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Stock Assessment of Haddock *(Melanogrammus aeglefinus)* on Eastern Georges Bank

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Foreword

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

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TABLE OF CONTENTS

ABSTRACT

The current assessment framework for eastern Georges Bank (EGB) Haddock is based on a statistical catch-at-age model developed and reviewed through the 2022 Georges Bank and EGB Haddock Research Track conducted jointly with the U.S. National Marine Fisheries Service of the National Oceanic and Atmospheric Administration. In this assessment, the EGB Haddock model is updated with data up to 2024 and catch advice is provided for 2026. The 2020 and 2021 year-classes remain the largest contributor to both the fishery and the surveys, and there continues to be improved growth for new cohorts. Even with the reduction of the density-dependent impacts associated with the 2013 cohort, the model-estimated natural mortality rate remains high. The addition of a deeper water stratum for the DFO Winter Ecosystem Research Vessel Survey improved model diagnostics and was the recommended model for catch advice in the short-term. Stock status is considered healthy for 2024, but model projections predict a decline in SSB for 2026 and 2027. The catch advice for 2026 ranged from 2,480 to 3,850 mt for the 25% to 75% risk of exceeding F_{ref}.

INTRODUCTION

Haddock *(Melanogrammus aeglefinus)* on eastern Georges Bank (DFO statistical unit areas 5Zj and 5Zm; EGB) is a transboundary stock that was previously jointly assessed by Fisheries and Oceans Canada (DFO) and the National Marine Fisheries Service (NMFS) under the Transboundary Resources Assessment Committee (TRAC) peer-review process. Since 2024, DFO and NMFS Science provide advice for this transboundary stock based on their respective domestic peer-reviewed assessments to support the management decision process.

The current assessment framework is based on a statistical catch-at-age model using a state-space framework (Woods Hole Assessment Model [WHAM], Stock and Miller 2021). This assessment framework was developed and reviewed at the 2022 Georges Bank and EGB Haddock Research Track peer review meeting. This model supports the working group analysis that suggested that natural mortality (M) was increasing in the EGB management unit area since 2010. The review panel recommended the EGB Haddock model be used for providing catch advice over the short-term (Kronlund et al. 2023).

In this assessment, the EGB Haddock model is updated with the 2024 Canadian and United States of America (U.S.) fisheries data, as well as the 2024 data from the DFO Winter Ecosystem Research Vessel Survey (herein referred to as DFO Winter RV Survey), NMFS Spring Survey, and the NMFS Fall Survey. Biological indicators from the 2025 DFO Winter RV Survey are also incorporated into the assessment of Haddock.

ASSESSMENT

FISHERY

Combined Canada and U.S. catches for EGB Haddock were 6,219 mt in 2024 (Figure 1, Table 1a,b,c), more than twice the catch in 2023, which corresponded with an increase in total allowable catch (TAC). In 2024, the total catch represented 62% of the combined (Canada and U.S.) quota.

The Canadian catch increased from 2,507 mt in 2023 to 5,908 mt in 2024. Discards in the groundfish fishery are considered to be negligible. Discards of Haddock by the Canadian Scallop fishery were 9 mt in 2024 and have ranged between 4 mt and 186 mt over the time series (1969–2024). Canada caught 86% of its 6,900 mt allocation in 2024.

The U.S. catches were 311 mt in 2024. Landings in 2024 were 285 mt and discards were estimated to be 26 mt. The U.S. caught 10% of its 3,100 mt allocation.

The 2021 year-class (age 3) was a major contributor to the 2024 Canadian fishery catch (landings and discards, 61% of the fish by number), followed by the 2020 year-class (age 4) (30% by number, Figure 2). In 2024, fish aged 9+ (includes the 2013 year-class) accounted for only 0.4% of the fish caught in the Canadian fishery. The size compositions of the 2024 Canadian fishery catches were derived from port samples and at-sea samples for the principal gear types. Catches peaked at lengths of 40.5 cm, 46.5 cm, and 38.5 cm for otter trawl, longline, and scallop dredge gears in 2024 (Figure 3).

The 2024 U.S. fishery catch-at-age (CAA) and catch-at-length (CAL) were not provided to DFO. The U.S. CAA was estimated using the Canadian fishery proportions-at-age for 2024 (Figure 2). Historically, the U.S. fishery weights-at-age (WAA) differ from the Canadian fishery, so the average ratio of U.S. and Canadian WAA from the last two years was applied to the 2024 Canadian WAA to obtain an estimate of the 2024 U.S. fishery WAA.

SURVEYS

Indicators from the DFO Winter RV, NMFS Spring, and NMFS Fall surveys are assessed annually for biomass, age composition, size-at-age, and survey catch distribution. The 2022 DFO Winter RV Survey used a new vessel and gear; conversion factors (Yin et al. 2025) were developed to make the data comparable to the time series. The 2023 NMFS Spring Survey was conducted using an altered sampling protocol and was excluded from the data inputs.

