Northeast Fisheries Science Center Technical Memorandum 335

Atlantic Herring Research Track Assessment Report

March 2025

Northeast Fisheries Science Center Technical Memorandum 335

Atlantic Herring Research Track Assessment Report

by the Northeast Fisheries Science Center

NOAA Fisheries, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

March 2025

Northeast Fisheries Science Center (NEFSC) Reference Documents

This document may be cited as:

Northeast Fisheries Science Center. Atlantic Herring Research Track Assessment Report. US Dept Commer, Northeast Fish Sci Tech Memo. 335; 91p.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PEER REVIEW PANEL SUMMARY REPORT

Report prepared by Peer Review Panel members:

- Dr. Conor McManus (Chair), New England Fisheries Management Council Science and Statistical Committee
- Dr. Henrik Sparholt, independent contractor with the Center for Independent Experts
- Dr. Florian Berg, independent contractor with the Center for Independent Experts
- Dr. Gary Melvin, independent contractor with the Center for Independent Experts

The Northeast Region Coordinating Council (NRCC)[1] has developed an enhanced stock assessment process to improve the quality of assessments. The process involves two tracks of assessment work: 1) a Management Track (MT) that includes routine updates of previously approved assessment methods to support regular management actions (e.g., annual catch limits), and 2) a Research Track (RT) that allows comprehensive research and development of improved assessments on a stock-by-stock or topical basis. The RT assessment process allows for a more thorough review of information available and for the evaluation of different assessment approaches than would be possible in a standard stock assessment process where the results are immediately needed for management advice. RT assessments are followed by MT assessments; occasionally, scientists can improve an RT assessment before or during a subsequent MT assessment. This Peer Review Panel (hereafter Panel) reviewed the RT Assessment for the Atlantic herring stock in United States waters.

Scientists first assessed Atlantic herring using Virtual Population Analysis (VPA) in the 1960s-70s. Since 2009, the Northeast Fisheries Science Center has assessed the stock using the Age Structured Assessment Program (ASAP), which it developed. Scientists conducted the last benchmark stock assessment in 2018, have provided updates every other year since, and most recently completed an MT assessment in 2024 using ASAP. The RT assessment for Atlantic herring aimed to develop an age-structured state space assessment model to estimate process and observation error and to consider environmental covariates within the model.

The Atlantic Herring RT Working Group (WG) used the Woods Hole Assessment Model (WHAM) platform to develop a state space model to be used in future MT assessments of the stock. Matt Cieri (MEDMR) chaired the WG that included staff from NEFMC, GARFO, Massachusetts Division of Marine Fisheries (MADMF), University of Massachusetts – Dartmouth School for Marine Science and Technology (SMAST), and Rutgers University. Terms of Reference (TORs) for the WG are provided in Appendix 1.

The Atlantic Herring RT assessment peer review took place in Woods Hole, MA, during March 10-14, 2025 using a hybrid meeting platform. The Panel included three independent scientists selected by the Center for Independent Experts (CIE): Henrik Sparholt, Florian Berg, and Gary

[1]Atlantic States Marine Fisheries Commission (ASFMC), Greater Atlantic Regional Fisheries Office (GARFO), Mid-Atlantic Fishery Management Council (MAFMC), New England Fishery Management Council (NEFMC), and Northeast Fisheries Science Center (NEFSC).

Melvin. Conor McManus (Member of the NEFMC Scientific and Statistical Committee) chaired the Panel. The agenda is located in Appendix 2 and attendees in Appendix 3.

The RT WG submitted the Assessment Report and supporting working papers to the Panel via the NEFSC data portal (https://apps-nefsc.fisheries.noaa.gov/saw/sasi.php) on February 21, 2025. The RT WG provided additional information requested by panelists during the peer review and uploaded it to the data portal. Listed items are in Appendix 4. Before the meeting, on March 6, 2025, members of the Panel met with Brian Hooper (NEFSC's Stock Assessment Process Lead) and Kristan Blackhart (Chief, NEFSC Population Dynamics Branch) to review and discuss the meeting agenda, reporting requirements, meeting logistics, and the overall process.

In addition to the report and working papers, WG members and Chair-invited participants made presentations available on the data portal during the RT Review. WG members attended the meeting to answer questions from the Panel, and NEFSC staff acted as rapporteurs to capture conversations between the Panel and WG, Panel consensus on various topics, and Panel recommendations. Panelists led drafting individual portions of this report, but the entire Panel edited and reviewed the report to ensure it represents the consensus views of the Panel. The Panel Chair compiled and edited this Summary Report with assistance from all panelists before submission of a draft report to the WG Chair and WG Lead Analyst. CIE Panelists will submit separate individual reviewer reports to the CIE.

The Panel agreed that all eight TORs were adequately addressed. With specific regard to the transition from ASAP to WHAM, the WG presented a series of WHAM runs testing the sensitivity of the model to various configurations and life history assumptions. The final candidate model recommended by the WG included many of the same data inputs as the previous 2024 MT ASAP configuration except for select elements outlined in the main WG report; however, the model now includes random effects being applied in the model, most notably on the numbers-at-age (NAA) transitions. After reviewing the various model variants the WG provided, and further investigation of the diagnostics and outputs from the models, the Panel agrees that WHAM is an appropriate tool for the Atlantic herring assessment and offers a scientific improvement over ASAP. Before the next MT assessment for Atlantic herring, the Panel provided several recommendations for consideration that strive for model diagnostic improvements, improved biological plausibility, and a deeper understanding of WHAM given its relatively nascent nature. In its recommendations, the Panel emphasized the importance of better understanding the impacts of the NAA random effects, including the stability of NAA estimates with additional years of data added through peel analyses, and their influence or utility in projections. While WHAM reduces retrospective patterns compared with the ASAP for this stock, the uncertainties around the projection methods need further investigation, particularly as they relate to projections beyond the bridge year and subsequent year. The Panel commended the WG for the substantial amount of work made in moving to the state space WHAM platform for the Atlantic herring stock and for the collegial nature of the review.

The Panel’s evaluation of the WG’s responses to the eight TORs is provided below.

Term of Reference (TOR) #1: *Identify relevant ecosystem and climate influences on the stock. Characterize the uncertainty in the relevant sources of data and their link to stock dynamics. Consider findings, as appropriate, in addressing other TORs. Report how the findings were considered under impacted TORs.*

The Panel concluded that this TOR was adequately addressed.

Significant progress has been made in the identification of ecosystem drivers that can influence Atlantic herring abundance and distribution. The findings in TOR 1 were addressed and further considered in TOR 4 and TOR 7. Uncertainty was documented through the analyses, both within TOR 1 via analyses and a literature review, and through evaluation of TOR 1 elements in TOR 4 (i.e., WHAM sensitivity runs).

The WG provided a thorough review of Atlantic herring life history and ecosystem drivers on the species (as documented in the literature) through an updated Ecosystem and Socioeconomic Profile (ESP). The ESP leveraged essential fish habitat and life history information previously collated and gathered new, more contemporary research. The processes that influence population dynamics and could be evaluated as environmentally explicit relationships in WHAM were better understood through the use of ESP. These endeavors led to a conceptual life history model that outlined the various ecosystem influences on the species in this region, with hypotheses for the impact of specific conditions on each life stage (Figure 1). This conceptual model was then used to identify possible environmental datasets for further exploration.

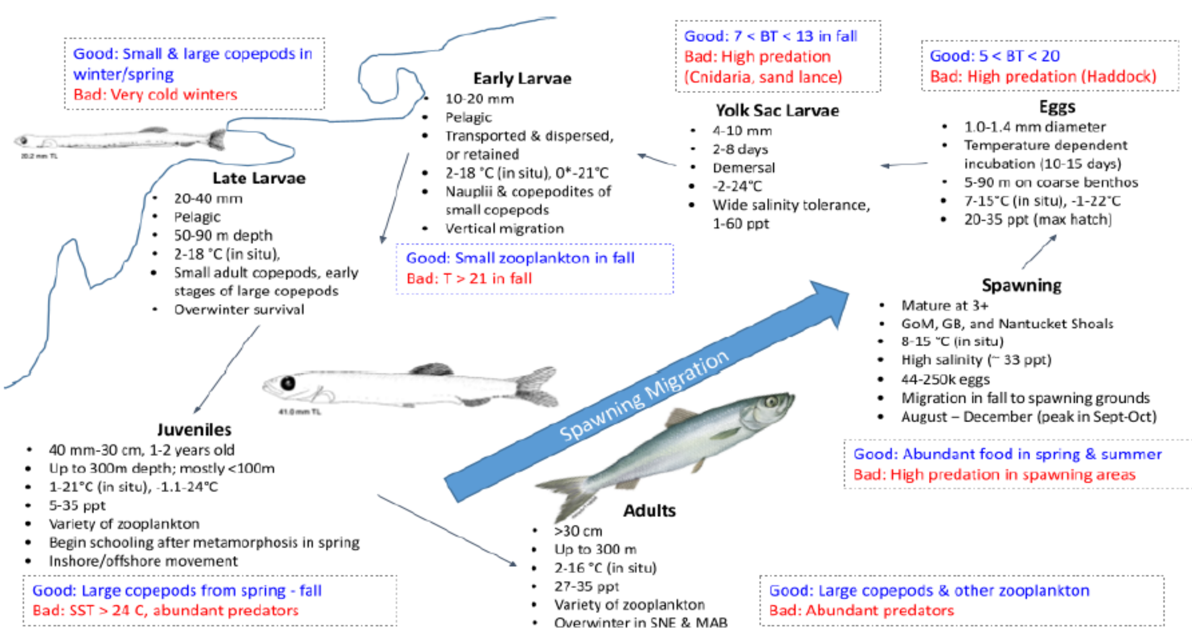

Figure 1. Life history diagram and ecosystem influence hypotheses for Atlantic herring as presented by the WG and in the assessment report.

The WG used boosted regression trees (BRTs) to understand which environmental factors influence Atlantic herring, and their relative importance compared with each other. Several covariates were explored (e.g., copepods, haddock, temperature indices) to understand influences on Atlantic herring (e.g., starvation/food availability, predation pressure, thermal mortality). The response variable for the BRTs was Atlantic herring recruitment estimated from the previous ASAP run to help guide how these covariates could be used in conjunction with recruitment estimates in WHAM.

The Panel commended the WG for its efforts within the ESP, as well as using both hypotheses for impacts on herring recruitment to guide model prioritization runs and ensure biological plausibility. In addition, the use of a tool (e.g., BRTs) was appreciated to determine which variables were most sensible for testing within WHAM.

The Panel recommended several future advancements for this work, including modifications to copepod and haddock predation indices to refine the indices and better capture the interactions between these factors and herring. In addition, the Panel suggested considering competition metrics (e.g., other forage fish abundance) in the future given the abundance and spatiotemporal changes in certain species that have been captured in the literature and reflected in the stakeholders' comments collected via this assessment. The environmental covariates constructed might also be used to understand other processes within the assessment model (e.g., catchability and selectivity, natural mortality, growth) as deemed appropriate in the future.

The Panel provided two substantive comments of caution for the BRTs going forward. The first concern was with regard to the BRT method. The Panel was unclear on whether the BRT was the best tool for this prioritization exercise compared with other methods (e.g., principal component analysis, dynamic factor analysis, other regression approaches). Testing WHAM and ASAP recruitment data for the BRTs suggested that variable importance conclusions may be subject to input data with the BRTs (Figure 2), and testing its robustness against other methods would be beneficial in the future. The second concern involved using assessment model output (i.e., Age-1 Atlantic herring estimates) for these analyses. Caution is raised when conducting post-hoc analyses using data output as the uncertainty in the assessment products themselves is often overlooked (Brooks and Deroba, 2015; Dickey-Collas et al., 2015). The differences in BRT results from using WHAM and ASAP-predicted recruitment also suggest this concern, in addition to the rather circular nature of these analyses (i.e., use WHAM-estimated recruitment to pick an environmental

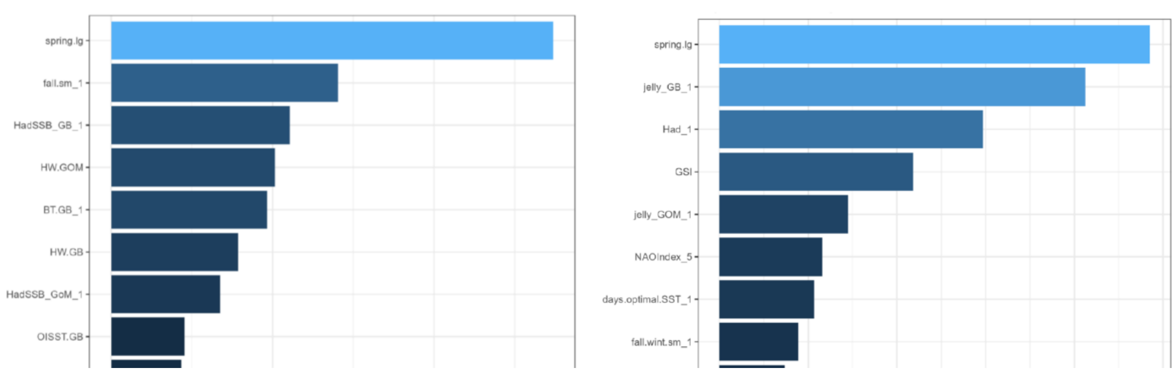

Figure 2. Boosted regression tree results for environmental variables explaining Atlantic herring recruitment estimates produced from ASAP (left) and WHAM (right). Figures were presented during the peer review.

covariate to include in modeling for revised WHAM-predicted recruitment). Efforts should be made to analyze Age-1 abundance indices from other sources (e.g., state surveys, seabird diet data) to avoid this circularity.

TOR #2: *Estimate catch from all sources, including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.*

The Panel concluded that this TOR was adequately addressed.

The information presented by the WG provided a good and general summary of the landings over time, by region, and gear type given the historical extent of the fishery and the magnitude of catches. They identified potential uncertainty associated with the different reporting mechanisms and how estimates of discards were integrated into the estimates of landings over time. Over the years, the authorities responsible for the data collection used several approaches to account for fishing mortality (catch and discards) from all sources. The implementation of CAMS in 2020 represents an improved methodology in this process and reflects the sequential approach in the enhancement of the catch monitoring/reporting system. While the WG met the TOR regarding fishing effort in the macro-sense, limited information was provided on the spatial and temporal changes or variability of the fishery (fleet activity), which occurred within a broad geographical area. Showing how and where fishing effort has spatially decoupled over time in relation to the available surveys and their coverage would have been informative. The Panel agreed with the decision to use CAMS to estimate catches and discards given its reasonable comparability with past approaches; however, a few inconsistencies were identified in the reporting with slight differences for the CAMS between the report and the presentation. These differences need resolution and correction in the reporting. The Panel strongly recommends comparative analyses presented from 2020 onward be conducted as far back as possible (e.g., 1996). This will allow for determining whether differences between previous methods and CAMS align with smaller differences observed from 2021 to 2023 or larger differences as observed in 2020 (i.e., up to a 25% difference).

The number of biological samples (50 fish/sample) from commercial catches has dramatically declined and the temporal coverage has contracted since 2019 due to the reduction in allowed catch and management restrictions. Although the total number of samples is the lowest in the time series (1964-present), the WG concluded that the level of sampling was adequate to describe the characteristics of the mobile fleet. Information on the fixed gear fishery (i.e., weir/shutoff) was provided by the Canadian Department of Fisheries and Oceans and resulted in some slight modifications, but inconsequential relative to the assessment. The weight at age for the commercial fishery, which showed a steep decline between 1980 and 1990 for most adult ages (i.e., representing a potential loss in productivity), appears to have leveled off and may even be increasing slightly for some age groups in recent years. This is consistent with observations for adjacent and ocean-wide herring stocks as well as many other fish species.

Spring spawning fish were mentioned on several occasions during the meeting. While traditionally, the stock has been dominated by fall spawners and remains so, the continued presence of spring spawners in catches and survey sampling may be a forerunner of things to come. Unfortunately, their presence appears more anecdotal with no quantification of their presence. The proportion of spring spawners in the resource and the fishery is not expected to be large or have an impact on the assessment at the current time but is worth considering in the future.

TOR #3: *Present the survey data used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, application of catchability and calibration studies, etc.) and provide a rationale for which data are used. Describe the spatial and temporal distribution of the data. Characterize the uncertainty in these sources of data.*

The Panel concluded that this TOR was adequately addressed.

The WG provided an overview of the fishery-independent surveys available and used in the Atlantic herring stock assessment. The four surveys currently used in the assessment model included the NEFSC Spring (1968-present) and Fall (1963-present) Bottom Trawl (BT) surveys, the Summer (Shrimp) survey (1980s-2023) and the Acoustic survey (1998-present) conducted as part of the Fall BT survey. The former three surveys focus on the near-bottom distribution and abundance of herring (Figure 3), while the latter quantifies fish throughout the water column. The Panel suggested that additional explorations of the Acoustic/BT survey data be undertaken to evaluate the catchability of the gear and potentially combining the Fall BT and Acoustic survey data into an age-based acoustic index given they are from the same ship and time.

All surveys have broad geographical coverage and incorporate the general extent of herring distribution at the time of the surveys. The NEFSC BT surveys time series have been split multiple times to account for gear and vessel changes. These surveys have been the subject of several evaluations in past assessments and the current configuration has been consistently applied since the 2018 framework review. The WG concluded that no new information warranted reevaluating the previously accepted characteristics of these surveys and calibration between the vessels or door changes.

One noted omission in the assessment was the larval survey series that extends back to the 1970s (Richardson et al. 2010). This extensive survey, which has a broad coverage, should be explored further as it may provide additional information on the early life history of herring. In addition, the survey has the potential to be used as an index of abundance to complement the limited data in the assessment surrounding recruitment (Age-1 herring) or herring in their first year of life. The Summer (Shrimp) survey was paused in 2024 and uncertainty about its future was expressed. The Panel suggested that the WG evaluate the impact of permanently losing a survey on the assessment beyond the traditional leave-one-out approach and hope for an ability to prioritize its continuation.

For many fish stocks, limited data exists to quantify recruitment and juvenile fish distribution/abundance (i.e., lack of an index of abundance). The WG explored five additional long-term surveys not included in the model: The MENH Spring and Fall BTS, the MADMF Spring and Fall surveys, and the seabird diet composition survey. Particular emphasis was placed on the seabird diet as a potential index of abundance for Age-1 fish. Combined, these surveys cover most nearshore (potentially broader) juvenile habitat and contain quantitative information on the abundance and distribution of juvenile fish. Although these surveys were dismissed from inclusion in the current assessment for various reasons, most of these surveys followed trends in abundance consistent with this assessment. The Panel highly recommended exploration of these surveys as indices of abundance and better leveraging the Age-1 composition data from the state surveys and the seabird diet. In addition, comparing the state surveys and the seabird diet might allow for confirming the accuracy of the diet data tracking inshore recruitment dynamics. Further, the Panel suggested that a more quantitative model-based approach (e.g., VAST, sdmTMB) might be useful to integrate surveys with spatial footprints smaller than the stock area into a single index for the assessment.

A limiting factor in the abundance indices currently used in the herring assessment is absence or poor representation of small fish (Age-1), although the sampling gear, in theory, is capable of capturing size fish of this size, when present. Selectivity for each survey clearly shows how the various ages are treated in the model and the limits imposed on the younger ages. Notably, acoustic technology will detect and quantify all age groups of herring if they are present. A knife-edge full selection for ages 3-8 may not be appropriate. Better understanding and quantification of the recruitment dynamics for this species is needed. Enhanced age composition data collection in recent years (i.e., 25 years) have improved the reliability of all indices.

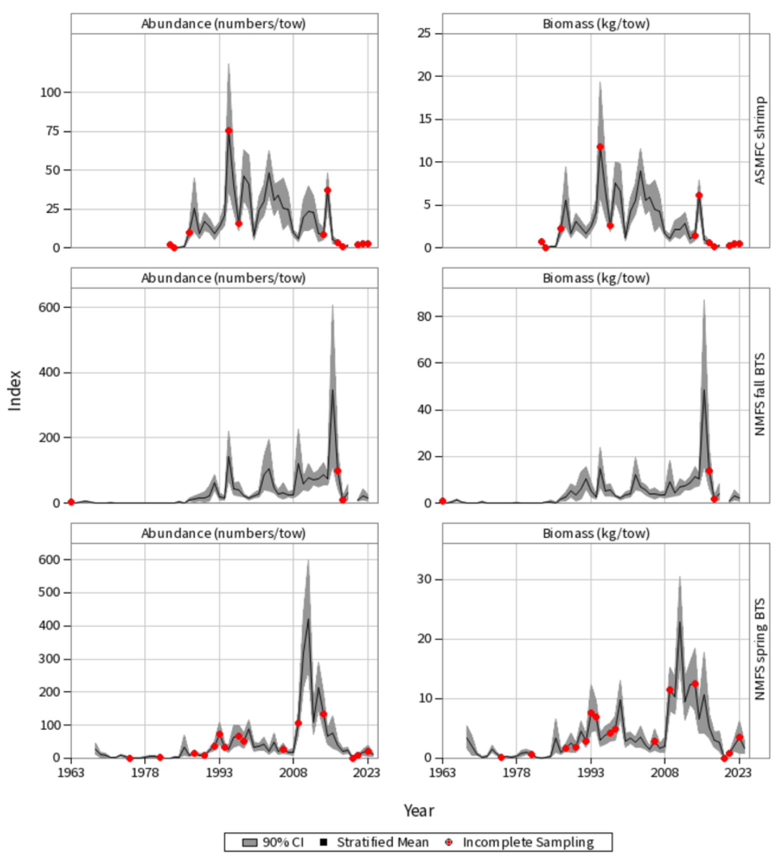

Figure 3. Stratified mean indices from NMFS trawl surveys (number per tow) as provided in the assessment report.

TOR #4: *Use appropriate assessment approach to estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Compare the time series of these estimates with those from the previously accepted assessment(s). Evaluate a suite of model fit diagnostics (e.g., residual patterns, sensitivity analyses, retrospective patterns), and (a) comment on likely causes of problematic issues, and (b), if possible and appropriate, account for those issues when providing scientific advice and evaluate the consequences of any correction(s) applied.*

The Panel concluded that this TOR was adequately addressed.

An underlying goal of the Atlantic herring RT assessment involved moving from ASAP used in previous Atlantic herring assessments to the WHAM platform. Although the WHAM platform was designed to utilize state space model formulations, the model offers many options for simplification, allowing the use of fixed effects similar to those in ASAP.

The basic data used in the assessment have gone unchanged since the 2018 benchmark stock assessment (NEFSC 2018), containing two fishing fleets: a mobile fleet and fixed fleet. The mobile fleet selectivity is age-based with selectivity fixed at 1.0 for ages 7 and 8 but estimated for all other ages. The fixed fleet selectivity is age-based with selectivity fixed at 1.0 for Age-2 but estimated for all other ages (see TOR 2 for more details). The surveys included in the assessment model are the NEFSC surveys: Spring Bottom Trawl, Fall Bottom Trawl, Summer, and Acoustic (see TOR 3 for more details).

A bridging analysis was constructed to define a WHAM model that mimics the most recent ASAP-based assessment (Figure 4). Run0 is "WHAM as ASAP" (i.e., no random effects, annual recruitments are fixed effects), and although the model did not converge, it replicated ASAP well.

Figure 4. Spawning stock biomass (left) and recruitment (right) using ASAP (ASAP 2022) and WHAM with no random effects used (Run0). Figures are from the assessment report.

After bridging to WHAM, the WG explored several model configurations using eight model evaluation criteria, including convergence, residuals, retrospective patterns, AIC, and self-test. Firstly, the WG tried to solve the convergence issue, which was achieved by making recruitment an ar1_y random effect process, but the model still had some selectivity parameters on bounds and patterned one-step-ahead (OSA) residuals. None of the proposed model configurations resulted in a model without convergence issues or patterned OSA residuals. Next, the WG tried beginning the model in 1987 when age composition observations first became available from the bottom trawl survey (only age composition data from the fishery is available before 1987). This truncation resolved most issues of unidentifiable parameters, convergence, and residual patterns. However, this truncation raised concern about the model's ability to possibly estimate a stock-recruit curve, although the WG further highlights those previous attempts to estimate a stock-recruit curve failed. Consequently, the WG agreed to begin the model in 1987. The Panel agrees with the conclusion of the WG but recommends the WG investigate any possibilities to include data before 1987 in the future, especially when estimating reference points.

The WG continued with the WHAM model development using the truncated time series. First, the likelihood used to fit the age composition data was reevaluated using dirchlet-multinomial, dirichlet-pool0, logistic-normal-miss0, logistic-normal-ar1-miss0, or logistic-normal-pool0. The WG agreed that the logistic-normal-ar1-miss0 option provided the best residual diagnostics, and used this in all subsequent model configurations. The Panel supported this conclusion. Next, a more thorough evaluation of including various combinations of process uncertainty and correlation structures was conducted, e.g., testing iid, ar1_a, ar1_y, 2dar1 structures of abundance transitions (i.e., NAA), fishery selectivity, natural mortality (M), or recruitment. More than 200 model configurations were tested by the WG, and it used a suite of diagnostics to evaluate the different configurations. The WG investigated potential causes for model configurations that failed the diagnostics and provided solutions to account for those issues. The final model configurations used (1) the time- and age-invariant M=0.35, (2) decoupled NAA and recruitment processes, (3) iid distribution for the recruitment process, (4) ar1_a NAA random effects, and (5) estimated initial numbers-at-age (results compared to previous MT ASAP run in Figure 5). The Panel supported the final selected model configuration. However, the Panel suggested the WG evaluate the possibility to estimate recruitment at Age-2, as the current recruitment estimates are solely based on computational estimations (Age-1) without any observations. Further, the effects of the NAA random effects need exploration, especially during the projections. In addition, the Panel recommends investigating more biologically plausible configurations (e.g., implementing an age-based natural mortality). The WG presented one model configuration with scaled age-dependent mortality rates, but from a modeling point of view, the estimates did not change and the less complex model was selected at this time. The Panel suggests the MT allow for some flexibility for age-dependent natural mortality investigations.

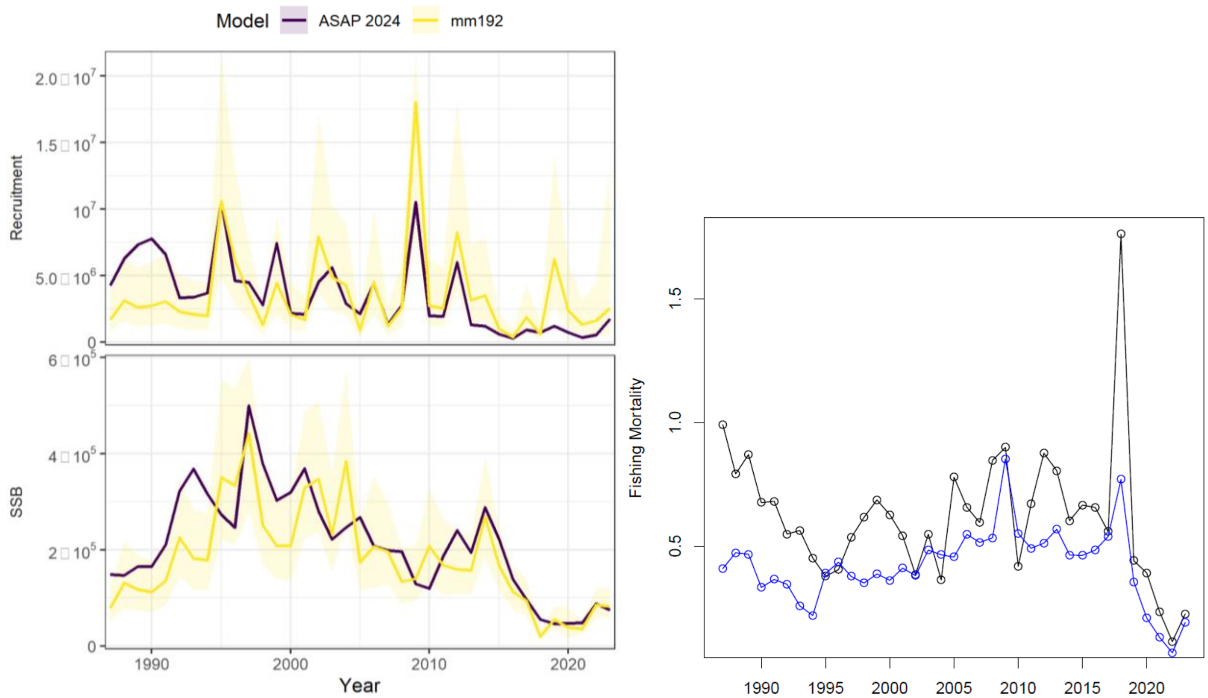

Figure 5: Results compared for the 2024 MT assessment (ASAP) and 2025 RT assessment (WHAM, mm192). Comparisons are provided for spawning stock biomass (SSB) and recruitment (left) and fishing mortality (right). For fishing mortality, the WHAM estimates are provided in black, and the ASAP results are presented in blue.

The Panel seeks to emphasize the effort of the WG to implement an Age-1 recruitment index based on seabird diet or the utilization of other environmental indices as covariates in the final WHAM model. In all cases, the data showed a positive signal, but the model did not improve enough to justify the inclusion of these extra parameters. In addition, some variables used produced counterintuitive relationships and thus need further exploration. The Panel recommends to continue work on this topic.

TOR #5: *Update or redefine status determination criteria (SDC; point estimates or proxies for BMSY, BTHRESHOLD, FMSY, and MSY reference points) and provide estimates of those criteria and their uncertainty, along with a description of the sources of uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for reference points. Compare estimates of current stock size and fishing mortality to existing, and any redefined, SDCs.*

The Panel concluded that this TOR was adequately addressed.

The principles of previous assessments have been maintained or slightly improved since previous assessments, and the parameter setting and updates of input data were deemed appropriate. As in previous assessments, a stock-recruit relationship was not established because even very low stock sizes are as likely to produce average recruitment as large stock sizes. In addition, the WG believed that stock-recruit data from WHAM did not suggest an identifiable relationship (Figure 6). Therefore, the WG used a proxy, F40% (based on SPR calculations) for Fmsy. Assuming continued average recruitment might be problematic at low stock sizes, but given the current management strategy of reducing F when SSB is below half B40% for the major fishing fleet (the mobile-fleet), this assumption results in a low fishing pressure at low stock size.

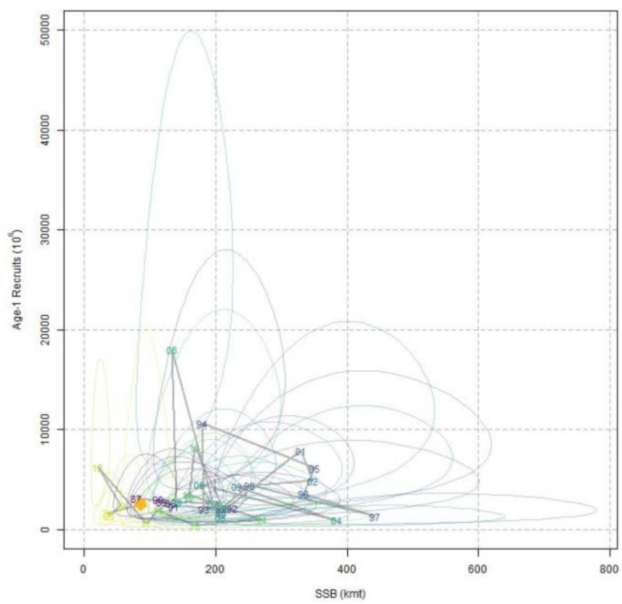

Figure 6. Stock-recruit plot from WHAM, as provided in the TOR 4-6 working paper.

