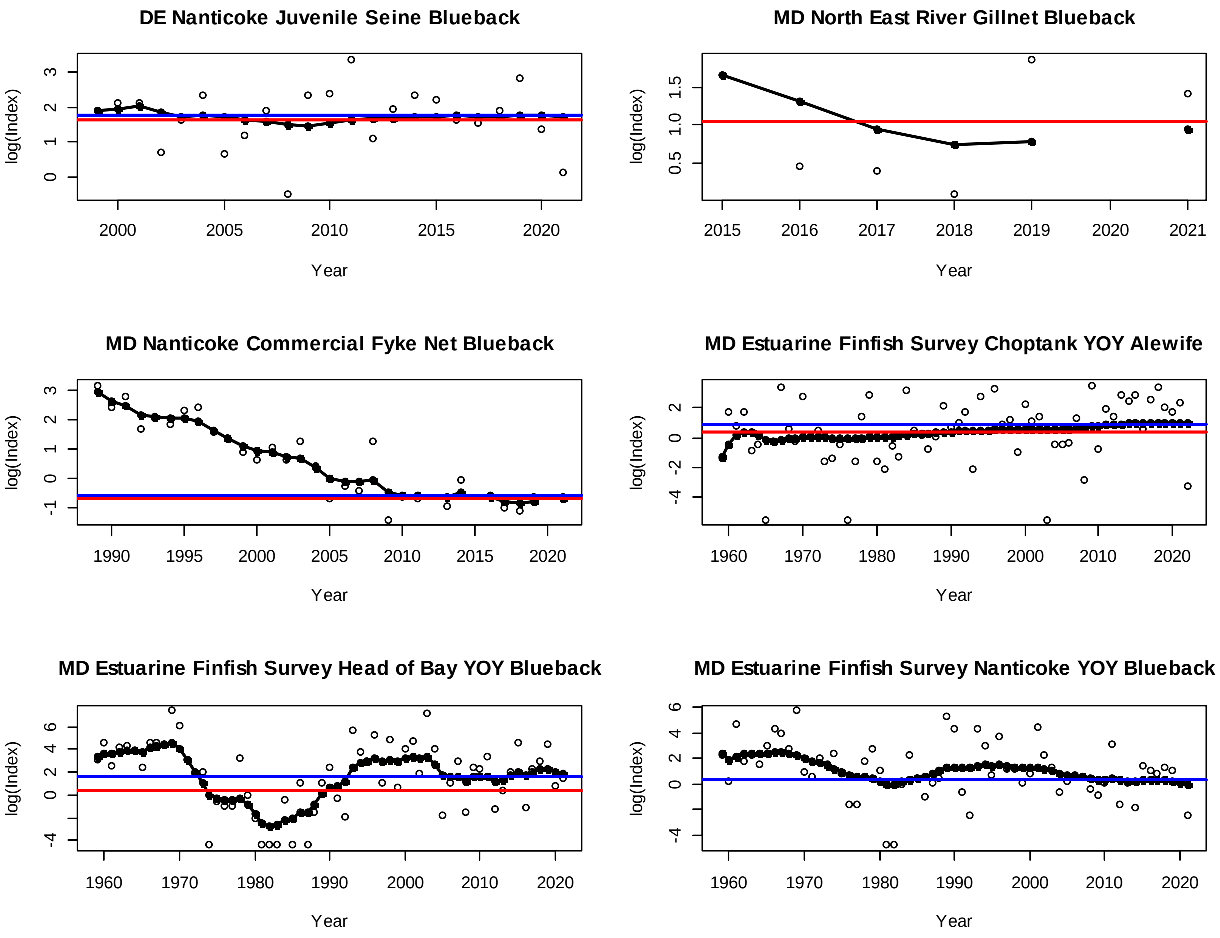
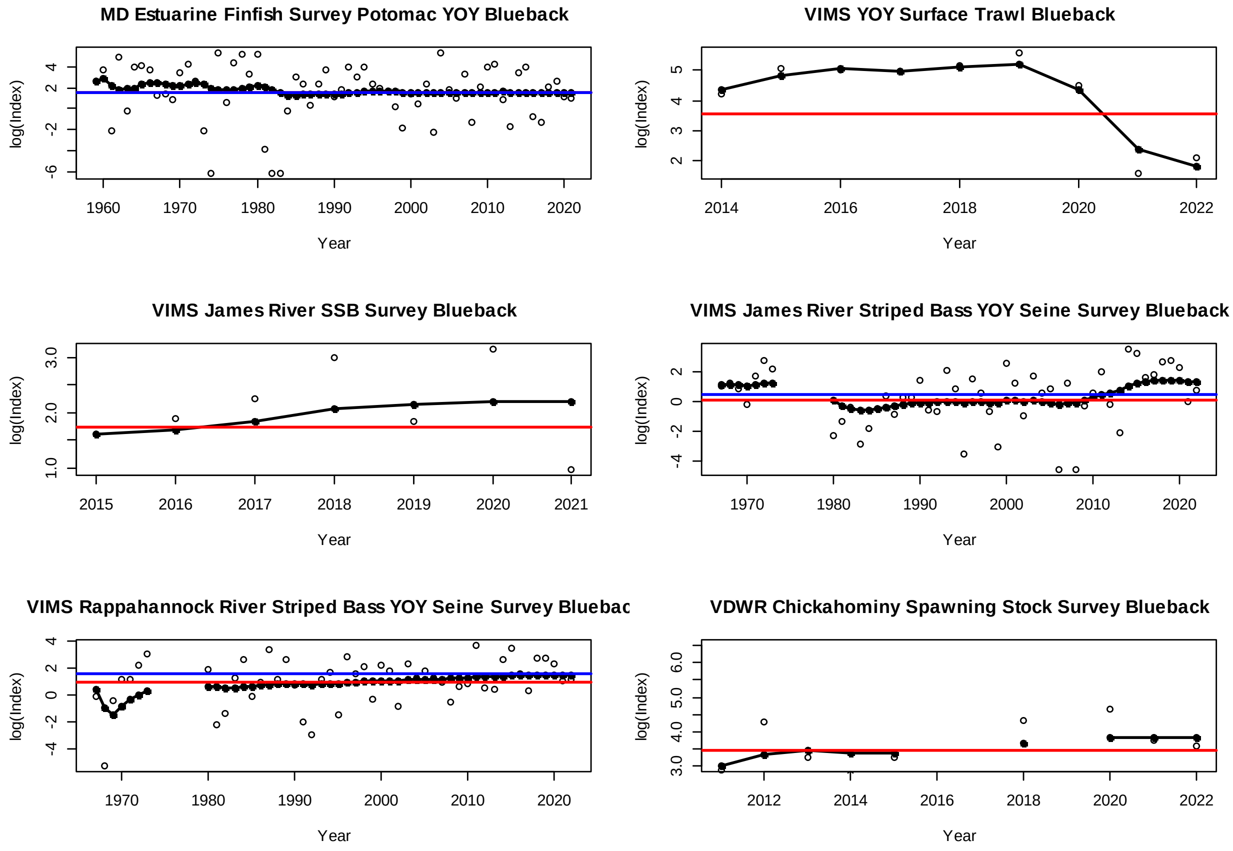


Figure 201 (cont.)


MD Estuarine Finfish Survey Potomac YOY Blueback

VIMS YOY Surface Trawl Blueback

VIMS James River SSB Survey Blueback

VIMS James River Striped Bass YOY Seine Survey Blueback

VIMS Rappahannock River Striped Bass YOY Seine Survey Bluebac

VDWR Chickahominy Spawning Stock Survey Blueback

Figure 201 (cont.)

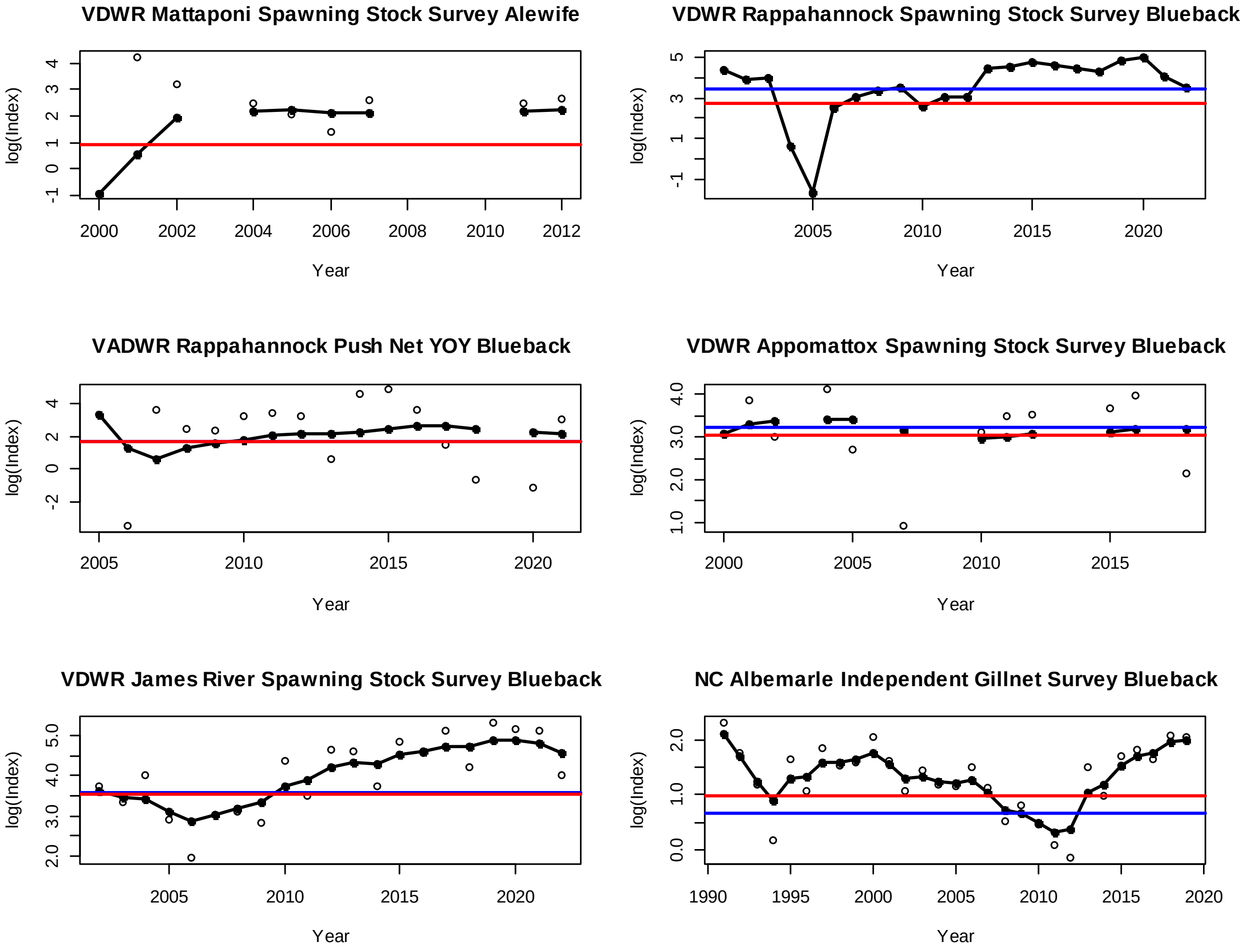


Figure 201 (cont.)

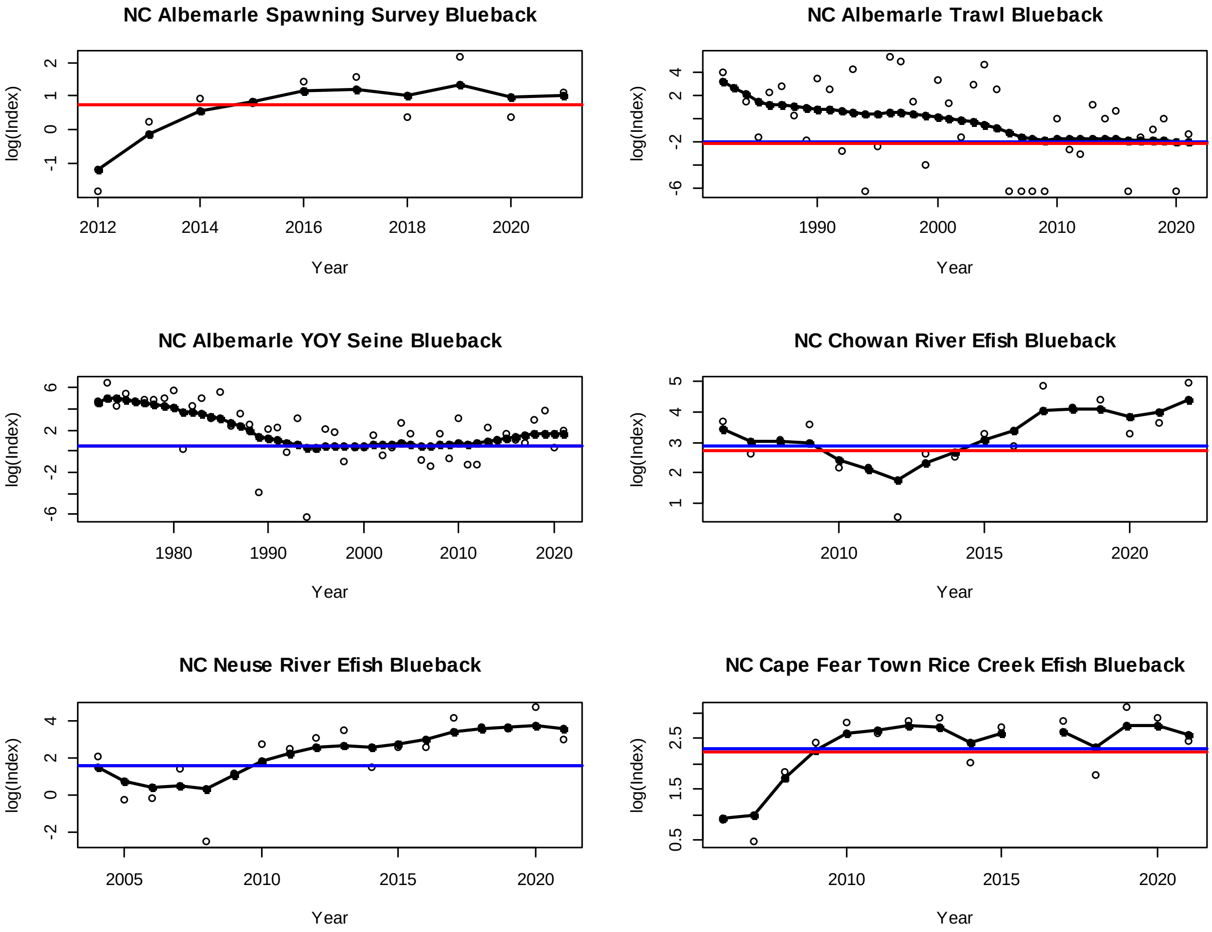
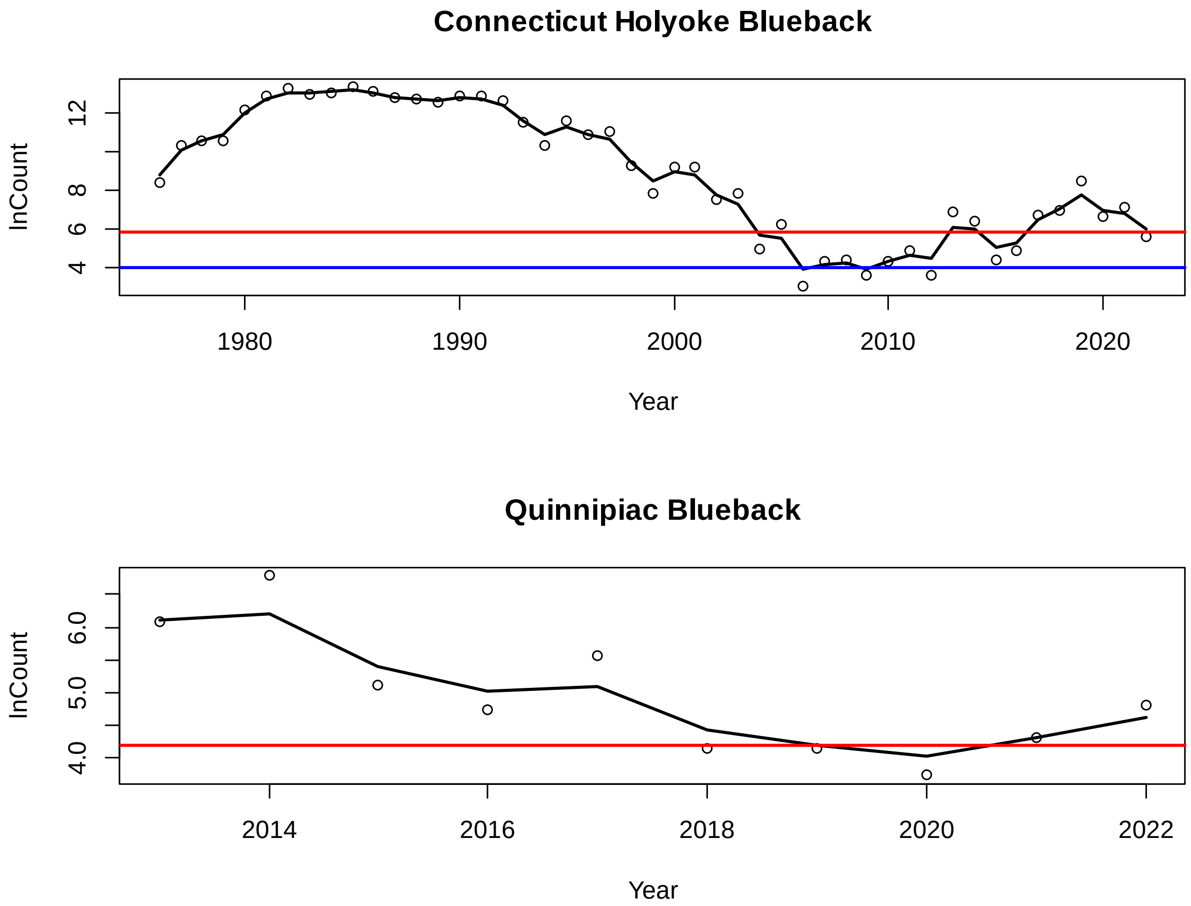


Figure 201 (cont.)