The swept-area biomass indices for the NMFS Fall and DFO Winter RV surveys are consistent and track each other well (Figure 4). There has been an increase and then a decline in Haddock catches in the last decade for both the DFO Winter RV and NMFS Fall surveys. Despite some year effects, surveys show a biomass recovery from the mid-1990s followed by an increase due to greater recruitment since the 2000s. The survey swept-area biomass increased from 10,288 mt in 2023 to 11,528 mt in 2024 for the NMFS Fall Survey and decreased from 58,617 mt in 2023 to 25,295 mt in 2024 for the DFO Winter RV Survey. The survey swept-biomass for the 2024 NMFS Spring Survey was 11,384 mt. The average swept-area biomass was 16,069 mt for 2024 for all three surveys, a decrease from the 2023 average of 34,453 mt. In 2025, the DFO Winter RV Survey swept-area biomass estimate declined to 12,151 mt.

The 2020 and 2021 year-classes (age 4 and 3) were a major component of the 2024 DFO Winter RV Survey catches (22% and 52% by number, respectively), followed by the 2022 year-class (age 2, 13%, Figure 5). For the 2025 DFO Winter RV Survey, the 2021 year-class (age 4) comprised 61% of the catch by number. For the 2024 NMFS Spring Survey, the 2020 and 2021 year-classes contributed 17% and 70% by number, respectively, to the catch. For the 2024 NMFS Fall Survey, the 2020 and 2021 year-classes contributed 32% and 58%, respectively, to the catch. Fish aged 9+ accounted for only 1% of the fish caught in the most recent surveys (Figure 5).

The length frequency distribution of the survey catch for the 2024 NMFS Spring Survey peaked at 38 cm. The 2024 NMFS Fall Survey and the 2025 DFO Winter RV Survey catches peaked at 40 cm (Figure 6). The spatial distribution patterns observed during these surveys are similar to the average patterns over the previous ten years. For the 2024 NMFS Spring Survey, all ages were spread across the bank consistent with the time series. For the 2024 NMFS Fall Survey and the 2025 DFO Winter RV Survey, Haddock were dispersed across the bank on the eastern side of the Hague line (Figures 7–9).

ASSESSMENT MODEL

Model Exploration

Alternative model configurations that were explored in the Haddock Research Track were re-examined during this assessment, but the base model continued to have the best diagnostics based on Akaike information criteria (AICs) and retrospective patterns (Mohn’s rho) compared to models with different specifications of M.

Two assessment models were presented during the peer-review meeting for consideration for catch advice, a) the base model and b) an alternative model that included an additional stratum for the DFO Winter RV Survey. This alternative model was based on the hypothesis that Haddock are changing their spatial distribution (i.e., moving to deeper water), the inclusion of the 5Z9 stratum was considered as a potential option for improving the model diagnostics. For this model run, all data inputs remained the same as the base model, with the only change being the DFO Winter RV Survey numbers-at-age (NAA) and mean biomass per tow from 2010–2024. Since data inputs prior to 2010 were not modified, incorporation of the 5Z9 survey data introduces the implicit assumption that pre-2010 Haddock density and relative age composition in 5Z9 were equivalent to the mean density and age structure observed in 5Z1–5Z4, rather than assuming a pre-2010 density of zero in 5Z9.

Model Diagnostics

Retrospective patterns suggest that an assessment model is mis-specified and can lead to challenges in producing robust catch advice for resource management (Cadrin 2025). Therefore, substantial retrospective patterns can be used to justify the rejection of an assessment model for determining stock status or catch advice (Legault 2009, Punt et al. 2020). In general, the EGB Haddock base model tends to overestimate both SSB and recruitment and underestimate fishing mortality. The mean Mohn's rho over a 7-year peel for SSB, F, and recruitment are reported (Figure 10). Guidance on the evaluation of retrospective patterns suggest that for short-lived species (<15 years), rho should not exceed -0.22 for a lower bound and 0.3 for an upper bound (Hurtado-Ferro et al. 2015). Based on the model diagnostics (Figure 10) both F and recruitment exceed the recommended bounds (rho= -0.293 for F and 0.459 for recruitment). An alternative method to evaluate the magnitude of a retrospective pattern is to compare point estimates from each retrospective peel to the 90% confidence intervals of those estimates from the model (Brooks and Legault 2016). Based on this analysis, three of the five recent peels were outside of the 90% confidence intervals for SSB and F (Figure 11).

The addition of 5Z9 into the DFO Winter RV Survey data inputs reduced the magnitude of the retrospective pattern relative to the base model. The mean rho from a 7-year peel is within the recommended bounds for both SSB (rho=0.128) and F (rho=-0.190). For recruitment, the magnitude of the retrospective pattern was also reduced relative to the base model, but the rho was still above of the upper bound of 0.3 (rho=0.366). This is consistent with the previous assessment where the absolute magnitude of change is small for the NAA-1 (Figure 12).

Model Outputs

During the peer-review, the model with 5Z9 included was recommended to assess the EGB Haddock stock for this year, and all outputs reported herein reflect that decision. The specifications of the EGB Haddock assessment model are provided in Table A1 and Table A2. In this model, M is fixed at 0.2 from 1969–2009 and is model-estimated as a time- and age-invariant value for the period 2010–2024.