Despite the difficulties in establishing a suitable stock-recruit relationship in most fish stocks, international efforts have trended toward this approach over the past decades. The International Council for the Exploration of the Sea (ICES) outlines various types of stock-recruit patterns and suggestions on models and software to apply and estimate stock-recruit model parameters (ICES 2003). One advantage of forcing a stock-recruit curve on the often very unclear stock-recruit pattern is forcing recruitment to zero when spawning stock is zero in the assessment. This will also allow for analytical reference points. As such, the Panel encourages a deeper investigation into prospective stock-recruit relationships for Atlantic herring in the future.

F40% is calculated differently in ASAP versus WHAM. In ASAP, the mobile-fleet selectivity is considered to find F40%, while the fixed-fleet is entirely ignored (so F40% will be higher in ASAP because the fixed-fleet is ignored). In contrast, WHAM estimates a global F40% that when distributed among the two fleets produces SPR40%, implicitly accounting of both fleets. WHAM estimates a global F40%, and then the fleet-specific F40%s are derived based on relative selectivity. B40% only slightly considers the fixed fleet in ASAP, but it is more accurate in the WHAM approach.

The very large difference in selectivity between the two fleets (Figure 7), makes interpretation of the F40% complicated when F is defined as F on Age-7, as done in the current assessment. Normally, F is expected to reflect fishing pressure on the dominating age groups in the fishery. For these two fleets, the dominating age groups are very different. To improve the situation, the Panel suggests to investigate new F metrics, such as the use of average F for Ages 2-6.

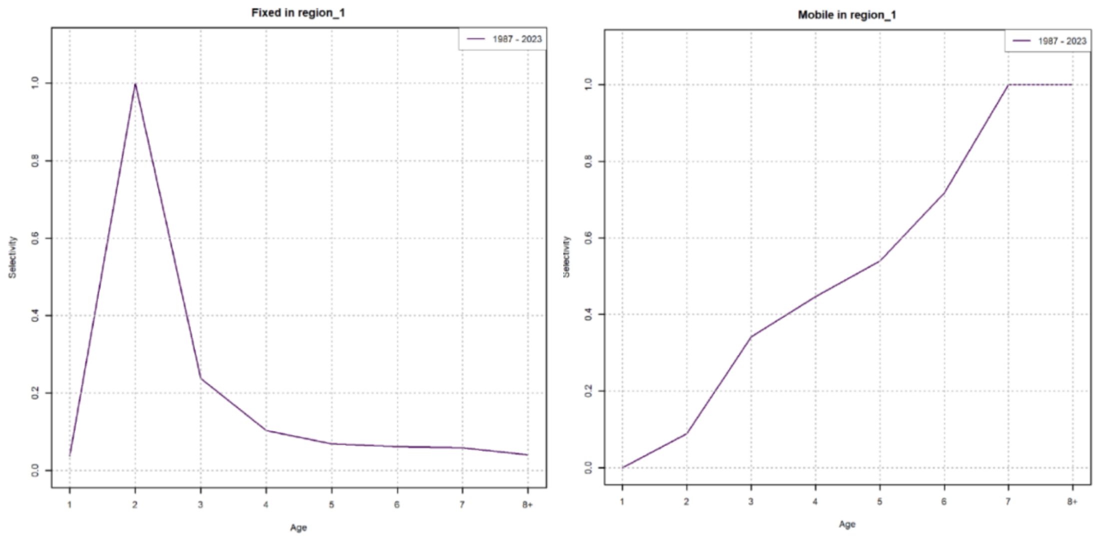

Figure 7. Selectivity patterns by age for the fixed (left) and mobile (right) fleets, as provided in the TOR 4-6 working paper.

In recent years internationally, focus increased on density-dependence (DD) in growth, maturity, and natural mortality in long-term projects, including in reference point calculations. DD in recruitment—to be more precise in survival from egg to recruitment—is appropriately addressed by using stock-recruit model or, as in this assessment, by assuming recruitment to be constant and independent of spawning stock. Density-dependence on recruitment is the main compensation mechanism for fishing in fish stocks generally, but recent science has shown that DD in growth, maturity, and natural mortality can also contribute substantially in fish stock dynamics, and missing it could result in an overestimation of stock size in reference points. This might be explored in future assessments of this stock as well.

While using F40% and B40% may be considered antiquated, they have worked reasonably well for many years when managing fish stocks. Newer science involving multispecies interactions, cannibalism, DD, and meta-analysis are available and may be worth considering. For instance, proxy Fmsy estimates based on life history parameters (e.g., age at 50% maturity and von Bertalanffy growth parameters K and Linf) are now available. Some of these new approaches could be considered. Or at minimum, comparing the results of these to F40% or B40% may be insightful. Alternative reference points (e.g., at 30% or 50%) were not presented, thus determining how sensitive results are to the reference point specification is difficult. Although intuitive regarding the directionality of reference point change impacts when considering alternative percentages, the magnitude of the impact could not be assessed by the Panel. While the Panel understands and ultimately supports the continued use of 40% based on life history information, further comparisons to other reference points would offer valuable insights.

TOR #6: *Define appropriate methods for producing projections; provide justification for assumptions of fishery selectivity, weights at age, maturity, and recruitment; and comment on the reliability of resulting projections considering the effects of uncertainty and sensitivity to projection assumptions.*

The Panel concluded that this TOR was adequately addressed.

The assumptions and input data to the projections were considered adequate by the Panel. However, the projection results seemed highly uncertain (e.g., Figure 8). As such, the Panel was uncertain on how useful projection estimates beyond the bridge year + 1 are for providing management advice. The Panel was of the opinion the median value projected showing a quite steep increase was a balanced result of the data and analysis available.

The Panel believed the SSB estimates are likely overestimated, given the projections suggest that SSB can be rebuilt to historic (or time-series high) levels within the next three to four years (Figure 8). Density-dependent effects on growth, maturity, and natural mortality would also likely be realized in this case and prevent these levels. Conversely, the lower confidence limit is probably an underestimate as the weight-at-age input data for the projections ignores a slight upward trend in weight-at-age in the most recent couple of years.

The rapid increase in the stock under the projections did not appear driven by recruitment assumptions, given these recruitment levels are small when compared with SSB in 2025 and 2026 and would not enter SSB before 2027 in significant numbers. However, the Panel did recommend further development in the WHAM code to allow for better sensitivity exercises on the recruitment projections (comparison in recruitment average values versus the recruitment parameter are provided in Figure 9). The random effects were discussed in length. They are ignored in the projections, but despite an ar_y process, the NAA random effects would quickly trend to 0. The negative random effects in recent years in the assessment was a concern of the Panel, but the model did not support a correlation between years.

A recommendation was proposed to conduct the projections in a retrospective manner. The increasing trend of SSB from 2018 to 2023 was theorized to influence projections. Changing to an earlier terminal year and re-running the projections would allow for understanding how optimistic projections are and whether the large uncertainties are linked to the method or recent years' data.

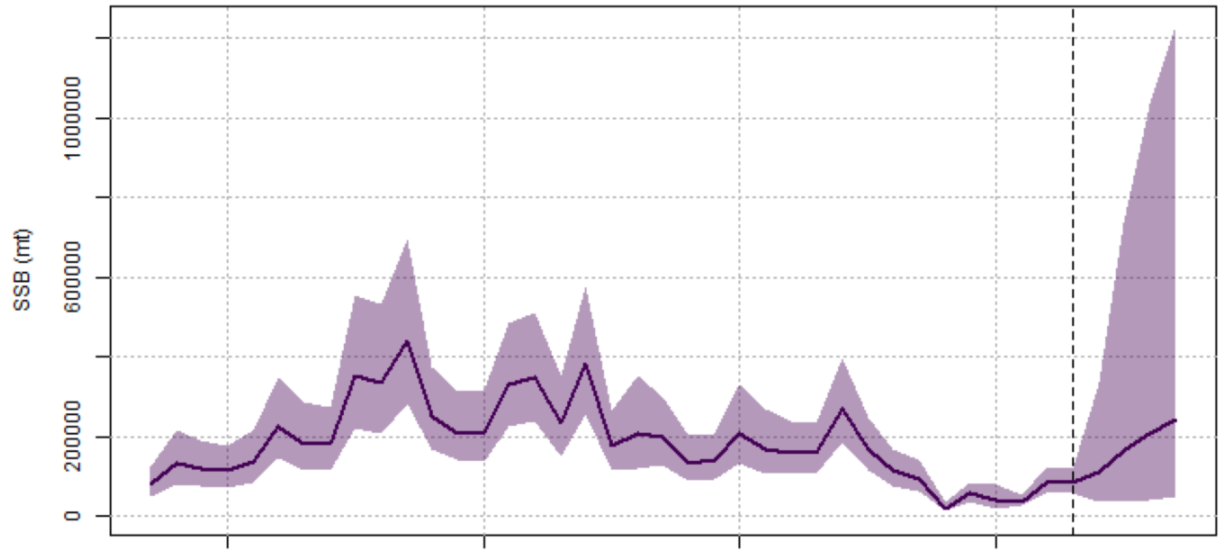

Figure 8. Estimated spawning stock biomass (SSB) from WHAM and projections. The vertical dashed line represents the demarcation between model estimates and projection estimates after 2023. Figure was provided in the TOR 4-6 working paper.

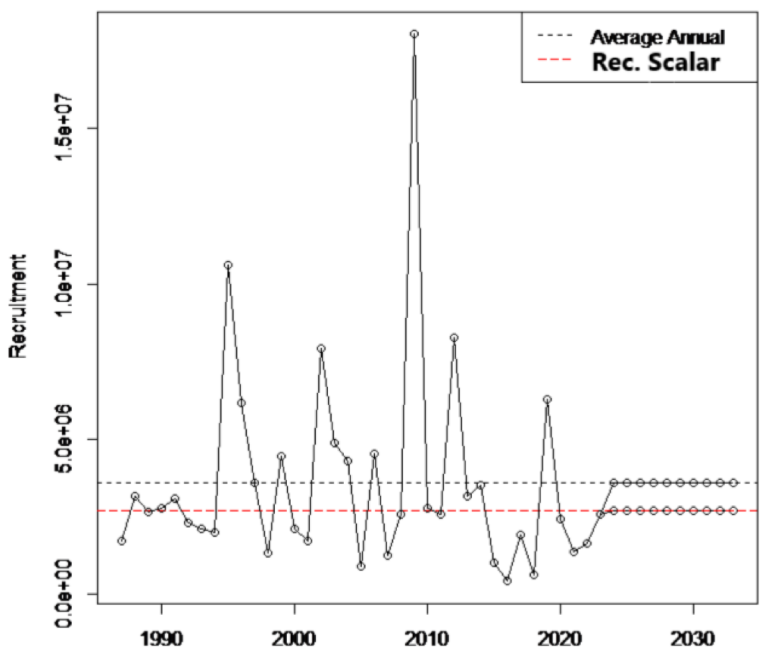

Figure 9. Recruitment time series from WHAM and recruitment projection values between recent time series averages (black) and recruitment estimates from the scalar parameter (red). Figure was provided during the review.

During the review, the Panel noted a forthcoming Projections RT WG that will evaluate how to improve short-term projection methods. The Panel strongly encouraged Atlantic herring being a case study within this RT.

TOR #7: *Review, evaluate, and report on the status of research recommendations from the last assessment peer review, including recommendations provided by the prior assessment working group, peer review panel, and SSC. Identify new recommendations for future research, data collection, and assessment methodology. If any ecosystem influences from TOR 2 could not be considered quantitatively under that or other TORs, describe next steps for development, testing, and review of quantitative relationships and how they could best inform assessments. Prioritize research recommendations.*

The Panel concluded that this TOR was adequately addressed.

The WG reviewed proposed recommendations from previous assessments, review panels, and SSC discussions. Some elements previously listed and noted from this exercise were not fully discussed or addressed by the WG (e.g., utility of the study fleet data, further expansion of acoustic surveys and research). The Panel asked for the WG to respond to these verbally during the Review. The Panel noted the research recommendations posed by the WG were not prioritized, resulting in challenges for the Panel to respond to recommendations on priorities with WG feedback. As such, during the Review, the Panel asked the WG to note the highest priority research fields from its list in the reports. These recommendations included three themes with sub-elements:

Survey Data

- Continue enhancing survey methodologies, such as incorporating age-length data, to improve reliability and consistency.
- Apply VAST methodologies to combined State and Federal Surveys.
- Evaluate the inclusion of innovative recruitment indices, like seabird diet data, for stock assessments.

Assessment Methods

- Explore alternative age-specific selectivity models and the use of random effects selectivity parameters.
- Investigate the use of larval indices as a potential index of recruitment.
- Refine projection models by integrating ecosystem indicators, such as zooplankton abundance and thermal habitat suitability.

Projection Methods

- Integrate environmental datasets, including temperature and prey availability indices, to refine projection assumptions.
- Address overly optimistic projections by exploring methods that better account for recruitment variability and environmental drivers.
- Evaluate how and if NAA random effects should be treated during the projection period.
- Consider refining how weight- and maturity-at-age are specified in the projection period (i.e., perhaps a recent 5-year average is not best, especially with trending traits).

The Panel supported this list, as well as its recommendations put forth in the other TORs. The Panel did iterate multiple research recommendations again to ensure they were pursued in the future. The first involved continuing investigating recruitment either as an index of abundance or redefining it in WHAM. Using the inshore surveys or the seabird diet data show promise in constructing a recruitment index for Atlantic herring. In addition, the WHAM could start at Age-2 as opposed to Age-1 given whether the consensus continues that no informative data for Age-1 abundance exists. The Panel reemphasized the need to better understand the impacts of NAA random effects on the WHAM model, particularly their influence on projections. Further development of the environmental covariates for future WHAM testing could be fruitful, as well as additional evaluation of natural mortality for a species that can have high natural mortality rates at younger age classes.

TOR #8: *Develop a backup assessment approach to providing scientific advice to managers if the proposed assessment approach does not pass peer review or the approved approach is rejected in a future management track assessment.*

The Panel concluded that this TOR was adequately addressed.

The WG concluded that if WHAM is rejected (WHAM configurations with random effects or those with fixed effects and thus replicating ASAP), the issues causing this rejection would not be resolvable within an alternative age-based assessment platform. Thus, the WG concluded that an index or survey trend-based backup would be appropriate. The WG chose the existing Ismooth approach (Legault et al. 2022) as an appropriate backup plan method, which has been used for several stocks in the northeast US region. The approach integrated all fisheries-independent survey indices used in the proposed WHAM model into the Ismooth approach. The WG noted that weighting the indices used in Ismooth based on some confidence criteria (e.g., by survey area coverage, likelihood values from previous ASAP or WHAM MT/RT assessments) could be evaluated as needed. However, the Panel noted that this was not a priority. The Panel concluded that the proposed backup approach would be appropriate if the WHAM model was rejected.

Appendix 1: Terms of Reference for the Atlantic Herring Research Track Stock Assessment

1. Identify relevant ecosystem and climate influences on the stock. Characterize the uncertainty in the relevant sources of data and their link to stock dynamics. Consider findings, as appropriate, in addressing other TORs. Report how the findings were considered under impacted TORs.

2. Estimate catch from all sources, including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.

3. Present the survey data used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, application of catchability and calibration studies, etc.) and provide a rationale for which data are used. Describe the spatial and temporal distribution of the data. Characterize the uncertainty in these sources of data.

4. Use the appropriate assessment approach to estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Compare the time series of these estimates with those from the previously accepted assessment(s). Evaluate a suite of model fit diagnostics (e.g., residual patterns, sensitivity analyses, retrospective patterns), and (a) comment on likely causes of problematic issues, and (b), if possible and appropriate, account for those issues when providing scientific advice and evaluate the consequences of any correction(s) applied.

5. Update or redefine Status Determination Criteria (SDC; point estimates or proxies for BMSY, BTHRESHOLD, FMSY, and MSY reference points) and provide estimates of those criteria and their uncertainty, along with a description of the sources of uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for reference points. Compare estimates of current stock size and fishing mortality to existing, and any redefined, SDCs.

6. Define appropriate methods for producing projections; provide justification for assumptions of fishery selectivity, weights at age, maturity, and recruitment; and comment on the reliability of resulting projections considering the effects of uncertainty and sensitivity to projection assumptions.

7. Review, evaluate, and report on the status of research recommendations from the last assessment peer review, including recommendations provided by the prior assessment working group, peer review panel, and SSC. Identify new recommendations for future research, data collection, and assessment methodology. If any ecosystem influences from TOR 1 could not be considered quantitatively under that or other TORs, describe next steps for development, testing, and review of quantitative relationships and how they could best inform assessments. Prioritize research recommendations.

8. Develop a backup assessment approach to providing scientific advice to managers if the proposed assessment approach does not pass peer review or the approved approach is rejected in a future management track assessment.

Appendix 2: Atlantic Herring Research Track Assessment Peer Review Meeting Draft Agenda (March 10-14, 2025)

Clark Conference Room, NEFSC Aquarium Building, Woods Hole, MA

Google Meet joining info: https://meet.google.com/her-pcjt-aog
or dial: (US) +1 316-536-0378 PIN: 521 394 633#

DRAFT AGENDA* (v. 2/12/2025)

**All times are approximate at the discretion of the Review Panel Chair. The meeting is open to the public; however, during the Report Writing sessions we ask that the public refrain from engaging in discussion with the Peer Review Panel.*

Monday, March 10, 2025

Time	Topic	Presenter(s)	Notes
9:00am - 9:15am	Welcome, Introductions, & Agenda Logistics	Conor McManus Brian Hooper	
9:15am - 9:30am	Research Track Process Overview	Kristan Blackhart	
9:30am - 10:00am	Overview of Herring RT	Matthew Cieri	
10:00am - 10:30am	Management History and Current Practices	Jamie Cournane	
10:30am - 10:45am	BREAK		
10:45am - 12:00pm	TOR 1 - Ecosystem and Socioeconomic Profile & Supporting Analyses	Adelle Molina	Ecosystem
12:00pm - 1:00pm	LUNCH		
1:00pm - 2:00pm	TOR 1 - Copepods & VAST	Sarah Gaichas	Ecosystem
2:00pm - 3:00pm	TOR 1 - Haddock Predation	Micah Dean	Ecosystem
3:00pm - 3:15pm	BREAK		
3:15pm - 4:00pm	TOR 1 - Stakeholder Observations	Jamie Cournane	Ecosystem
4:00pm - 4:15pm	Public Comment	Public	
4:15pm - 5:00pm	Discussion/Summary	Review Panel	Conclusions, Recommendations, & Final Wrap-up for TOR 1
5:00pm	ADJOURN		

Tuesday, March 11, 2025

Time	Topic	Presenter(s)	Notes
9:00am - 9:05am	Welcome/Logistics/Agenda	Conor McManus Brian Hooper	
9:05am - 10:30am	TOR 2	Ashley Asci Matthew Cieri	Catch
10:30am - 10:45am	BREAK		
10:45am - 12:00am	TOR 3	Matthew Cieri	Surveys
12:00pm - 1:00pm	LUNCH		
1:00pm - 3:00pm	TOR 4	Jonathan Deroba	Model
3:00pm - 3:15pm	BREAK		
3:15pm - 3:45pm	TOR 4, continued	Jonathan Deroba	Model
3:45pm - 4:00pm	Public Comment	Public	
4:00pm - 5:00pm	Discussion/Summary	Review Panel	Conclusions, Recommendations, & Final Wrap-up for TORs 2, 3, & 4
5:00pm	ADJOURN		

Wednesday, March 12, 2025

Time	Topic	Presenter(s)	Notes
9:00am - 9:05am	Welcome/Logistics/Agenda	Conor McManus Brian Hooper	
9:05am - 10:00am	Review Homework	Conor McManus	If needed
10:00am - 10:30am	TOR 5	Jonathan Deroba	BRPs
10:30am - 10:45am	BREAK		
10:45am - 12:00pm	TOR 5, continued	Jonathan Deroba	BRPs
12:00pm - 1:00pm	LUNCH		
1:00pm - 3:00pm	TOR 6	Jonathan Deroba	Projections
3:00pm - 3:15pm	BREAK		
3:15pm - 3:45 pm	TOR 8	Jonathan Deroba	Backup Approach
3:45pm - 4:00pm	Public Comment	Public	

Time	Topic	Presenter(s)	Notes
4:00pm - 5:00pm	Discussion/Summary	Review Panel	Conclusions, Recommendations, & Final Wrap-up for TORs 4, 5, 6, & 8
5:00pm	ADJOURN		

Thursday, March 13, 2025

Time	Topic	Presenter(s)	Notes
9:00am - 9:05am	Welcome/Logistics/Agenda	Conor McManus Brian Hooper	
9:05am - 10:00am	Review Homework	Conor McManus	If needed
10:00am - 10:30am	TOR 7	Jamie Cournane	Research Recommendations
10:30am - 10:45am	BREAK		
10:45am - 12:00pm	TOR 7, continued	Jamie Cournane	Research Recommendations
12:00pm - 1:00pm	LUNCH		
1:00pm - 3:00pm	Revisit any remaining issues	Conor McManus	If needed
3:00pm - 3:15pm	BREAK		
3:15pm - 3:30pm	Public Comment	Public	
3:30pm - 5:00pm	Discussion/Summary	Review Panel	Conclusions, Recommendations, & Final Wrap-up for TOR 7, any remaining issues
5:00pm	ADJOURN		

Friday, March 14, 2025

Time	Topic	Presenter(s)	Notes
9:00am - 5:00pm	Closed panel writing session	Review Panel	*If necessary, open session may be reconvened to revisit any remaining issues
5:00pm	ADJOURN		

Appendix 3: Atlantic Herring Research Track Assessment Peer Review Attendees (March 10-13, 2025)

CIE - Center for Independent Experts
GARFO - Greater Atlantic Regional Fisheries Office
MAFMC - Mid-Atlantic Fisheries Management Council
NEFMC - New England Fishery Management Council
NEFSC - Northeast Fisheries Science Center
SSC - Science and Statistical Committee
~~~~~~

Peer Review Panel

First	Last	Affiliation
Conor	McManus	NEFMC SSC (Chair)
Henrik	Sparholt	CIE
Lorian	Berg	CIE
Gary	Melvin	CIE

Working Group

First	Last	Affiliation
Ashley	Asci	GARFO
Matt	Cieri	Maine DMR (Chair)
Jamie	Cournane	NEFMC
Kiersten	Curti	NEFSC
Micah	Dean	MA DMF
Jonathan	Deroba	NEFSC (Assessment Lead)
Sarah	Gaichas	NEFSC
Gavin	Fay	SMAST
John	Wiedenmann	Rutgers

Attendees

First	Last	Affiliation
Emilie	Franke	ASMFC
Richard	Klyver	Blue Green Future
Gerry	O Neill	Cape Seafoods Inc
Gareth	Lawson	Conservation Law Foundation
Kurt	Gottschall	CT DEEP
Kevin	Job	CT DEEP
M	Smith	Public
Tim	Barrett	Fisheries and Oceans Canada
~~~~~~

First	Last	Affiliation
Nathan	Hebert	Fisheries and Oceans Canada
Kaleigh	Hill	GARFO
Carrie	Nordeen	GARFO
Ashley	Trudeau	GARFO
Jonathan	Watson	GARFO
Raffaela	Terzo	Gloucester Fishermen's Wives Association
Jeff	Kaelin	Lunds Fisheries
Sefatia	Romeo Theken	MA Department of Fish and Game (FWE)
Melanie	Griffin	MA DMF
Kelly	Whitmore	MA DMF
Jason	Didden	MAFMC
Brandon	Muffley	MAFMC
Megan	Ware	Maine Department of Marine Resources
Addie	Binstock	ME DMR
Andrew	Applegate	NEFMC
Emily	Bodell	NEFMC
Rachel	Feeney	NEFMC
Cate	OKeefe	NEFMC
Charles	Adams	NEFSC
Larry	Alade	NEFSC
Christina	Asante	NEFSC
Brandon	Beltz	NEFSC
Kristan	Blackhart	NEFSC
Jason	Boucher	NEFSC
Russell	Brown	NEFSC
Maxwell	Grezlik	NEFSC
Amanda	Hart	NEFSC
Daniel	Hennen	NEFSC
Cameron	Hodgdon	NEFSC
Brian	Hooper	NEFSC
Christopher	Legault	NEFSC
Chengxue	li	NEFSC
Emily	Liljestrand	NEFSC
Brian	Linton	NEFSC
Tim	Miller	NEFSC
Adelle	Molina	NEFSC
Paul	Nitschke	NEFSC
Stephanie	Owen	NEFSC

First	Last	Affiliation
Charles	Peretti	NEFSC
Burton	Shank	NEFSC
Laura	Solinger	NEFSC
Katherine	Sosebee	NEFSC
Michele	Traver	NEFSC
Samuel	Truesdell	NEFSC
Abigail	Tyrell	NEFSC
Sara	Weeks	NEFSC
Anthony	Wood	NEFSC
Renee	Zobel	NH Fish & Game
Cheri	Patterson	NH Fish & Game
Joseph	Warren	NOAA Affiliate
Mary Beth	Tooely	O'Hara Corporation
Justin	Didden	Public
Bill	Lucey	Save the Sound
Alexander	Jensen	SEFSC
Maria Cristina	Perez	SMAST
Jaclyn	Higgins	Theodore Roosevelt Conservation Partnership
Andrew	Jacobs	WTGHA

Appendix 4: Materials Provided or Referenced During the Atlantic Herring Research Track Stock Assessment Peer Review Meeting

Working papers and presentations are available on a NEFSC website https://apps-nefsc.fisheries.noaa.gov/saw/sasi.php by selecting the species and year of assessment.

Working Papers and Background Documentation

Information Type	File Name
All Files	2025_HER_UNIT_1.zip
All Files	2025_HER_UNIT_2.zip
Assessment Report	2025_Herring_RT_assessment report_final_508.pdf
Figures	Figures_Homework and other_Deroba_revised.pdf
Background	Acoustic-WP.pdf
Background	Boosted Regression Tree-WP.pdf

Information Type	File Name
Background	CAMS-WP.pdf
Background	Copepod Indices-WP.pdf
Background	ESP-WP.pdf
Background	Fecundity-WP.pdf
Background	Haddock_predation-WP.pdf
Background	Management-WP.pdf
Background	RecCovariates-WP.pdf
Background	Seabird_Diet-derived_Recruitment_Index-WP.pdf
Background	Spawn_timing-WP.pdf
Background	Stakeholder-WP.pdf
Background	TOR_2-WP.pdf
Background	TOR_3-WP.pdf
Background	TOR_4-5-6-WP.pdf
Background	TOR_7- WP.pdf
Background	TOR_8-WP.pdf
Background	Threshold-WP.pdf
Background	ToR_1-WP.pdf
Background	_Working_paper_list.pdf
Presentations	Presentation_Management History and Current Practices_Cournane.pdf
Presentations	Presentation_Overview_TORs_2-3_Cieri.pdf
Presentations	Presentation_TOR 1_Copepods and VAST_Gaichas.pdf
Presentations	Presentation_TOR 1_Ecosystem and Socioeconomic Profile_Molina.pdf
Presentations	Presentation_TOR 1_Stakeholder Engagement_Cournane.pdf
Presentations	Presentation_TOR 1_haddock predation_Dean.pdf
Presentations	Presentation_TOR 2_Asci.pdf
Presentations	Presentation_TOR 4-6_Deroba.pdf
Presentations	Presentation_TOR 4_Zooplankton indices as covariates in WHAM_Gaichas.pdf
Presentations	Presentation_TOR 7_Cournane.pdf
Presentations	Presentation_TOR 8_Deroba.pdf

RESEARCH TRACK WORKING GROUP REPORT

Report prepared by members of the Atlantic Herring Research Track Working Group:

- Matt Cieri, MEDMR
- Jon Deroba, NEFSC
- Kiersten Curti, NEFSC
- Sarah Gaichas, NEFSC
- Jamie Cournane, NEFMC
- Ashley Asci, GARFO
- Micah Dean, MADMF
- John Wiedenmann, Rutgers University
- Gavin Fay, University of Massachusetts / SMAST

The Atlantic herring stock assessment working group met multiple times online, as well as conducting two in-person meetings in Woods Hole, MA at the NEFSC.

PARTICIPANTS

Working Group (WG)

Name	Affiliation
Matt Cieri	MEDMR, chair
Jon Deroba	NEFSC, assessment lead
Kiersten Curti	NEFSC
Sarah Gaichas	NEFSC
Jamie Cournane	NEFMC
Ashley Asci	GARFO
Micah Dean	MADMF
John Wiedenmann	Rutgers University
Gavin Fay	University of Massachusetts / SMAST

GARFO - Greater Atlantic Regional Fisheries Office
NEFSC - Northeast Fisheries Science Center
NEFMC - New England Fishery Management Council
MEDMR - Maine Dept. of Marine Resources
MADMF - MA Div. of Marine Fisheries
SMAST - School for Marines Science and Technology

In addition to the Working Group members, the following individuals participated heavily in either the analysis or the stakeholder engagement session:

Chair-invited participants	
Adelle Molina	NOAA Affiliate
Addie Binstock	MEDMR
Emily Bodell	NEFMC
Mark Wuenschel	NEFSC
Mike Jech	NEFSC
James Gartland	VIMS
Sean Hardison	University of Alaska

ACKNOWLEDGEMENTS

The WG would like to acknowledge the many people responsible for data collection that are too numerous to list. In addition, the WG appreciated input from Atlantic herring stakeholders throughout the process. Lastly, the WG thanks Chris Legault for regularly attending WG meetings and providing helpful guidance.

EXECUTIVE SUMMARY

Term of Reference (TOR) #1: *Identify relevant ecosystem and climate influences on the stock. Characterize the uncertainty in the relevant sources of data and their link to stock dynamics. Consider findings, as appropriate, in addressing other TORs. Report how the findings were considered under impacted TORs.*

Atlantic herring (*Clupea harengus*) are schooling planktonic feeding fish inhabiting the Western Atlantic. While ranging from Newfoundland, Canada to the Mid-Atlantic, United States, this stock assessment focused on the Gulf of Maine/Georges Bank stock complex found in US waters. Atlantic herring exhibits a complex life cycle, transitioning from planktonic larvae to forming coastal schools as juveniles. In this region, spawning occurs primarily in autumn across inshore and offshore banks, with egg deposition occurring in dense mats that hatch within 14 to 21 days. Critical recruitment drivers include food availability, larval temperature stress, and egg predation, particularly from haddock (*Melanogrammus aeglefinus*). Analysis using dynamic linear models linked predator consumption to herring abundance, supporting a constant predation mortality rate.

Temperature bottlenecks were identified, with bottom temperatures suitable for embryos but sea surface temperatures increasingly stressful for larval stages, especially during prolonged summer conditions. These temperature challenges reduce the optimal thermal window for larval survival, potentially increasing density-independent mortality. Prolonged periods of unsuitable thermal conditions may delay the onset of fall cooling, further constraining larval survival rates. In addition, fecundity assessments revealed stable-to-increasing reproductive output, highlighting significant maternal effects, particularly in larger, older females, which contribute disproportionately to egg production. Research suggests that maternal effects, such as enhanced fecundity and larval viability, could be further explored to refine stock assessment models and improve projections. Integration of these maternal factors may also provide insights into recruitment variability and stock resilience under changing environmental conditions.

The results of this TOR suggested two additional model runs as sensitivities: a run to examine these recruitment covariates, and another to examine the effects of haddock predation on herring eggs. Efforts to model time-varying natural mortality were abandoned because of diagnostic issues and lack of support (e.g., fit statistics, external support).