Connecticut Holyoke Blueback

Quinnipiac Blueback

Figure 202. ARIMA model fits to blueback herring run counts from the MAT stock-region. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

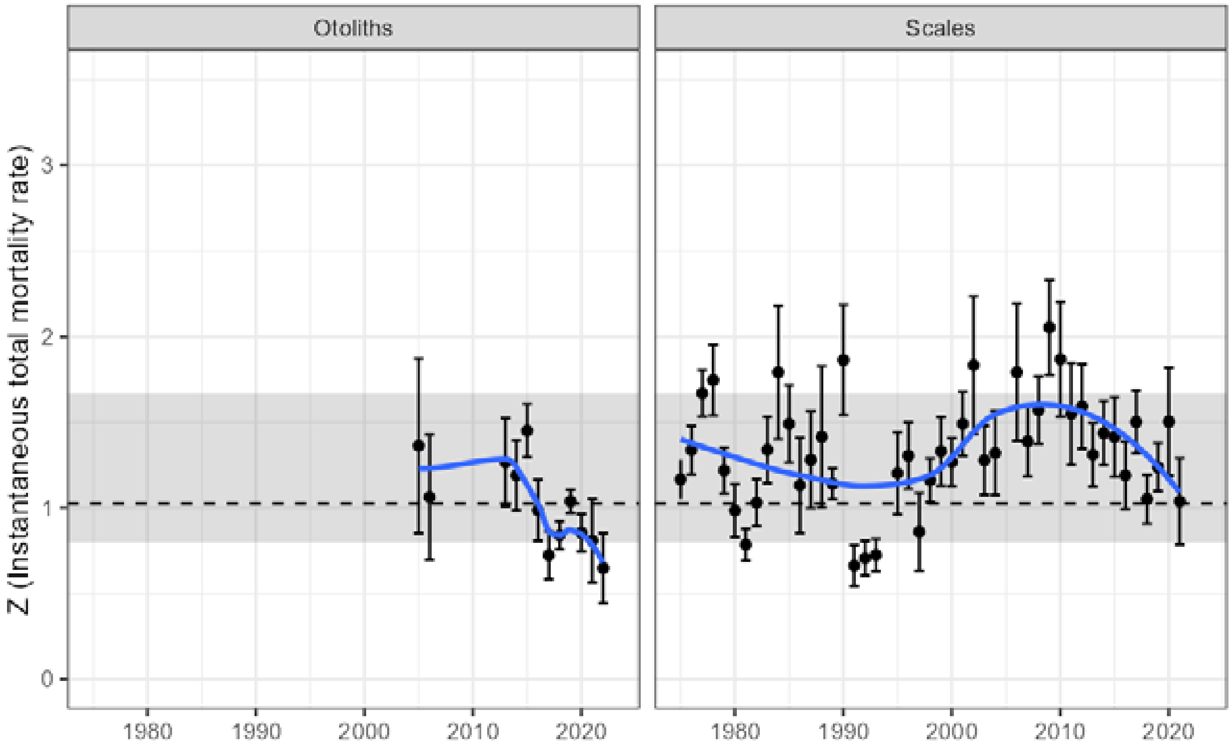


Figure 203. Estimates of total instantaneous mortality (Z) for blueback herring from the MAT stock-region by ageing structure, plotted with the $Z_{40\%SPR}$ reference points for the MAT stock-region. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

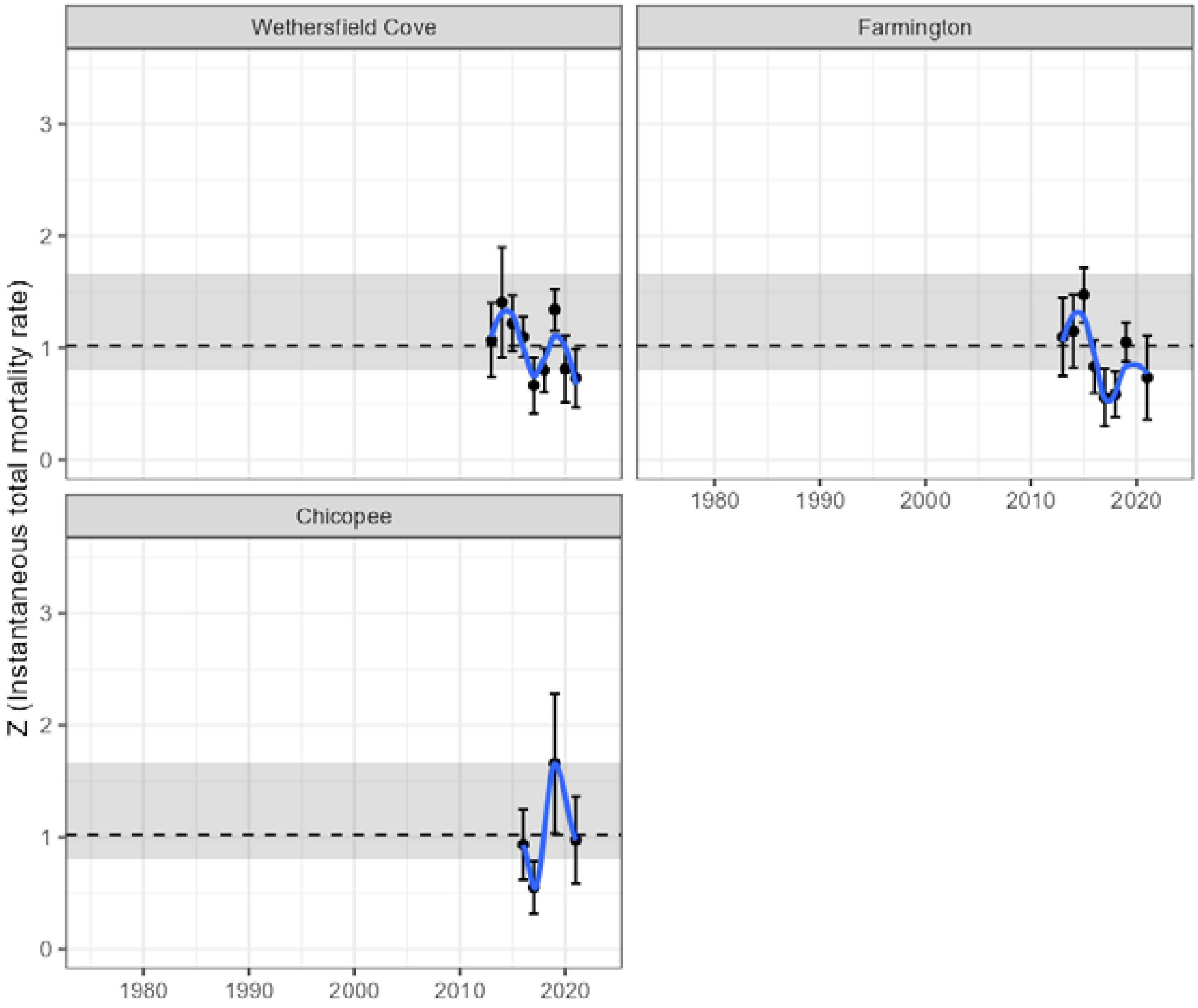


Figure 204. Age-based estimates of total instantaneous mortality for blueback (from otolith data) for tributaries of the Connecticut River by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

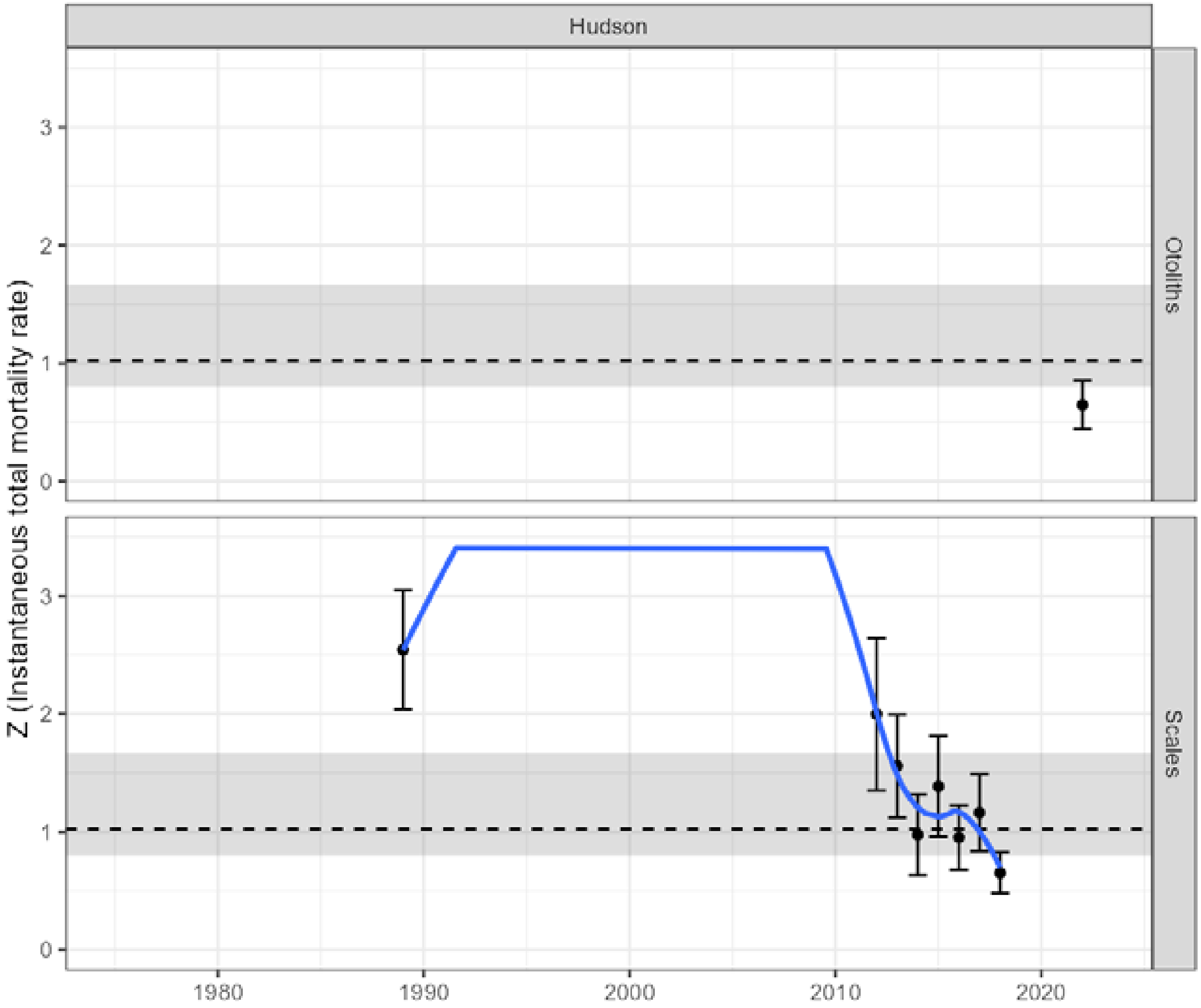


Figure 205. Age-based estimates of total instantaneous mortality for MAT blueback herring in New York by river, year, and ageing structure. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

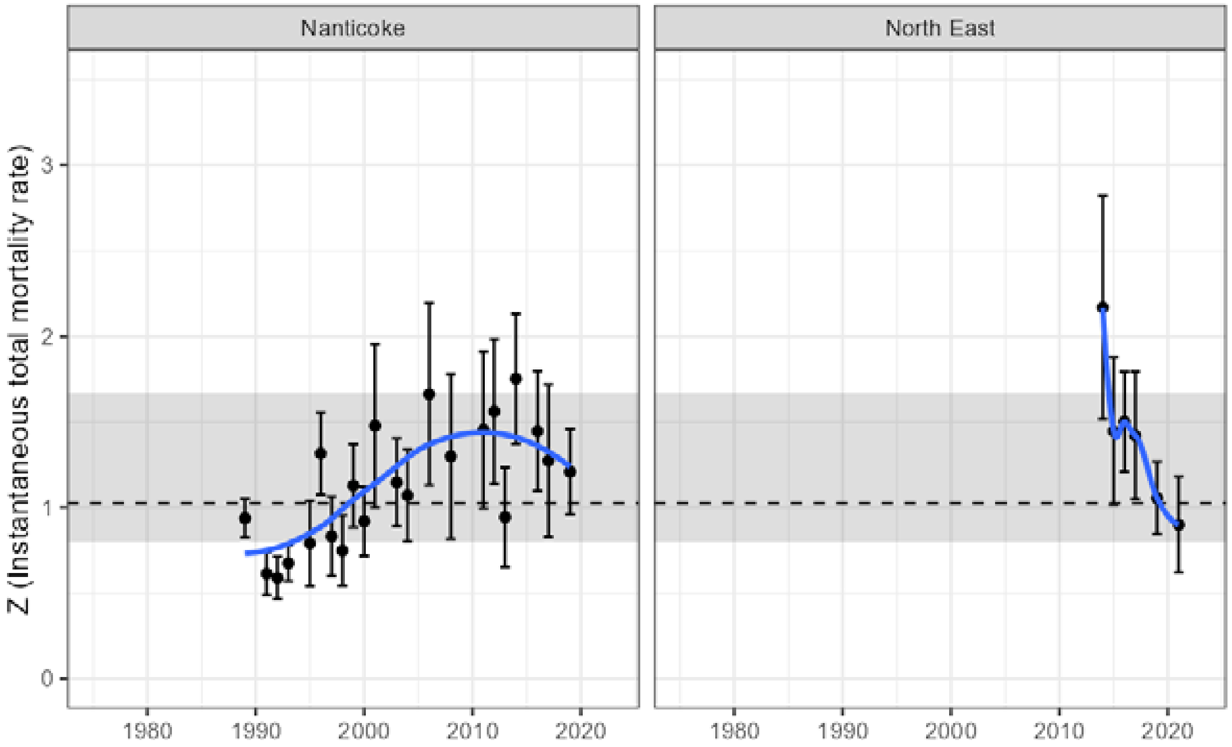


Figure 206. Age-based estimates of total instantaneous mortality for blueback (from scale data) in Maryland by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

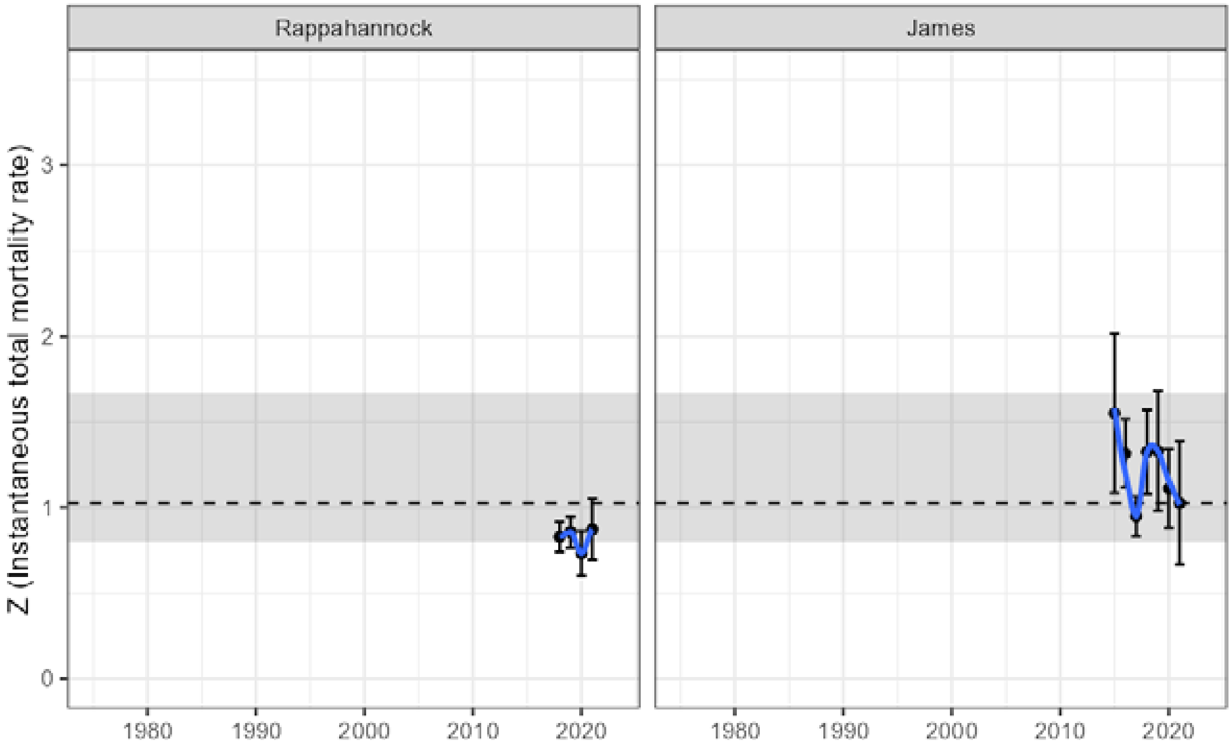


Figure 207. Age-based estimates of total instantaneous mortality for MAT blueback herring (from otolith data) in Virginia by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

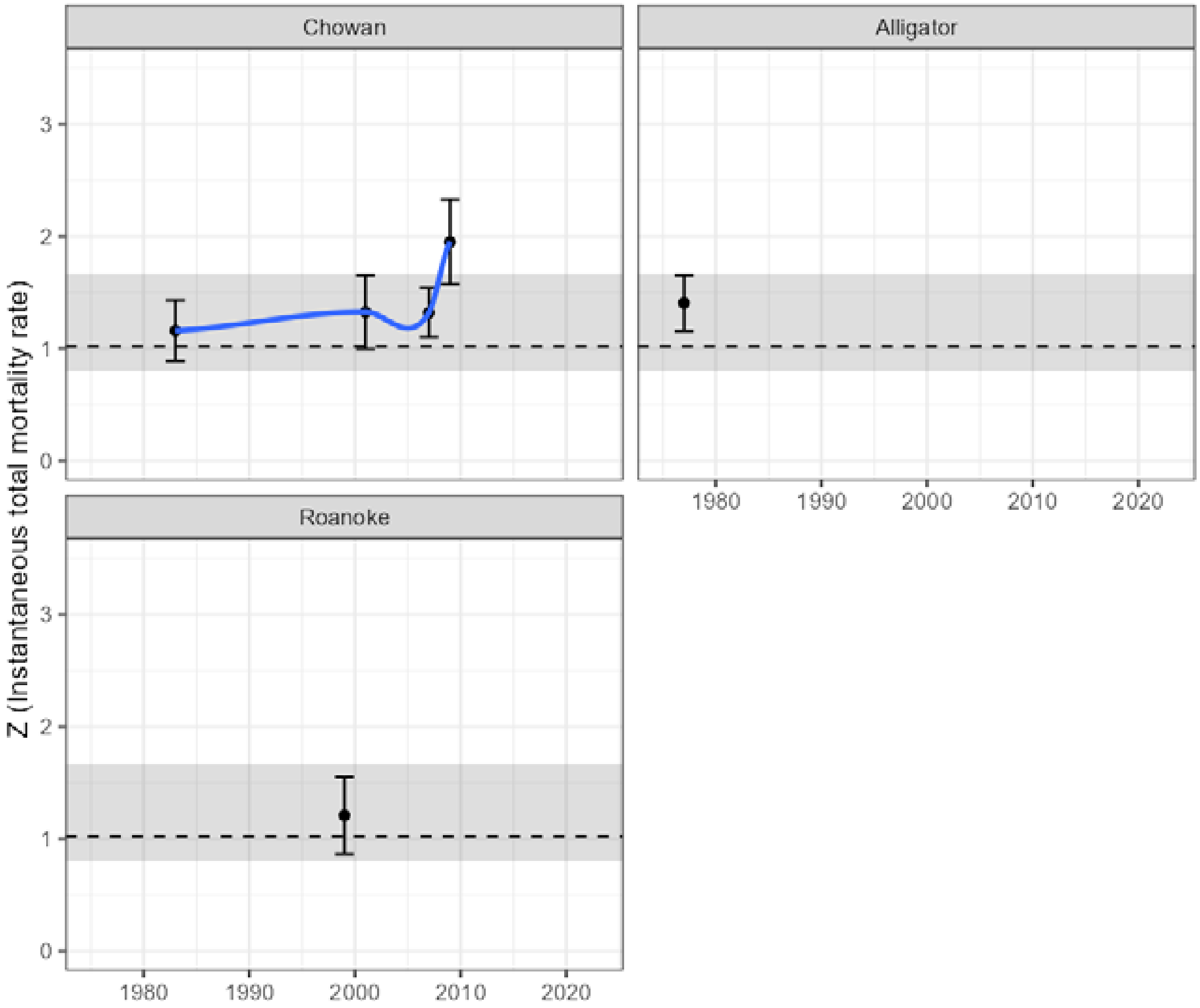


Figure 208. Age-based estimates of total instantaneous mortality for MAT blueback herring (from fishery independent scale data) in North Carolina by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