TOR #2: *Estimate catch from all sources, including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.*

Atlantic herring catch data reflects significant historical variability, influenced by changes in management, fleet composition, availability, utilization, and ecosystem influences. During the 1960s and 70s, catches peaked at more than 450,000 metric tons (mt) because of intense fishing by domestic, Canadian, and distant-water fleets. This was followed by a sharp decline in catches with the implementation of the Magnuson-Stevens Fishery Conservation and Management Act in 1978 and reduced fishing effort. After the early 1980s, the catch increased as the stock rebounded from depletion to above 100,000 mt by the early 2000s. In recent decades, the catch has since declined and currently ranges from 4,000 to 9,000 mt due to low abundance and correspondingly low quotas. The current fishery primarily targets herring as bait for American lobster (*Homarus americanus*) operations by using midwater trawl, purse seine, and bottom trawl gear, although alternative bait sources have reduced dependency on herring.

The transition to NOAA's Catch Accounting and Monitoring System (CAMS) for this stock assessment has improved the consistency and accuracy of catch data. Historical comparisons between CAMS and previous systems have shown minor differences, confirming the reliability of the updated methodology. CAMS integrates multiple data sources, including vessel trip reports (VTRs), dealer reports, and observer data, providing a unified approach to catch for quota monitoring and stock assessments. Use of CAMS is recommended going forward.

The fishery biological sampling programs continue to monitor biological data, such as size, age, and reproductive stage, ensuring robust data collection and aiding assessment for this stock. These improvements in data collection and integration support more accurate assessments of fishing impacts and enhance the understanding of temporal and spatial catch patterns, particularly for assessing regional differences in herring utilization and management compliance.

TOR #3: *Present the survey data used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, application of catchability and calibration studies, etc.) and provide a rationale for which data are used. Describe the spatial and temporal distribution of the data. Characterize the uncertainty in these sources of data.*

Survey data for Atlantic herring include the National Marine Fisheries Service (NMFS) spring and fall bottom trawl surveys, NMFS acoustic surveys, and the NMFS summer (shrimp) survey. Key surveys, such as the NMFS spring and fall bottom trawl and summer shrimp surveys, have shown consistent cohort tracking but declining indices since 2009, reflecting broader declines in abundance. These surveys provide critical data on age composition, abundance, and spatial distribution, which are essential for modeling stock dynamics.

Methodological updates, including improved age composition data collection, have enhanced the reliability of these indices. The spring and fall Maine/New Hampshire and Massachusetts state bottom trawl surveys provide valuable insights into inshore recruitment dynamics, particularly for younger age classes. However, they were excluded from the final models because of restricted spatial coverage and potential bias favoring inshore components.

To address data gaps, a novel approach to integrate seabird diet data was explored, providing an innovative recruitment index for stock assessments. Despite this, the seabird diet index was not used in any of the final model runs. These innovative methodologies contribute to a more comprehensive understanding of herring recruitment patterns and help identify critical habitat areas for management and conservation efforts.

TOR #4: *Use appropriate assessment approach to estimate annual fishing mortality, recruitment, and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Compare the time series of these estimates with those from the previously accepted assessment(s). Evaluate a suite of model fit diagnostics (e.g., residual patterns, sensitivity analyses, retrospective patterns), and (a) comment on likely causes of problematic issues, and (b), if possible and appropriate, account for those issues when providing scientific advice and evaluate the consequences of any correction(s) applied.*

This assessment transitioned Atlantic herring from the Age-Structured Assessment Program (ASAP) to the Woods Hole Assessment Model (WHAM), which offers improved flexibility for incorporating environmental covariates and improved estimation of process and observation uncertainty. Diagnostic evaluations indicated acceptable performance, with improvements in retrospective patterns achieved through the integration of random effects on numbers-at-age transitions. This approach reduced biases and improved the reliability of stock status determinations.

The WHAM model provided a robust platform for evaluating stock dynamics, revealing critical insights into herring population trends. Natural mortality was maintained at a fixed constant rate (M=0.35), aligning with historical assumptions and predator-prey relationships observed in the ecosystem. Time-invariant selectivity patterns were applied to ensure consistency across age classes and gear types. Recruitment, modeled as independent and identically distributed (iid) random effects, highlighted variability linked to environmental factors and fishery-independent indices. The integration of random effects on numbers-at-age transitions enhanced the model's accuracy, particularly in accounting for strong and weak year classes. While haddock biomass and the effects of temperature, as well as food availability, were tested as potential recruitment covariates, no significant correlation was observed, indicating other drivers or multiple drivers may play a more prominent role in recruitment variability.

In addition, the WHAM model underscored the importance of environmental conditions, such as temperature and prey availability, in shaping recruitment and stock resilience. These findings suggest that incorporating additional ecosystem indicators, such as zooplankton abundance and thermal habitat suitability, could further refine future assessments. Sensitivity analyses highlighted the model's robustness to parameter adjustments, reinforcing confidence in its application for stock evaluation and management.

TOR #5: *Update or redefine status determination criteria (SDC; point estimates or proxies for BMSY, BTHRESHOLD, FMSY, and MSY reference points) and provide estimates of those criteria and their uncertainty, along with a description of the sources of uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for reference points. Compare estimates of current stock size and fishing mortality to existing, and any redefined, SDCs.*

The WG continued using F40% as the F_{MSY} proxy, applying life history traits based on a recent five-year average. The recruitment scalar parameter from the WHAM model was selected to determine B40%, minimizing subjective decision-making and ensuring internal consistency with model parameters. This approach provides a stable foundation for estimating biological reference points and evaluating stock status.

Current reference points include B40% = 233,176 mt and global F40% = 0.358. Terminal year (2023) estimates showed spawning stock biomass (SSB) at 82,402 mt (90% CI: 60,582–112,082), with fishing mortality at 0.225.

The objective of this research track is to develop the assessment and projection methodology that will be used in subsequent management track assessments. As such, stock status recommendations are not part of the research track Terms of Reference, and the results from this research track assessment will not be used directly in management. Instead, this research track assessment will inform a management track assessment scheduled for June 2026. The 2026 management track assessment will provide updated estimates of stock status using data through 2025 and will be used to inform management measures for 2027-28.

TOR #6: *Define appropriate methods for producing projections; provide justification for assumptions of fishery selectivity, weights at age, maturity, and recruitment; and comment on the reliability of resulting projections considering the effects of uncertainty and sensitivity to projection assumptions.*

Projections were developed using processes consistent with the preferred WHAM model. Results indicated rapid increases in SSB and catch under current fishing mortality rates below F40%. This optimistic outlook is attributed to assumptions of iid recruitment and the absence of negative random effects in the projection period. Without temporal correlation, recent poor recruitment events are not projected to persist, allowing for more favorable projections. The WG suggests these overly optimistic results may not be accurate given past stock recruitment.

Further exploration of uncertainty revealed that the use of iid recruitment could overestimate stock recovery rates if environmental drivers or density-dependent effects are not accounted for. While the projections demonstrate potential for rapid rebuilding, the WG noted that the absence of negative random effects in the projection period may not fully capture real-world dynamics.

In addition, the group identified the importance of integrating environmental datasets, including temperature and prey availability indices, to refine projection assumptions. Sensitivity analyses showed that projections were sensitive to fishing mortality rates, highlighting the need for continuous refinement and evaluation of projection models. These enhancements will improve the reliability of projections and support more robust decision-making processes, ensuring that management strategies remain adaptive to evolving stock conditions and environmental factors.

TOR #7: *Review, evaluate, and report on the status of research recommendations from the last assessment peer review, including recommendations provided by the prior assessment working group, peer review panel, and SSC. Identify new recommendations for future research, data collection, and assessment methodology. If any ecosystem influences from TOR 1 could not be considered quantitatively under that or other TORs, describe next steps for development, testing, and review of quantitative relationships and how they could best inform assessments. Prioritize research recommendations.*

The WG addressed prior recommendations and identified new research priorities to enhance future Atlantic herring assessments as outlined below.

Review of Past Research Recommendations

Low Recruitment Mechanisms:

- The WG examined recruitment variability (TOR 4), finding no significant decline but noted retention variability and explored covariates (e.g., haddock predation, temperature, plankton). No single driver was identified.

Projections and Reference Points:

- Change Point Analysis Consistency: No longer relevant.
- F40% in Lower Productivity: No evidence for revising F40% as an FMSY proxy (TOR 5).
- Direct FMSY Estimation: MSY-based reference points remain incalculable; proxies B40% and F40% are retained.

Fleet Selectivity:

- The WG retained the two-fleet structure, finding no support for increased selectivity of younger fish by the mobile fleet.

Recruitment Index via Seabird Diet:

- Addressed in TOR 3.

Natural Mortality (M):

- Little support for time- or age-varying mortality models (TOR 1, TOR 4).

Stock Structure and Movement:

- Deferred to genetics studies planned for 2025-26.

Survey Data and Age Observations:

- Uncertainty persists regarding summer surveys, with no data collected in 2024 and future surveys unlikely. Related impacts remain unresolved.

Recruitment Penalties and Missing Data:

- Recruitment penalties are not used in WHAM. Missing 2020 survey data were addressed, resolving retrospective issues.

Condition, Growth, and Fecundity:

- Examined under TOR 1 and related working papers.

New Research Recommendations

Maternal Effects and Fecundity:

- Refine reference points using maternal effects, including fecundity and body condition metrics.

Spawning Timing:

- Prioritize spring body condition indices to avoid fall spawning weight confounding.

Egg Predation:

- Study haddock predation impacts on recruitment.

Larval Temperature Stress:

- Investigate warming impacts on larval survival and mortality.

Food Availability:

- Develop zooplankton indices for critical herring life stages.

Natural Mortality:

- Enhance predator-prey models for mortality estimates.

Survey Data:

- Improve methodologies and sampling (e.g., age-length data, seabird diet indices), including additional biological sampling and standardized collections of seabird diet, and formal data-sharing agreements to make data access easier.

Assessment Methods:

- Explore new selectivity models, larval indices, and ecosystem indicators for projections.

Projection Methods:

- Refine environmental data integration, recruitment variability, and NAA random effects in projections.

After careful consideration, the WG concluded that the aforementioned Research Recommendations should improve the Atlantic herring assessment going forward.

TOR #8: *Develop a backup assessment approach to providing scientific advice to managers if the proposed assessment approach does not pass peer review or the approved approach is rejected in a future management track assessment.*

In the event of diagnostics failure in the primary WHAM model, the Ismooth approach was identified as the preferred backup. The Ismooth approach would use all indices of abundance included in the age-based assessment. This trend-based method uses standardized abundance indices to provide catch advice, ensuring robustness in rebuilding scenarios. The Ismooth approach integrates recent survey observations, including those from the spring following the terminal year, to enhance its responsiveness to changing stock conditions.

Adjustments to the indices used in Ismooth may be necessary, depending on survey availability and spatial coverage. For example, the suspension of the NMFS summer shrimp survey in 2024 may require reconsideration of its inclusion in the backup methodology. The Ismooth approach offers a practical contingency plan, balancing simplicity with reliability in data-limited scenarios. This flexibility ensures that management decisions remain data-informed, including cases where primary assessment methodologies encounter challenges.

INTRODUCTION

Atlantic herring (*Clupea harengus*) is a small schooling Clupeid that ranges in the Western Atlantic from Newfoundland, Canada through the Mid-Atlantic, US Atlantic herring are obligate planktonic feeders, forming large dense schools. Spawning generally occurs in the autumn, across a number of both inshore and offshore banks (Figure 10) when fish are mature: generally, age 3 or older. Eggs are sticky and demersal, with hatching occurring from dense mats approximately 14 to 21 days after spawning. The resulting larvae are planktonic, feeding on smaller plankton in the water column until spring, when they become more coastal and start forming schools. These juvenile herring, called "brit" in some locations, feed and grow until adulthood. Generally, Atlantic herring live until at least age 10-14. Throughout its life cycle, herring are an important consumer, of zooplankton, as well as important forage for commercially and recreationally important species such as bluefin tuna, striped bass, dogfish, and cod. Further, herring can be an important food item for seabirds, whales, dolphins, and seals. A full examination of the life history of Atlantic herring can be found in TOR 1 as well as TOR 1-WP.

The subject of this stock assessment is the Georges Bank/Gulf of Maine stock complex. This stock is composed of at least two subcomponents, the inshore Gulf of Maine (GOM) and the offshore Georges Bank (GB). Both components mix during non-spawning seasons, resulting in distinguishing these two components in the catch being difficult to nearly impossible using current methods. Given this uncertainty in substructure, the US Atlantic herring stock is assessed as a single unit, incorporating both inshore and offshore components.

While some degree of mixing between the GB/GOM US stock and the Canadian 4WX unit occurs, the degree of this mixing is uncertain and is the subject of ongoing research. Nonetheless, a portion of the Canadian catches are assumed to be from the US GB/GOM stock complex. The New Brunswick weir and stop seine fishery, which operates in the southwest region of New Brunswick, is generally believed to catch mostly juveniles from the US GB/GOM stock.

Exploited well before European colonization, herring has been an important source of sustenance, fertilizer, and bait for other commercial fisheries for centuries. Before the 1970s and the institution of the 200-mile exclusive economic zone, herring was the subject of substantial removals via foreign fleets. Currently, the fishery is mostly prosecuted for bait to supply the economically important American lobster fishery. As a low-value, high-volume fishery, the principal gear types used in the fishery are mobile gear (midwater trawl, purse seine, and bottom trawl) and fixed gear (stop seine and weir).

Atlantic herring has a long history of assessment. The resource was first assessed using Virtual Population Analysis (VPA) in the 1960s and 70s as part of the International Commission for the Northwest Atlantic Fisheries (ICNAF), and later as part of the Transboundary Resource Assessment Committee (TRAC) with the Canadian Fisheries and Oceans (DFO) through the 1990s and early 2000s. The last TRAC assessment for this stock occurred in 2009. Since 2009 the stock has been assessed using the Age Structured Assessment Program (ASAP) by the Northeast Fisheries Science Center (NEFSC). The last benchmark stock assessment was conducted in 2018, with updates occurring every other year in 2020, 2022, and most recently in 2024.

The Atlantic herring population has fluctuated relatively dramatically since the 1960s, according to the most recent Management Track Stock Assessment (Figure 11) conducted in 2024 (NEFSC 2024). Since the late 1960s, the herring population declined precipitously from near-historic highs to very low levels by the late 1970s and early 1980s. Rebuilding occurred in the late 1980s through the late 1990s, with a peak in abundance observed in 1997. Since then, the stock has declined, although this decline was variable, often offset by strong year classes for periods of time. Since 2012 recruitment has been at or near historic lows, leading to a steep decline in stock abundance to well below B_{MSY}. Currently, the stock is below ½ B_{MSY} and is both overfished and in a rebuilding plan. However, the harvest is below proxy FMSY and is not considered to be experiencing overfishing.

Current management of Atlantic herring is by the New England Fishery Management Council (NEFMC), the Atlantic States Marine Fisheries Commission (ASMFC), and NOAA Fisheries. Atlantic herring is a quota-managed fishery, with catches being monitored in-season with limits in four management areas (Figure 12) linked to accountability measures, with the goal of preventing overharvest of the smaller subcomponents. Other management measures include permit/license conditions, specifications on vessel size, closed areas, and seasons, as well as catch caps for non-target species of river herring and shad, as well as haddock. Further, Atlantic herring has a harvest control rule (HCR), which sets the level of catch and exploitation based on stock conditions. This HCR was selected after extensive stakeholder engagement through a Management Strategy Evaluation (Feeney et al. 2018, NEFMC 2019). Further exploration of the history of herring management can be found in the Management-WP.

The goal of the current assessment is to transition this stock to the state space modeling approach, the Woods Hole Assessment Model (WHAM), to allow for the future consideration of environmental covariates, as well as the ability to estimate process and observation uncertainty for this variable stock. To accomplish this, nine Terms of Reference (TOR) should be examined:

1. **** Identify relevant ecosystem and climate influences on the stock. Characterize the uncertainty in the relevant sources of data and their link to stock dynamics. Consider findings, as appropriate, in addressing other TORs. Report how the findings were considered under impacted TORs.

2. Estimate catch from all sources, including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.

3. Present the survey data used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, application of catchability and calibration studies, etc.) and provide a rationale for which data are used. Describe the spatial and temporal distribution of the data. Characterize the uncertainty in these sources of data.

4. Use the appropriate assessment approach to estimate annual fishing mortality, recruitment, and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Compare the time series of these estimates with those from the previously accepted assessment(s). Evaluate a suite of model fit diagnostics (e.g., residual patterns, sensitivity analyses, retrospective patterns), and (a) comment on likely causes of problematic

issues, and (b), if possible and appropriate, account for those issues when providing scientific advice and evaluate the consequences of any correction(s) applied.

5. Update or redefine Status Determination Criteria (SDC; point estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, F_{MSY}, and MSY reference points) and provide estimates of those criteria and their uncertainty, along with a description of the sources of uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for reference points. Compare estimates of current stock size and fishing mortality to existing, and any redefined, SDCs.

6. Define appropriate methods for producing projections; provide justification for assumptions of fishery selectivity, weights at age, maturity, and recruitment; and comment on the reliability of resulting projections considering the effects of uncertainty and sensitivity to projection assumptions.

7. Review, evaluate, and report on the status of research recommendations from the last assessment peer review, including recommendations provided by the prior assessment working group, peer review panel, and SSC. Identify new recommendations for future research, data collection, and assessment methodology. If any ecosystem influences from TOR 1 could not be considered quantitatively under that or other TORs, describe the next steps for development, testing, and review of quantitative relationships and how they could best inform assessments. Prioritize research recommendations.

8. Develop a backup assessment approach to providing scientific advice to managers if the proposed assessment approach does not pass peer review or the approved approach is rejected in a future management track assessment.

9. Identify and consider any additional stock-specific analyses or investigations that are critical for this assessment and warrant peer review and develop additional TOR(s) to address as needed.

Notably, this report represents a summary report. Most, but not all, of the TORs are more fully analyzed in dedicated TOR Working Papers. These in turn draw on specific Additional Working Papers.

ECOSYSTEM, CLIMATE, AND OTHER INFLUENCES

> ***Term of Reference (TOR) #1:*** *Identify relevant ecosystem and climate influences on the stock. Characterize the uncertainty in the relevant sources of data and their link to stock dynamics. Consider findings, as appropriate, in addressing other TORs. Report how the findings were considered under impacted TORs.*

Relevant Ecosystem and Climate Influences on the Stock

Key ecosystem and climate factors impacting Atlantic herring in the Northeast US were identified across spawning, egg, larval, juvenile, and adult stages (see ESP-WP). These insights are presented in a conceptual model (Figure 13) and life history table (see TOR 1-WP). Critical recruitment drivers include food availability, egg predation, and larval temperature stress (Figure 14). Spawning timing and maternal effects were noted as secondary but significant factors.

Boosted regression tree analysis highlighted recruitment drivers: food availability for larvae and juveniles, egg predation, and larval temperature stress. These indicators guided recruitment covariate testing in the stock assessment model.

Management History

The Atlantic herring fishery in waters off the US has been managed since 1972, with international management from 1972-76, federal management from 1978-1982, interstate management from 1983-2000, and joint federal and state management under the Atlantic States Marine Fisheries Commission (ASMFC) and the New England Fishery Management Council (NEFMC) since 2001. The fishery is currently managed using a stock-wide annual catch limit (ACL) that is assigned to sub-ACLs in four spatial management units. The stock-wide ACL is derived using an acceptable biological catch (ABC) control rule designed to account for herring's role as forage in the ecosystem that was developed using stakeholder-driven management strategy evaluation and implemented in 2021.

Stock status is currently overfished (below ½ the spawning stock biomass target level) but not subject to overfishing (fishing mortality is below the fishing mortality limit).

Atlantic herring are primarily used as bait in lobster fisheries and are targeted with purse seine, midwater trawl, and bottom trawl gear. Recent herring catches range from 4,000-9,000 metric tons, down from catches in the 50,000-95,000 metric ton range 2010-17.

For more details, see the Atlantic herring management summary working paper (Management-WP).

Stakeholder Observations

A June 2024 stakeholder engagement session identified key market and ecological dynamics influencing Atlantic herring (Stakeholder-WP). Participants highlighted herring's diminished role in the regional bait market, now dominated by menhaden and frozen alternatives, attributed to declining and inconsistent herring catches, increased prices, and lower quotas. These challenges, compounded by rising fuel costs, have discouraged exploratory fishing and reduced communication among fishers.

Environmental concerns included warming waters and zooplankton shifts impacting recruitment, alongside haddock predation on herring eggs. Participants stressed the need for detailed analysis of zooplankton interactions, changing forage bases, and predator nutritional stress. Notable ecological shifts included predator dietary transitions favoring menhaden over herring. Recommendations included examining herring fecundity, fat content, and aggregation patterns through acoustic detection.

Natural Mortality

Dynamic linear modeling (DLM) linked predator consumption to herring abundance, supporting a constant predation mortality rate (Figure 15). Attempts to model time-varying mortality faced diagnostic challenges or failed to improve fit (e.g., likelihood), leading to its exclusion.

Abundant predators were identified as a key ecosystem influence on juvenile, adult, and spawning herring. Historical assessments used predator consumption data to infer time-varying natural mortality rates, but uncertainties in predator sampling, particularly for striped bass, undermined reliability. Consequently, the 2018 benchmark adopted a constant mortality rate (M) across ages and time. The 2025 research track revisited these assumptions to evaluate potential improvements (see TOR 4).

Gartland and Latour (2024) estimated herring consumption using spatiotemporal modeling of predator stomach contents and survey data (1978-2019). Consumption rates, higher in fall than in spring, fluctuated over time, with lows in the 1980s and greater variability post-2000. Analysis revealed no consistent trend in consumption relative to biomass but identified a rising trend in consumption relative to catch.

DLM examined nine potential drivers, including atmospheric and oceanographic indices (North Atlantic Oscillation, Southern Oscillation), regional oceanography (Gulf Stream extent, cold pool area, warm slope water proportions), zooplankton ratios, herring survey indices, and catch. Results indicated that predator consumption of herring closely tracked herring abundance in spring and fall (Figure 15), suggesting a constant predation mortality rate.

Despite the insights, efforts to incorporate time-varying natural mortality into stock assessments encountered challenges, including poor diagnostic performance and overfitting risks. These limitations reaffirmed the use of a constant M in the assessment model. However, the findings underscore the importance of continued monitoring and refinement of predator-prey interactions to improve mortality estimates.

Maternal Effects and Fecundity

Spawning stock biomass (SSB) as a reproductive potential indicator assumes proportional fecundity to spawner weight at age. However, fecundity tends to be higher in larger, older females, leading to potential overestimation of reproductive potential as age structure skews toward younger fish. Research on Nova Scotia, Canada herring stocks demonstrated non-proportional egg production relative to SSB (Barrett et al. 2022).

Fecundity assessments for mature female herring (2011-19) in the Gulf of Maine revealed stable-to-increasing fecundity, suggesting that reduced fecundity did not drive population declines. Lower fecundity was noted from 2011-15, followed by increases in 2016-18, potentially influenced by environmental or density-dependent factors. Significantly higher reproductive output was observed in 2018-19.

Maternal effects analysis indicated a hyper-allometric relationship between fecundity and both length and weight, with weight showing a stronger correlation. Females exceeding 200 g exhibited higher-than-expected fecundity. Preliminary findings by Joseph Warren (UMass) suggest that fall spawners may have greater fecundity than spring spawners, with larger females contributing disproportionately to egg production. These findings, derived from NEFSC and MADMF surveys (2021-23), highlight the importance of maternal effects.

Further analysis is recommended to refine reference points incorporating maternal effects. For comprehensive details, see the fecundity and maternal effects working paper (Fecundity-WP).

Spawning Timing

Macroscopic maturity data collected during NEFSC spring and fall bottom trawl surveys were analyzed to determine the proportions of developing, ripe, spent, and resting mature female Atlantic herring across seasons. Multinomial regressions evaluated the influence of sampling week, bottom temperature, and decade on observed spawning conditions, providing insights into potential temporal and environmental shifts in spawning phenology.

The Atlantic herring population is dominated by fall spawners, with spring spawning contributing a minor amount. An observed increase in developing fish during spring surveys since 2000 is partly, but not solely, attributed to a shift in survey timing closer to the spring spawning season. Before 2000, spring surveys primarily sampled fish before spawning. Fall surveys have similarly shifted later in the year since the early 2000s, coinciding with an increased proportion of resting fish, which suggests that these later surveys now capture the end of the spawning season. Despite these timing changes, fall bottom temperatures have continued to rise, indicating that warming waters are not directly altering the timing of spawning but may influence other spawning-related dynamics.

Given the declining prevalence of spring spawners, prioritizing spring body condition indices when analyzing changes in herring body condition is recommended. This approach avoids the confounding effects of significant weight fluctuations (15-20% of body weight) associated with the fall spawning season.

For a more comprehensive analysis, see the spawning phenology working paper (Spawn_timing-WP).

Egg Predation

Haddock, identified as an important predator of Atlantic herring eggs (Haddock_predation-WP), experienced a population surge between 2010 and 2020, coinciding with a decline in herring recruitment. A haddock species distribution model (SDM) was developed to explore this relationship using NEFSC offshore and Massachusetts–Maine–New Hampshire inshore bottom trawl survey data from fall (September-November), the herring spawning season. The spatiotemporal model, built using the sdmTMB package in R, employed haddock catch per unit effort as the response variable, with depth, seafloor complexity, year, time of day, and survey platform as predictors. All predictors except seafloor complexity were included in the final model. Herring egg distribution was synthesized from the literature, and from where herring eggs were observed in haddock diet data.

The haddock SDM and herring egg distribution data created an egg predation index. Annual fall haddock biomass density was predicted across the region using a 5-km grid. The index calculated the annual average haddock density within areas likely to contain herring eggs, with uncertainty estimated via the “emmeans” package.

The index revealed high haddock predation on herring eggs in the 1960s, a decline through the 1980s and 1990s, a peak from 2010 to 2020, and a subsequent decrease in recent years (Figure 16). A significant negative correlation ($R = -0.33$; $p = 0.011$) was observed between the index and herring recruits-per-spawner (R/SSB) as estimated in the 2022 stock assessment model updated through 2023 (Figure 16).

These findings suggest that haddock predation may play a substantial role in herring recruitment dynamics. See the haddock egg predation index working paper for more details (Haddock_predation-WP).

The haddock egg predation index was tested as a recruitment covariate within the Atlantic herring assessment model (see TOR 4).

Larval Temperature Stress

Two temperature bottlenecks for Atlantic herring were identified in the conceptual model. Bottom temperatures between August and December impact embryos and yolk sac larvae, while sea surface temperatures affect early and late larval stages during fall. Temperatures exceeding 16°C are considered stressful, and those above 21°C are lethal.

For embryos and yolk sac larvae, bottom temperatures in the Gulf of Maine and Georges Bank are generally suitable, with predation and other factors likely having a more significant role. However, sea surface temperatures pose a critical challenge for pelagic larval stages. Stressful conditions before winter and lethal temperatures during several days in the last decade have been documented. Prolonged summer conditions mean lethal temperatures persist later into the year, delaying the onset of fall cooling and reducing the optimal thermal window for larval survival.

The duration of the optimal thermal window has declined over time (Figure 17), although exceptions in years like 2010 and 2018 showed longer windows, comparable to earlier decades.

Extended optimal windows improve larval survival by minimizing exposure to lethal temperatures. Overall, warming fall surface temperatures near spawning grounds represent a significant source of density-independent mortality for larval herring. For more detailed information, see the Threshold-WP.

Food Availability

Existing zooplankton indices for the Northeast US were implemented for general ecosystem reporting rather than tailored to Atlantic herring life history. Therefore, new zooplankton indices were developed using VAST spatiotemporal modeling of NEFSC zooplankton survey data collected between 1982-2022. Based on the results of the Ecosystem and Socioeconomic Profile (ESP) literature review and the boosted regression tree analysis (ESP-WP), the first two indices are large copepods in spring (influencing the growth of herring post-larvae and juveniles), and small copepods in fall (influencing survival of herring larvae over the winter). The spatial scale of these indices is the Atlantic herring bottom trawl survey strata in spring and fall, respectively.

Large copepods include the taxa *Calanus finmarchicus*, *Metridia lucens*, *Calanus minor*, *Eucalanus* spp., and *Calanus* spp. Small copepods include the taxa *Centropages typicus*, *Pseudocalanus* spp., *Temora longicornis*, *Centropages hamatus*, *Paracalanus parvus*, *Acartia* spp., *Clausocalanus arcuicornis*, *Acartia longiremis*, *Clausocalanus furcatus*, *Temora stylifera*, *Temora* spp., *Tortanus discaudatus*, and *Paracalanus* spp.

The third index is more refined to focus on herring larval food and habitat, using temporal and spatial bounds defined by herring larvae observations in the zooplankton dataset. This third index focuses on small copepods from September to February in the area where more than 70% of herring larval density was identified between 1982-2022.

The indices suggest that spring large copepods increased to a relatively high level in 2015 but have been declining since, although no long-term trend appears in the time series. Fall small copepods have generally increased from a low in the mid-2000s and have remained relatively stable from 2010-present and similarly have no long-term trend in the time series (Figure 18).

For a more detailed analysis see Zooplankton and VAST Working Paper

Consideration of Findings in Other TORs

TOR 4

The results of this TOR suggested two additional model runs as sensitivities: a run to examine these recruitment covariates, and another to examine the effects of haddock predation on herring eggs. Efforts to model time-varying natural mortality were abandoned because of diagnostic issues.

TOR 7

Research recommendations include exploring maternal effects and alternative reference points beyond SSB, such as age-structured fecundity metrics and body condition indices.

CATCH & SAMPLING

TOR #2: *Estimate catch from all sources, including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.*

A more comprehensive analysis of this TOR can be found in the TOR 2 working paper (TOR 2-WP).

Historic Trends in Catch

As shown in Figure 19, herring catches surged during the 1960s and 70s because of domestic, Canadian, and distant-water fleets, peaking at more than 450,000 mt before the Magnuson–Stevens Fishery Conservation and Management Act (MSA) implementation in 1978. However, catch data from this period, particularly from Russian and Polish vessels, are uncertain because of self-reporting issues. Gear used before the early 1980s included bottom trawls, purse seines, weirs, and stop seines, with industrial fleets favoring purse seines and trawls. Post-1987 records provide greater certainty, with midwater trawls dominating from the mid-1990s onward (Figure 20).

More recent management measures, such as the inshore summer prohibition on midwater trawls (implemented in 2010), shifted catches further offshore. Declining US quotas due to low herring abundance have increased the relative proportion of Canadian fixed-gear catches, which remain stable due to the absence of quota restrictions. Regional catch trends are illustrated in Figure 21.

Market and Utilization

Before ICNAF fisheries, most landed herring supported Maine's sardine industry, targeting smaller fish (ages 1-2) for canning (Anthony & Waring 1980). During ICNAF operations, catches shifted to spawning-aged fish (3+), largely for export markets. The 1980s marked the rise of the lobster bait market, which demanded larger fish unsuitable for canning. Mechanized canning in the 1990s further increased the preferred fish size, resulting in canned herring "steaks," a product still common in Canada.

By the late 2000s, nearly all herring landings supported the lobster industry, peaking at 100,000 mt annually. With the 2010 closure of the last US canning plant in Prospect Harbor, nearly all US Atlantic herring now serves as lobster bait, with minor amounts for aquariums and zoos.

Catch and Landings Data

Catch data before the MSA primarily originated from sardine facilities and ICNAF quota monitoring. Improved dealer reporting in the 1990s captured landings outside sardine operations, while the introduction of vessel trip reports (VTR) and interactive voice reporting (IVR) in 1999 standardized reporting.