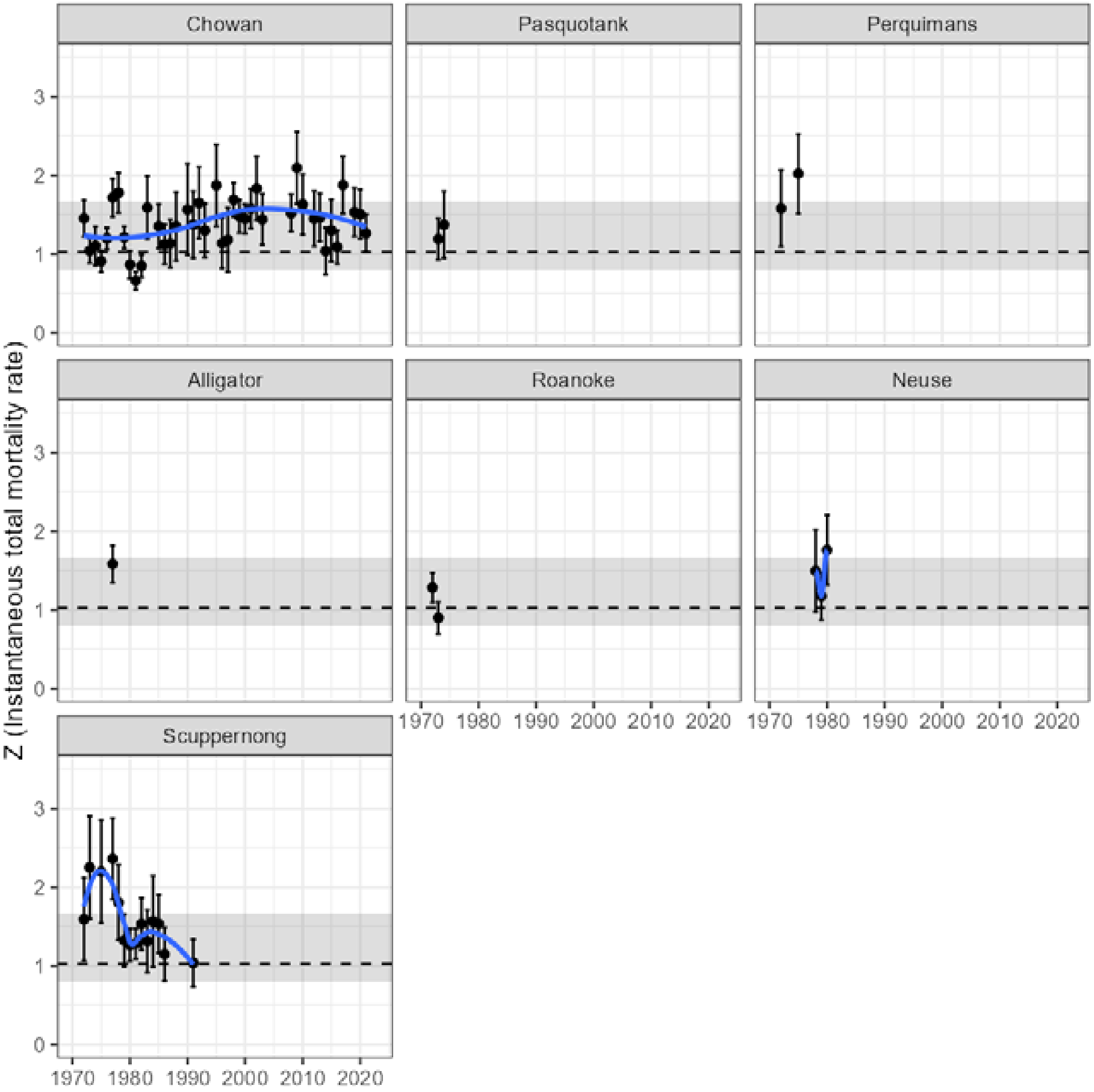


Figure 209. Age-based estimates of total instantaneous mortality for MAT blueback herring (from fishery dependent scale data) in North Carolina by river and year. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the MAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

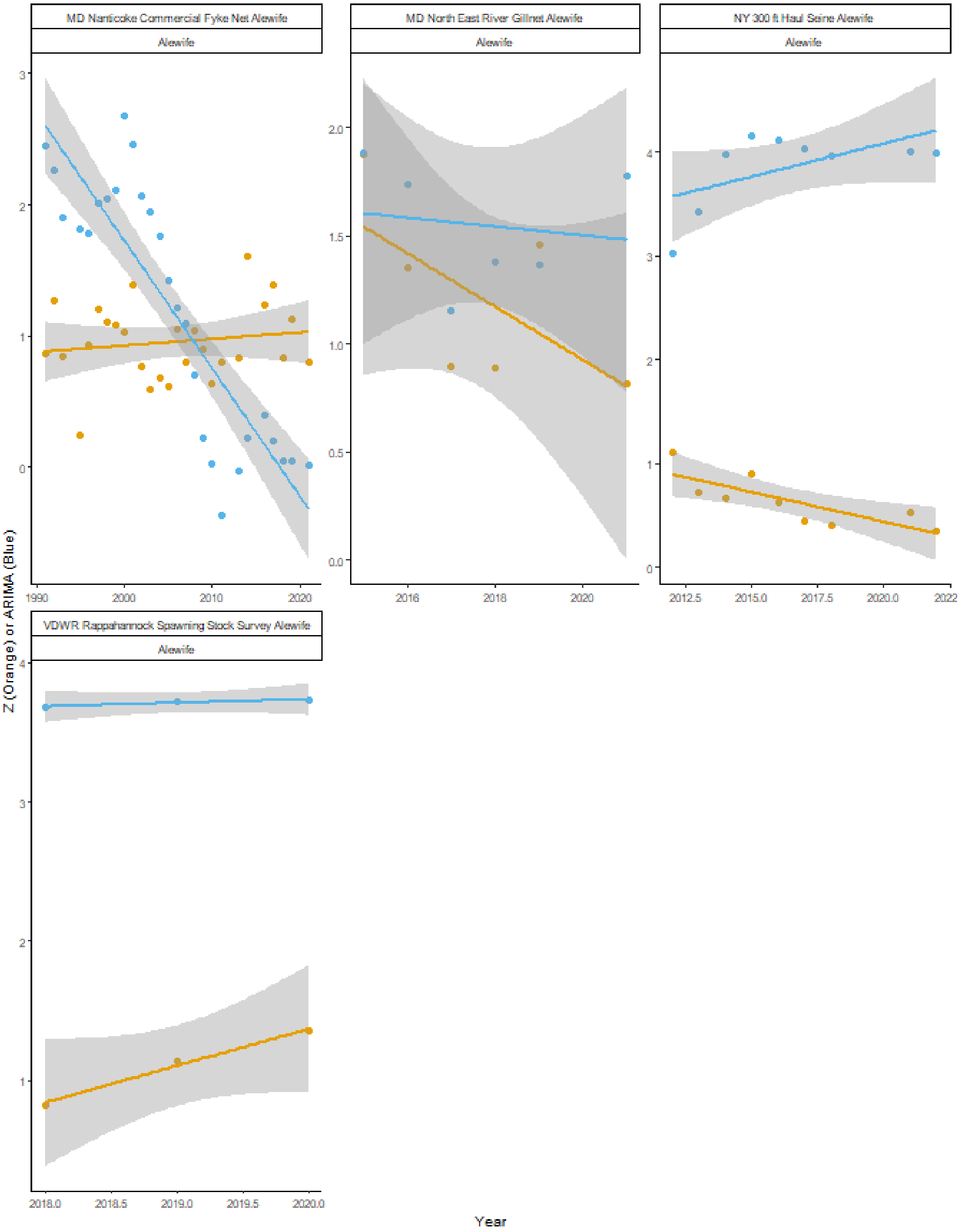


Figure 210. Comparison of Z (orange lines/points) and ARIMA indices of adult blueback herring (blue lines/points) for the MAT stock-region for systems where both metrics are available.

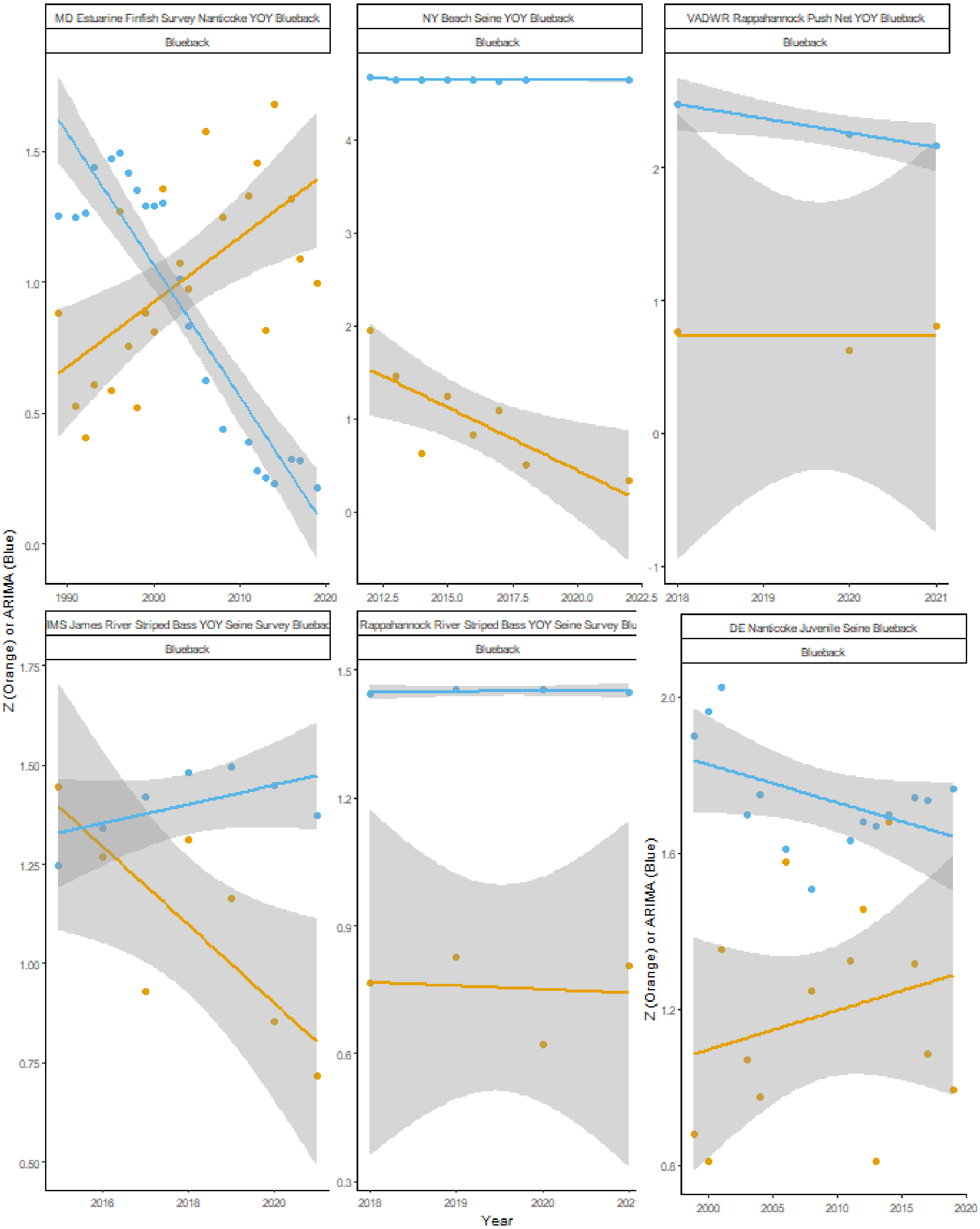


Figure 211. Comparison of Z (orange lines/points) and ARIMA indices of juvenile or YOY blueback herring (blue lines/points) for the MAT stock-region for systems where both metrics are available.

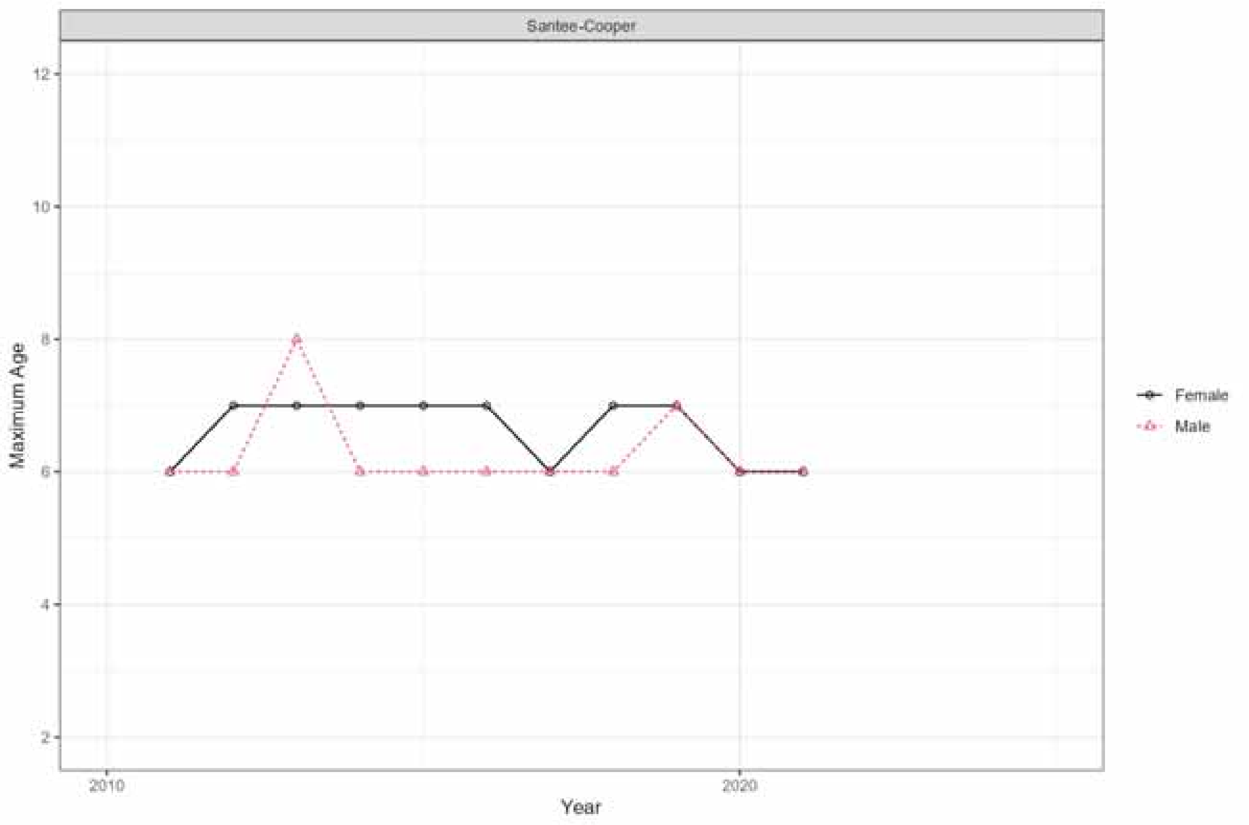


Figure 212. Maximum scale-based ages for female and male blueback herring by river in the SAT stock-region.

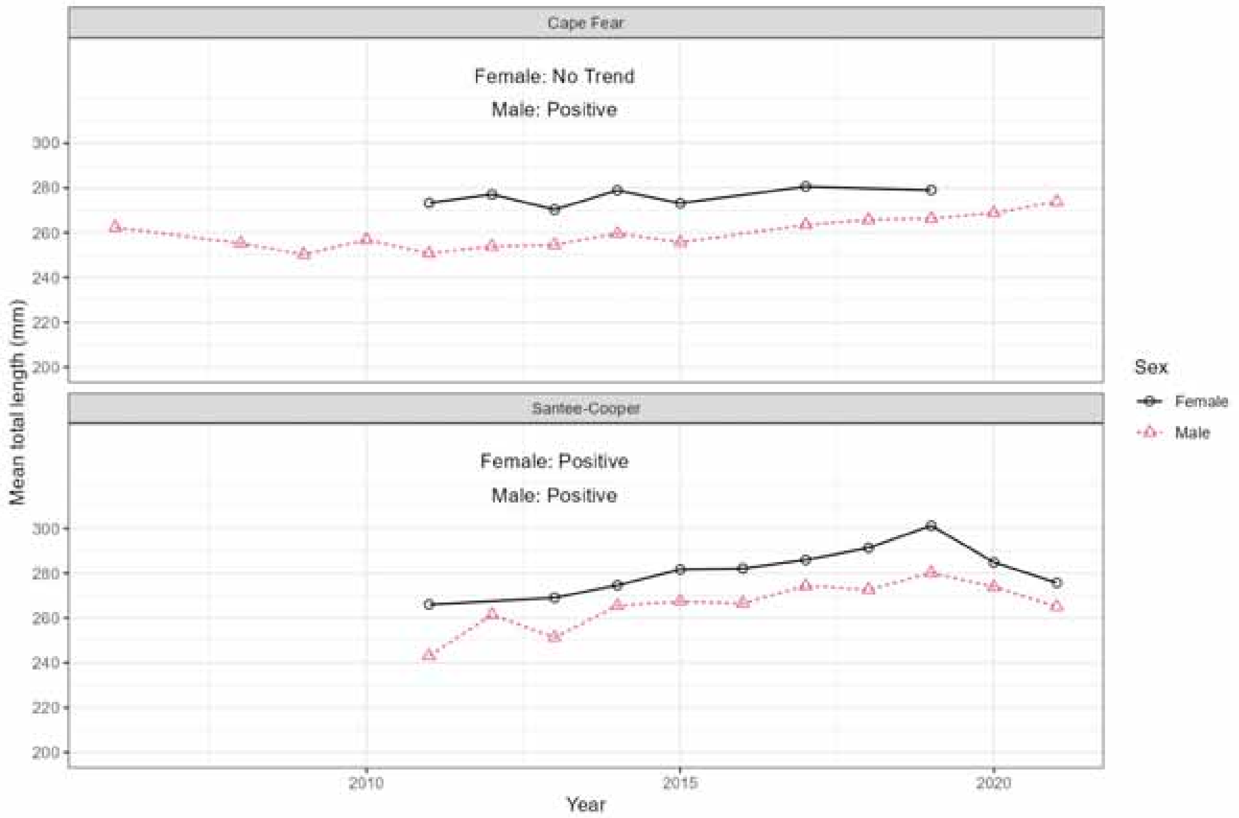


Figure 213. Mean length by year for female and male blueback herring in two river systems from the SAT stock-region.