Until this Research Track, VTR data served as the primary source of catch data for assessments. Maine DMR conducted QA/QC checks on VTR data, correcting errors and reconciling discrepancies before submitting data to NOAA. However, inconsistencies between VTR and quota monitoring systems prompted the WG to evaluate alternative methods.

NOAA's Catch Accounting and Monitoring System (CAMS) was developed as a unified source of catch (landings and discards) data for stock assessments, quota monitoring, and related analyses in New England and Mid-Atlantic fisheries. A working paper on the details of the transition to using CAMS for Atlantic herring can be found elsewhere (CAMS-WP). The working paper analyzes a refinement in discard estimation methods within CAMS. The transition aligns Atlantic herring discard estimation with other federally managed species using the calendar year (CY) approach. CAMS integrates multiple fishery-dependent data sources, including VTRs, dealer reports, and observer data, offering consistent estimates for both landings and discards.

Based on these results, the WG concluded that the use of the CAMS CY approach was the preferred method to estimate discards. A comparison between the previous catch accounting system performed by Maine DMR and CAMS is shown in Table 1. The differences between the two catch accounting systems are relatively minor, and the WG was comfortable going forward with the CAMS CY approach as the primary system in this and subsequent assessments. In addition, the stock assessment was insensitive to the switch to CAMS.

An additional source of catch and landings information for this assessment comes from DFO Canada. Catches in the New Brunswick (NB) fixed-gear fishery are assumed to be from the US GOM/GB stock complex (NEFSC 2018) and mainly consist of juvenile fish. Canada updated the catch time series it provided since the 2024 management track assessment. The differences in the time series were largely induced by changes to the gear types used for age-length keys and a move to standardized code used to calculate the catches. The changes were relatively minor (Figure 22) and had negligible effects on the stock assessment.

Fishery Sampling

Atlantic herring have been sampled for length, weight, and age since before the 1970s. Early sampling efforts were conducted by the offshore ICNAF fishery and inshore sardine operations. By the 1980s, sampling shifted primarily to sardine canneries, with occasional collections from bait operations.

The Maine DMR established a standardized sampling program in the late 1990s, funded by the Inter-Jurisdictional Fisheries (IJF) and Atlantic Coastal Cooperative Statistics Program (ACCSP). This program collects two 50-fish samples per gear type, per statistical area, on a bimonthly basis during the fishing season with the total number of samples per year fluctuating based on fleet activity (Figure 23). Additional fresh fish samples are collected to monitor spawning areas under ASMFC management, implemented in 1999. Sampling is conducted across all states where herring are landed, from Maine to New Jersey.

Since 1999, sampling has targeted vessels using vessel monitoring system (VMS)/VTR reports to align with the program's design. Samples are either analyzed immediately or frozen for later examination. Fish are measured for weight and length, and two fish per centimeter size bin are randomly selected for further analysis. These fish are aged using otoliths, which are extracted, dried, and embedded in epoxy resin. Gonads are also removed, weighed, sexed, and staged according to ICNAF protocols. Since 2011 fresh fish in spawning stages higher than five are included in a fecundity study (see Fecundity-WP).

Aging is performed under a microscope, with images archived for QA/QC. Calibrations between Maine DMR, NOAA's Age and Growth Lab, and DFO occur every 3-7 years to ensure consistency.

All sampling data is stored in a Maine DMR relational database, linked to NOAA's VTR records to trace individual catch events and locations. In addition, this database contains digitized historical data from ICNAF and sardine cannery sampling programs. These datasets support stock assessments, management decisions, and academic research (Becker et al. 2020).

Data on size and age from the NB fixed gear fishery is supplied directly from DFO.

SURVEY DATA

> ***TOR #3:*** *Present the survey data used in the assessment (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, application of catchability and calibration studies, etc.) and provide a rationale for which data are used. Describe the spatial and temporal distribution of the data. Characterize the uncertainty in these sources of data.*

Recent assessments relied on several comprehensive surveys to evaluate trends and stock dynamics. Key surveys include:

- NMFS spring bottom trawl survey (1968-present), NMFS fall bottom trawl survey (1965-present), and NMFS summer shrimp survey (1983-present).
- NMFS acoustic surveys conducted during the fall bottom trawl surveys since 1998.

The methodologies applied to these surveys remain consistent with the standards set in the 2018 benchmark stock assessment (NEFSC 2018 TORB2). Significant effort has been directed toward addressing data gaps, particularly by developing an age-1 recruitment index based on seabird diet data, as early cohort strength observations remain limited. While Massachusetts and Maine/New Hampshire state surveys were analyzed, their restricted spatial coverage led to their exclusion from assessment models. Moreover, the WG noted that because both surveys sampled more inshore component fish, a risk that including these surveys would bias the data in favor of this one component was present.

NMFS Spring Bottom Trawl Survey

The NMFS Spring bottom trawl survey has undergone no methodological changes since the 2018 benchmark assessment (NEFSC 2018). The survey's index trends have shown a steady decline since 2009 (Figure 24). Age composition data demonstrates clear cohort tracking over time, validating its utility in stock assessment. The WG's preferred model continues to split the survey into two distinct time series to account for the transition from the Albatross to the Bigelow vessel in 2008 and 2009.

NMFS Fall Bottom Trawl Survey

Similarly, no methodological adjustments have been instituted to the NMFS fall bottom trawl survey. In addition, index trends from this survey have exhibited a declining trajectory since 2009 (Figure 24). Age composition patterns highlight consistent cohort tracking. As is the case with the spring survey, the fall survey is split into two time series to accommodate vessel changes, ensuring data continuity and reliability within the WG's preferred modeling framework.

NMFS Gulf of Maine Northern Shrimp (summer) Survey

Since 2018 the primary methodological update for the NMFS summer shrimp survey involves replacing borrowed age-length keys with directly collected age composition data. This adjustment, implemented during the 2022 management track assessment, enhances the accuracy of stock age data. Recent years have shown declining index trends for this survey (Figure 24). Given operational challenges, this survey was not conducted in 2024, and the timeline for its resumption remains uncertain.

NMFS Acoustic Survey

The NMFS acoustic survey, conducted during the fall bottom trawl survey, continues to provide critical data. Details regarding its methodology and findings are documented comprehensively in the working document authored by Jech (Acoustics-WP).

Age-1 Recruitment Index via Seabird Diet Data

Efforts to develop an age-1 recruitment index using seabird diet data address a key data gap in cohort strength observations. The detailed methodologies and outcomes of this work are elaborated in the document Seabird_Diet-derived_Recruitment_Index-WP.pdf.

Maine/New Hampshire Survey

The Maine/New Hampshire (ME-NH) survey has operated since 2000, utilizing a stratified random sampling design across four depth strata and five geographic regions. Sampling stations, revisited in spring and fall, involve 20-minute tows using a modified shrimp net. Species-specific measurements include length, weight, and, where applicable, maturity assessments. Catch numbers and weights have declined since its inception (Figure 25 & Figure 26), although trends exhibit variability. Despite being excluded from final modeling, the ME-NH survey aligns with trends observed in other surveys, offering insights into the inshore recruitment dynamics of Atlantic herring.

Massachusetts Survey

The Massachusetts Division of Marine Fisheries (MADMF) has conducted seasonal inshore trawl surveys since 1978, with spring and fall cruises. Spring surveys predominantly capture age-1 herring (~6 cm), while fall surveys often capture larger individuals, typically representing age-1

(~11 cm) and age-2+ (~24 cm) cohorts (Figure 27 & Figure 28). Significant interannual variability in herring indices is observed, with large shifts linked to spatial availability and bottom temperature fluctuations (Figure 29, 30, & 31). Herring are most frequently encountered in the deepest, coldest regions of Massachusetts state waters, emphasizing the influence of environmental conditions on survey results.

ASSESSMENT METHODS

> ***TOR #4:*** *Use appropriate assessment approach to estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Compare the time series of these estimates with those from the previously accepted assessment(s). Evaluate a suite of model fit diagnostics (e.g., residual patterns, sensitivity analyses, retrospective patterns), and (a) comment on likely causes of problematic issues, and (b), if possible and appropriate, account for those issues when providing scientific advice and evaluate the consequences of any correction(s) applied.*

Model Evaluation Criteria

Throughout model development, some combination of the list below was used for model selection. During stages of development that required comparison among many models, selection relied largely on convergence properties and AIC because visual comparisons of residual plots and diagnostics that require simulation (e.g., jitter, self-tests) are impractical for more than a few model alternatives. At stages when the WG was evaluating just a few models (~ <10), a fuller suite of the diagnostics below were used. More details can be found in the TOR_4-5-6-WP.

- **Convergence:** To be considered acceptable, all models were required to converge to a solution with a maximum gradient <e-10 and an invertible Hessian. Models with retrospective peels that all converged were also preferred over models that did not.

- Models with standard deviation (SD) estimates of zero for any random effects process were eliminated from consideration.

- **Residuals:** Models with fewer patterns in standard Pearson residuals and OSA residuals were preferred over models with more obvious patterning. Residuals were examined for patterns among years, ages, cohorts, and observations.

- Retrospective patterns were examined visually and summarized using Mohn’s rho. Patterns in fishing mortality, spawning stock biomass (SSB), and recruitment were all examined. Retrospective patterns in recruitment are typically not used for model selection, but the WG found them to be indicative of model sensitivity to data inputs on a few occasions (see below).

- AIC was used to compare models with a preference for smaller AIC values. When two models had similar AIC, the negative log-likelihood was also examined to evaluate whether the model alternative with more parameters was having any significant effect on fit. Given similar AIC and likelihood values, the simpler model with fewer parameters was preferred.

- **Self-tests:** Pseudo-data were generated from model fits with observation uncertainty only (i.e., parameters fixed at their estimated values and no process uncertainty), and then the model refits to each pseudo-dataset. Relative error was then summarized for time series estimates of F, SSB, and R. Acceptable models would not have relative errors that were systematically different from zero or trend among years.

- Tests of normality and the standard deviation of OSA residuals were also used for model selection. OSA residuals should be approximately normal (Trijoulet et al. 2023 and Li et al. 2024), and OSA residuals for age composition data should not have a standard deviation >>1, which can be indicative of model misspecification (Li et al. 2024).

Mean absolute scaled error (MASE; Carvalho et al., 2021; Kell et al., 2021), a measure of predictive skill, was calculated but is generally not useful for model selection (Li et al., 2024).

Summary of Preferred Model

Data

More details can be found in (TOR_4-5-6-WP). All input data for the preferred model was identical to the 2024 Management Track stock assessment (NOAA 2024) with two exceptions: 1) the Canadian catch and weight-at-age time series were revised, and 2) US catch and discards used CAMS estimates from 2020 onward (See TOR 2-WP). Both of these changes had negligible effects on the assessment. Age compositions by fleet and proportion of the catch by fleets are given in Figure 32 & Figure 33, respectively. Age compositions by each index are given in Figure 34, 35, & 36, while both the nominal and the log-scaled indices are shown in Figure 36.

Age Composition Likelihoods

A broad suite of alternatives for age composition likelihoods was explored. The WG agreed that the logistic-normal-ar1-miss0 provided the best overall diagnostics, and in particular, improved the OSA residuals for the fit to age composition data from the spring and fall bottom trawl survey since 2009 (i.e., during the Bigelow years).

Initial numbers-at-age

Estimating initial numbers-at-age improved fit and was supported by AIC over assuming these values were at equilibrium. These values were estimated in the preferred model.

Selectivity

With some exceptions, the selectivity forms applied were the same as recent management track assessments as outlined below.

- **Mobile fleet:** selectivity-at-age is estimated for ages 1-6 and fixed at 1.0 for ages 7-8.

- **Fixed fleet:** selectivity-at-age is estimated for all ages except age-2, which is fixed at 1.0.
- **Summer (Shrimp) survey:** selectivity-at-age-3 is estimated while younger ages are fixed at 0.0 and older ages are fixed at 1.0.
- **Acoustic survey:** has no age composition data and selectivity is knife-edged with full selection for ages 3-8.
- **Spring bottom trawl 1987-2008:** selectivity-at-age-2 is estimated while younger ages are fixed at 0.0 and older ages are fixed at 1.0.
- **Fall bottom trawl 1987-2008:** uses logistic selectivity.
- **Spring bottom trawl 2009-2023:** estimates selectivity-at-age for ages 2-3, while younger ages are fixed at 0.0 and older ages are fixed at 1.0.
- **Fall bottom trawl 2009-2023:** uses logistic selectivity.

A broad suite of age- and time-varying selectivity random effects were evaluated for the mobile and fixed fleets. In all cases, the SD of these random effects was zero, very small, or did not improve fit based on AIC. As such, time invariant selectivity is used in the preferred model. The WG did not see any justification for considering time-varying selectivity for the indices.

Natural Mortality

A broad suite of age- and time-varying natural mortality parameterizations were evaluated. This included combinations of fixed effects estimated as age-varying or age- and time-invariant parameters and random effects with various age or time correlation structures. Estimating M as fixed effects did not improve fit based on AIC and had odd retrospective patterns. While model fit improved with M as iid random effects, the estimates appeared to be chasing observation noise and did not represent real changes in M. In addition, self-tests on models with random effects on M had low rates of convergence and bias. Random effects on M also caused volatility in reference points, and recent research suggests that time-varying M should only be included with strong, external, corroborating evidence. In this case, external evidence supported time-invariant M. Consequently, the preferred model had a constant M=0.35 (status quo).

Estimates of Atlantic herring consumption based on piscivore stomach contents data were made for the 2018 benchmark stock assessment (Figure 37). Using the same data, Gartland and Latour (2024) applied a VAST model with a range of covariates and estimated Atlantic herring consumption (Figure 37). The number of dead fish implied by an assumed M=0.35 generally matched the scale and trend of both of these estimates of consumption. Values from Gartland and Latour (2024) had to be doubled for comparison to the assessment because they only provided estimates for six months of each year (i.e., spring and fall) and warned against out-of-sample extrapolation to estimate annual consumption. While reassuring that these estimates are generally similar, the approach likely violates sound statistical practice.

Numbers-at-age Transitions

The model was started in 1987 when age data became available from the bottom trawl surveys. Including random effects on the numbers-at-age transitions greatly improved fit and reduced the retrospective pattern. Fit and AIC diagnostics supported the use of transitions correlated among ages, but not years. This correlation was not coupled with age-1 recruitment. Consequently, the preferred model has random effects on the numbers-at-age transitions with an ar1_a correlation (Figure 38).

Recruitment

Fit and AIC diagnostics supported the use of iid random effects for recruitment. The preferred model estimates a fixed effect recruitment scaling parameter and annual recruitments as iid random effects around the scaling parameter (i.e., the log scale mean of the iid random effects distribution). SSB and recruitment are shown in Figure 39; SSB and fishing mortality are given in Figure 40, how the F is portioned among the fleets in Figure 41; and the estimated numbers at age by year in Figure 42.

Covariates and Other Explorations

A variant of the preferred model used a haddock predation index as a covariate for recruitment (Haddock_predation-WP). This covariate did not improve model fit or reduce the process SD for recruitment, and the confidence interval around the covariate parameter included zero (i.e., no effect), which suggested that haddock were not a primary driver of variance in annual recruitment.

Similarly, three additional variants of the preferred model used indices of small zooplankton (larval herring food), large zooplankton (juvenile herring food), and optimal herring larval temperature duration, respectively, as covariates for recruitment. Results were similar for the haddock biomass covariate: within the preferred model structure, these covariates did not substantially improve model fit or reduce the process SD for recruitment, and confidence intervals around the covariate parameters included zero. Further, the estimated larval and juvenile food covariate parameters were negative (suggesting low zooplankton is associated with higher recruitment, and high zooplankton is associated with lower recruitment; opposite of our working hypothesis).

In two recruitment covariate sensitivity runs with NAA RE turned off, both haddock predation and optimal larval temperature duration covariates improved model fit, reduced the process SD for recruitment, and estimated covariate parameters with confidence intervals that did not include 0. However, the overall model fit was greatly reduced without NAA RE included.

Diagnostics

The WG had no major concerns about any diagnostics. Jitter analyses, self-tests, and the normality of OSA age composition residuals all had SD <1. Nearly all the OSA age composition residuals were significantly different from normality, but this was likely due to the high power of the statistical test rather than concerning deviations from normality. Given that no retrospective adjustment was necessary (TOR_4-5-6-WP), retrospective plots are not shown.

STATUS DETERMINATION CRITERIA

TOR #5: *Update or redefine status determination criteria (SDC; point estimates or proxies for BMSY, BTHRESHOLD, FMSY, and MSY reference points) and provide estimates of those criteria and their uncertainty, along with a description of the sources of uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for reference points. Compare estimates of current stock size and fishing mortality to existing, and any redefined, SDCs.*

The WG agreed to the continued use of $F_{40\%}$ as an F_{MSY} proxy. Life history traits and other necessary inputs to the per-recruit calculations will continue to use a recent 5-year average. As is also current practice (NEFSC 2022; NEFSC in press), only the $F_{40\%}$ specific to the mobile fleet should be used for official overfishing determination. This approach is taken because the fixed fleet is almost entirely Canadian, and overfishing status should not be driven by a foreign fleet without quota controls. WHAM can produce a "global" $F_{40\%}$ and an $F_{40\%}$ specific to the fixed fleet, and these values might be informative but should not be used for official status determination. More details can be found in the TOR_4-5-6-WP.

$B_{40\%}$ is found by multiplying $SPR_{40\%}$ by a recruitment scalar (e.g., mean recruitment over some years). In recent assessments, including the 2024 management track, mean recruitment was averaged over 1992-2021 (the last two years dropped due to uncertainty), and this stanza was chosen based on a change point analysis applied to the R/SSB time series that suggested a possible environmental change since 1992 that has led to reduced productivity. The R/SSB time series from the preferred WHAM model does not suggest the same changes, thus the WG agreed that a reduced time stanza is no longer needed. The differences in the R/SSB time series between the 2024 management track ASAP model and the preferred WHAM model were traced to the presence of NAA random effects in WHAM.

The WG considered two methods to define the recruitment scalar that will be used to determine $B_{40\%}$. One method involved taking the time series average of the annual estimated recruitments from the preferred WHAM model. The second method involved using the recruitment scaling parameter from which the annual recruitment random effect deviations are estimated. This recruitment scaling parameter is often mistaken for the mean or median recruitment of the natural scale recruitment estimates, but it does not necessarily equal either one. The WG agreed to use the recruitment scaling parameter because: 1) It is more stable than a time series average because it is less affected by extreme recruitment estimates; 2) It avoids subjective decision-making about whether some recruitment estimates (e.g., terminal year) are too uncertain to be included in the time series average; and 3) Using the recruitment scaling parameter creates internal consistency because it is the value from which the log scale recruitments deviate, represents the mean of the log scale recruitment process, and allows for the recruitment process to be used in short-term projections making the estimation model and projection model entirely consistent.

The reference points using this approach were:

- $B_{40\%}$ = 233,176mt (90%CI 152,540-356,439),
- Global $F_{40\%}$=0.358, $F_{40\%}$ for the mobile fleet = 0.349 (90%CI 0.305-0.440), $F_{40\%}$ for the fixed fleet = 0.008,
- Global MSY = 63,835mt, MSY for the mobile fleet = 51,001mt, and MSY for the fixed fleet = 12,835mt.

The SD of the fleet-specific $F_{40\%}$ is not reported by WHAM, and thus the SD of the global $F_{40\%}$ was used as a proxy in calculating the mobile fleet $F_{40\%}$ confidence interval.

Terminal year (2023) mobile fleet F = 0.225 (90%CI = 0.16-0.32). Terminal year (2023) SSB = 82,402mt (90%CI = 60,582-112,082). Mohn's rho for SSB = 0.27 and F = -0.16, and retrospective adjustments were unnecessary.

By comparison from the 2024 management track assessment:

- $B_{40\%}$ = 186,367mt
- mobile fleet $F_{40\%}$ = 0.45
- global MSY = 78,710mt.

Rho adjusted terminal year (2023) SSB = 47,955mt, which was 26% of $B_{40\%}$. Rho adjusted terminal year (2023) mobile fleet F = 0.263, which was 58% of $F_{40\%}$. However, direct comparisons between the results of the 2024 management track assessment and the findings of this research track are inappropriate because of the change in the modeling platform and other advances in methodology for the Atlantic herring assessment.

PROJECTION METHODS

***TOR #6:** Define appropriate methods for producing projections; provide justification for assumptions of fishery selectivity, weights at age, maturity, and recruitment; and comment on the reliability of resulting projections considering the effects of uncertainty and sensitivity to projection assumptions*

As mentioned above, the WG agreed to use the recruitment scaling parameter for reference points and continue the recruitment random effect process into projections (i.e., iid lognormal recruitment), consistent with the estimation model. Using an iid lognormal distribution for recruitment differs from the current projection methodology that uses an ar1 recruitment process. In addition, as noted above, WHAM found no evidence of a significant correlation in the recruitment time series, thus autocorrelation in recruitment was not included. The other basic projection methodologies agreed to by the WG are largely consistent with existing methods. The US mobile fleet catch is specified by applying the NEFMC ABC control rule, which determines the ABC in year *y+1* in response to the ratio of B to B_{MSY} proxy in year *y* using a "hockey-stick" shaped control rule. The fixed fleet catch is held constant in projections at the most recent 10-year average, consistent with recent management practice. However, this value is considered part of management uncertainty and subject to change as recommended by the NEFMC in its specifications process. See TOR_4-5-6-WP for more details.

Projections using these methods resulted in relatively rapid increases in SSB and mobile fleet catch (Figure 43). There are several reasons for these results. The stock will trend toward $B_{40\%}$ and higher when fished below $F_{40\%}$ (the ABC control rule has a maximum fishing mortality of 80% $F_{40\%}$, and target F declines linearly to zero below half $B_{40\%}$). During the estimation model period through 2023, recent NAA random effects have been negative, which will remove fish from the population faster than the reductions caused by just fishing mortality and M. Without temporal correlation, these negative random effects do not persist into the projection period (i.e., they equal zero), and thus recent cohorts (even if relatively poor) will contribute to SSB more quickly and for a longer period than in the presence of negative NAA random effects.

Similarly, recruitment is projected as iid as opposed to the ar1y process currently used in the ASAP model. Therefore, recruitment does not remain relatively low into the projection period (Figure 44), and instead immediately reverts to the recruitment scaling parameter value. However, the WG agreed that the absence of NAA random effects in the projection period is likely more influential than the recruitment assumption. Catches for the mobile fleet also increase more quickly relative to the 2024 management track methods because WHAM estimates a slightly better stock condition (Figure 45), which permits higher fishing mortality rates for the mobile fleet. Further, the catch will increase exponentially as F increases linearly based on the ABC control rule.

The WG expressed concern that these projections were overly optimistic but did not have any immediate solutions. The issue of overly optimistic projections is not unique to this Atlantic herring Research Track and might be addressed more broadly through the upcoming Research Track stock assessment on projection methodologies scheduled for 2027.

RESEARCH RECOMMENDATIONS

TOR #7: *Review, evaluate, and report on the status of research recommendations from the last assessment peer review, including recommendations provided by the prior assessment working group, peer review panel, and SSC. Identify new recommendations for future research, data collection, and assessment methodology. If any ecosystem influences from TOR 1 could not be considered quantitatively under that or other TORs, describe the next steps for development, testing, and review of quantitative relationships and how they could best inform assessments. Prioritize research recommendations.*

The WG examined past Research Recommendations to see whether they were still relevant and what progress had been made. In addition, the WG made recommendations on future work that would improve the Atlantic herring assessment. See TOR_7-WP for more details.

The following summarizes the WG's response to previous research recommendations.

Past Recommendations

Investigate mechanisms behind low recruitment:

The WG has examined this issue in detail (see TOR 4). The main conclusion is that while variable, recruitment has not declined as much as previously understood. Rather, NAA transitions suggest lower retention of fish as they move to older ages in some years. Several covariates on recruitment were also attempted, including haddock predation on eggs, temperature, and plankton abundance (i.e., food availability). Results suggested that these may be partial drivers of recruitment, but no single covariate was identified as largely responsible for herring recruitment patterns.

Consider informing projections with R/S for consistency with change point analysis:

This recommendation is no longer relevant.

Investigate whether $F_{40\%}$ needs to be changed/reduced in the lower productivity regime:

The issue of reference points and $F_{40\%}$ can be found in TOR 5. Briefly, no evidence indicates that the continued use of $F_{40\%}$ as a proxy of F_{MSY} is untenable. Given that the evidence for a lower productivity regime has deteriorated, this issue is less urgent.

Estimate F_{MSY} directly:

The WG has concluded that MSY-based reference points are still incalculable for Atlantic herring and have retained $B_{40\%}$ and $F_{40\%}$ as MSY proxies.

Consider younger ages as fully selected by the mobile fleet:

This assessment did not directly address the recommendation. Instead, the WG continued with the use of a two-fleet structure. The Fixed Gear fleet focuses mainly on smaller, younger fish, while the Mobile fleet targets older and larger fish. The WG attempted many assessment model runs with time—and age-varying selectivity—and no support was found to suggest that younger ages should be more fully selected.

Consider recruitment index based on seabird diet:

This recommendation is addressed in TOR 3.

Explore approaches to estimating M, especially time-varying:

As outlined in TOR 1 and TOR 4, little support for time- or age-varying natural mortality existed.

Examine stock structure and movement:

Given this Research Track's goals and time frame, a full examination of stock structure or migration patterns was not possible. Future work on herring genetics in the Gulf of Maine and Georges Bank is planned for 2025-26.

Explore model-based indices:

This recommendation was thoroughly addressed in the 2012 benchmark.

Continue collecting age data during the summer survey:

The fate of the summer survey as a whole remains uncertain. While age data has been collected, the survey was not conducted in 2024 and is unlikely to be conducted again in 2025.

Evaluate the impact of switching from borrowed ALKs to direct age observations from the summer survey:

No progress has occurred on this recommendation as of this Research track.

Explore the effect of likelihood penalties on recruitment estimation:

This is no longer relevant as recruitment penalties are not used in WHAM.

Monitor the impact of missing 2020 survey data on assessments:

This recommendation was addressed in the 2022 and 2024 Management Track assessments. Further, missing 2020 survey data combined with NAA random effects caused problems with retrospective analysis in this research track, which was monitored and resolved.

Examine reproductive status and condition over time:

This recommendation was addressed at length in TOR 1.

Improve our understanding of fleet dynamics and the relationship to herring spatial dynamics:

TORs 1 and 2 partially address this recommendation. In addition, the NEFMC is working to examine this issue in more detail.

Analyze condition, growth, and fecundity:

TOR 1 and the additional working papers referenced therein examine this issue in greater detail.

The WG recommends the following new research recommendations grouped by category:

New Recommendations include:

Maternal Effects and Fecundity:

- Further analysis is recommended to refine reference points incorporating maternal effects, such as age-structured fecundity metrics and body condition indices.

Spawning Timing:

- Prioritize spring body condition indices when analyzing changes in herring body condition to avoid confounding effects of significant weight fluctuations associated with the fall spawning season.

Egg Predation:

- Further analysis of haddock predation on herring eggs and its relationship to recruitment dynamics is recommended.

Larval Temperature Stress:

- Investigate the implications of warming sea surface temperatures and the reduced optimal thermal window on larval survival to refine models of density-independent mortality.

Food Availability:

- Develop zooplankton indices tailored to Atlantic herring life history, focusing on spring large copepods and fall small copepods to assess their influence on herring recruitment.

Natural Mortality:

- Explore and refine predator-prey interaction models to improve natural mortality estimates.

Survey Data:

- Continue enhancing survey methodologies, such as incorporating age-length data and calibration studies, to improve reliability and consistency.

- Evaluate the inclusion of innovative recruitment indices, like seabird diet data, for stock assessments.

- Apply VAST methodologies to combined State and Federal Surveys.

Assessment Methods:

- Explore alternative age-specific selectivity models and the use of random effects selectivity parameters.

- Investigate the use of larval indices as a potential index of recruitment.

- Refine projection models by integrating ecosystem indicators, such as zooplankton abundance and thermal habitat suitability.

Projection Methods:

- Integrate environmental datasets, including temperature and prey availability indices, to refine projection assumptions.

- Address overly optimistic projections by exploring methods that better account for recruitment variability and environmental drivers.
- Evaluate if and how NAA random effects should be treated during the projection period.
- Consider refining how weight- and maturity-at-age are specified in the projection period (i.e., investigate alternatives to a recent 5-year average, especially for trending traits).

BACKUP ASSESSMENT APPROACH

TOR #8: *Develop a backup assessment approach to providing scientific advice to managers if the proposed assessment approach does not pass peer review or the approved approach is rejected in a future management track assessment.*

The WG concluded that if the preferred WHAM model configuration were to be rejected it would likely be due to unacceptable diagnostics (e.g., residual patterns, unresolvable data conflicts) that may not be resolvable within an age-based assessment. Consequently, the WG concluded that a trend-based backup would be appropriate, and the WG chose the existing Ismooth approach. The Ismooth approach performed relatively well when tested in a management strategy evaluation and was especially good for rebuilding depleted stocks (Legault et al. 2022). The Ismooth approach would use all indices of abundance included in the age-based assessment. Each index would be divided by its time series to standardize all time series to a similar scale. If the Ismooth approach is needed, then spring survey in the year following the terminal year of the age-based assessment will likely be available.

This spring observation would be included in the Ismooth to take advantage of the most recent survey observation. The Ismooth approach uses the mean across indices each year in the application of a LOESS-smoothed average index of abundance. The time series other than the spring survey will be lagged forward one year so that the most recent observation from each survey will be used when taking the annual means (e.g., the fall observation from year y will be averaged with the spring observation from year y+1). The multiplier produced by Ismooth would be applied to a recent average catch to provide catch advice. The multiplier using the data in this research track was 1.56.

The WG noted that the NMFS Gulf of Maine Northern Shrimp survey has been suspended and was not conducted in 2024. Future management tracks should reconsider whether this survey should remain in the Ismooth backup assessment approach. More generally, the indices considered in the Ismooth may need reconsideration depending on survey availability and temporal or spatial coverage (e.g., vessel breakdowns, incomplete strata sampling).

OTHER ADDITIONAL TORs

TOR #9: *Identify and consider any additional stock-specific analyses or investigations that are critical for this assessment and warrant peer review, and develop additional TOR(s)* to address as needed.*

No additional TORs were necessary.

TABLES

Table 1. Comparison between current catch accounting and CAMS for fishery-wide catch by year. All catches are in mt from US vessels.