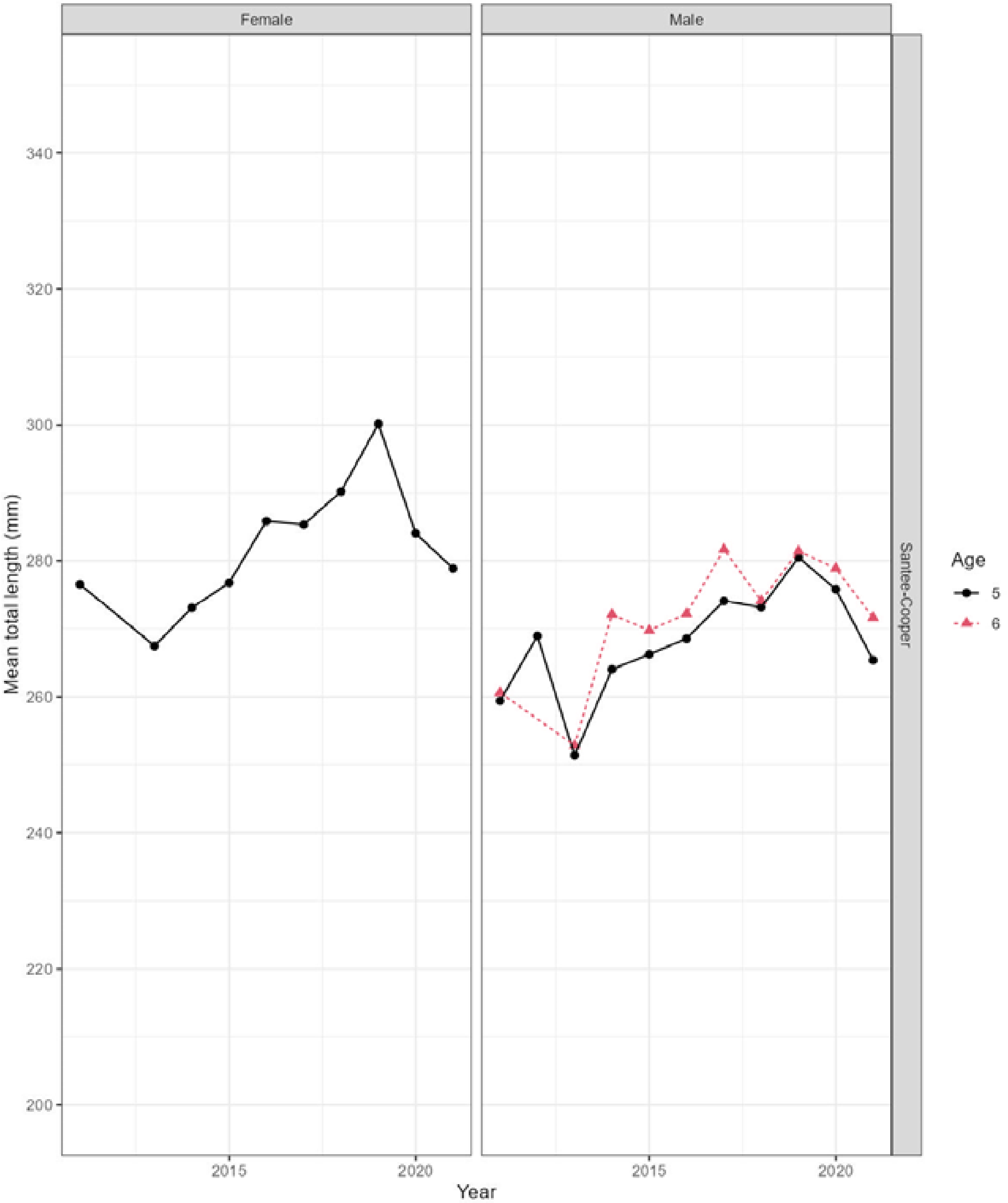


Figure 214. Mean lengths-at-age of male and female blueback herring from the Santee-Cooper River in the SAT stock-region by sex, age, and year.

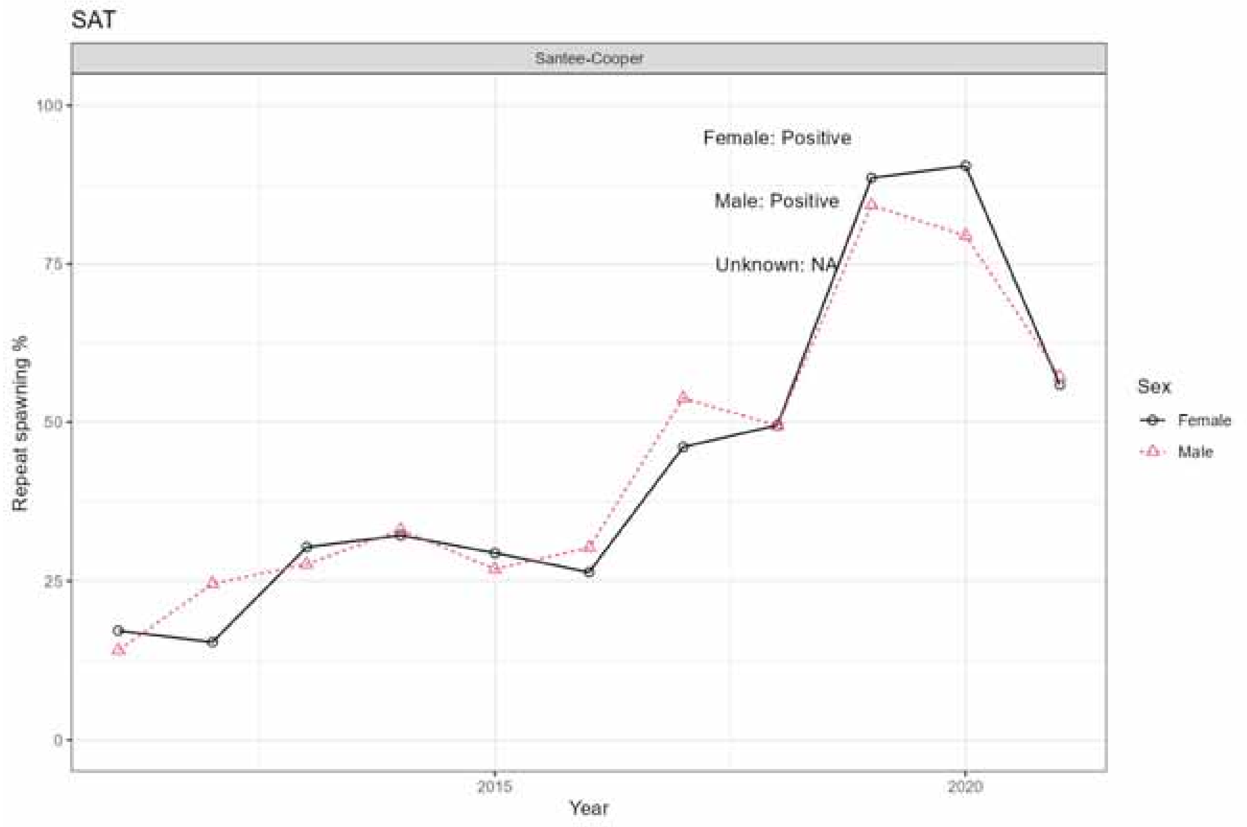


Figure 215. **Trends in repeat spawner percentage for blueback herring from rivers in the SAT stock-region.**

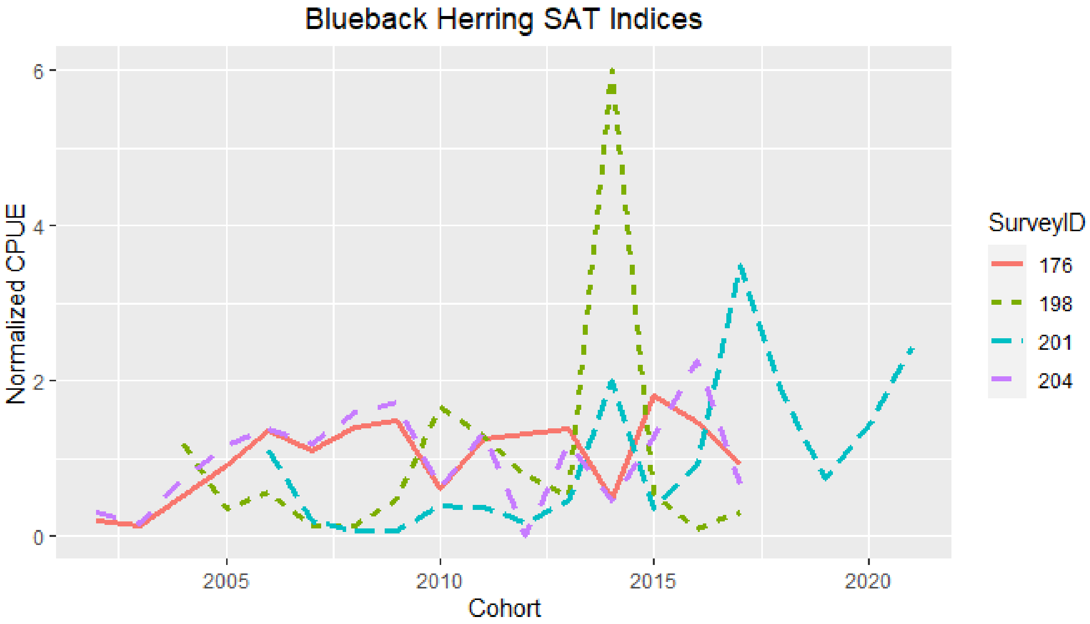


Figure 216. Normalized fishery-independent indices for the blueback herring SAT stock-region plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.

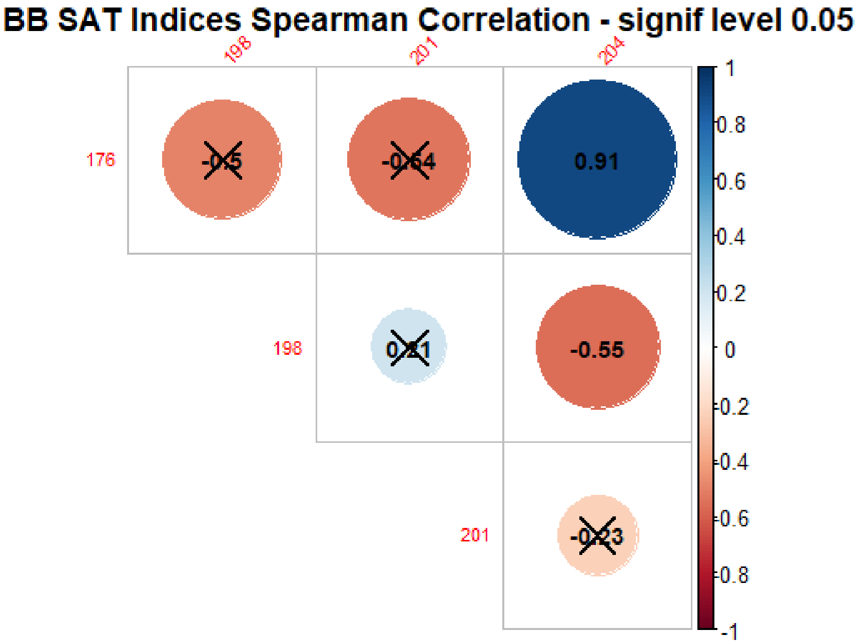


Figure 217. Spearman correlations among fishery-independent indices in the blueback herring SAT stock-region. Crossed-out cells indicate no significant correlation at the p<0.05 level. See Appendix 6 for survey names corresponding to SurveyID.

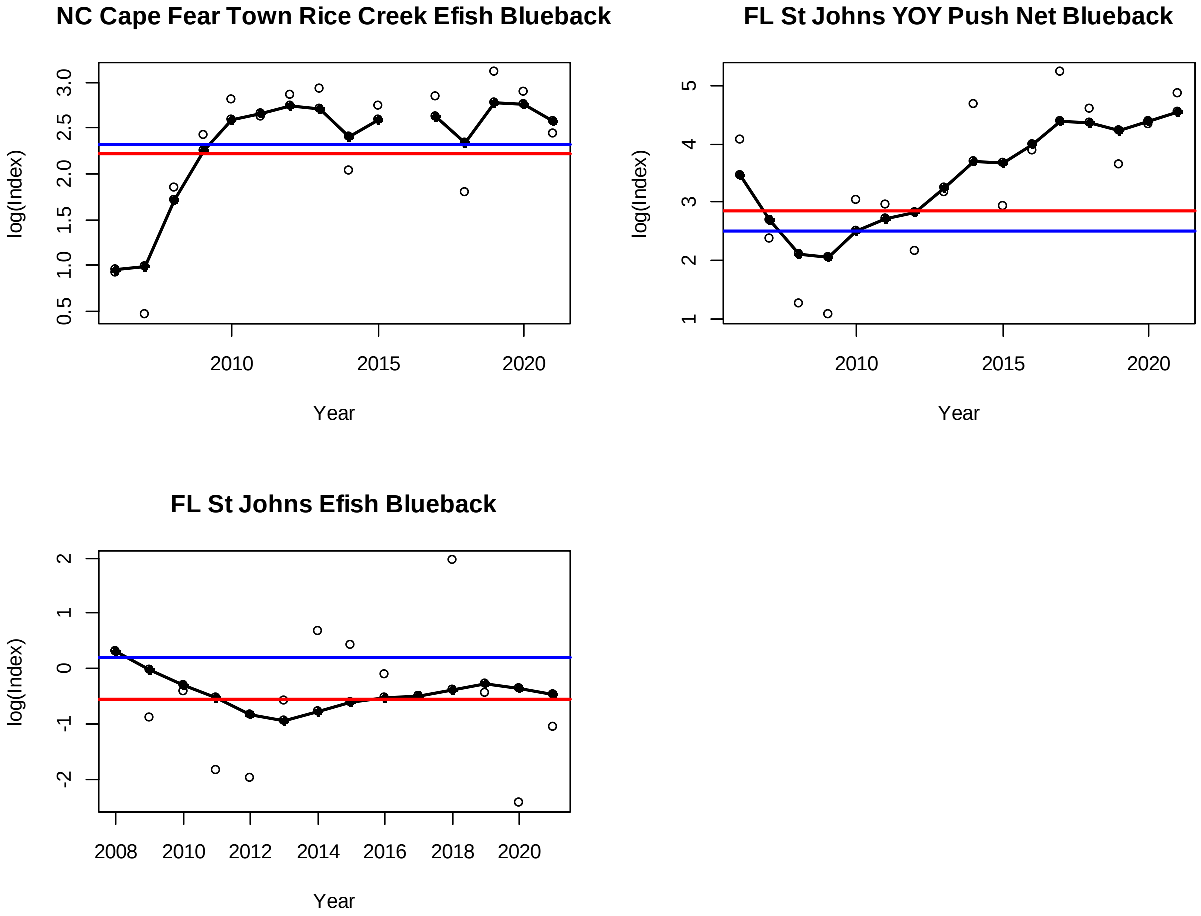


Figure 218. ARIMA model fits to blueback herring survey indices from the SAT stock-region. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

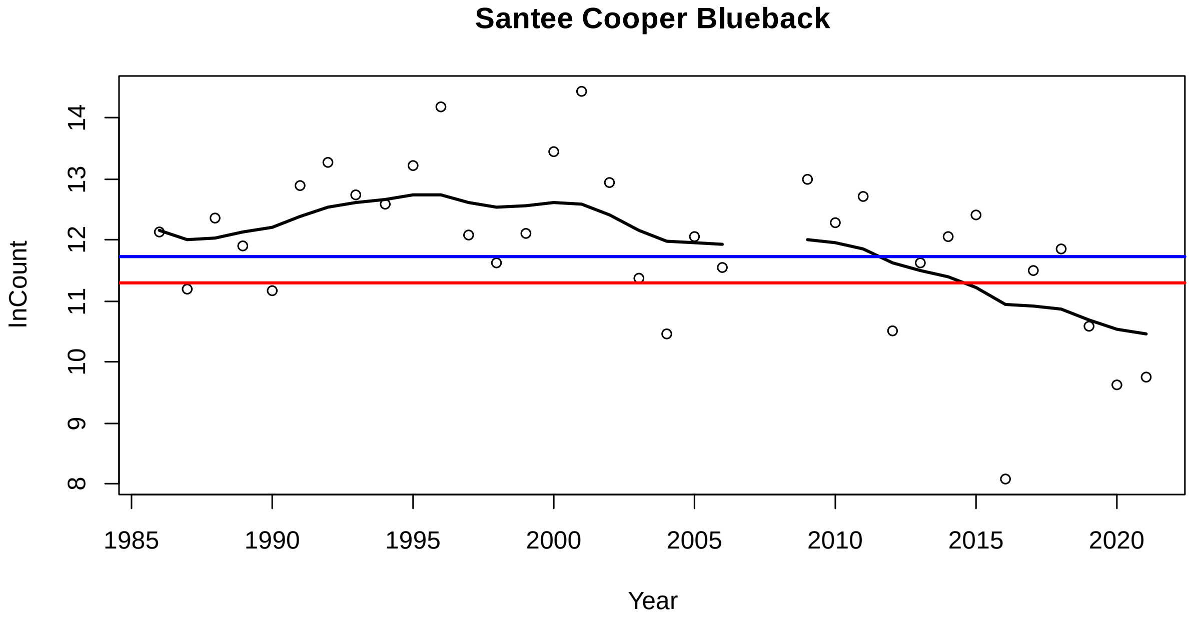


Figure 219. **ARIMA model fit to blueback herring run counts from the Santee-Cooper River system (the only run count in the SAT region). Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.**

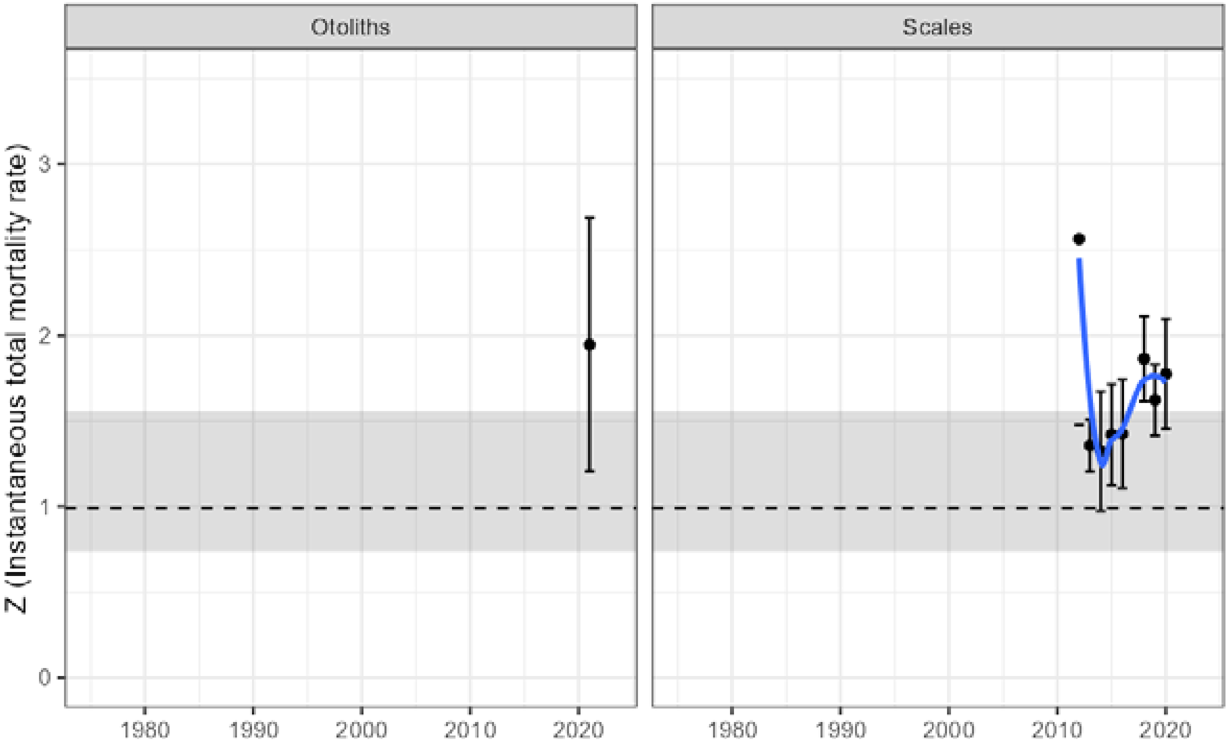


Figure 220. Estimates of total instantaneous mortality (Z) for blueback herring from the SAT stock-region by ageing structure, plotted with the $Z_{40\%SPR}$ reference points for the SAT stock-region. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the SAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.

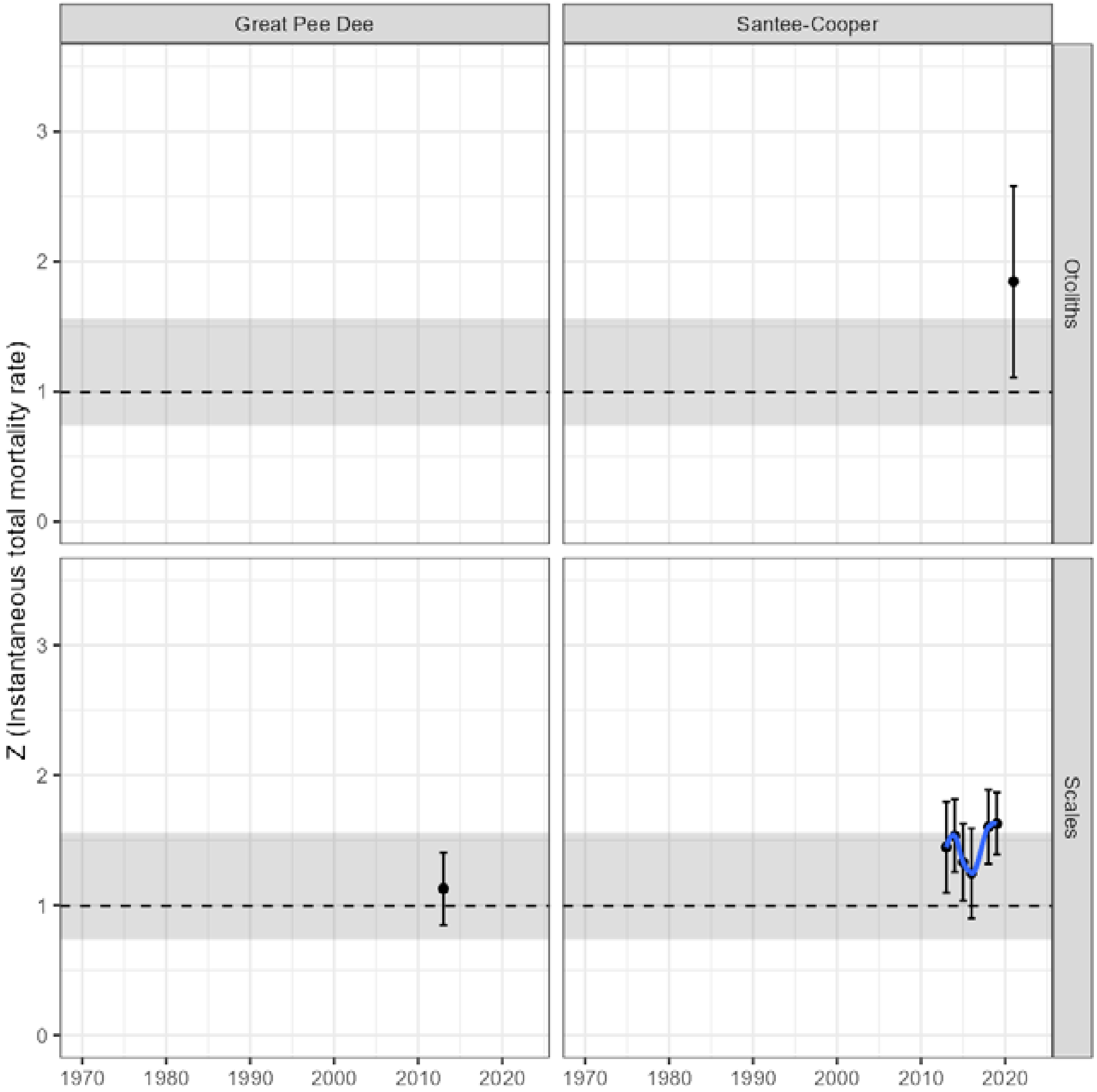


Figure 221. **Age-based estimates of total instantaneous mortality for SAT blueback herring from fishery dependent data in South Carolina by river, year, and ageing structure. Blue lines are loess fits to indicate trends. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the SAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.**

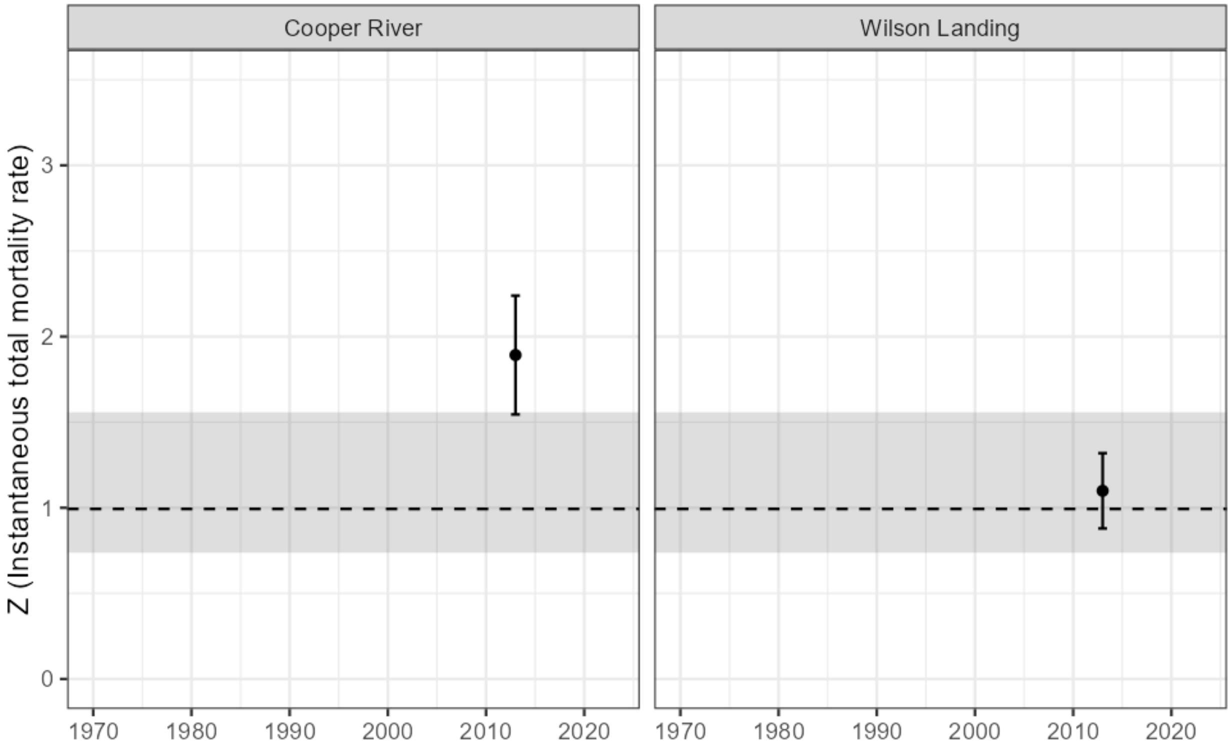


Figure 222. **Age-based estimates of total instantaneous mortality for SAT blueback herring (from recreational fishery dependent scale data) in South Carolina by river and year. Error bars are 95% confidence intervals of the Z estimates, the dashed line is the $Z_{40\%}$ reference point for the SAT stock-region, and the shaded area indicates the 2.5th and 97.5th percentiles of the reference point.**

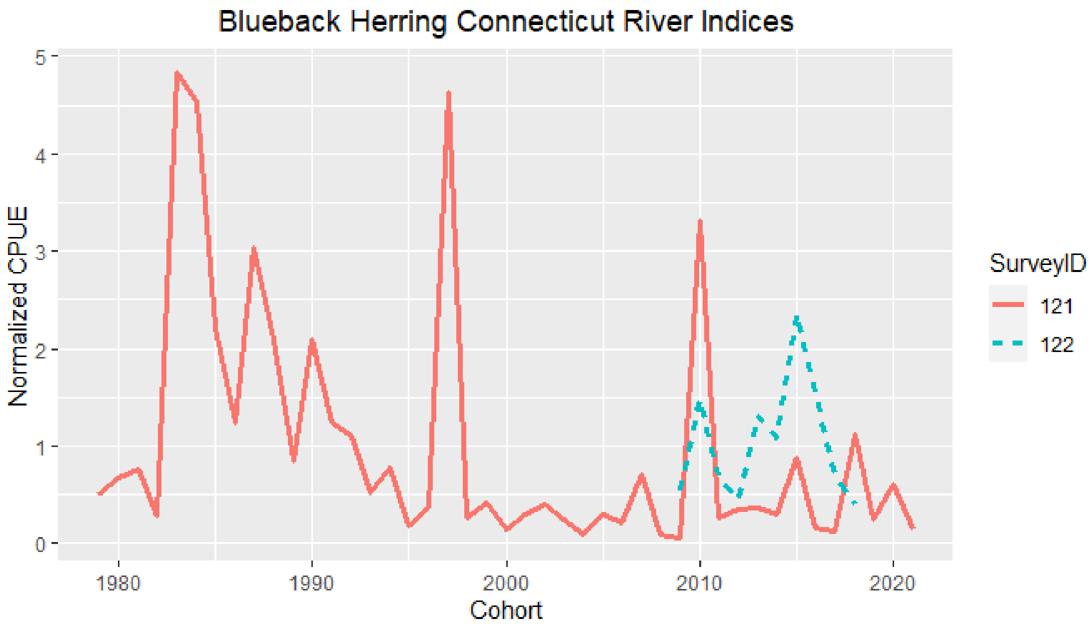


Figure 223. Normalized fishery-independent indices for Connecticut River blueback herring plotted by cohort year See Appendix 6 for survey names corresponding to SurveyID.

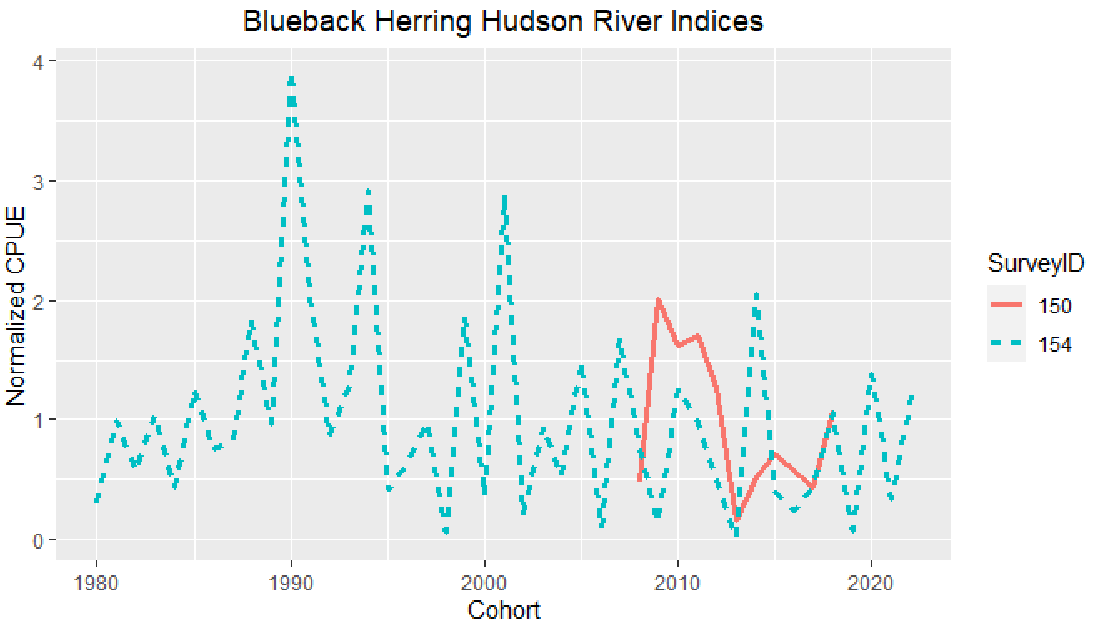


Figure 224. Normalized fishery-independent indices for Hudson River blueback herring plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.

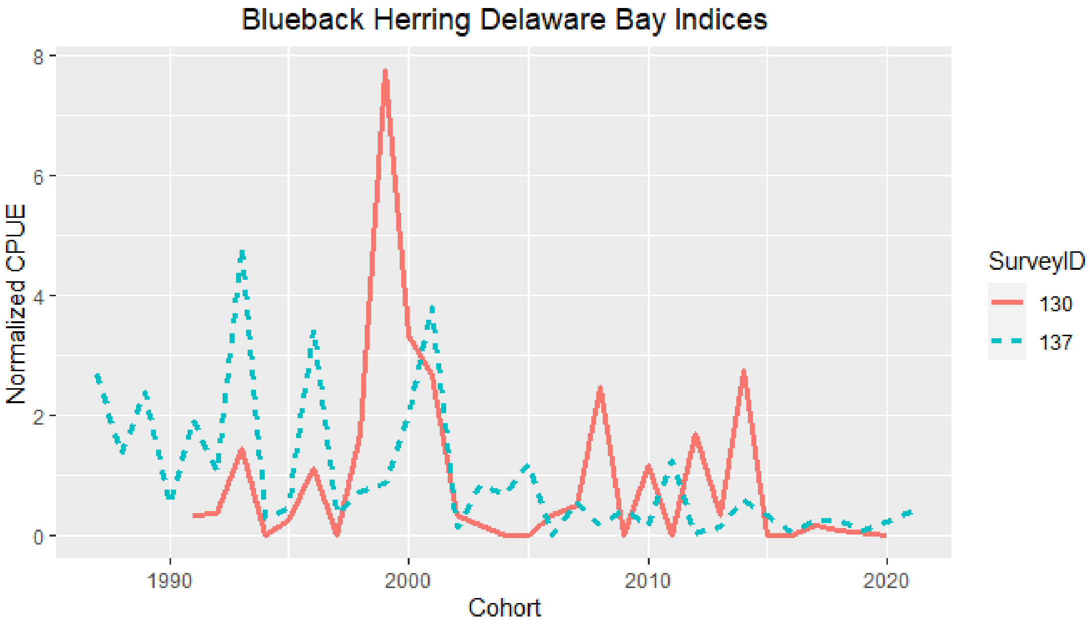


Figure 225. Normalized fishery-independent indices for Delaware Bay blueback herring plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.

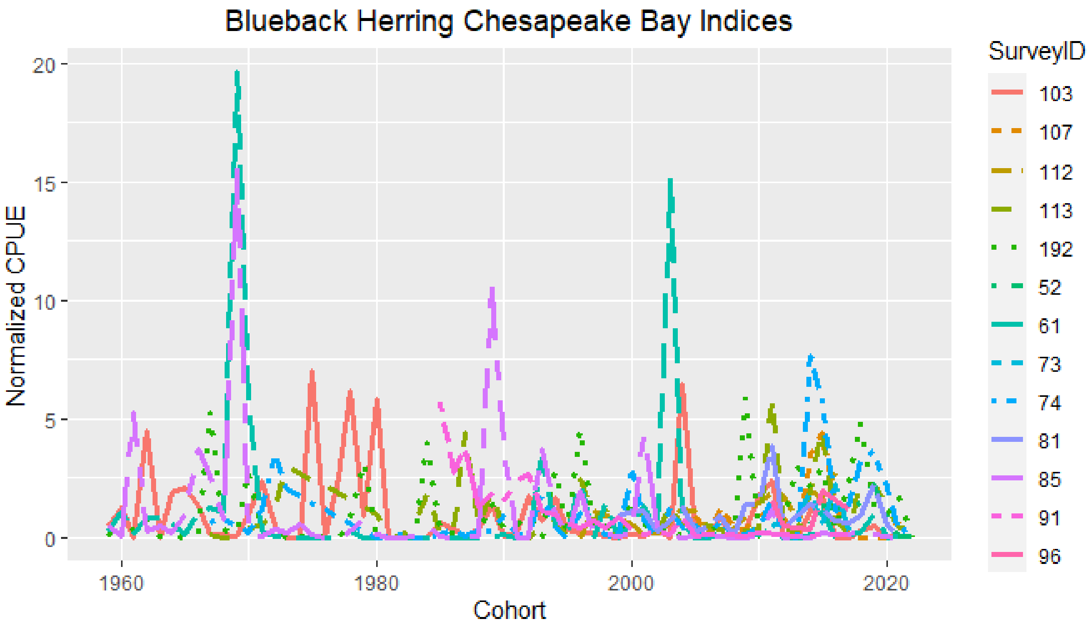


Figure 226. **Normalized fishery-independent indices for Chesapeake Bay blueback herring plotted by cohort year** See Appendix 6 for survey names corresponding to SurveyID.

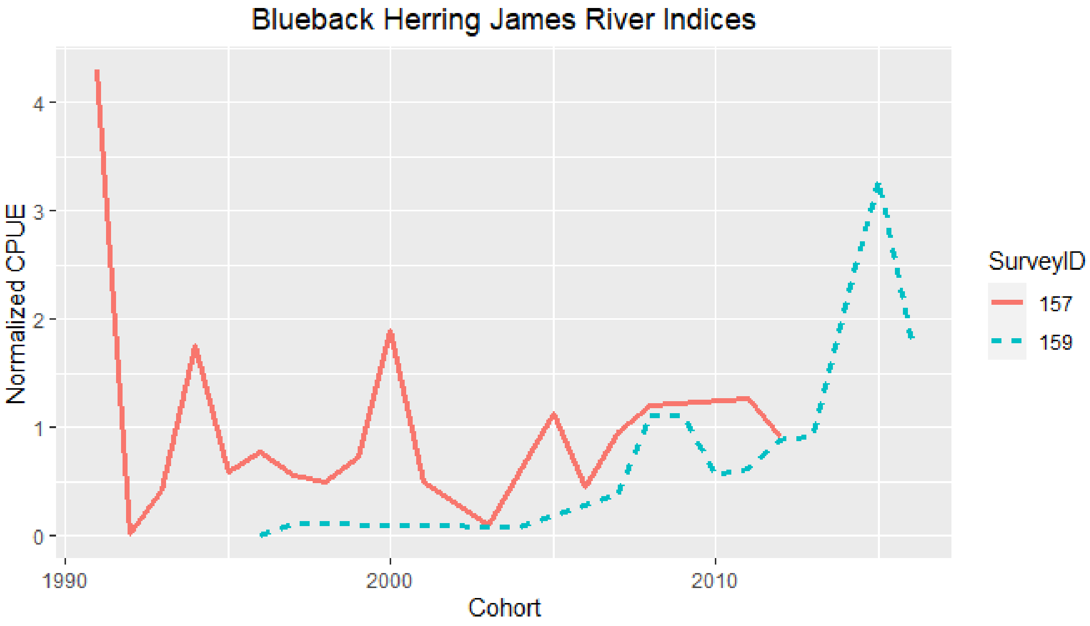


Figure 227. Normalized fishery-independent indices for James River blueback herring plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.