Year	Current Approach	CAMS	Difference
2020	8,069	9,866	(1,797)
2021	5,236	5,216	20
2022	3,921	4,295	(374)
2023	9,500	10,118	(618)

FIGURES

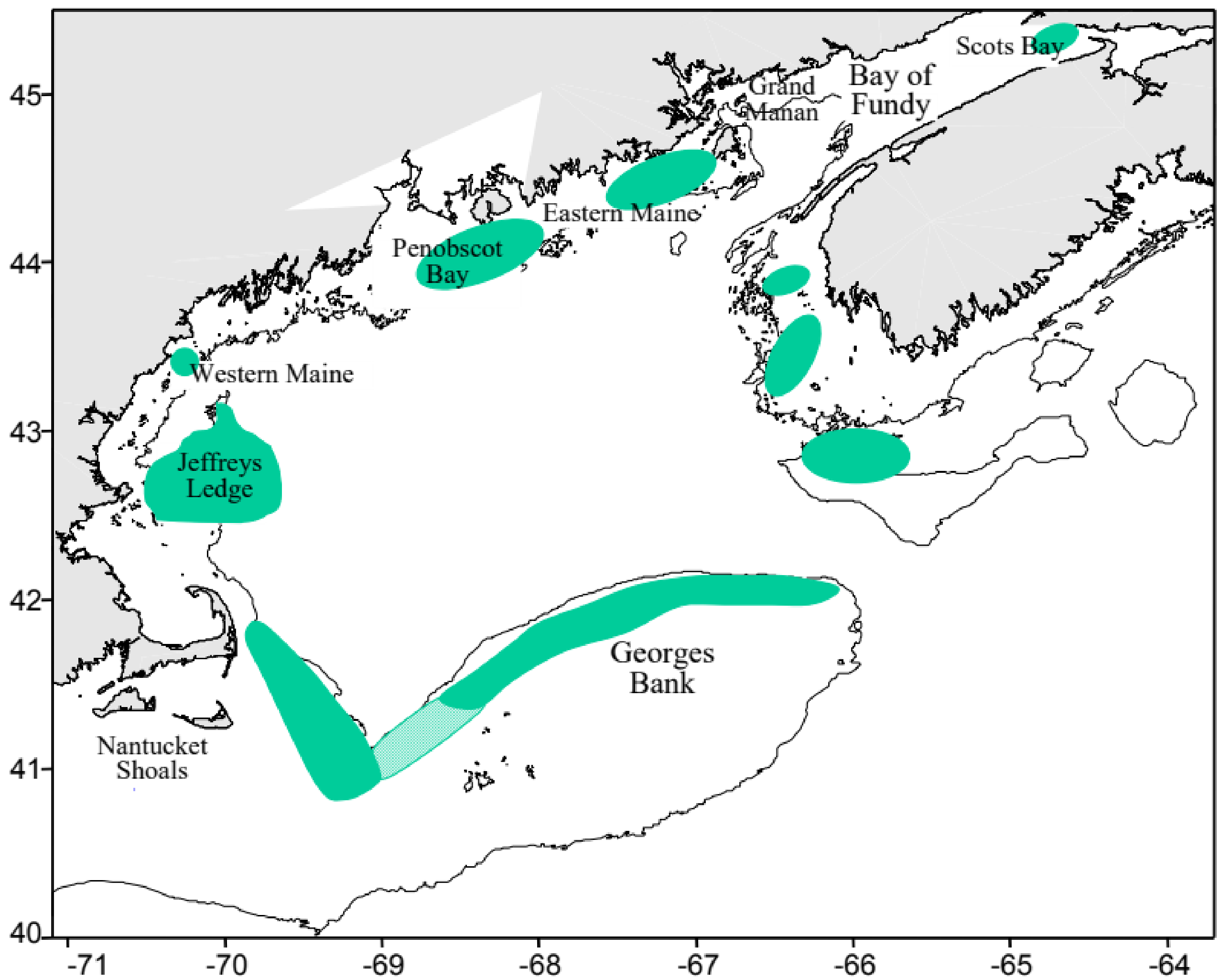

Figure 10. Generalized view of the current major herring spawning areas in the Gulf of Maine and on George Bank. From Overholtz et al. 2024

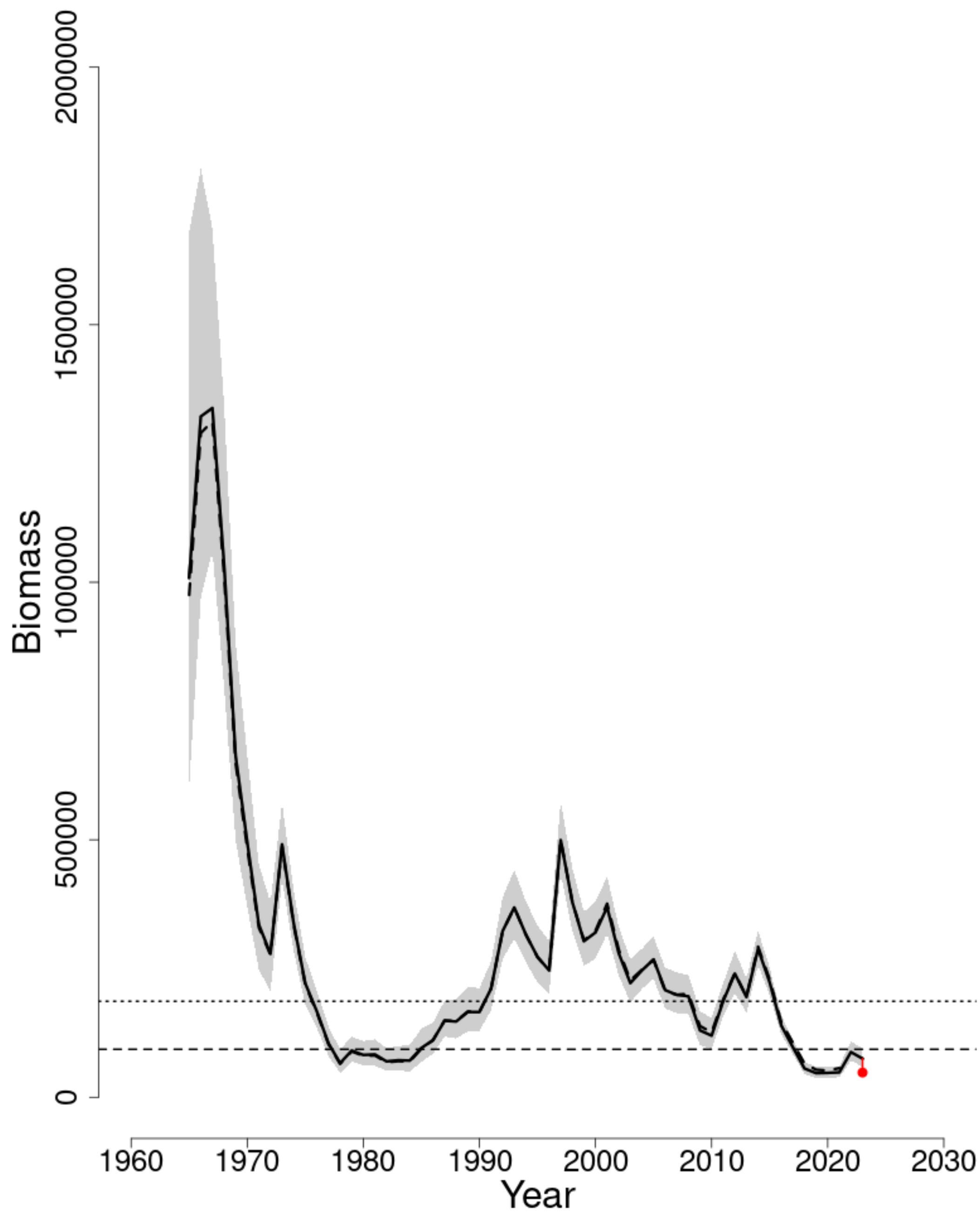

Figure 11. Trends in spawning stock biomass of Atlantic Herring between 1965 Trends in spawning stock biomass of Atlantic Herring between 1965 and 2023 from the current (solid line) and previous (dashed line) assessment and the corresponding $SSB_{Threshold}$ (1/2 $SSBMSY_{proxy}$; horizontal dashed line) as well as SSB_{Target} (SSBMSY proxy; horizontal dotted line) based on the 2024 assessment. The approximate 90% confidence intervals are shown. The red line and dot show the value from the 2024 assessment adjusted for the retrospective pattern. From NEFSC 2024.

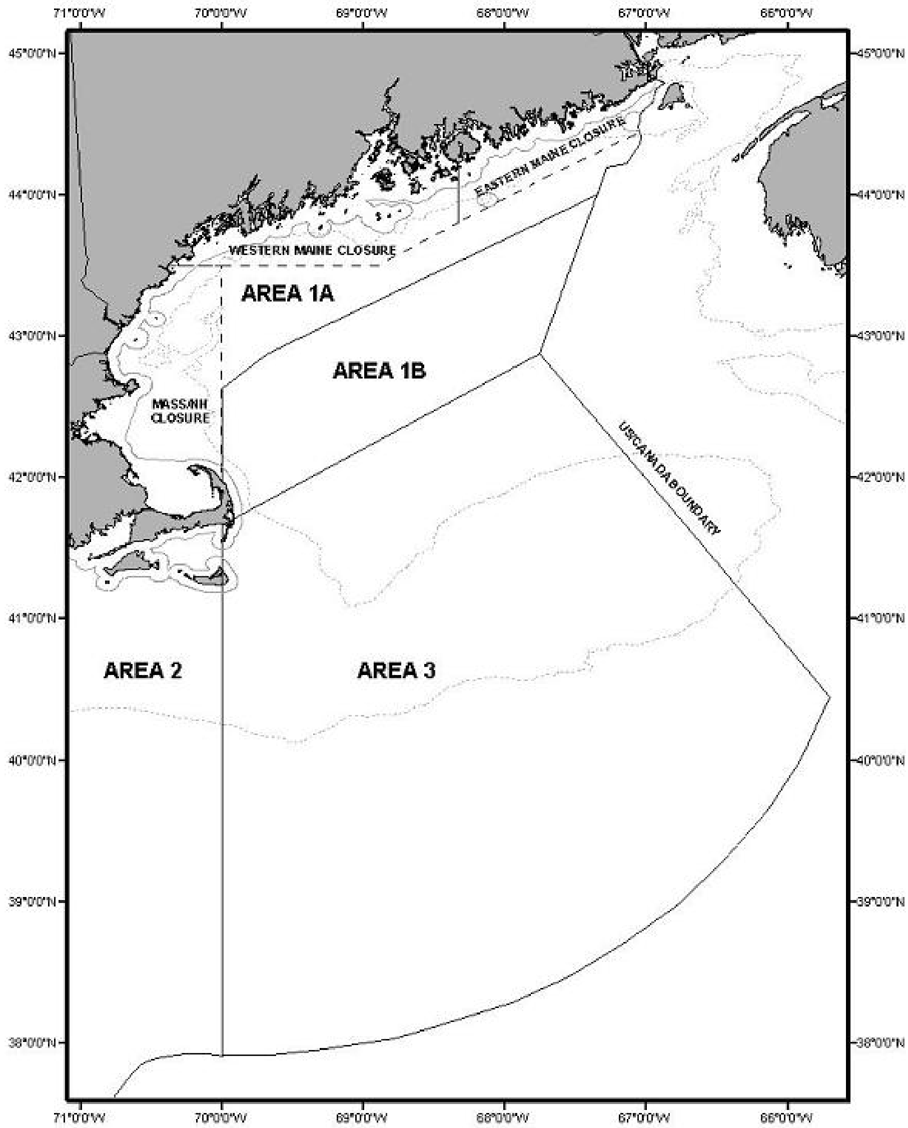

Figure 12. Atlantic herring fishery management areas including spawning closures. https://www.maine.gov/dmr/science/species-information/atlantic-herring-biology-and-research. **Note:** Area 2 extends further south to Cape Hatteras, North Carolina (not shown). See: https://www.fisheries.noaa.gov/resource/map/herring-management-areas

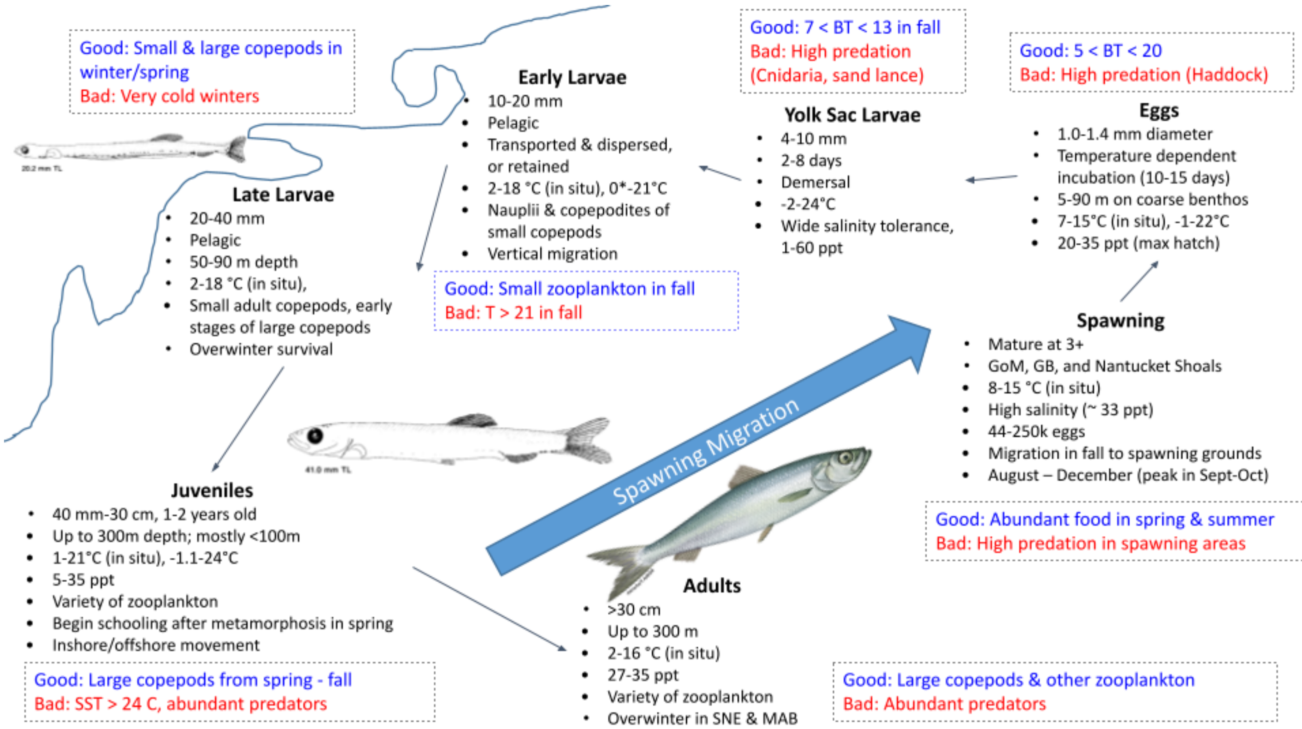

Figure 13. Atlantic herring conceptual model.

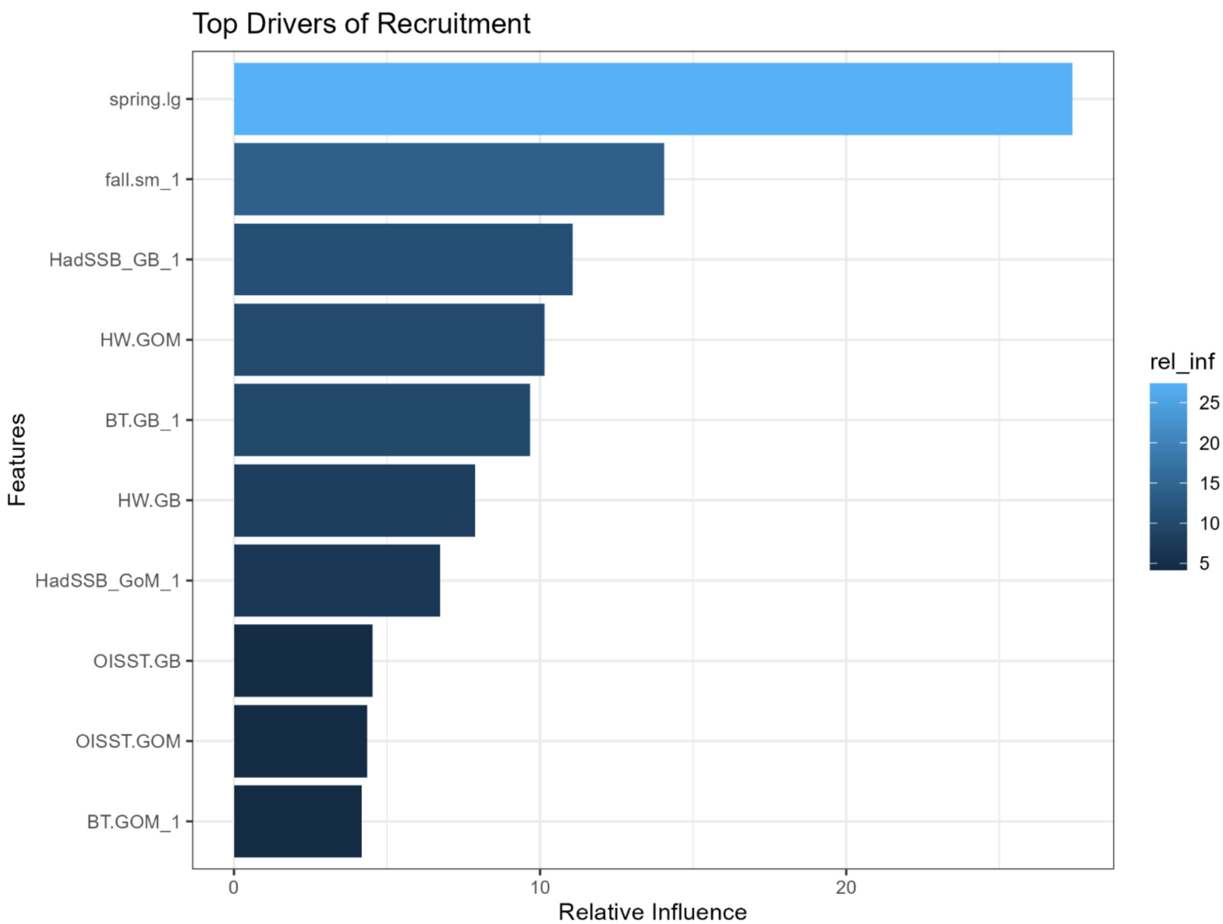

Figure 14. Relative influence of different climate and ecosystem drivers on Atlantic herring recruitment. Drivers: unlagged spring large copepods (spring_lg), lag 1 fall small copepods (fall.sm_1), lag 1 haddock spawning stock biomass on Georges Bank (HadSSB_GB_1), sea surface temperature on Georges Bank (OISST.GB), sea surface temperature Gulf of Maine (OISST.GOM), and lag 1 bottom temperature in the Gulf of Maine (BT.GOM_1).

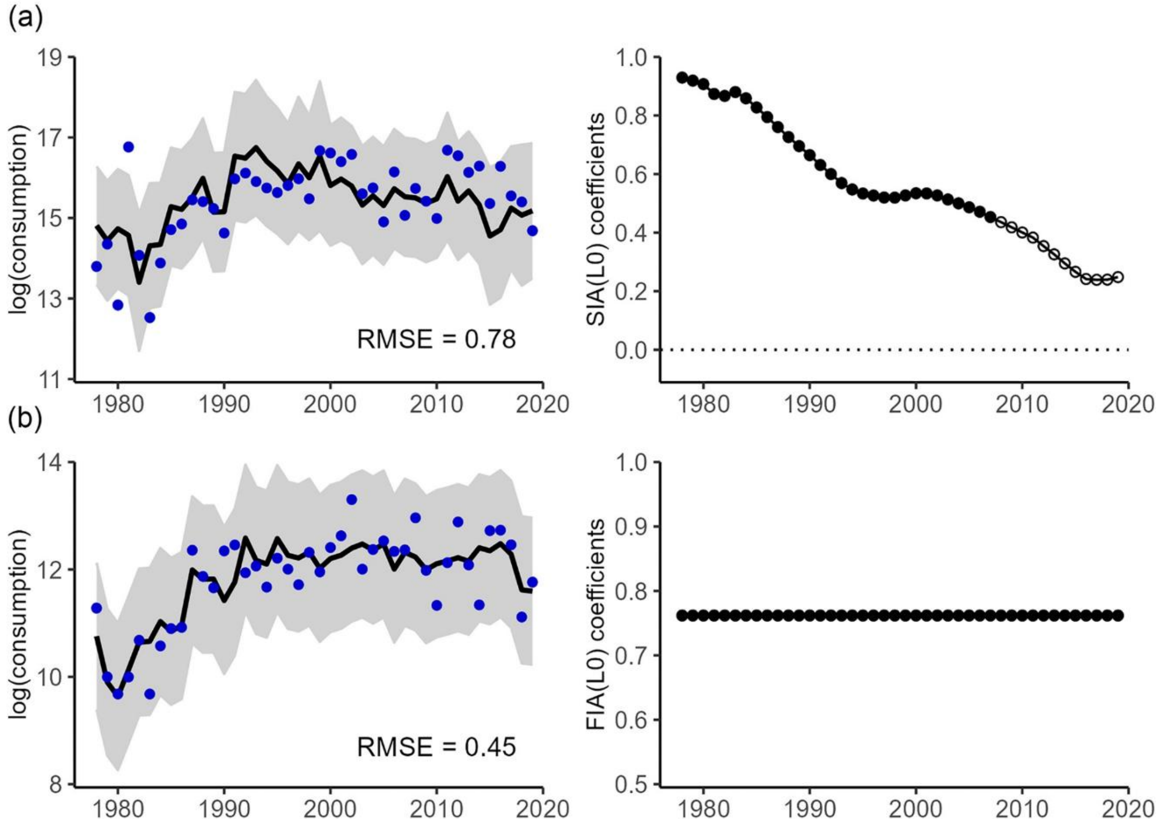

Figure 15. Figure 4 from Gartland and Latour 2024. "DLM fits (left panels, lines) and 95% prediction intervals (shading) from relating (a) the spring time-series of Atlantic herring consumption (points) to the spring index of relative abundance for this species at lag-0 (SIA, L0) and (b) the fall time-series of consumption (points) to the fall index of relative abundance at lag-0 (FIA, L0). RMSE of the model fits is given for each season. The right panels provide the associated time-series of coefficient estimates for SIA, L0 and FIA, L0 (a. spring; b. fall). Closed circles represent years in which the 95% CI of these estimates did not overlap zero. Model fits and parameter estimates are provided only for the most supported (ΔAICc = 0) DLM from each season."

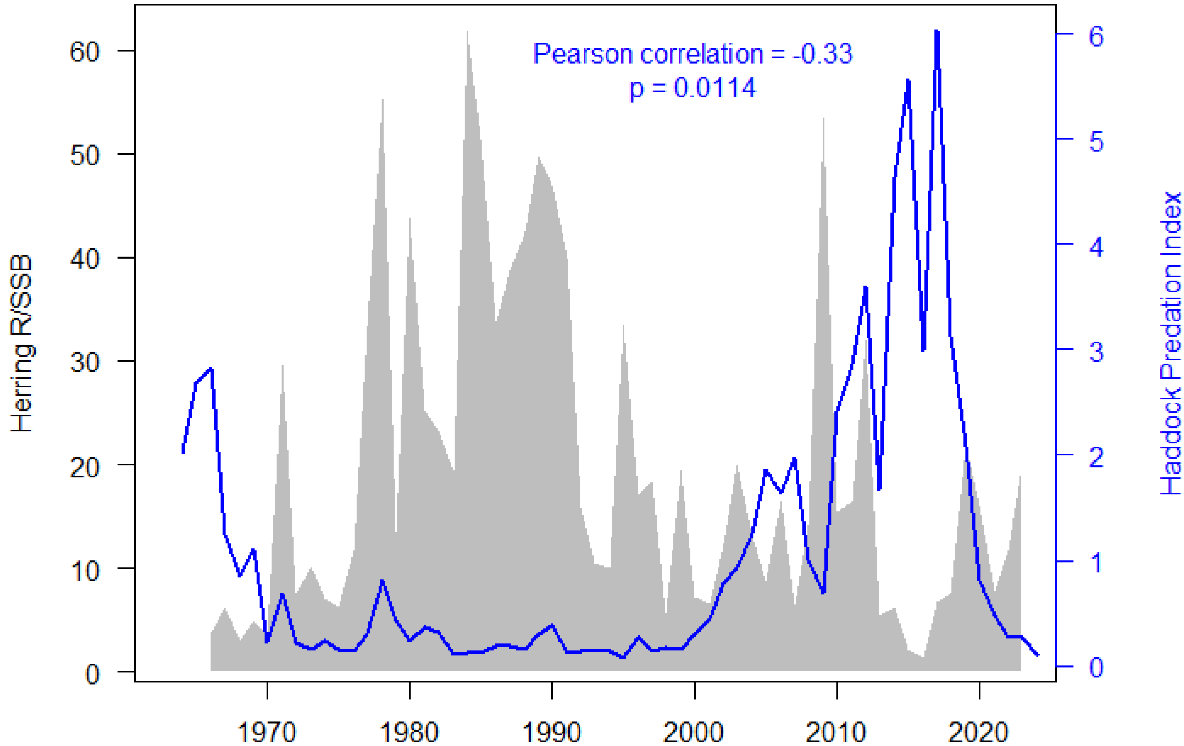

Figure 16. Correlation between the haddock predation index (blue line) and herring recruit-per-spawner (grey region) from the 2022 assessment model (updated with data through 2023).

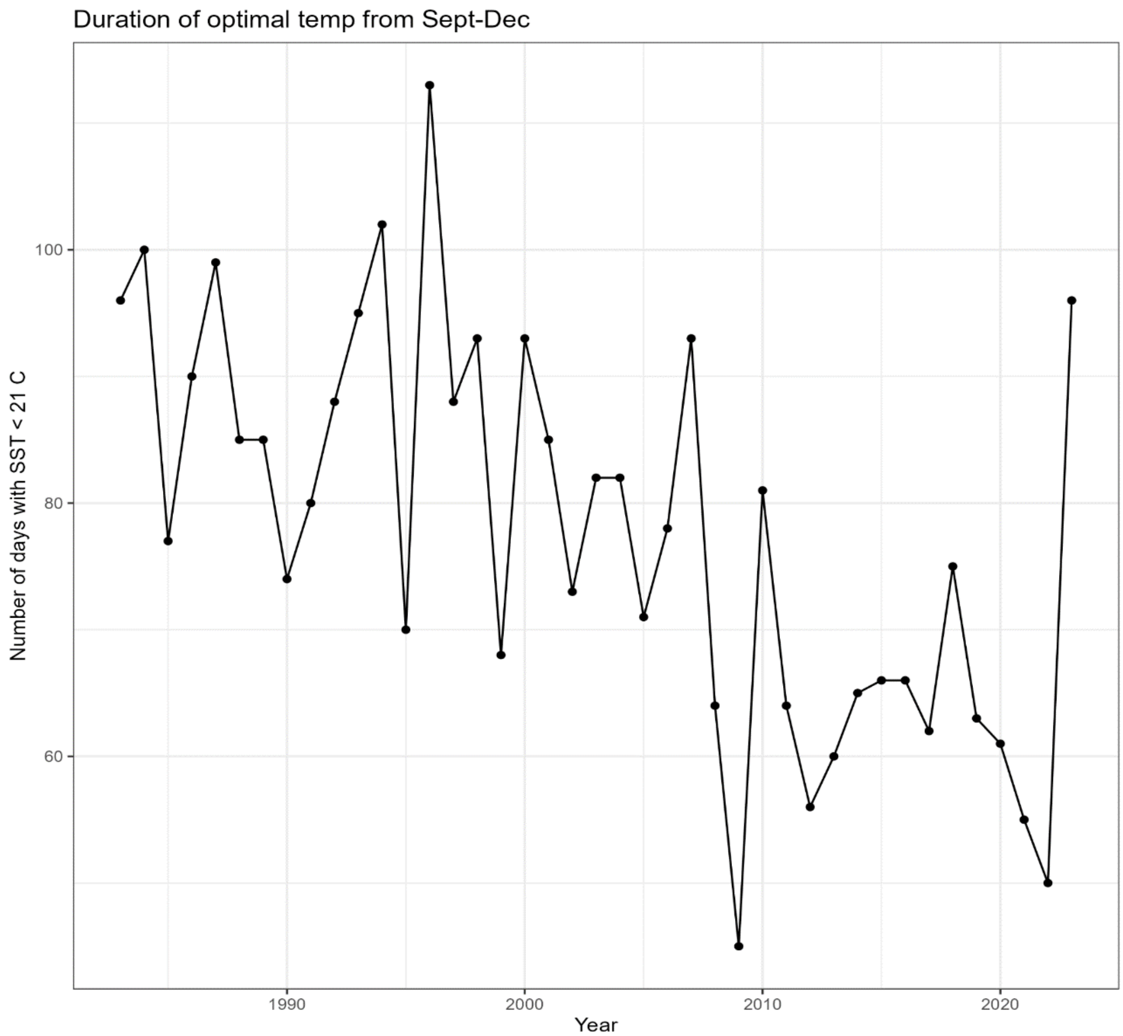

Figure 17. Duration of optimal thermal window for herring larvae in the fall (September-December). This is the number of days where none of the sea surface temperature grid cells in the fall NEFSC herring strata are greater than the lethal threshold of 21 C. Duration of optimal temperature has been decreasing over time.

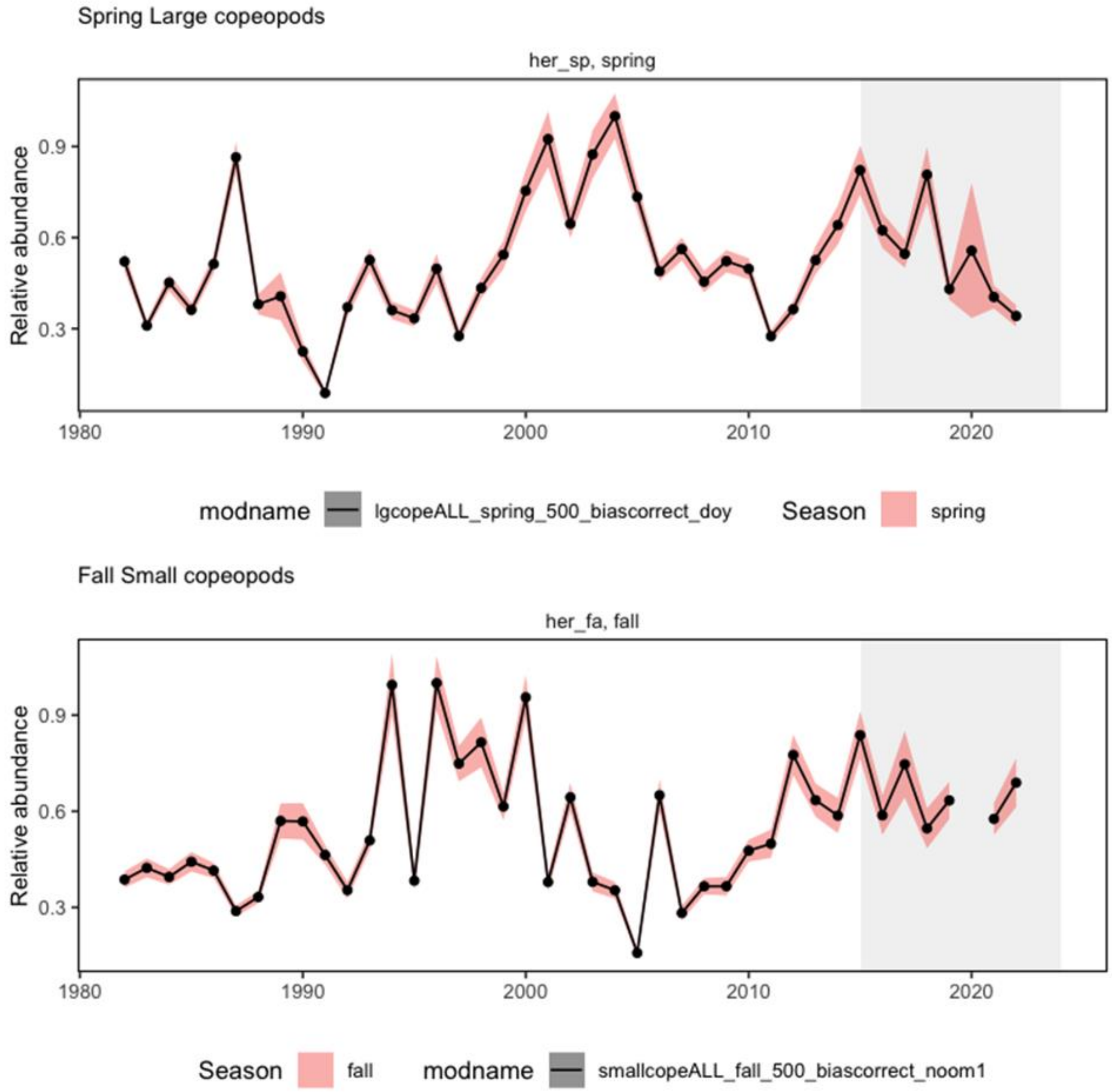

Figure 18. VAST-derived copepod indices, 1982-2022. Top panel: Spring (January-June) large copepods in spring Atlantic herring bottom trawl survey strata. Bottom panel: Fall (July-December) small copepods in fall Atlantic herring bottom trawl survey strata.

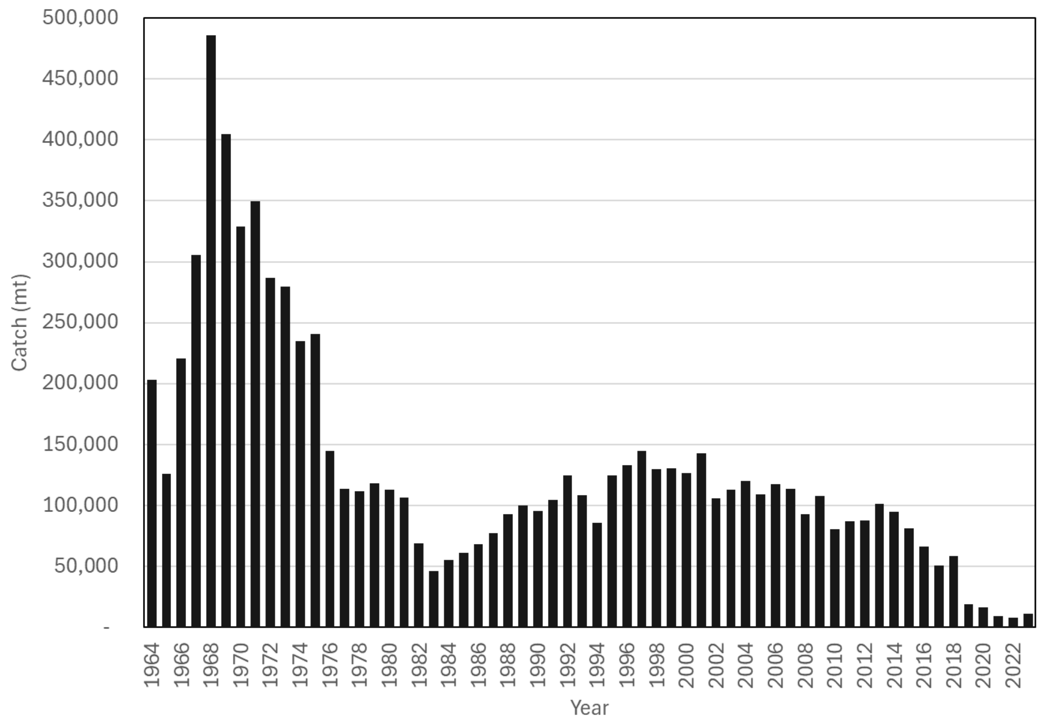

Figure 19. Atlantic herring catch by year: 1964 to 2023.

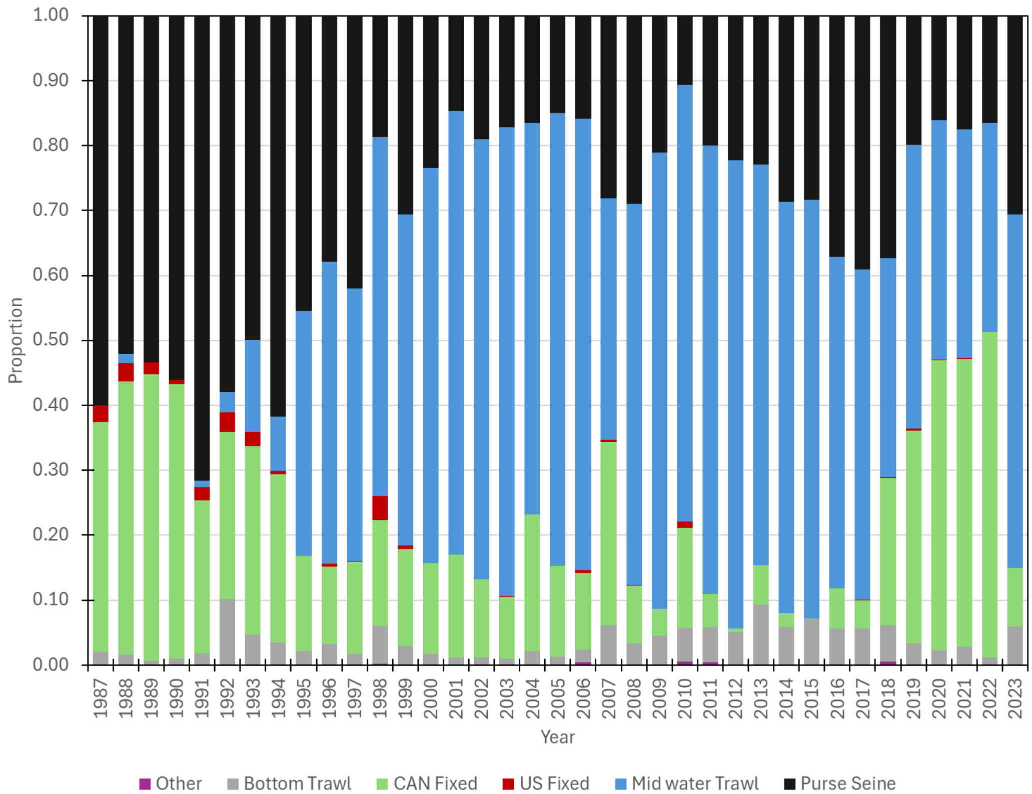

Figure 20. Atlantic herring catch by gear type as a proportion of the total catch.

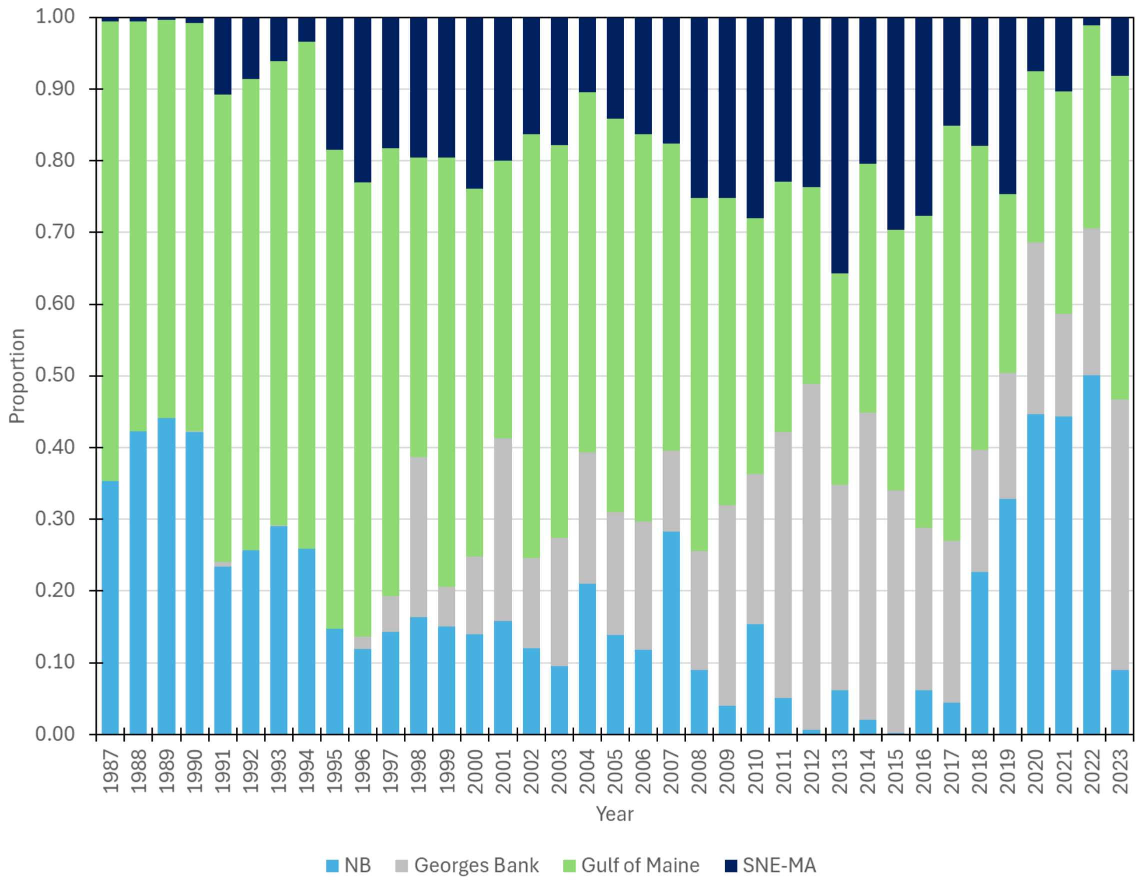

Figure 21. Atlantic herring catch by region as a proportion of the total catch.

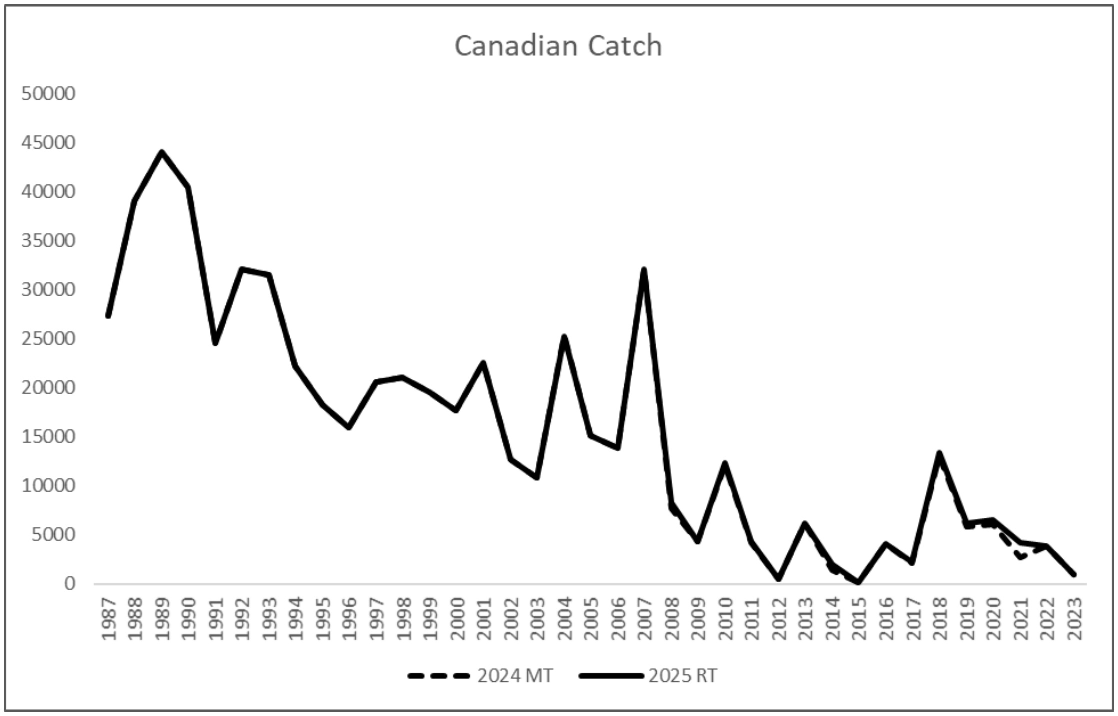

Figure 22. Canadian Catch 1987-2023.

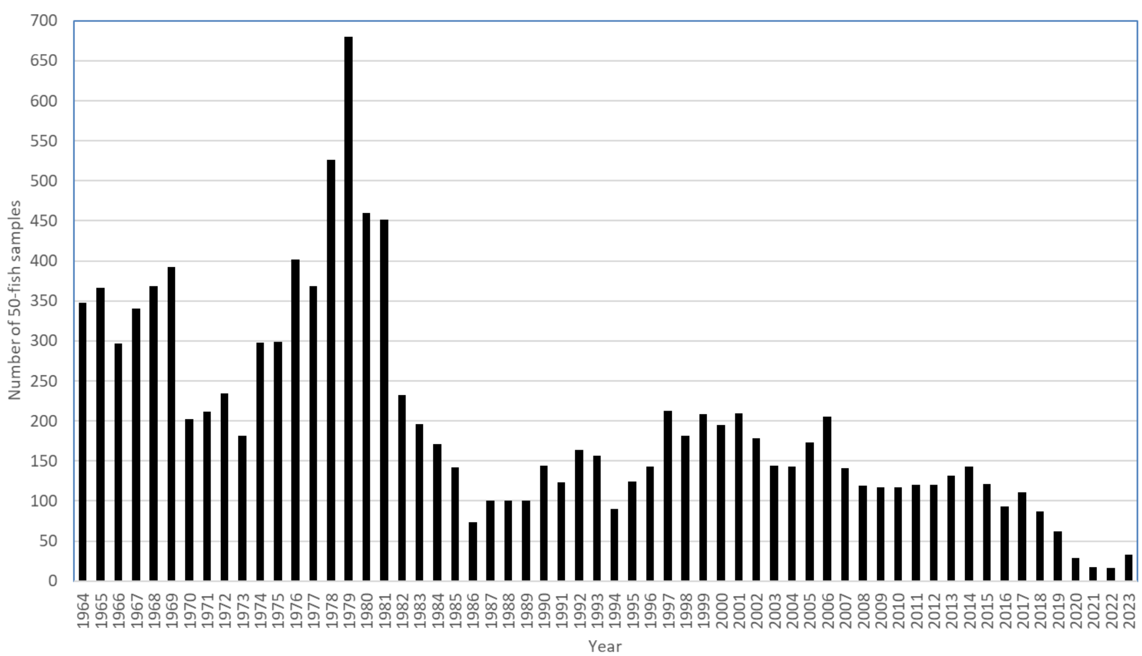

Figure 23. Number of 50-fish samples taken as part of the biological sampling program.

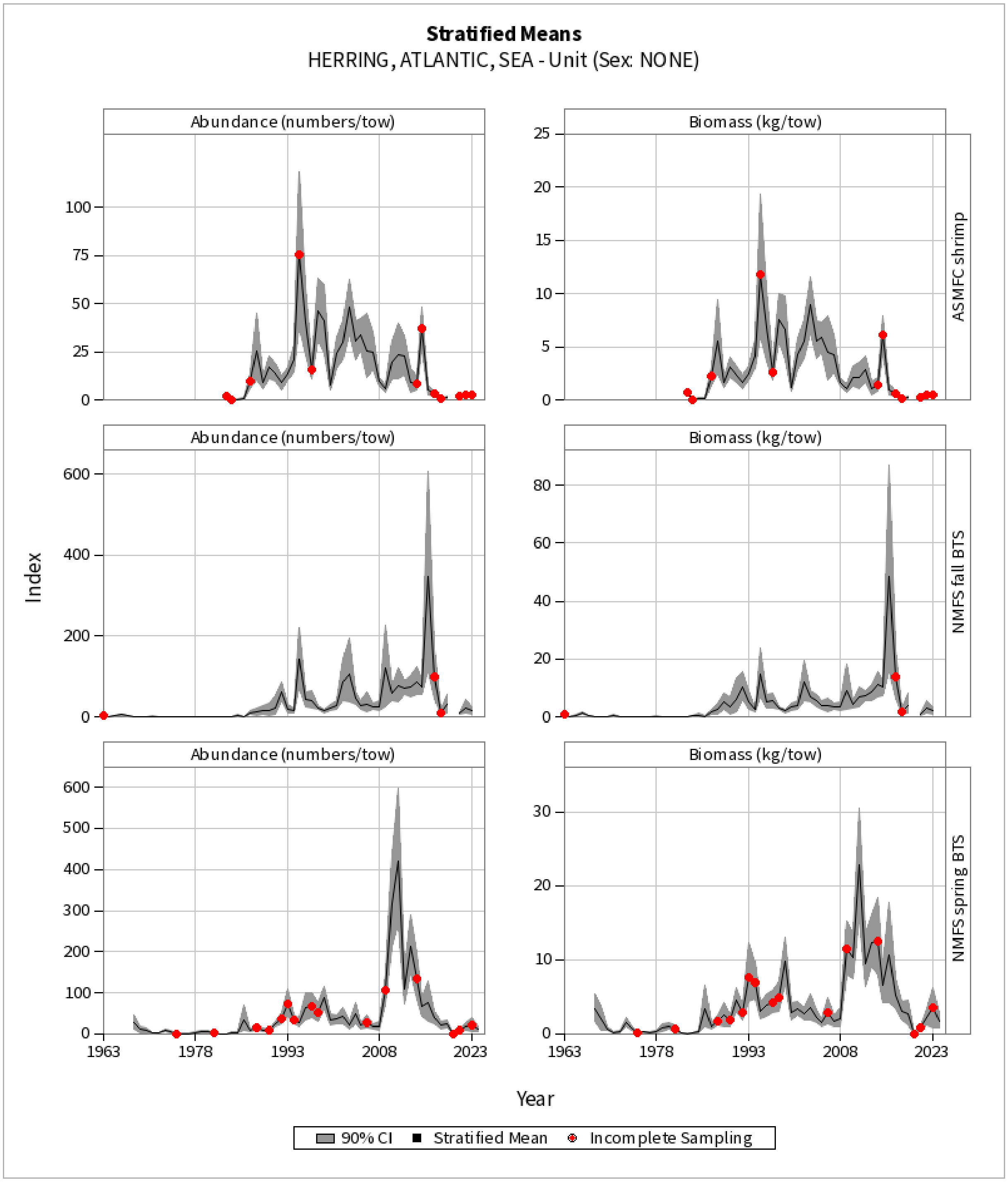

Figure 24. Stratified mean indices from NMFS bottom trawl surveys. The assessment uses numbers per tow.

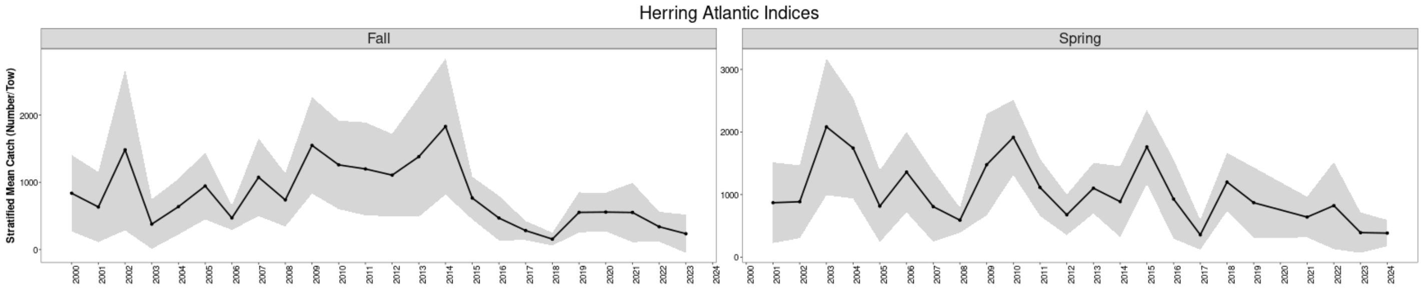

Figure 25. Spring and Fall ME-NH survey catch in Number. Shaded area 95% confidence.

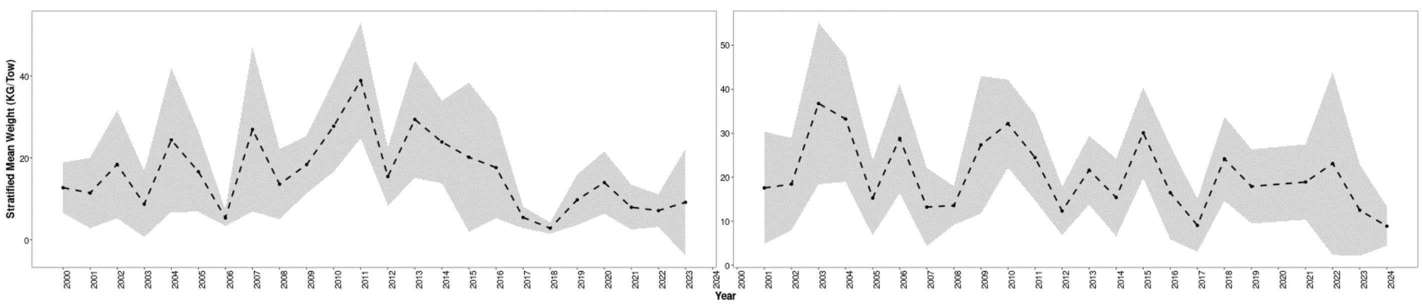

Figure 26. Spring and Fall ME-NH survey catch in weight. Shaded area 95% confidence.

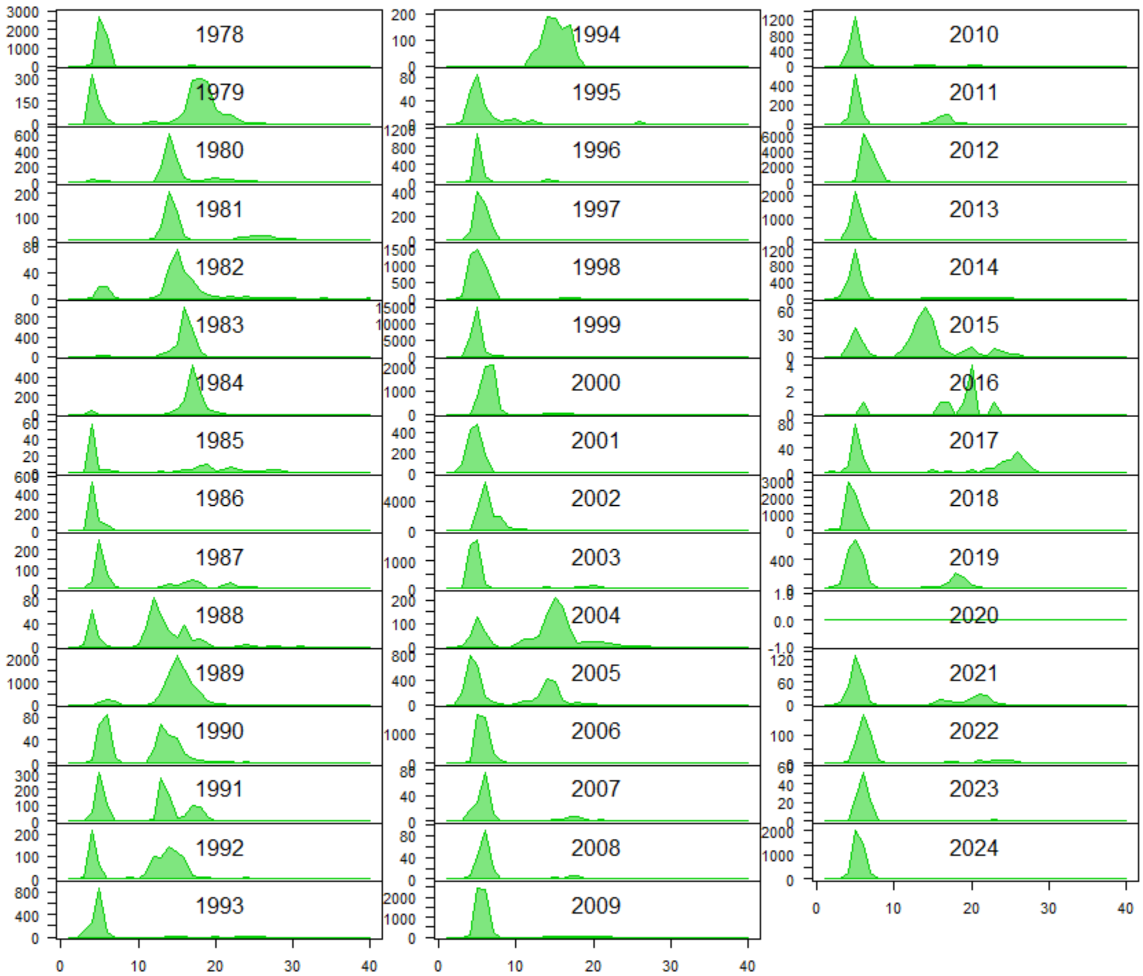

Figure 27. Length distribution of Atlantic herring catch from the Spring MADMF inshore trawl survey.

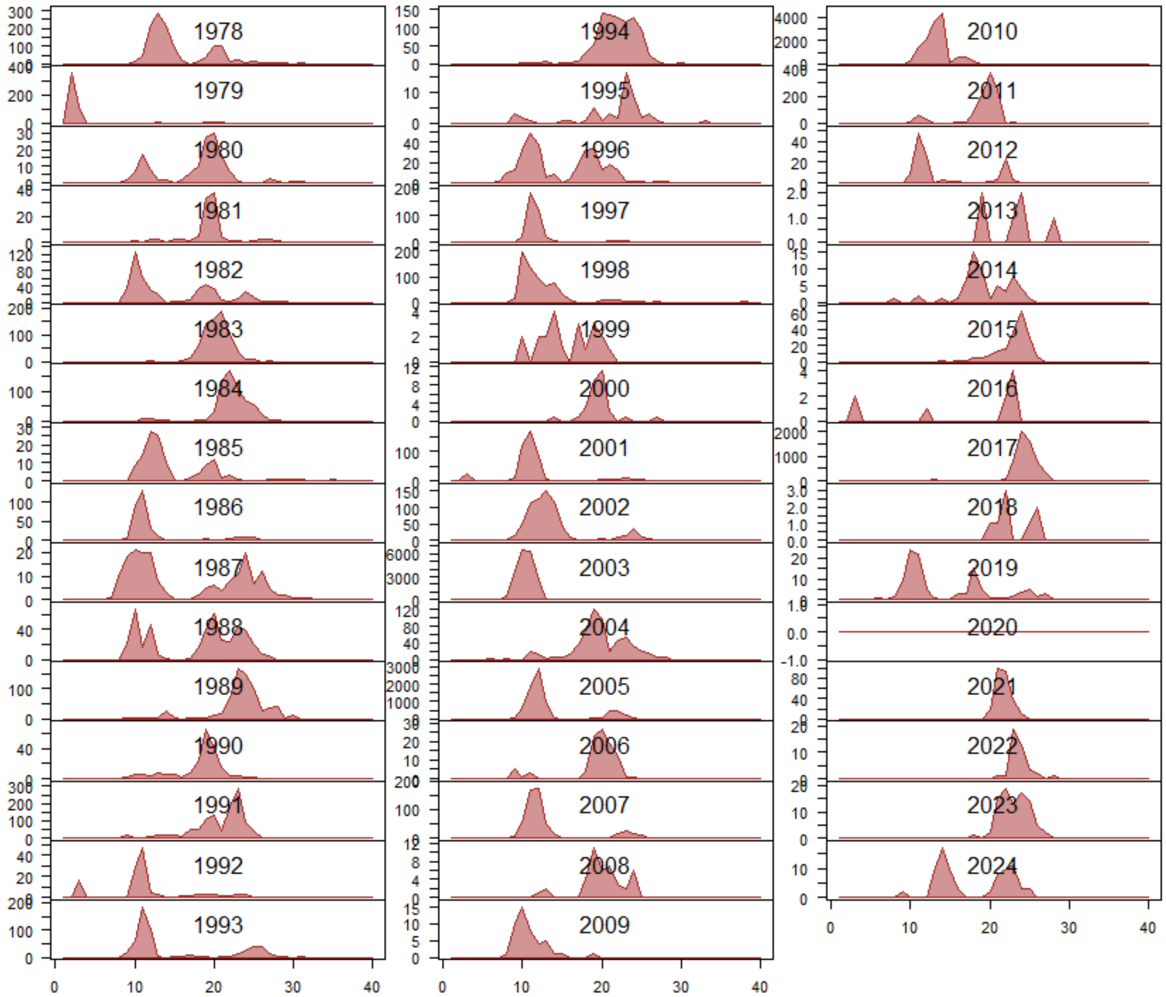

Figure 28. Length distribution of Atlantic herring catch from the Fall MADMF inshore trawl survey.

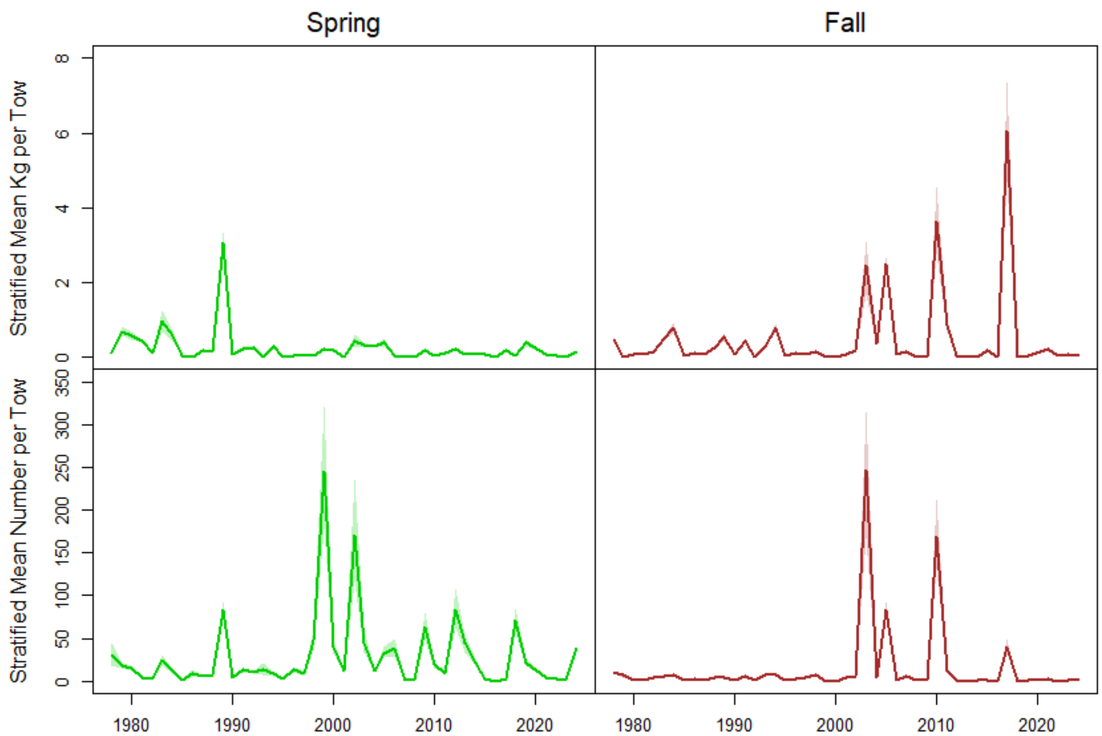

Figure 29. Stratified mean herring catch per tow in numbers (bottom) and Kg (top) for the spring (left) and fall (right) MADMF inshore trawl survey.