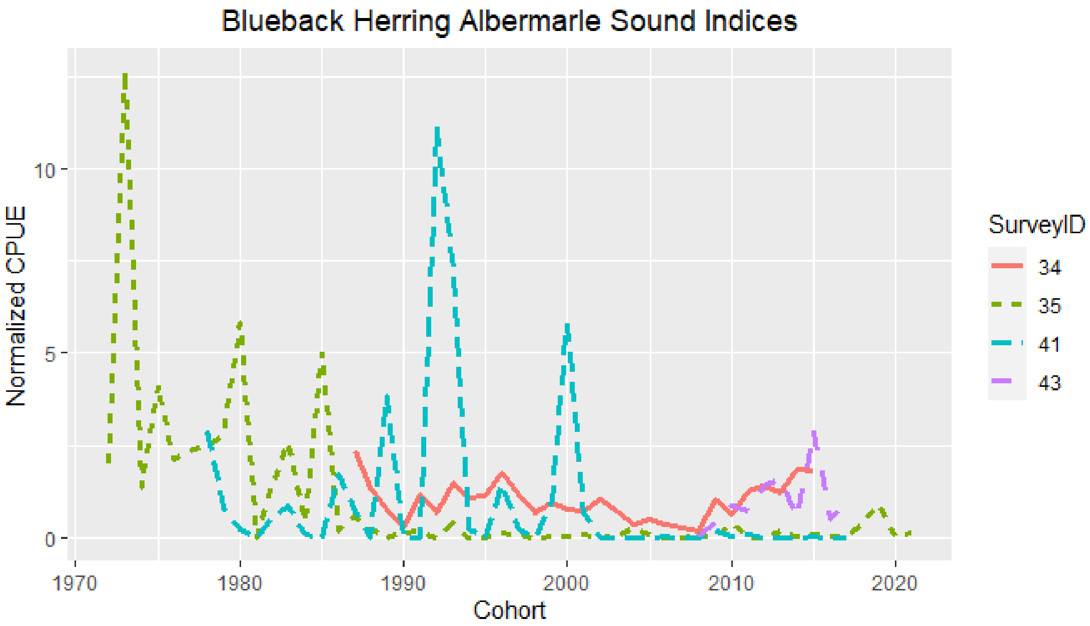


Figure 228. Normalized fishery-independent indices for Albemarle Sound blueback herring plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.

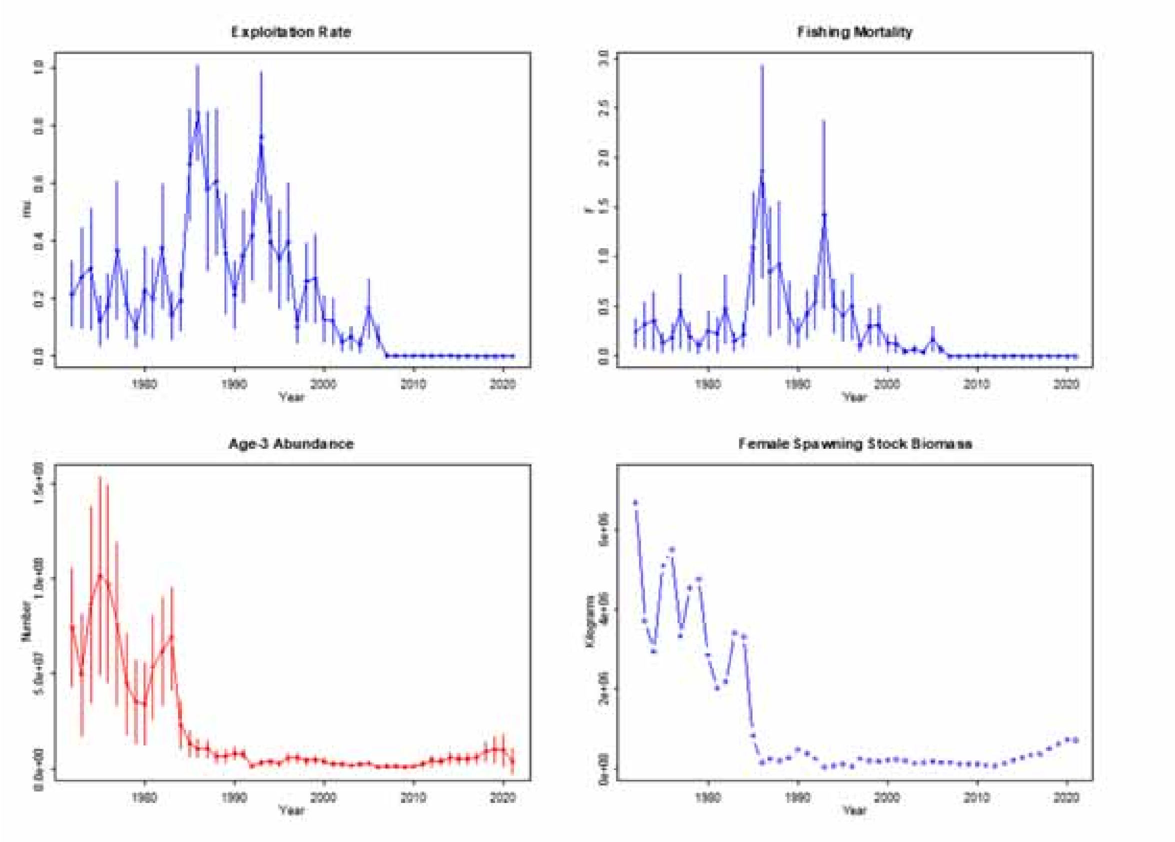


Figure 229. Estimates of exploitation rates, derived fishing mortality rates, recruitment (age-3 numbers), and estimates of female spawning stock biomass (in kilograms) for Chowan River blueback herring. Vertical lines, where present, represent 95% confidence intervals.

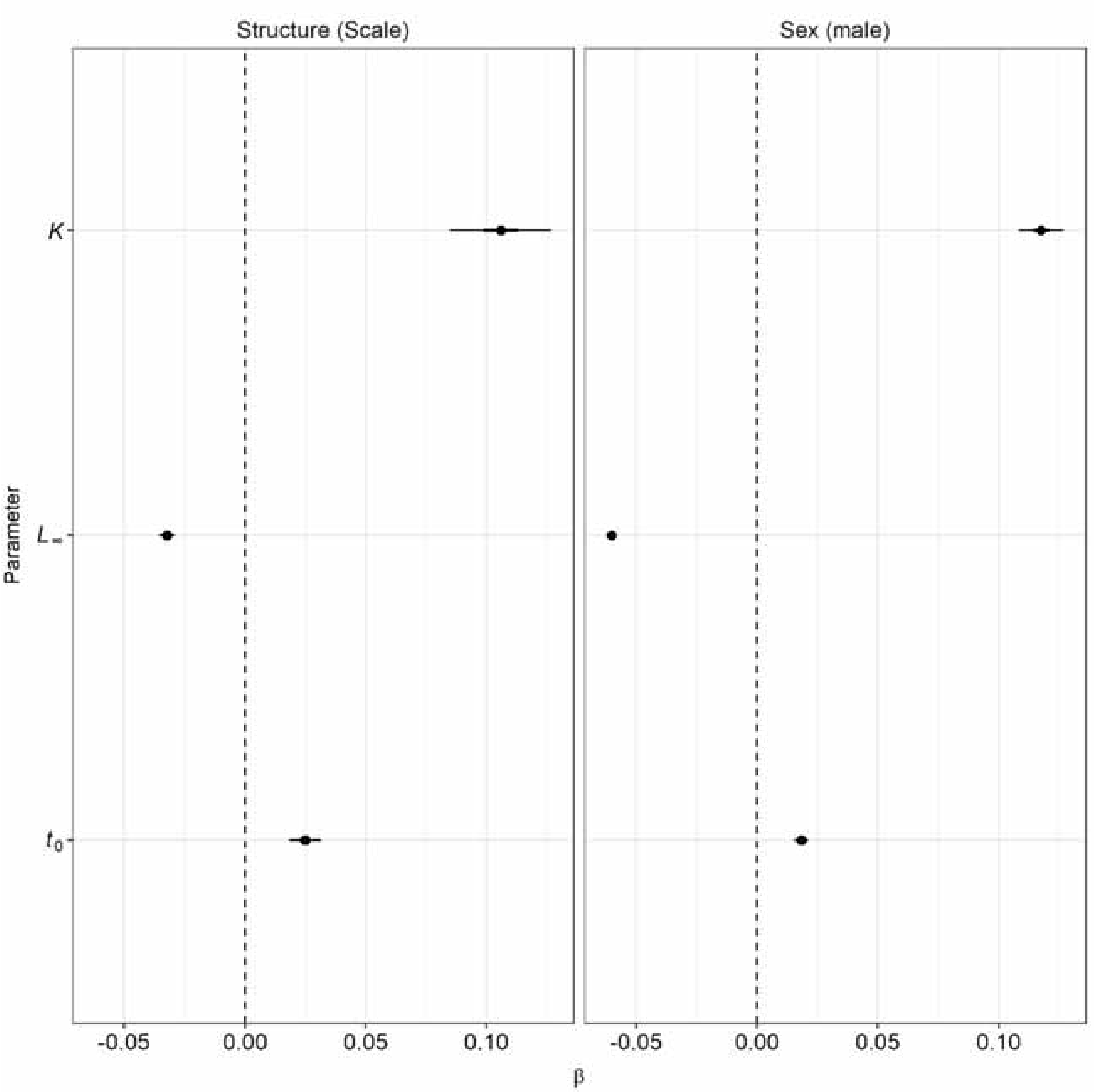


Figure 230. **Estimated regression coefficients (β) for additive effects of aging structure (left) and sex (right) on parameters of the sex-specific von Bertalanffy growth function for blueback herring across rivers.**

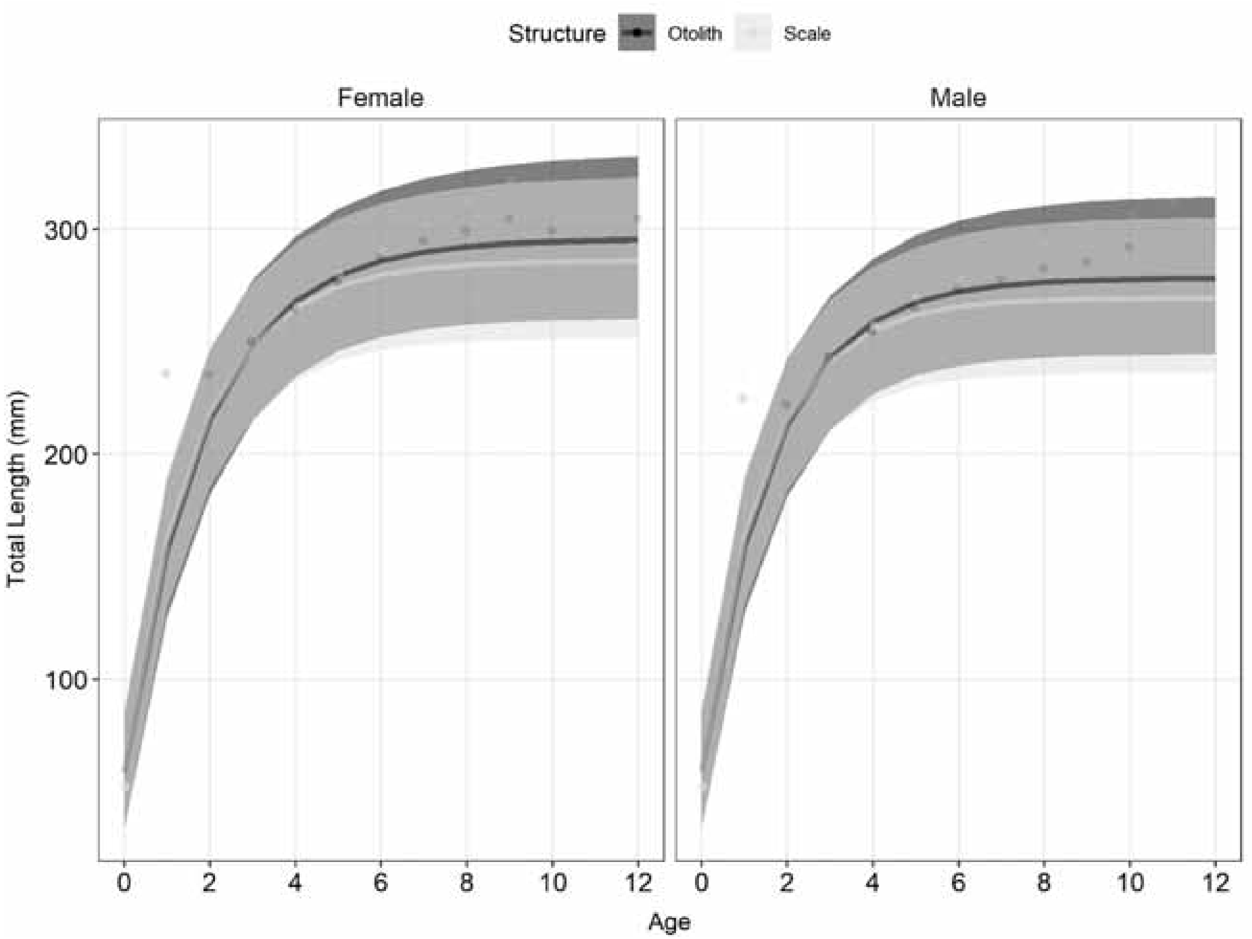


Figure 231. Coastwide growth of female (left) and male (right) blueback herring by ageing structure from the sex-specific von Bertalanffy growth function. Points represent coastwide mean length at age from the raw data for otoliths (dark gray) and scales (light gray). More opaque points indicate larger sample sizes. Lines represent posterior predicted median length at age and ribbons represent 95% credible intervals.

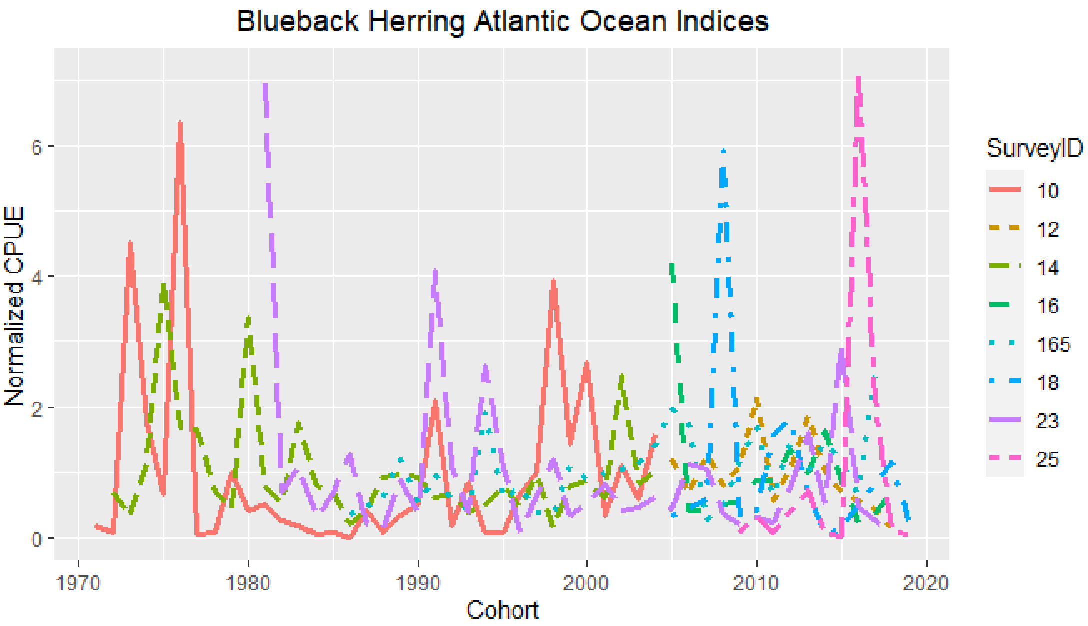


Figure 232. Normalized fishery-independent indices for the ocean/mixed stock blueback herring plotted by cohort year. See Appendix 6 for survey names corresponding to SurveyID.

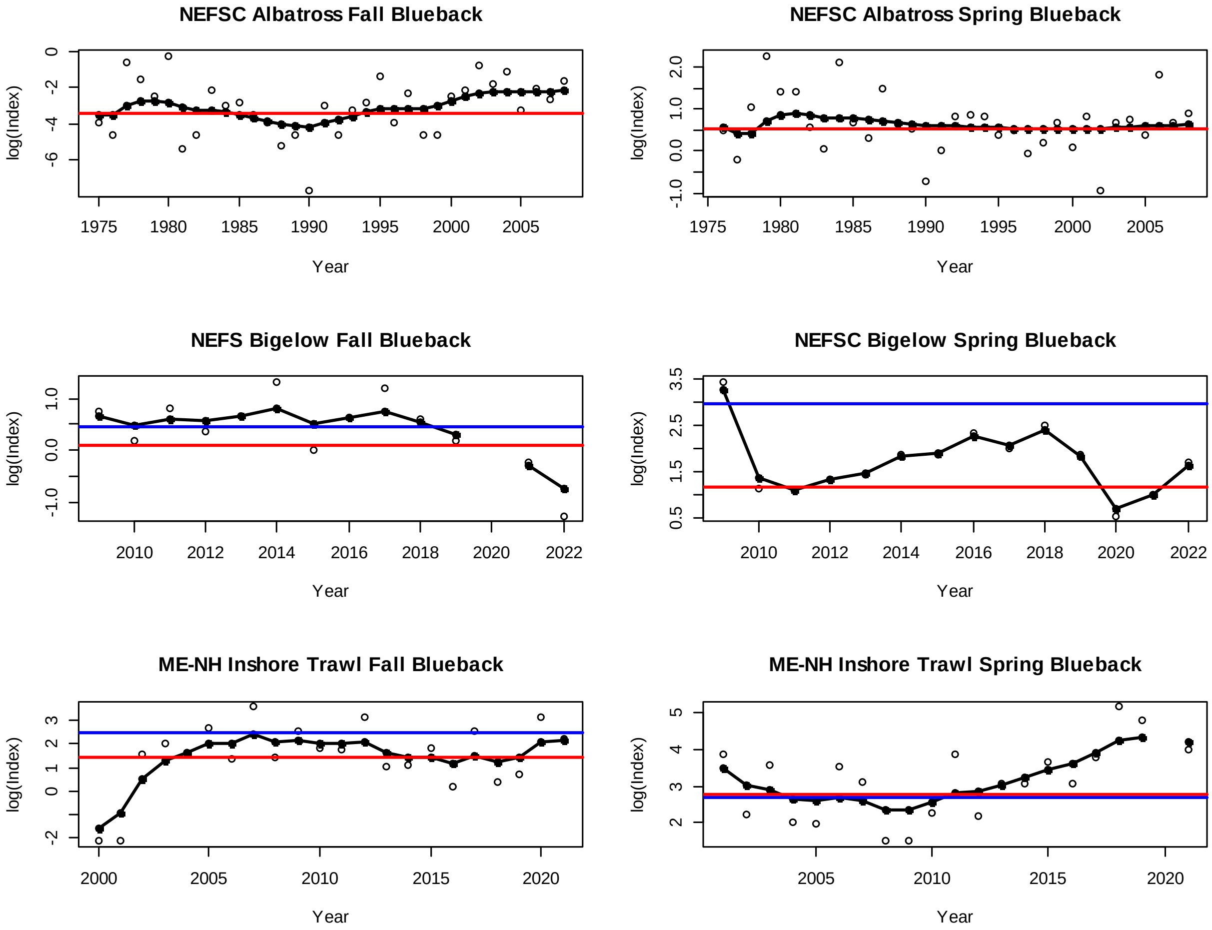


Figure 233. ARIMA model fits to mixed-stock blueback herring survey indices from the ocean. Open circles represent ln transformed indices and the solid circles with black line represent the fitted indices. The red horizontal line represents the Q_{25} reference point and the blue horizontal like represents the 2009 reference point.