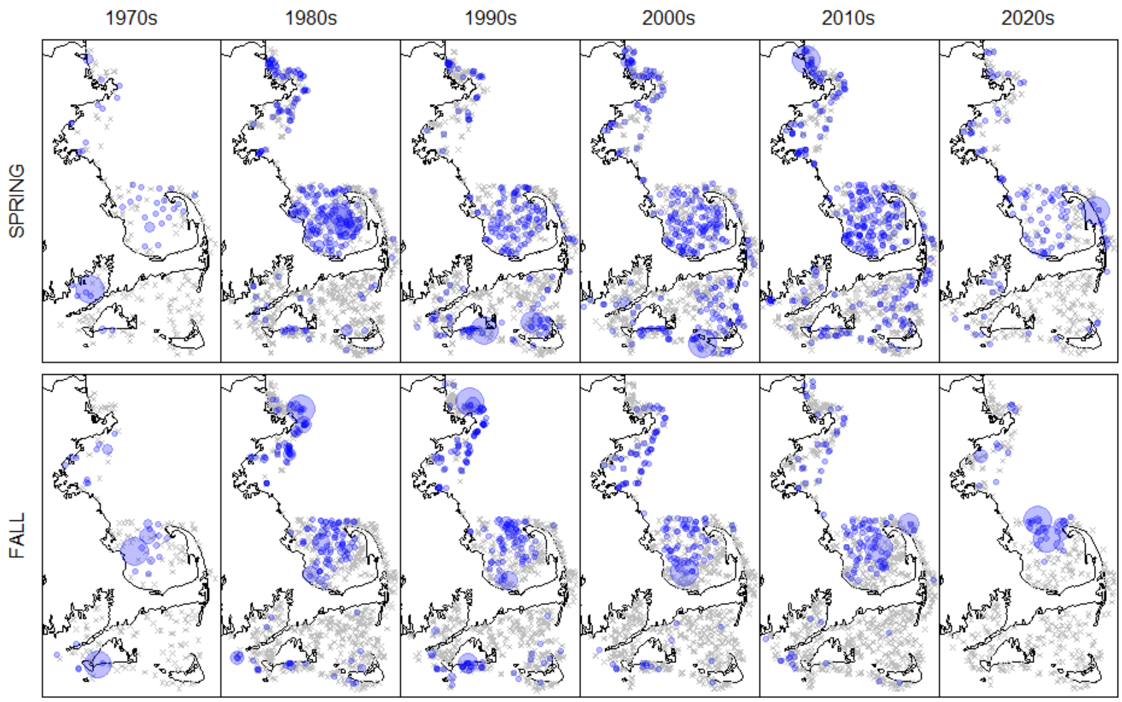

Figure 30. Spatial distribution of herring catch by decade and season from the MADMF inshore trawl survey.

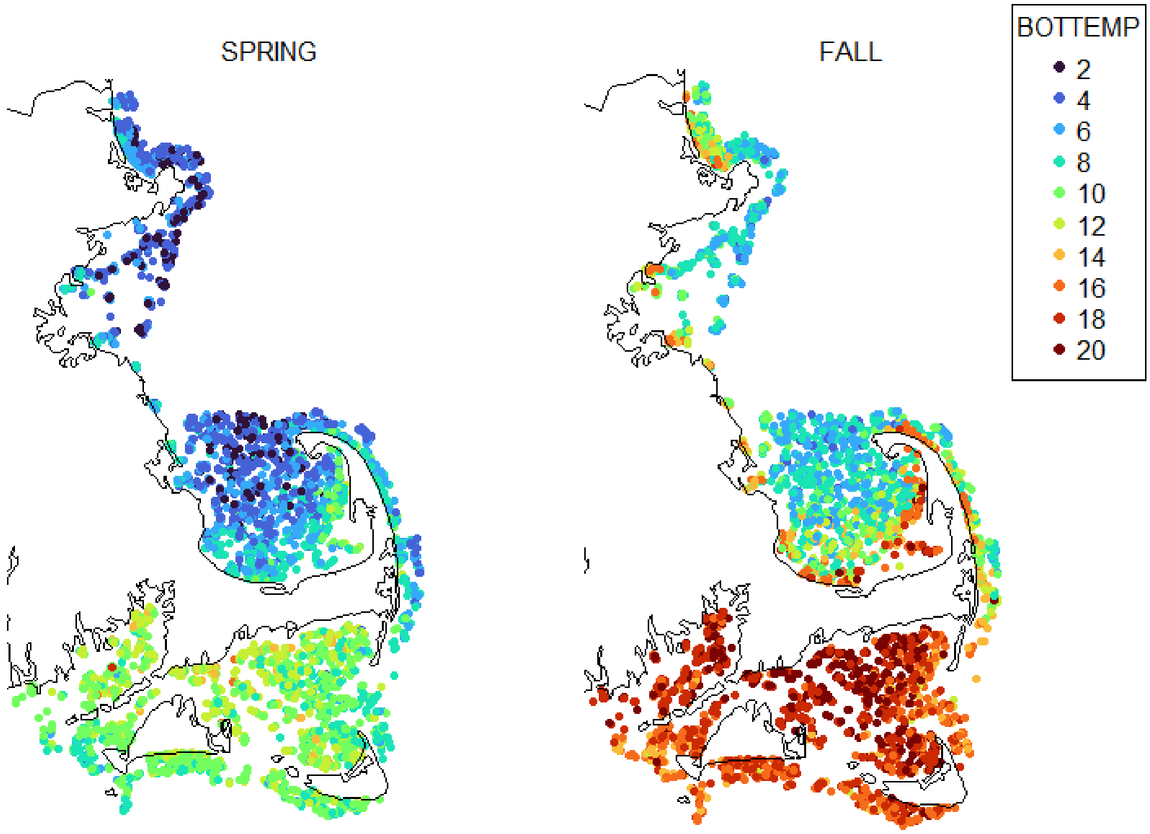

Figure 31. Spatial distribution of bottom temperature in the MADMF inshore trawl survey.

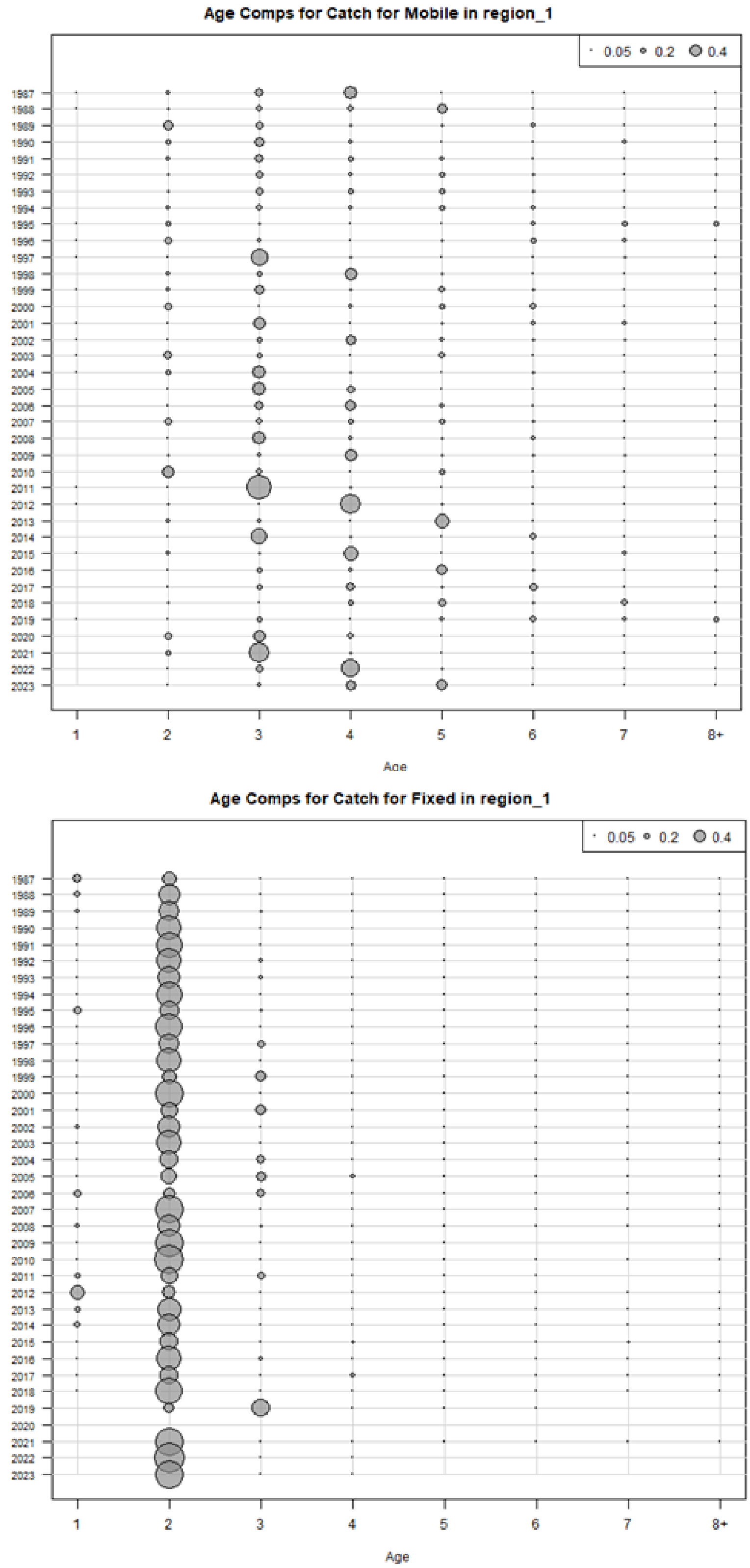

Figure 32. Age compositions by fleet. Top Mobile, Bottom Fixed.

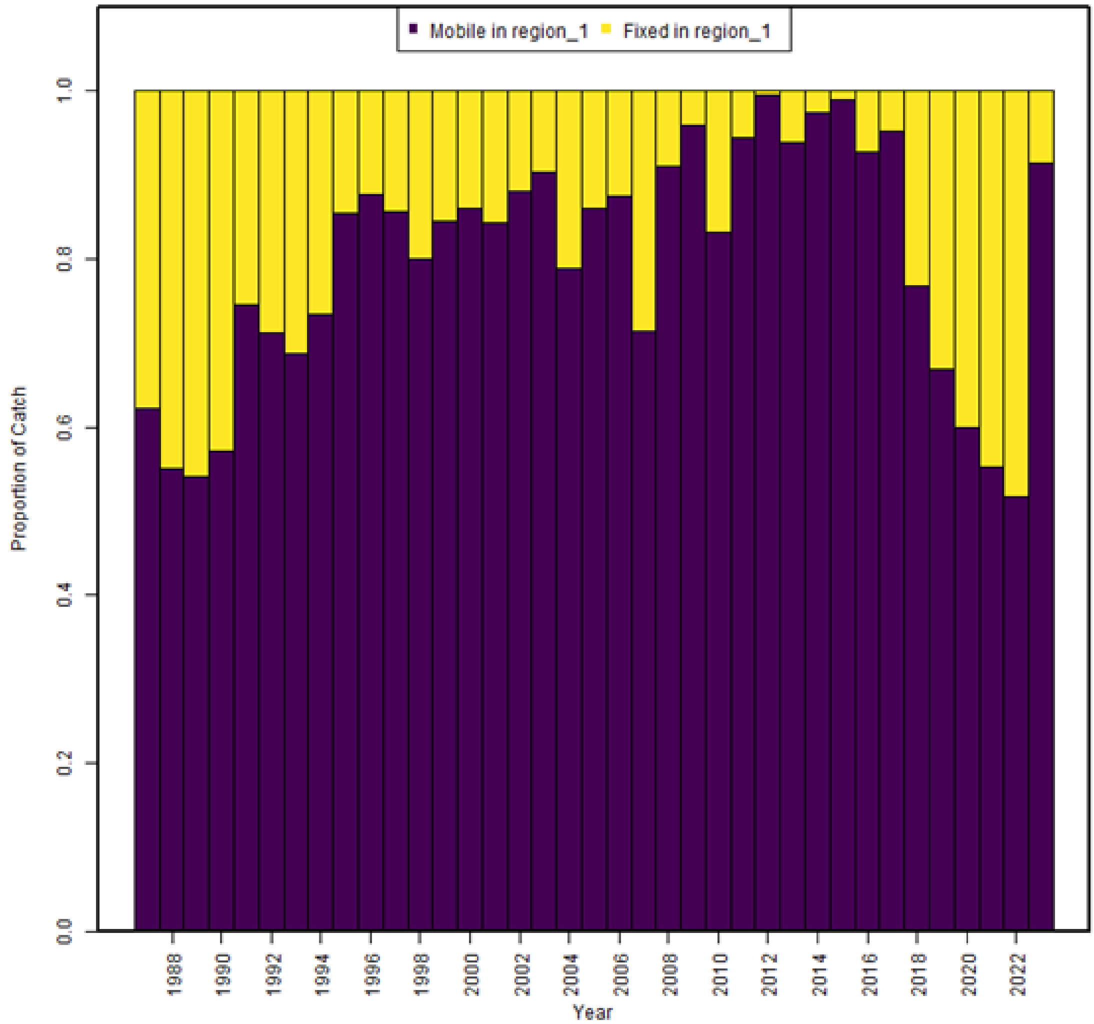

Figure 33. Proportion of catch by Mobile and Fixed Gear fleets.

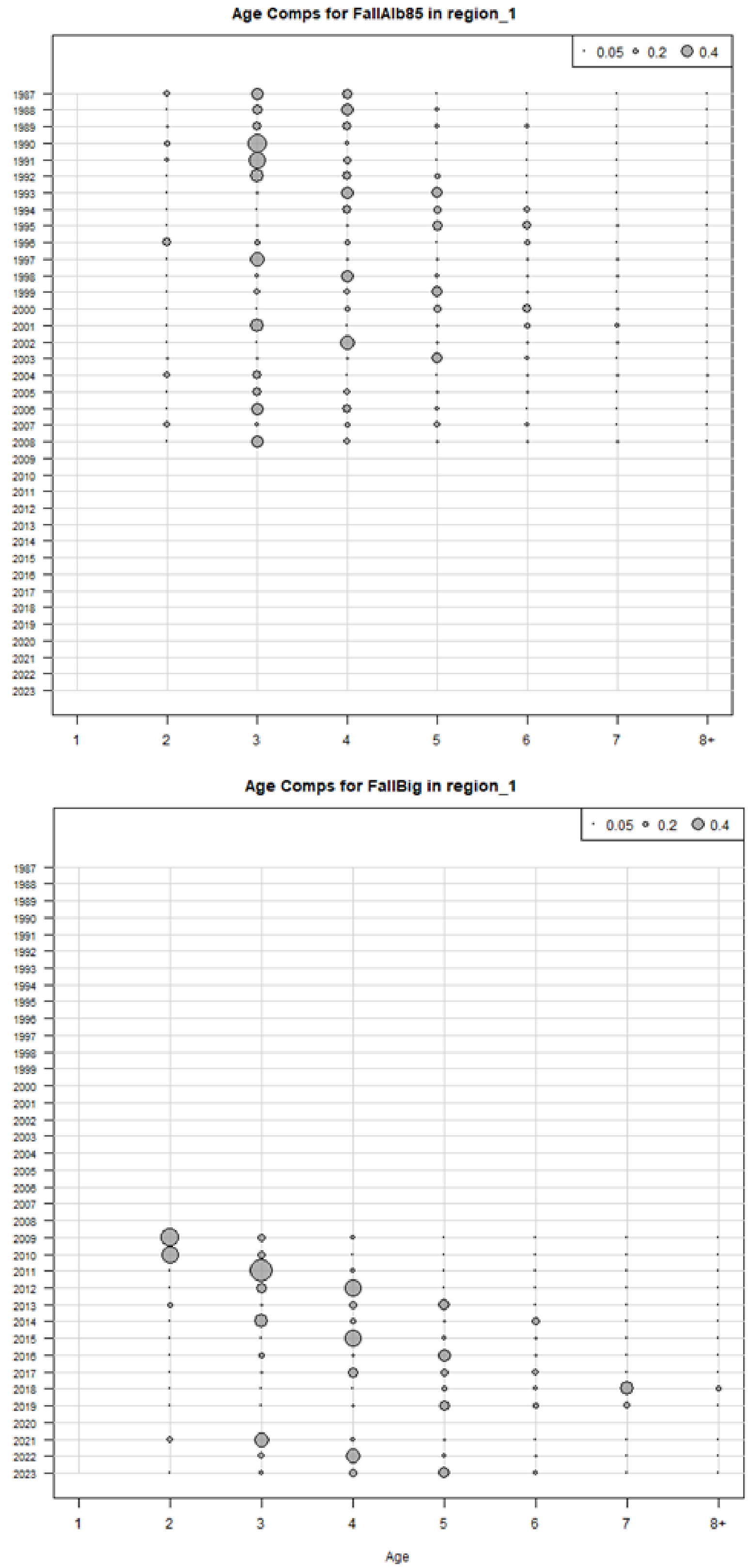

Figure 34. Age composition by survey in the Fall. Top Albatross, bottom Bigelow.

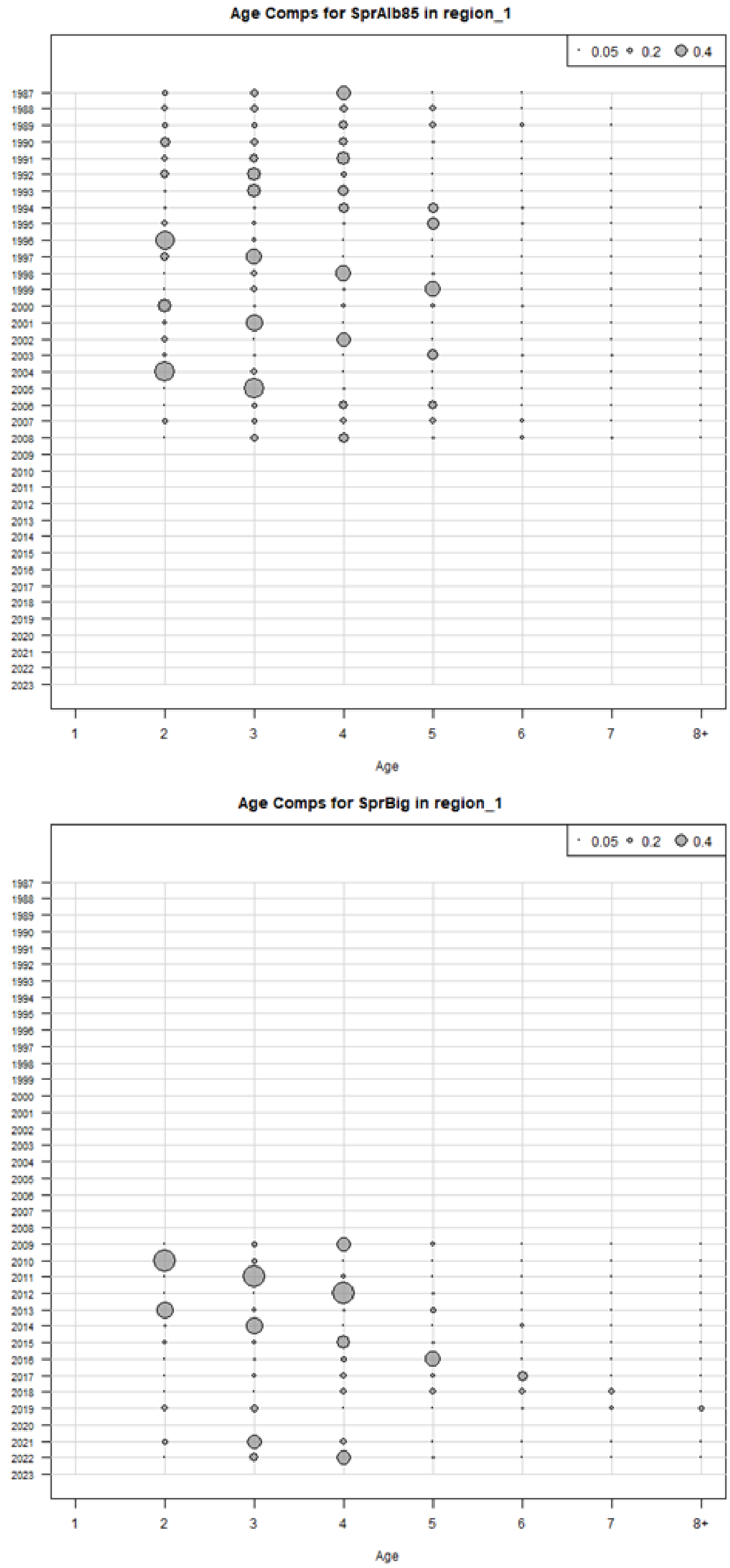

Figure 35. Age composition by survey in the Spring. Top Albatross, bottom Bigelow.

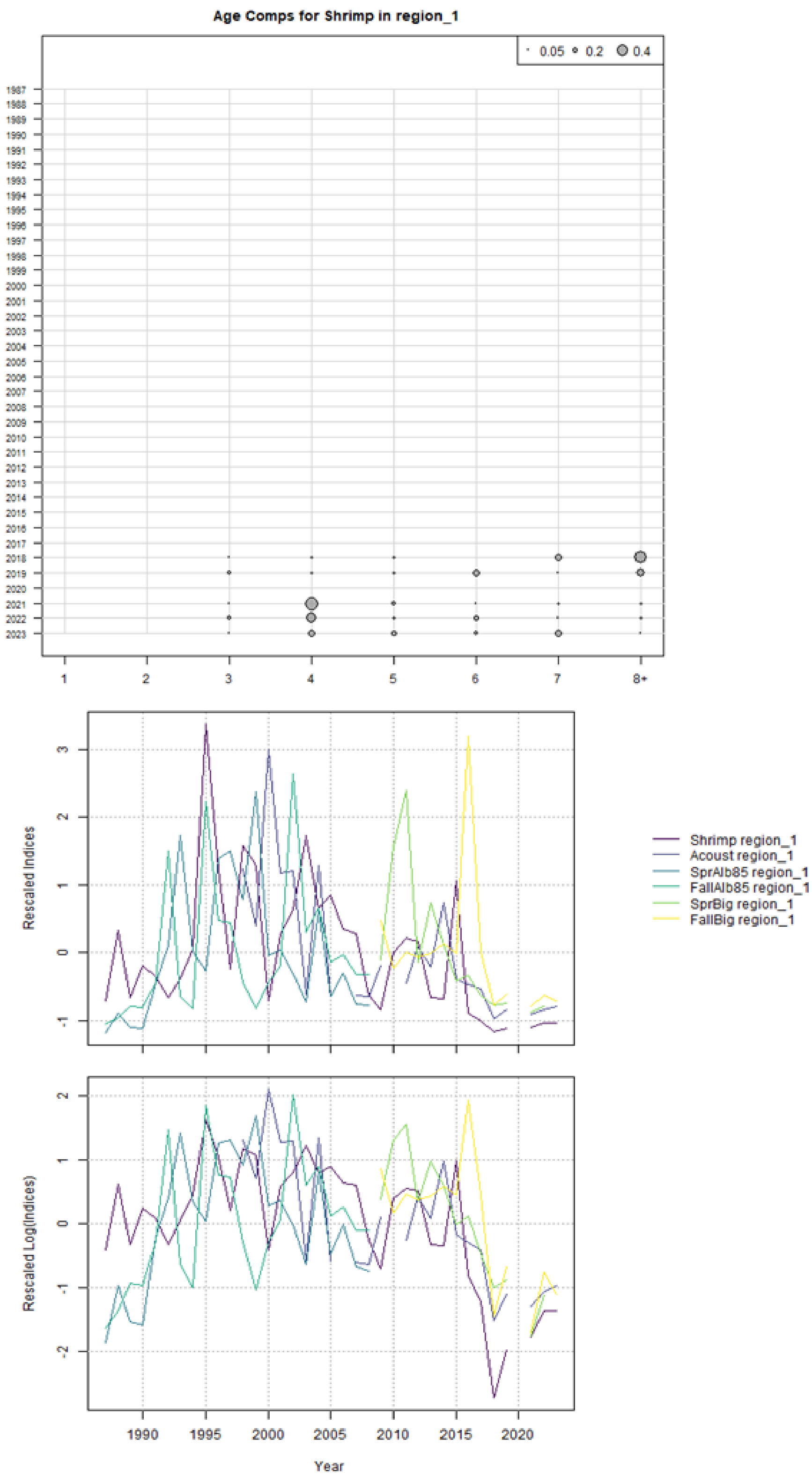

Figure 36. NMFS summer (Shrimp) survey age composition (top). Indices of abundance nominal (middle) and log scaled (bottom).

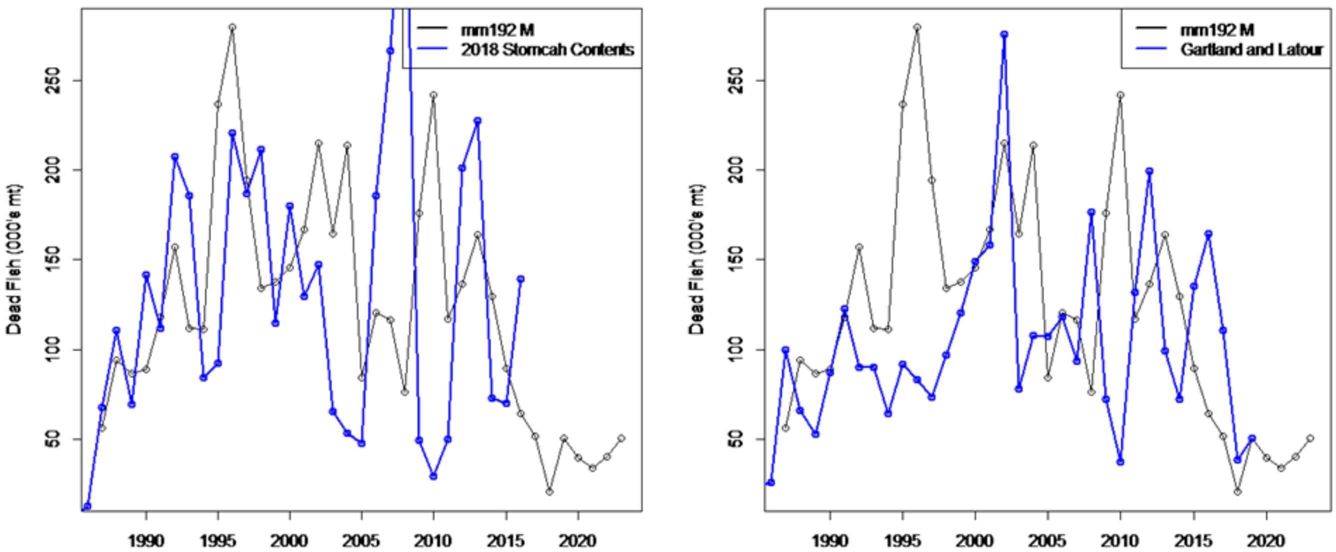

Figure 37. Number of dead herring implied by use of an M of 0.35 compared to estimates using stomach contents of predators (left) and estimates from Gartland and Latour 2024 (right).

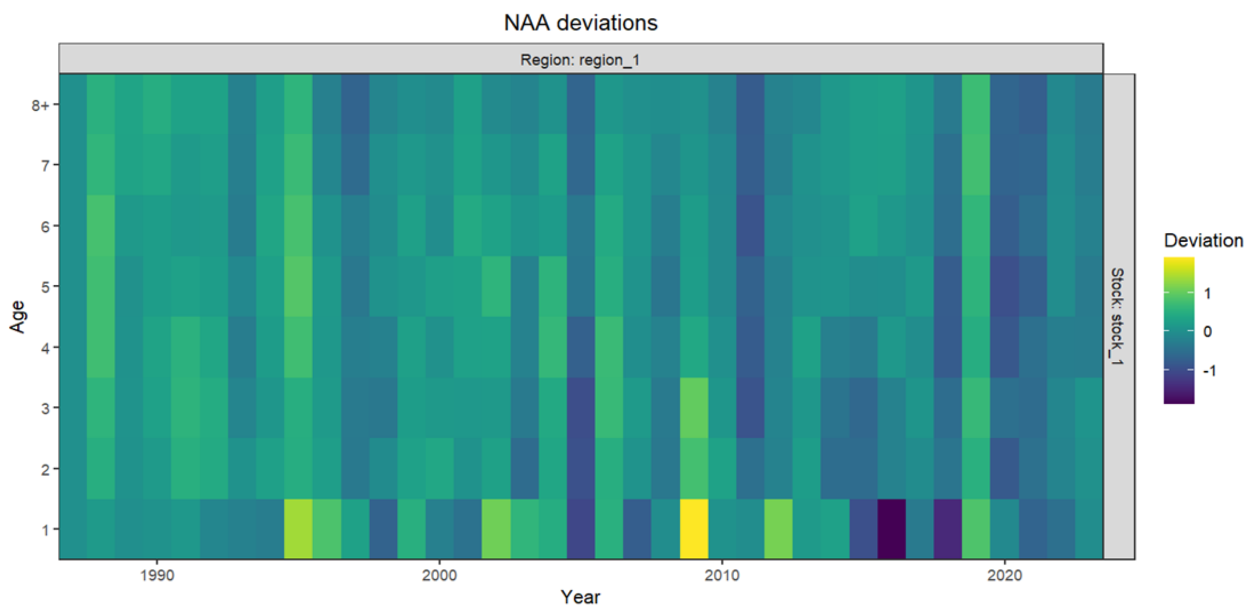

Figure 38. NAA deviations by year and age.

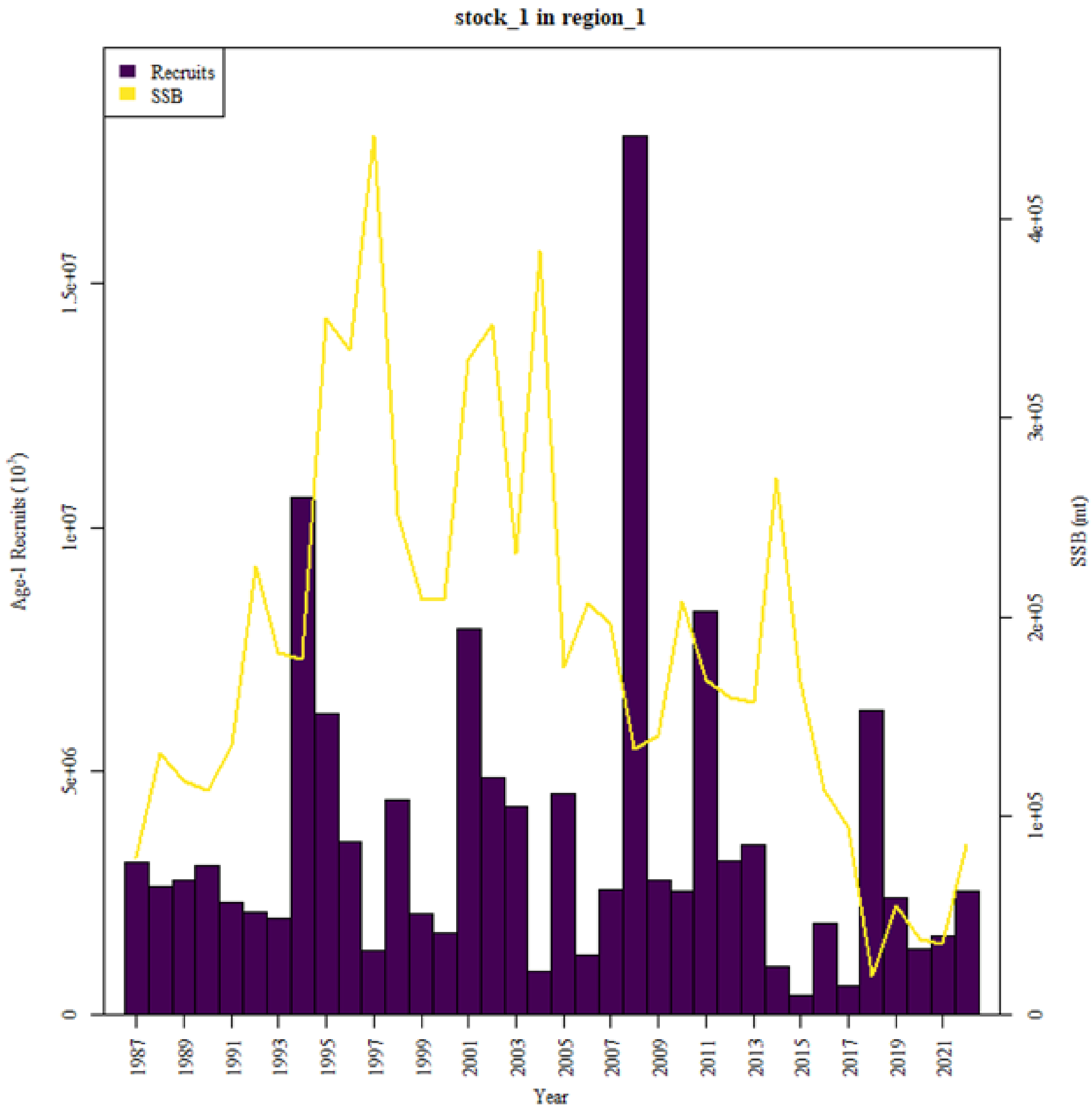

Figure 39. Recruitment (bars) and SSB (line) by year. Note scale change.