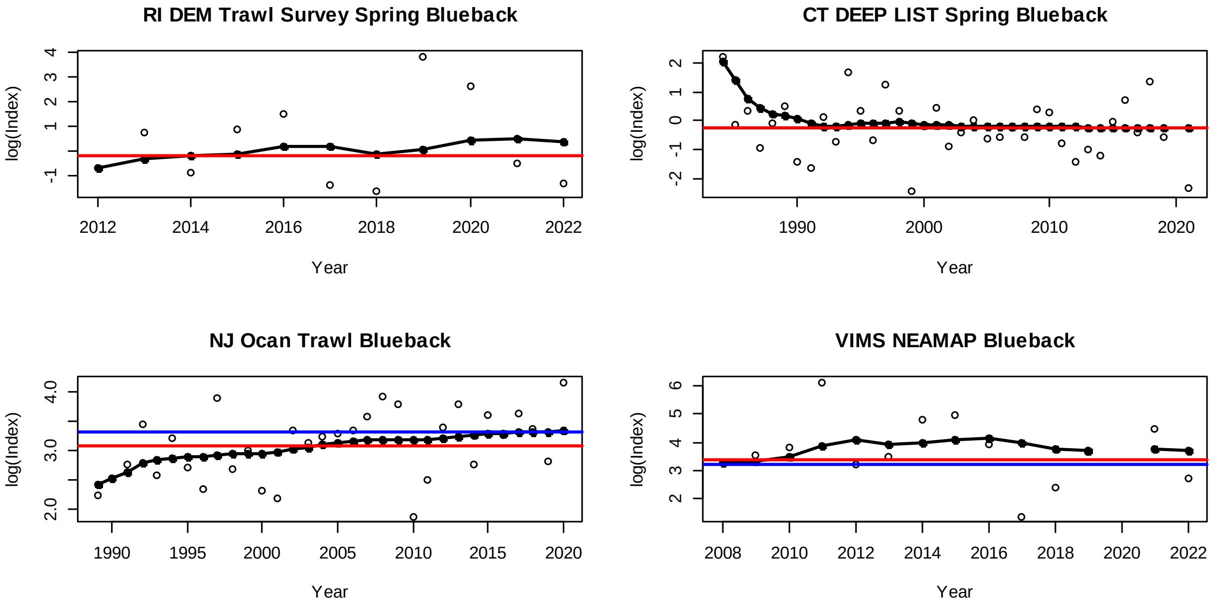


Figure 233 (cont.)

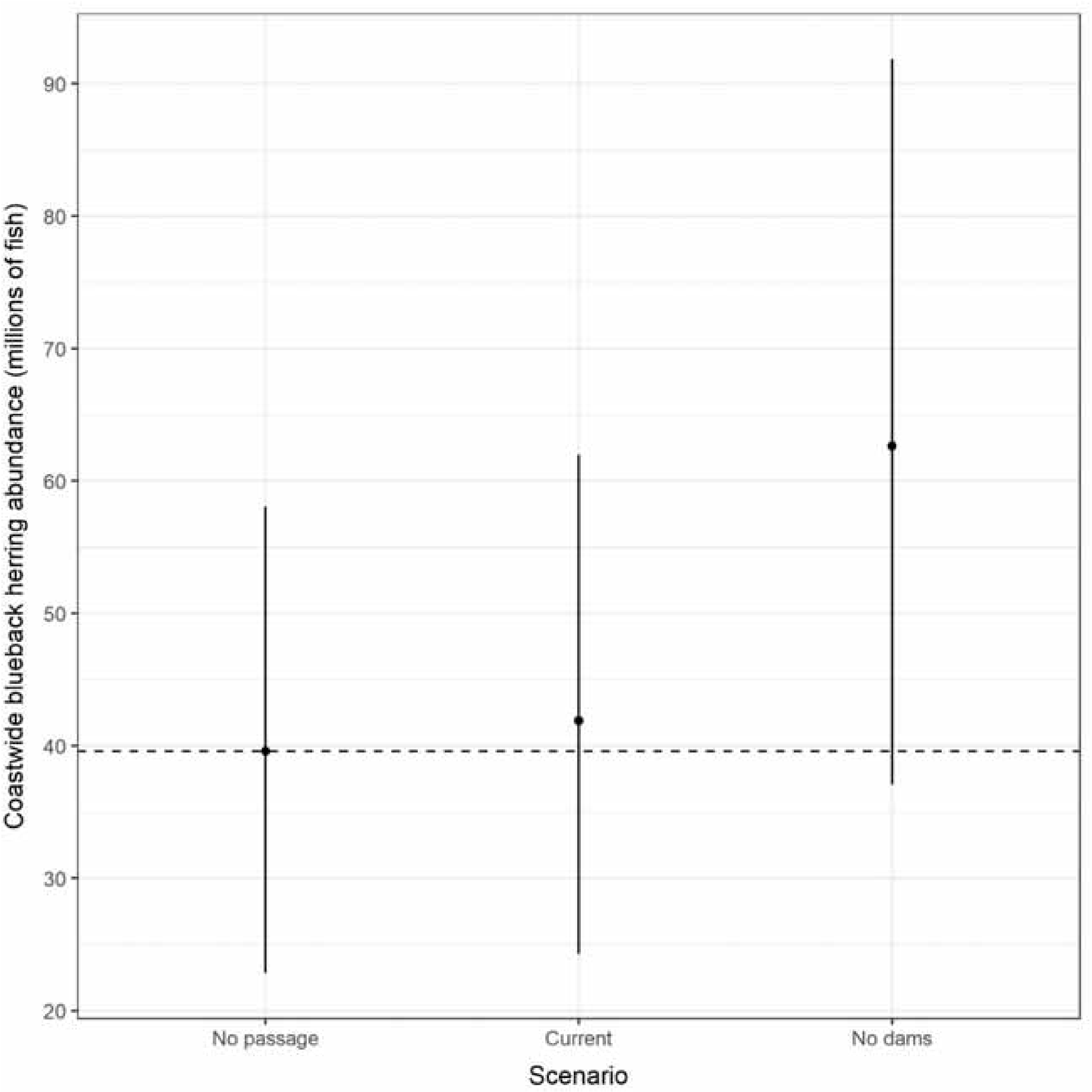


Figure 234. **Predicted coast-wide abundance of spawning blueback herring in watersheds on the east coast of the United States under "no passage", "current conditions", and "no dams" scenarios. Points are mean of simulated abundance, vertical lines are 95% confidence intervals, and the dashed horizontal line is abundance under the no-passage scenario.**

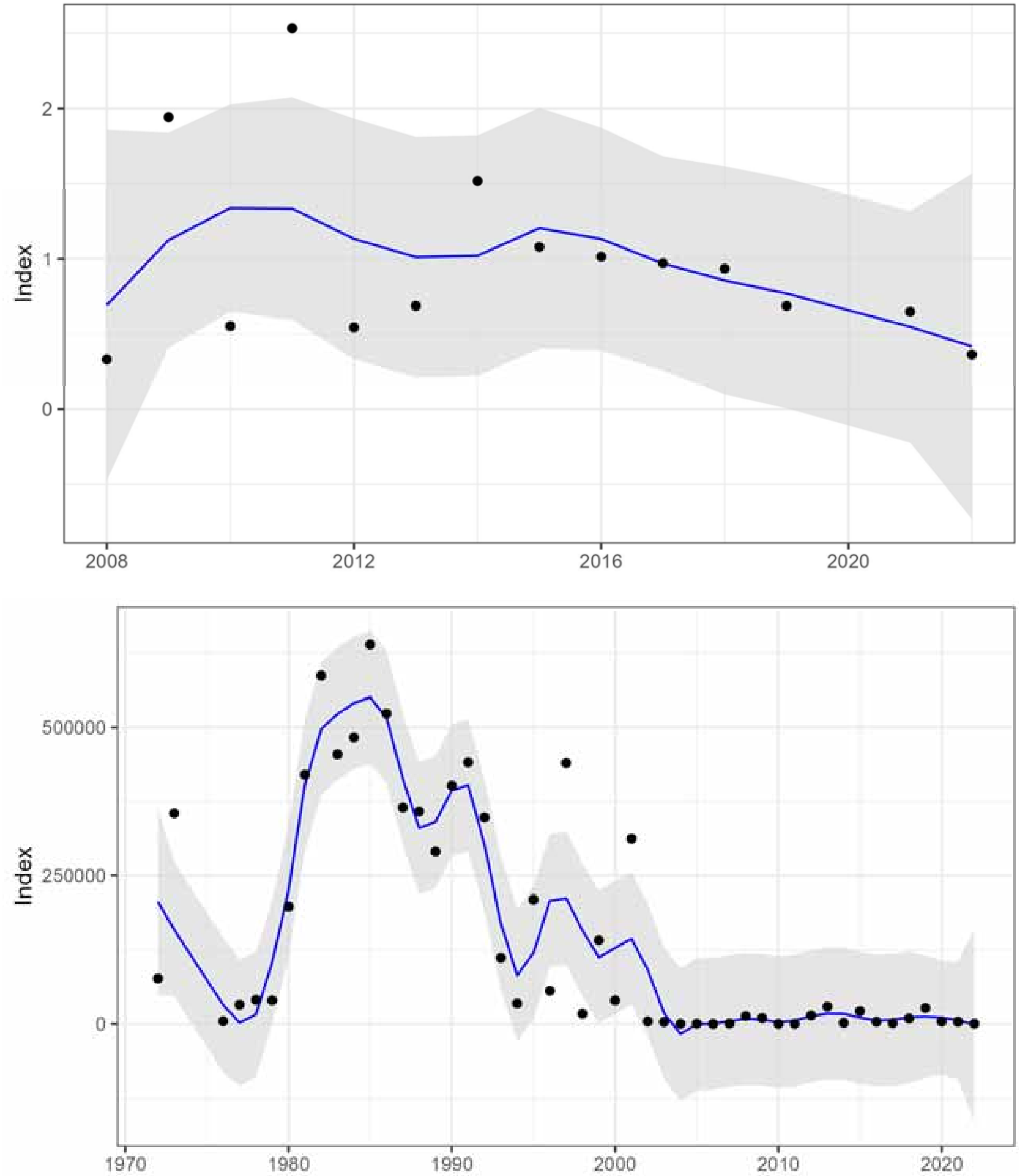


Figure 235. Indices used in the data limited catch cap approaches for blueback herring developed from fishery independent indices (top) and run counts for the SNE stock region, with the loess smoother (blue line) and its confidence intervals (grey area) for the iSmooth approach.

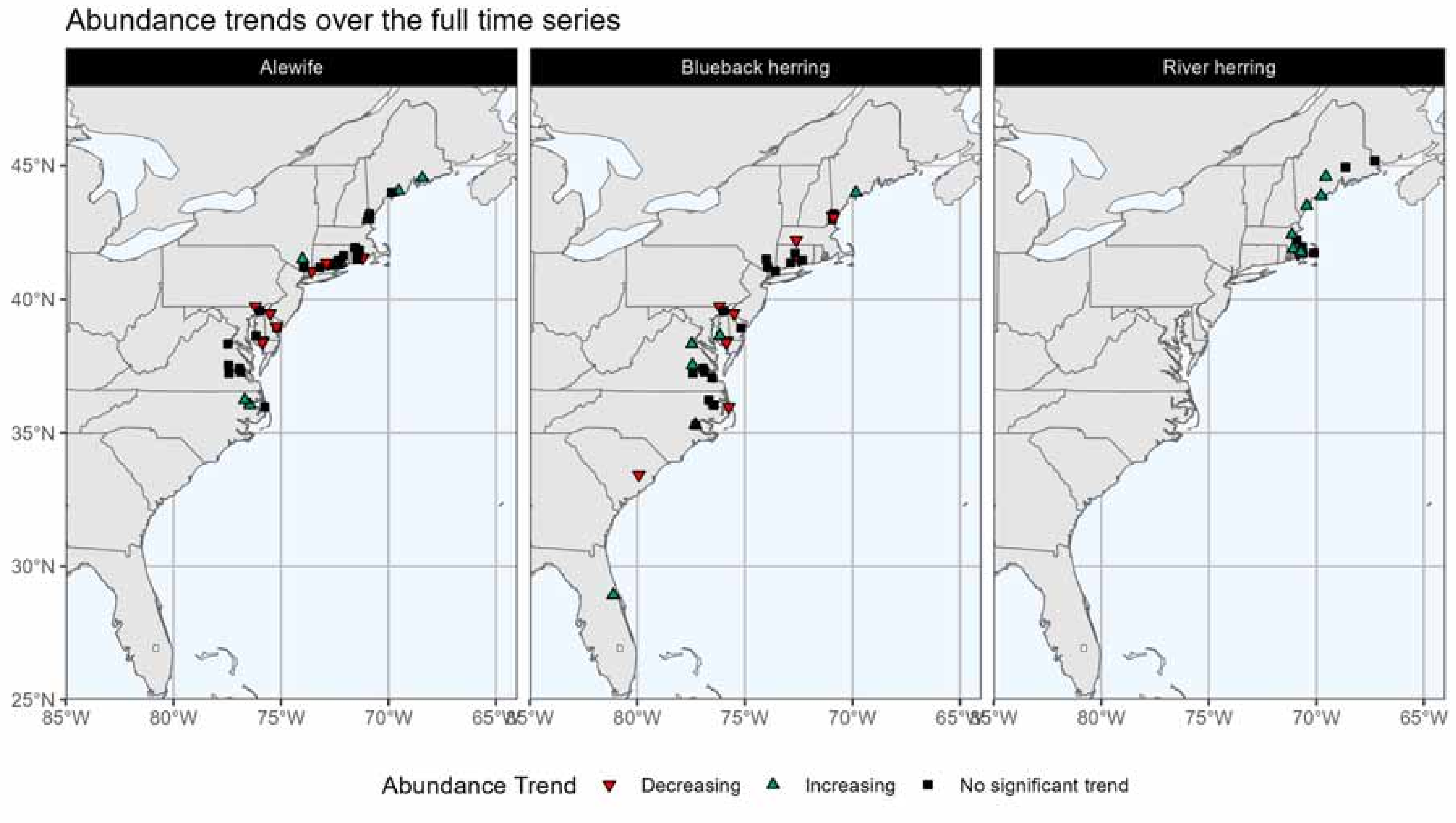


Figure 236. **Map of the results of the Mann-Kendall trend analysis over the full time series for each abundance time-series. "River herring" indicates run counts that are not differentiated by species.**

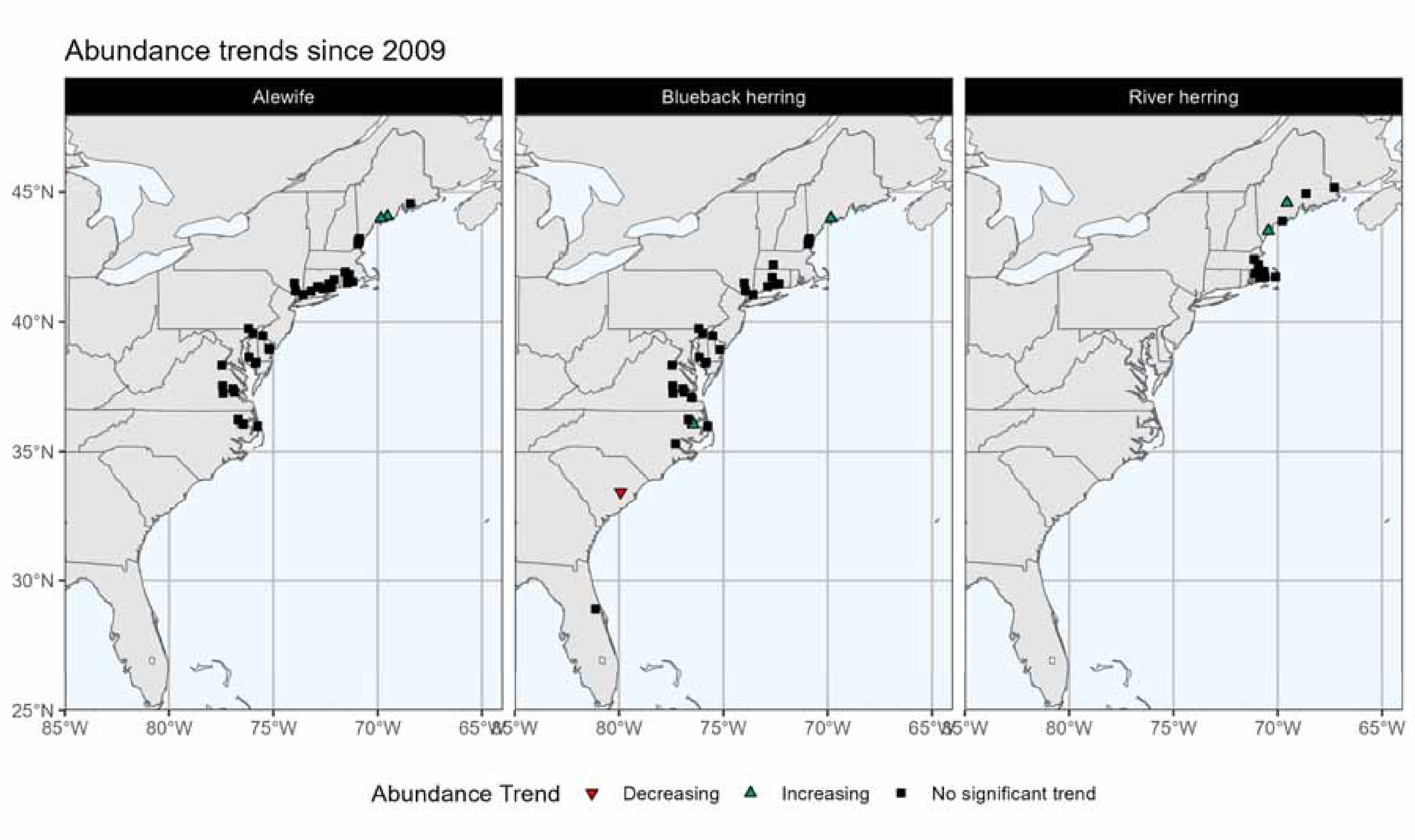


Figure 237. **Map of the results of the Mann-Kendall trend analysis since 2009 for each abundance time-series. "River herring" indicates run counts that are not differentiated by species.**

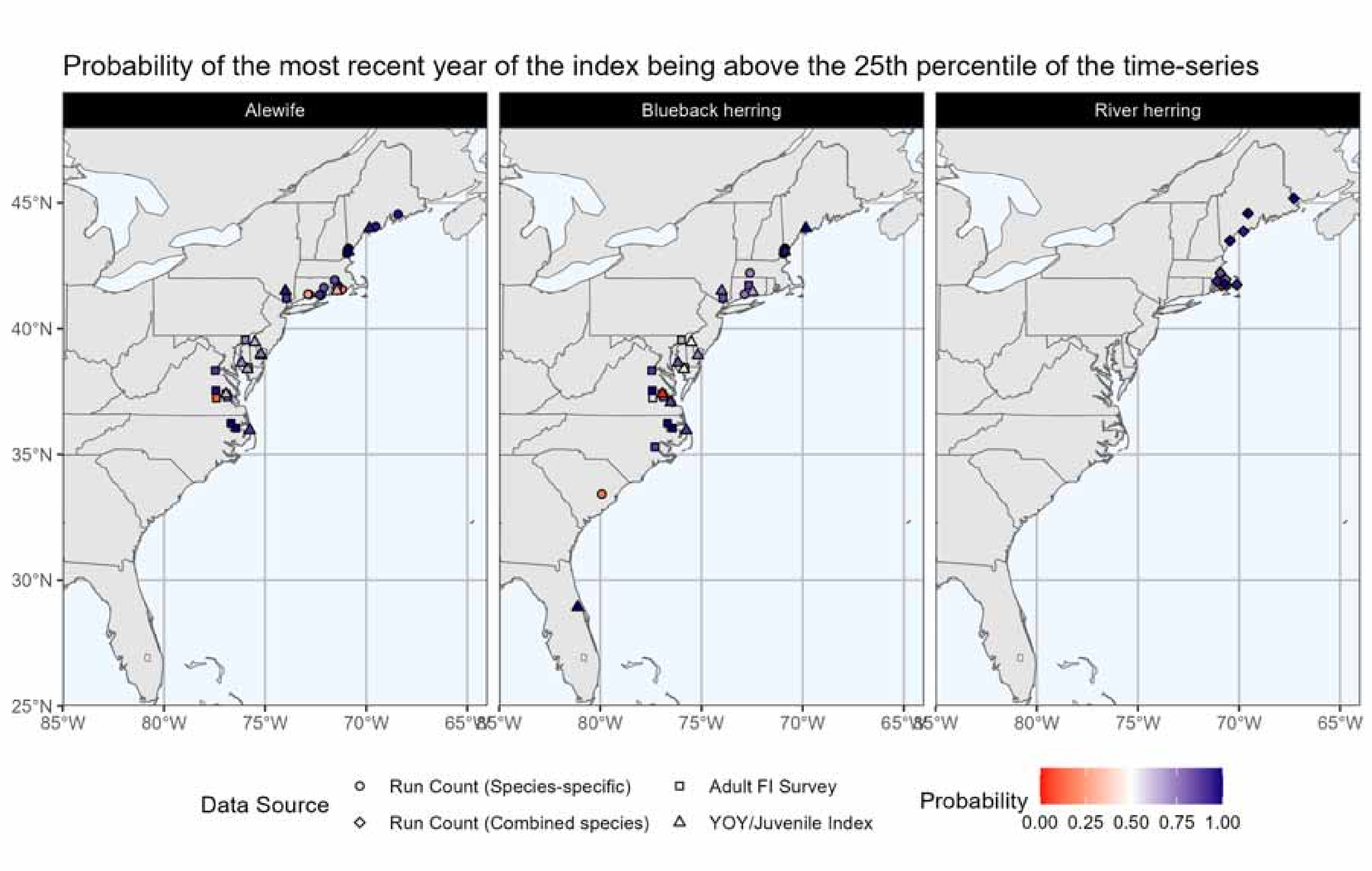


Figure 238. Map of the results of the ARIMA analysis showing the probability that the terminal year of the index is greater than the 25th percentile of the time-series. "River herring" indicates run counts that are not differentiated by species.

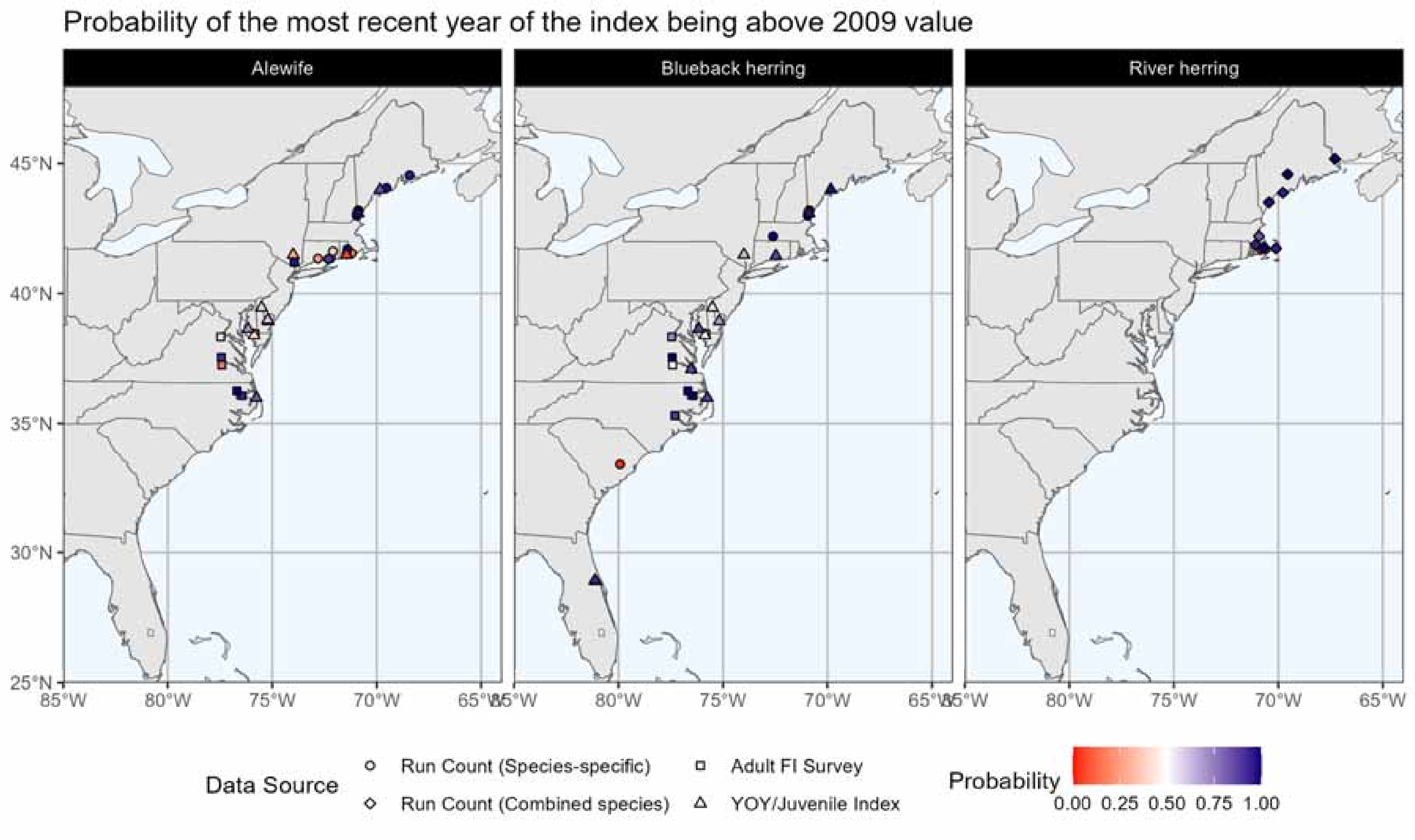


Figure 239. Map of the results of the ARIMA analysis showing the probability that the terminal year of the index is greater than the 2009 value. "River herring" indicates run counts that are not differentiated by species.

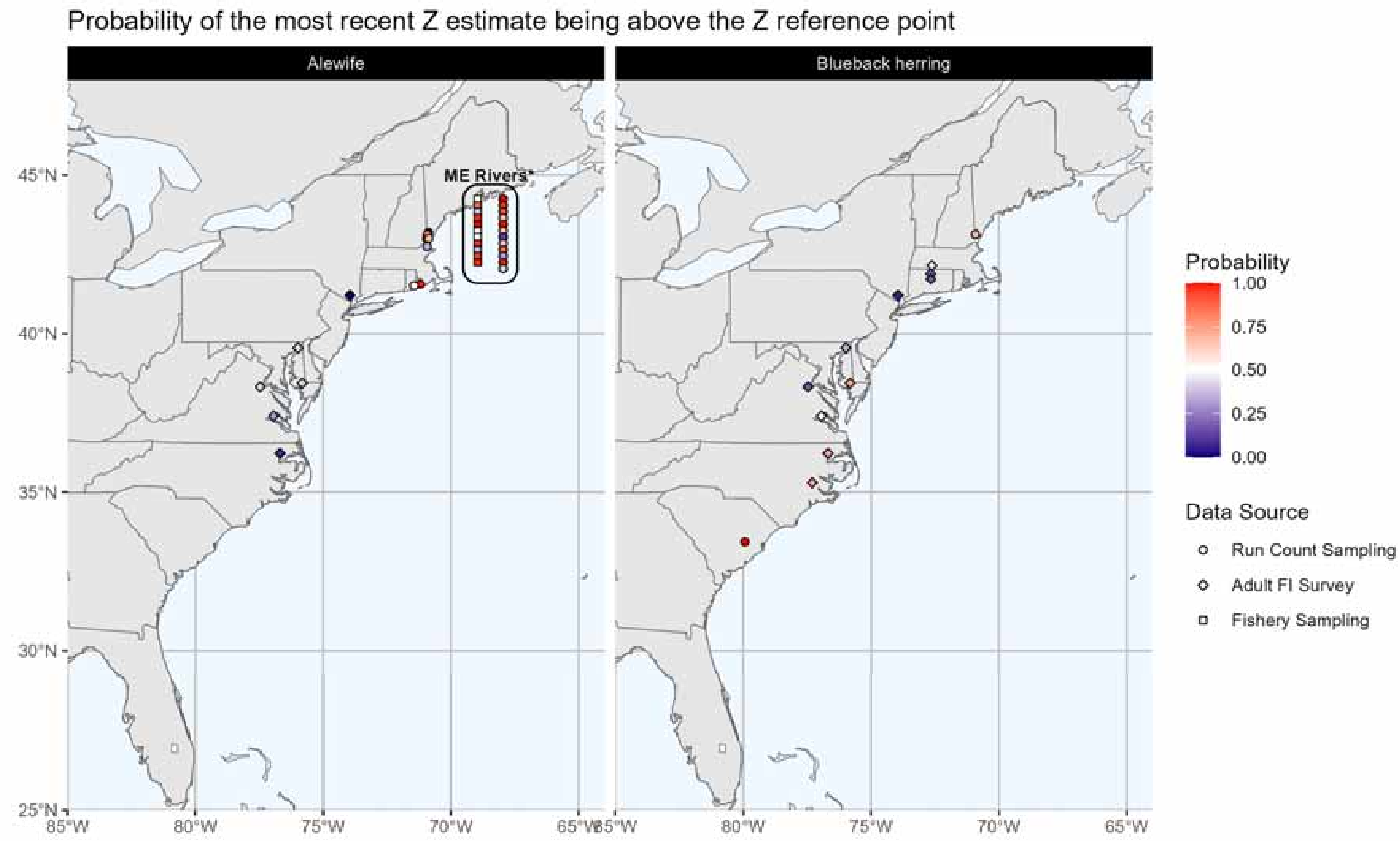


Figure 240. **Map of the probability that the most recent *Z* estimate is above the $Z_{40\%SPR}$ reference point. *ME Rivers: Maine rivers are not plotted geographically to preserve confidentiality.**

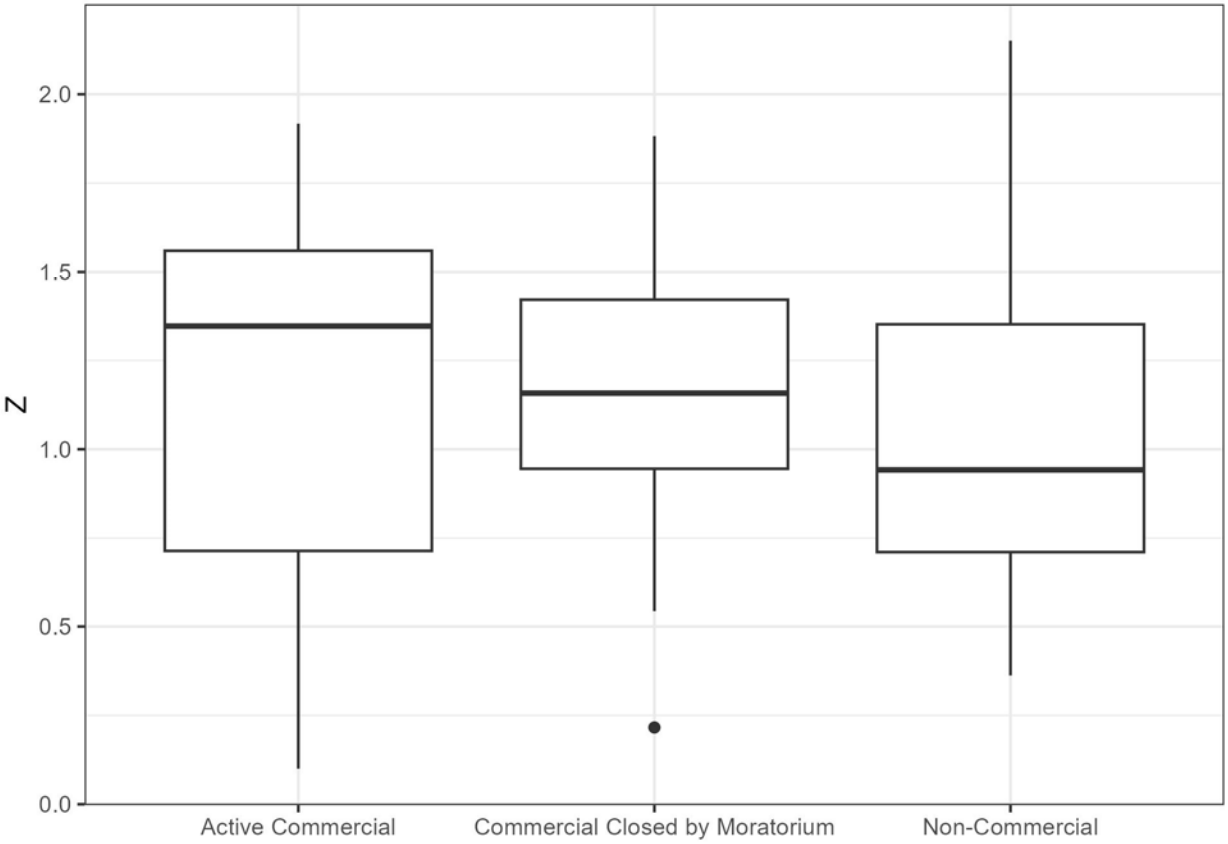


Figure 241. Recent estimates of Z (2017-2021) from Maine rivers broken down by whether the river has an active commercial fishery. Although the medians differ, the differences were not significant.

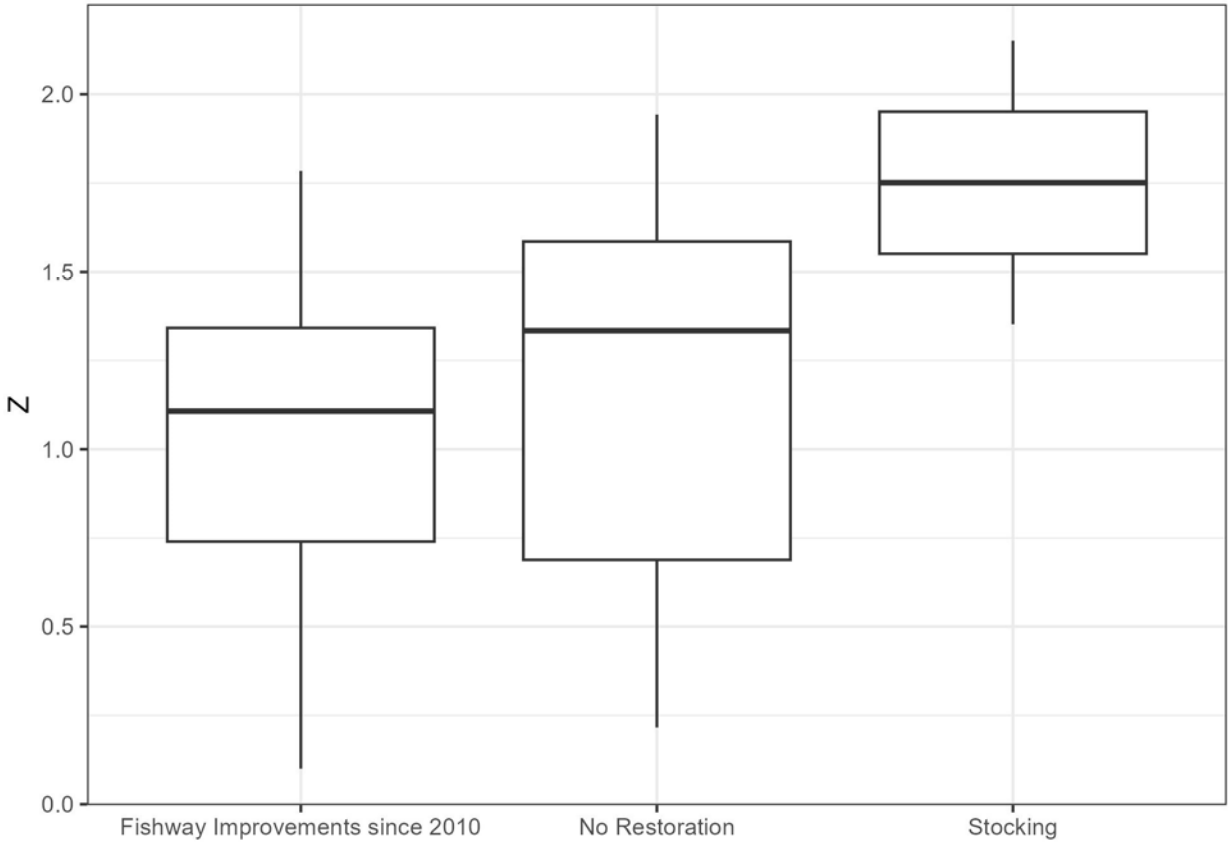


Figure 242. **Recent estimates of Z (2017-2021) from Maine rivers broken down by whether the river has had restoration efforts since 2010. Although the medians differ, the differences were not significant.**