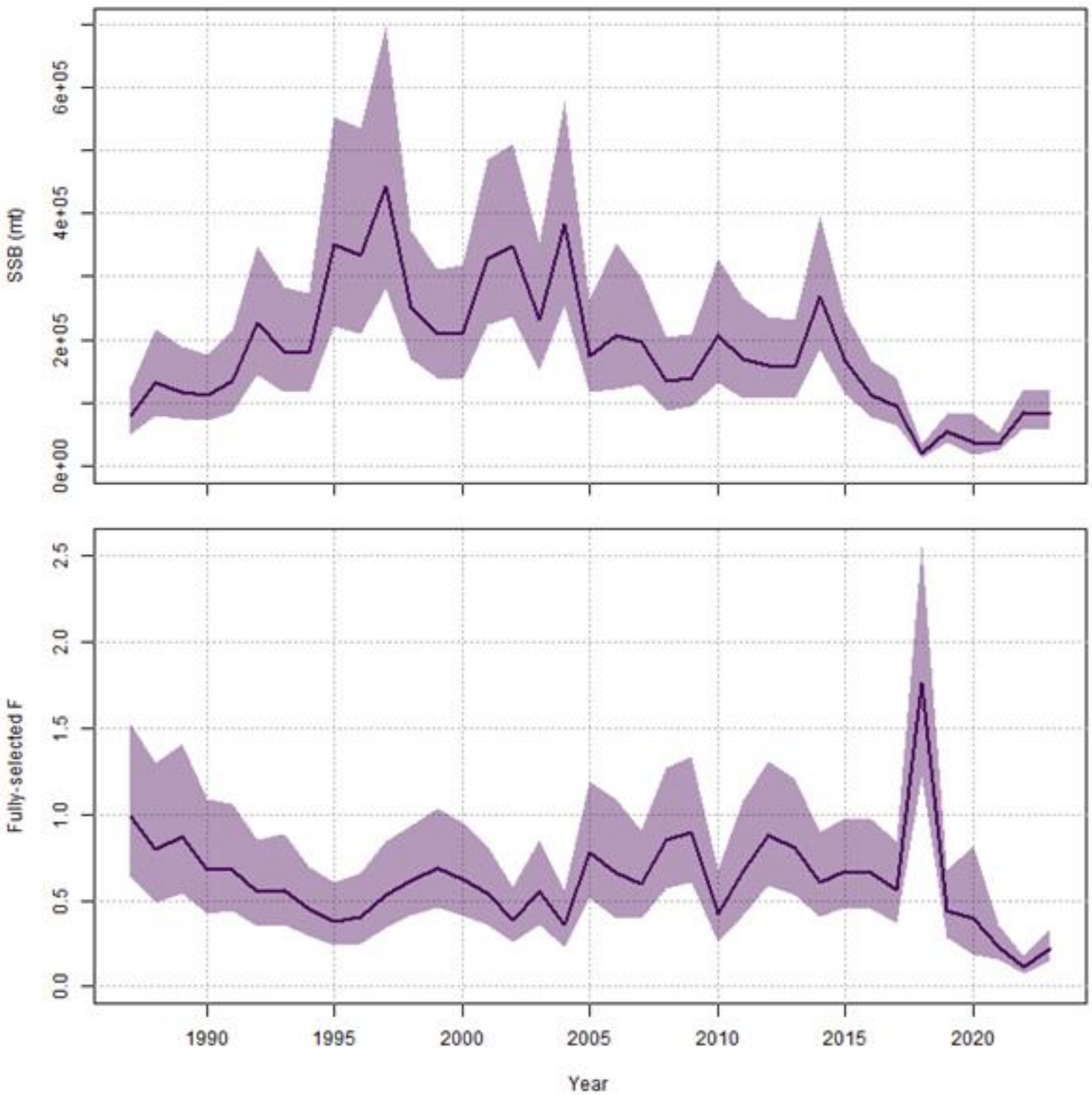

Figure 40. SSB (top) and F (bottom) by year with 95% confidence limits.

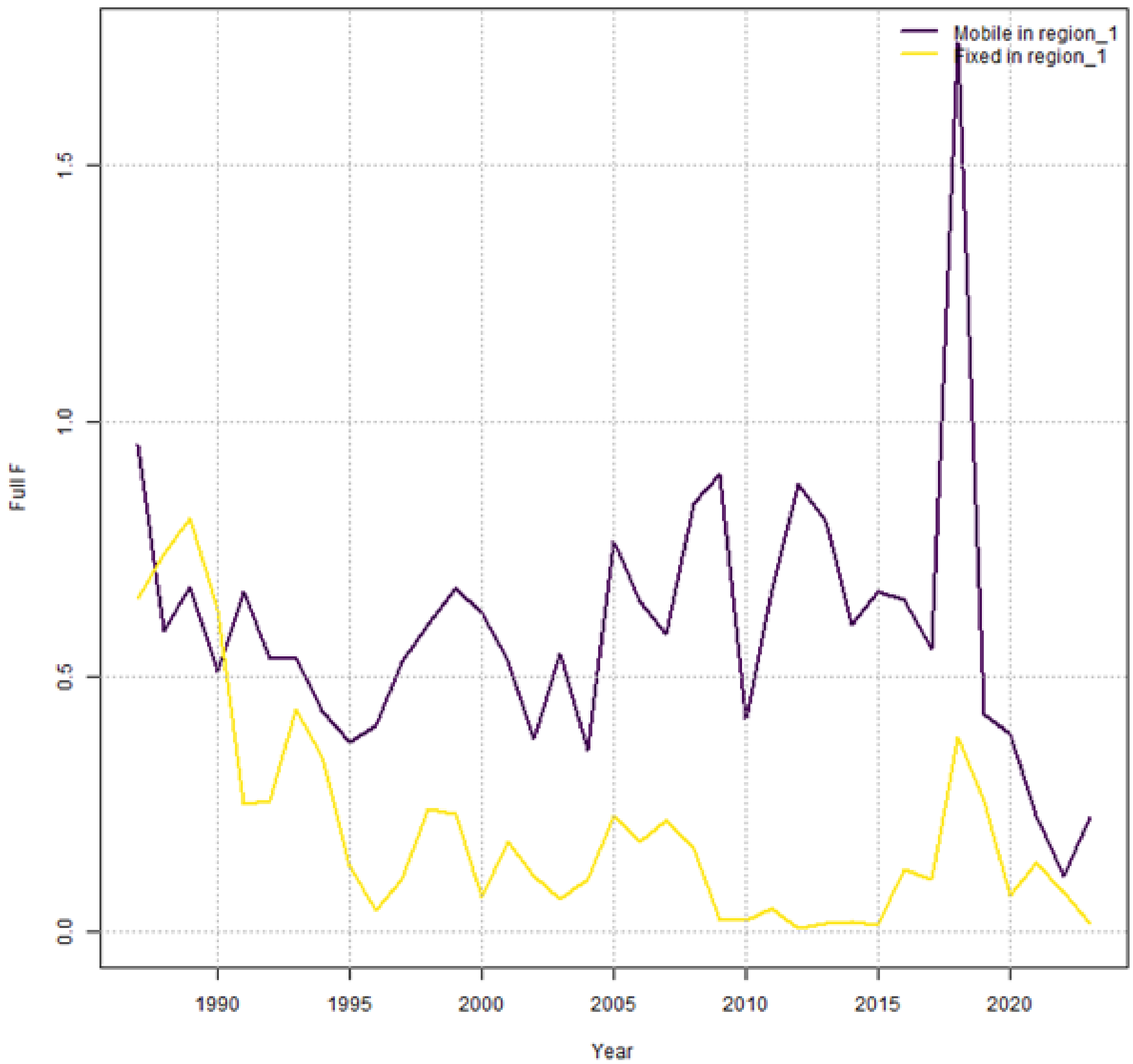

Figure 41. Fishing mortality by year by fleet. Purple Mobile, Yellow Fixed.

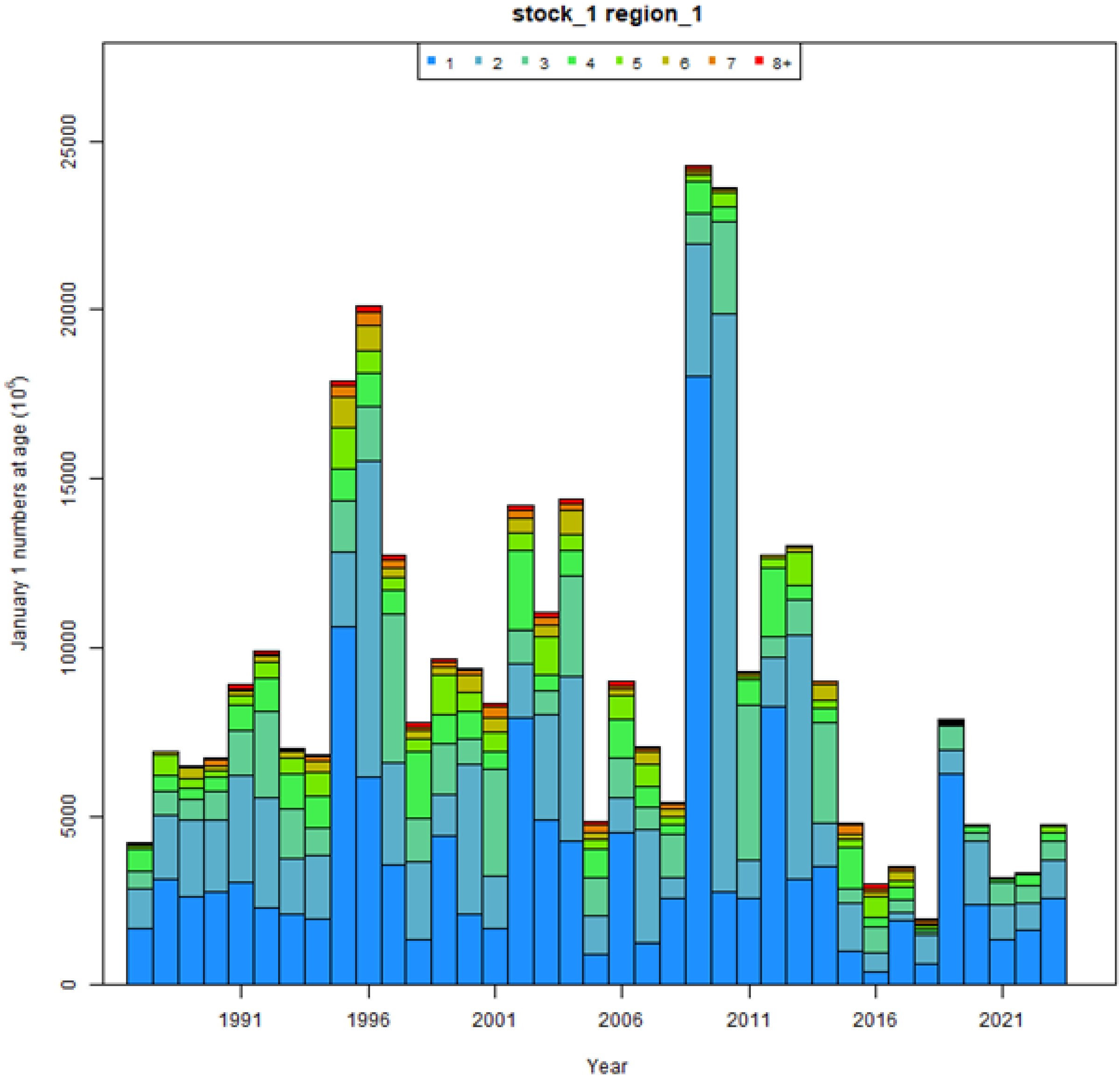

Figure 42. Estimated abundance by year and age.

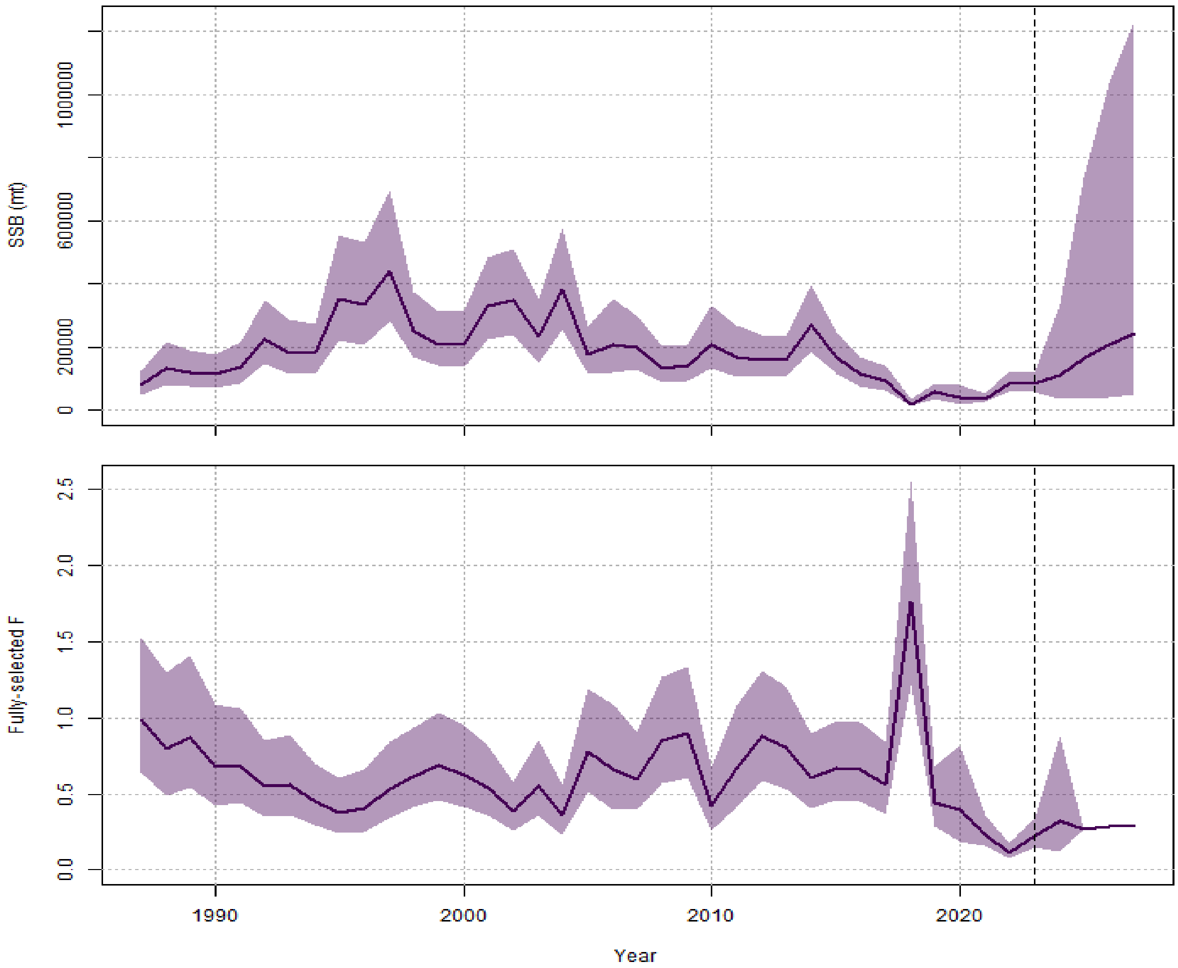

Figure 43. SSB (top) and F (bottom) across the years and in the projection. The dashed line indicates the start of the projection, while shading is the 95% confidence limit.

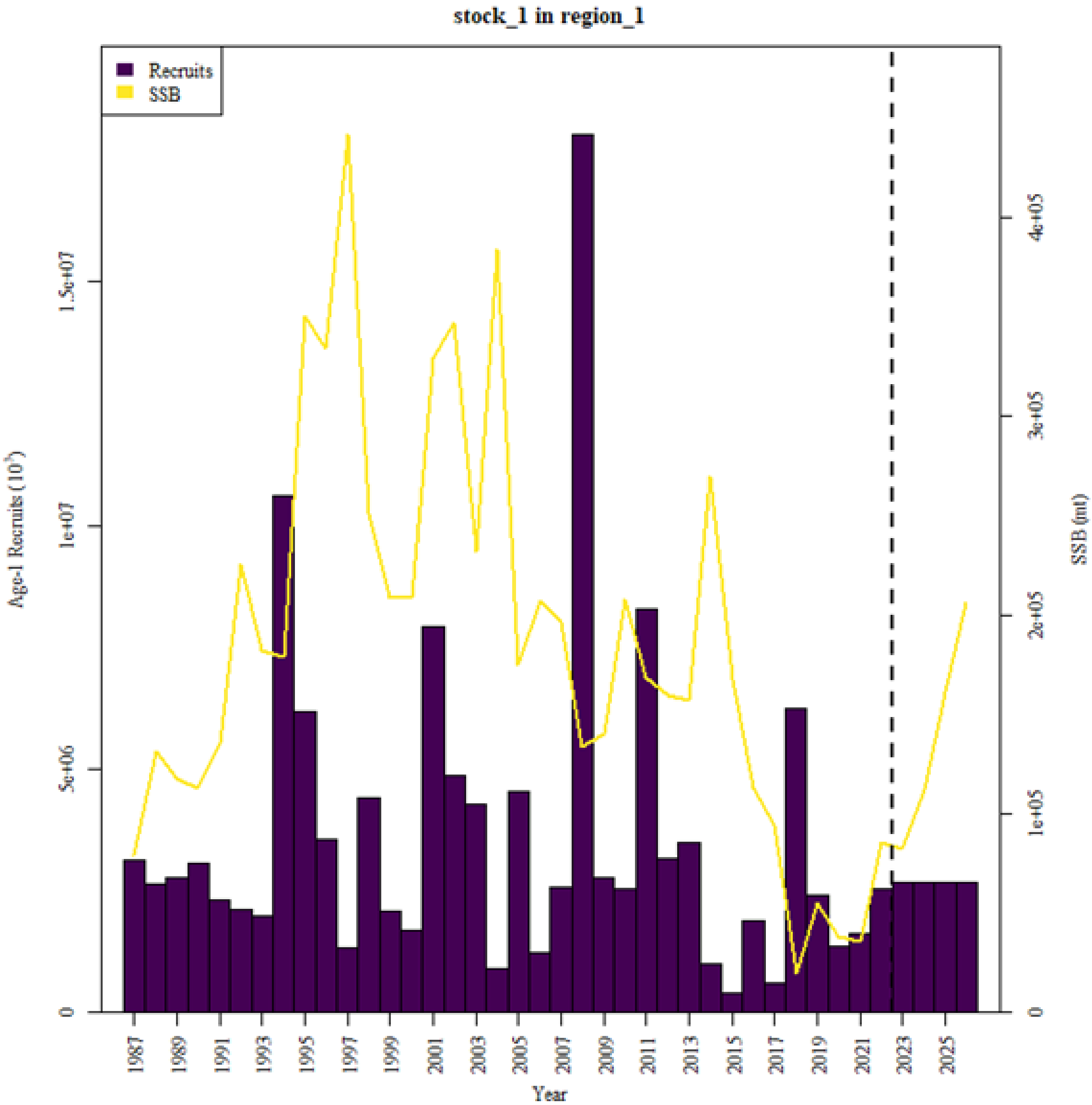

Figure 44. Recruitment (bars) and SSB (line) across years. The dash line is the start of the projection period.

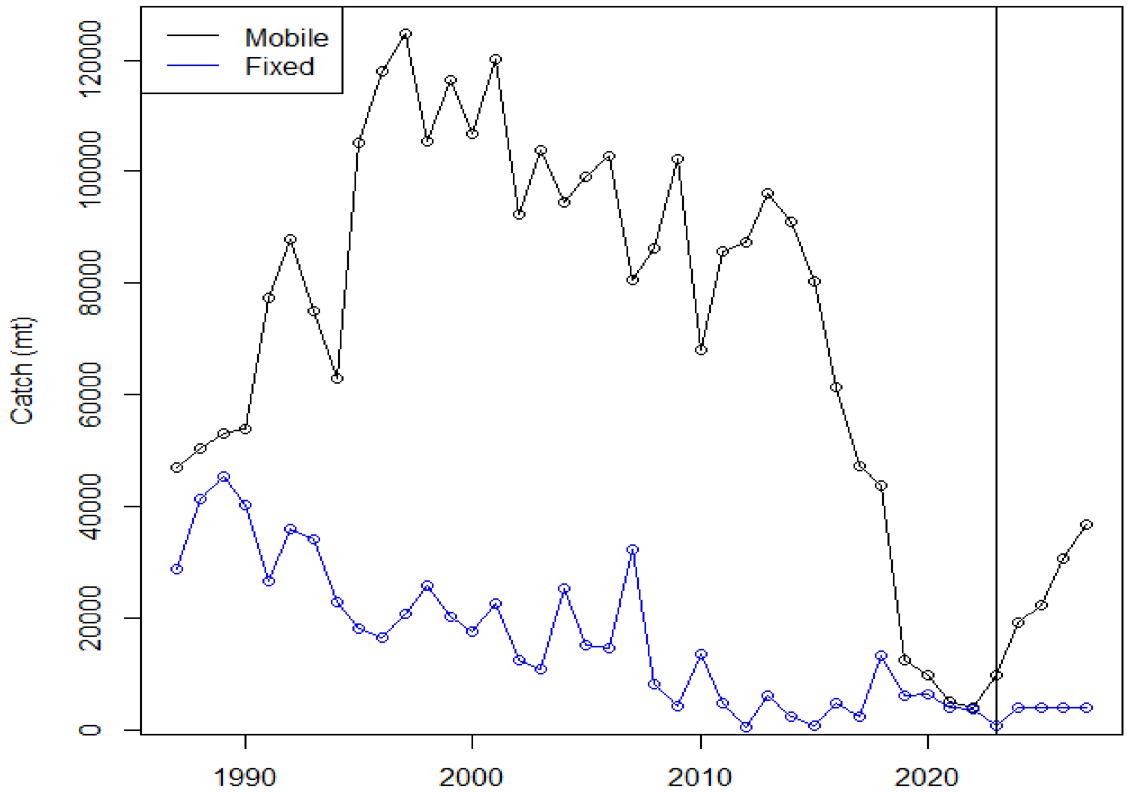

Figure 45. Historical and projected catch by fleet and year. Solid vertical line is the start of the projection period.

REFERENCES

Brooks, E.N., and Deroba, J.J. 2015. When "data" are not data: the pitfalls of post hoc analyses that use stock assessment model output. Canadian Journal of Fisheries and Aquatic Sciences. 72(4): 634-641.

Dickey-Collas, M., Hintzen N. T., Nash, R.D.M., Schön, P-J., and Payne, M. R. Quirky patterns in time-series of estimates of recruitment could be artefacts. – ICES Journal of Marine Science, 72: 111–116.

ICES 2003. Report of the Study Group on Precautionary Reference Points For Advice on Fishery Management. ICES CM documents. 2003/ACFM:15.

Legault, C.M. et al. 2022. Data-rich but model-resistant: an evaluation of data-limited methods to manage fisheries with failed age-based stock assessments. CJFAS 80:27-42. http://dx.doi.org/10.1139/cjfas-2022-0045.

NEFSC. 2018. 65th Northeast Regional Stock Assessment Workshop (65th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 18-11; 659 p.

Richardson, D. E., Hare, J. A., Overholtz, W. J., and Johnson, D. L. 2010. Development of long-term larval indices for Atlantic herring (Clupea harengus) on the northeast US continental shelf. ICES Journal of Marine Science, 67: 617–627.

Anthony, V., Waring , G. 1980. The assessment and management of the Georges Bank herring fishery. Rapp. P.-v. Reunion Cons. Int. Explor. Mer. 177: 72-111 https://www.digishelf.de/objekt/017445124_D/72/

ASMFC. 2018. Amendment 3 to the Interstate Fishery Management Plan for Atlantic Herring. Atlantic States Marine Fisheries Commission. 1050 N. Highland Street, Suite 200 A-N, Arlington, VA 22201. https://asmfc.org/uploads/file/5b2138d8AtlHerringAmendment3_revisedJune2018.pdf

Barrett, T., Hordyk,. Barrett, M., van den Heuvel, M. 2022. Spatial and temporal differences in fecundity of Atlantic herring (*Clupea harengus*) off Nova Scotia and consequences for biological reference points. Canadian Journal of Fisheries and Aquatic Sciences. 79(7): 1086-1096. https://doi.org/10.1139/cjfas-2021-0269

Becker, J., Cieri, M., Libby, D., St. Gelais, A., Sherwood, G., Chen, Y. 2020. Temporal variability in size and growth of Atlantic herring in the Gulf of Maine. J Fish Biol. 2020 Oct;97(4):953-963. https://doi.org/10.1111/jfb.14430

Carvalho, F. et al. 2021. A cookbook for using model diagnostics in integrated stock assessments. Fisheries Research 240. https://doi.org/10.1016/j.fishres.2021.105959

Feeney, R., Boelke, D., Deroba, J., Gaichas S., Irwin, B., Lee, M-Y. 2018. Integrating management strategy evaluation into fisheries management: Advancing best practices for stakeholder inclusion based on an MSE for Northeast US Atlantic herring. Canadian Journal of Fisheries and Aquatic Sciences. v 76, num 7 https://doi.org/10.1139/cjfas-2018-0125

Gartland, J. Latour, R. 2024. Disentangling bottom-up and top-down controls on fish consumption of key prey in the Northeast US Shelf ecosystem, ICES Journal of Marine Science, Volume 81, Issue 8, p 1669–1684, https://doi.org/10.1093/icesjms/fsae115

Kell, L.T. et al. 2021. Validation of stock assessment methods: is it me or my model talking? ICES Journal of Marine Science 78(6). https://doi.org/10.1093/icesjms/fsab104

Li, C., Deroba, J., Miller, T., Legault, C., Perretti, C. 2024. An evaluation of common stock assessment diagnostic tools for choosing among state-space models with multiple random effects processes. Fisheries Research 273. https://doi.org/10.1016/j.fishres.2024.106968

Legault, C.M. et al. 2022. Data-rich but model-resistant: an evaluation of data-limited methods to manage fisheries with failed age-based stock assessments. CJFAS 80:27-42. http://dx.doi.org/10.1139/cjfas-2022-0045

NEFMC. 2019. Amendment 8 to the Atlantic Herring Fishery Management Plan. New England Fishery Management Council. 50 Water Street, Mill 2, Newburyport, MA 01950. https://www.nefmc.org/library/amendment-8-2

NEFSC. 2018. 65th Northeast Regional Stock Assessment Workshop (65th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 18-11; 659 p. Available from: http://www.nefsc.noaa.gov/publications/

NEFSC. 2022. Management Track Assessments Spring 2022. US DOC, NEFSC https://apps-nefsc.fisheries.noaa.gov/saw/sasi.php

NEFSC. 2024. Spring Yellowtail Flounder Research Track Assessment. https://apps-nefsc.fisheries.noaa.gov/saw/sasi.php

NEFSC. In press. Management Track Assessments Spring 2024. US DOC, NEFSC Tech Memo. https://apps-nefsc.fisheries.noaa.gov/saw/sasi.php

NOAA. 2024. Atlantic Herring 2024 Management Track Assessment Report. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA. See https://apps-nefsc.fisheries.noaa.gov/saw/sasi.php

Overholtz, W.J., Jacobson, L.D,. Melvin, G.D., Cieri, M., Power, M., Libby, D., Clark, K. 2004. Stock assessment of the Gulf of Maine - Georges Bank Atlantic herring complex, 2003. Northeast Fish. Sci. Cent. Ref. Doc. 04-06; 290 p. Available from: National Marine Fisheries Service, 166 Water St., Woods Hole, MA 02543. https://repository.library.noaa.gov/view/noaa/5350

Trijoulet, V. et al. 2023. Model validation for compositional data in stock assessment models: calculating residuals with correct properties. Fisheries Research 257. https://doi.org/10.1016/j.fishres.2022.106487

Procedures for Issuing Manuscripts in the Northeast Fisheries Science Center Reference Document (CRD) and the Technical Memorandum (TM) Series

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of the nation's ocean resources and their habitat." As the research arm of the NMFS's Greater Atlantic Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS's mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on the Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (e.g., anonymously peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own series.

NOAA Technical Memorandum NMFS-NE – This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review, and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document – This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review, and most issues receive copy editing.

CLEARANCE

All manuscripts submitted for issuance as CRDs must have cleared the NEFSC's manuscript/abstract/webpage review process. If your manuscript includes material from another work which has been copyrighted, you will need to work with the NEFSC's Editorial Office to arrange for permission to use that material by securing release signatures on the "NEFSC Use-of-Copyrighted-Work Permission Form."

STYLE

The CRD series is obligated to conform to the style contained in the current edition of the United States Government Printing Office Style Manual; however, that style manual is silent on many aspects of scientific manuscripts. The CRD series relies more on the CSE Style Manual. Manuscripts should be prepared to conform to both style manuals.

The CRD series uses the Integrated Taxonomic Information System, the American Fisheries Society's guides, and the Society for Marine Mammalogy's guide for verifying scientific species names.

For in-text citations, use the name-date system. A special effort should be made to ensure all necessary bibliographic information is included in the list of references cited. Personal communications must include the date, full name, and full mailing address of the contact.

PREPARATION

Once your document has cleared the review process, the Editorial Office will contact you with publication needs—for example, revised text (if necessary) and separate digital figures and tables if they are embedded in the document. Materials may be submitted to the Editorial Office as email attachments or intranet downloads. Text files should be in Microsoft Word, tables may be in Word or Excel, and graphics files may be in a variety of formats (JPG, GIF, Excel, PowerPoint, etc.).

PRODUCTION AND DISTRIBUTION

The Editorial Office will perform a copy edit of the document and may request further revisions. The Editorial Office will develop the inside and outside front covers, the inside and outside back covers, and the title and bibliographic control pages of the document.

Once the CRD is ready, the Editorial Office will contact you to review it and submit corrections or changes before the document is posted online. Several organizations and individuals in the Northeast Region will be notified by e-mail of the availability of the document online.