Historically, significant changes in the dynamics of the resource have been a function of year-class strength, with the 2013 year-class sustaining the fishery since it recruited. Subsequent individual year-classes have not had a large contribution to the fishery. Density-dependent changes in growth have occurred, but presently, the contribution of the large 2013 year-class to the stock is minimal. Preliminary evidence by survey NAA suggested relatively strong 2020 and 2021 year-classes would recruit to the fishery in 2024 (Figure 2); however, survey indices suggest the strength of these year-classes are not as comparable to other large cohorts observed in the past (Figure 5).

Higher recruitment since 1990, lower exploitation, and reduced capture of small fish in the fishery contributed to the SSB estimate increasing to 53,000 mt in 2003. A subsequent increase to 85,000 mt in 2009 was largely due to the strong 2003 year-class, estimated at 204 million age-1 fish. The biomass decreased after the 2009 high, and in 2012 the SSB was estimated at 24,000 mt. When the strong 2010 and 2013 year-classes became sexually mature, the estimated SSB increased to 81,000 mt in 2016, followed by a continued decline in the subsequent years. Despite the recruitment being much higher for the 2010 and 2013 year-classes, compared to the 2003 year-class, the SSB did not increase as much, hypothesized to be due to a higher M beginning in 2010. The current SSB estimate for 2024 is 27,343 mt, which is above the median SSB of 24,553 mt for the time series (1969–2024, Figure 13).

Recruitment at age-1 has fluctuated between 1.7 and 90 million since 1990, except for the strong year-classes. The 2003, 2010, and 2013 year-classes were estimated at 204, 353, and 928 million, respectively. The model estimates of the 2020 and 2021 year-classes are 90 and 69 million age-1 fish. The median recruitment for the time series (1968–2023 year-class) is 8.8 million (Figure 13).

The model assumes logistic fishery selectivity, estimated as time-varying from 1992–2024. Fully-selected fishing mortality has varied throughout the time series, fluctuating between 0.18 in 2008 to 0.71 during the mid-2010s (Figure 14). Fishing mortality was estimated to be on average approximately 0.48 over the last five years with a decrease to 0.31 for 2024.

Productivity

Recruitment, natural mortality, growth, and condition reflect changes in the productive potential of the stock. Recruitment has been highly variable. This stock produced eight strong year-classes in the last two decades. However, the assessment model estimated a substantial increase in M from the historical assumed level of 0.2 to the recent time block (2010–2024) where M was estimated at 0.502 (0.46–0.54). Estimated relative total mortality (Z) was high in 2021 and 2022 for the DFO Winter RV Survey (Figure 15) corresponding with higher estimates of relative fishing mortality (catch/survey; Figure 16) followed by a decline in both for 2023. A similar elevated relative Z was evident for 2021 in the NMFS Spring Survey; however, missing surveys in 2020 and 2023 make it difficult to interpret any trends in the available data (Figure 15, Figure 16).

Both fishery and survey average lengths- and weights-at-age have declined considerably since 2000, coinciding with an increase in stock biomass. With density-dependent effects, changes in growth in response to changes in stock biomass and episodes of strong recruitments have been observed throughout the history of this stock. With the sharp decrease in biomass in the last few years, Haddock length- and weight-at-age have increased for most ages in both the fishery and survey data, although both did exhibit declines for 2024 (Figure 17). The most recent year-classes continue to show improved average growth based on DFO Winter RV Survey (Figure 18). Fish condition has been consistent in recent years, with an increase for the NMFS Spring Survey over the last 5 years (Figure 19).

Harvest Strategy

The Transboundary Management Guidance Committee (TMGC) adopted a harvest strategy to maintain a low to neutral risk of exceeding the fishing mortality reference (F_{ref}). In 2022, an F_{ref}=0.367 was estimated using $F_{40\%SPR}$ (fishing mortality rate at a spawning potential ratio of 40%) as a proxy for F_{MSY} (fishing mortality rate at maximum sustainable yield; Wang et al. In Prep[1]). At the time of development, retrospective forecasting was used to evaluate trade-offs in terms of biomass, catch, and annual variability in catch, based on different combinations of time periods (5, 10, 15, and 25 years) for the biological and fishery selectivity data used in the estimation, and the appropriate time interval (2 to 7 years) for updating the F_{ref}. The TMGC decided that F_{ref} should be updated every 3 years using the most recent 5 years of data. The F_{ref}

[1] Wang Y., C. Regnier-McKellar and K. Kraska In Prep. Assessment of Haddock on Eastern Georges Bank for 2022. TRAC Reference Document.

was therefore updated for this assessment as $F_{40\%SPR}$ using data inputs from 2020–2024 and was estimated to be 0.339.

Projections

An estimate of catch for 2025 is required for the model projections and two catch scenarios were considered; 1) full utilization of TAC in 2025 (7,410 mt); and 2) partial utilization (6,200 mt) consistent with previous assessments. However, it was decided during the peer-review meeting that only the full utilization be used.

For projections, the WHAM assessment model was converted to an openMSE (Hordyk et al. 2024) operating model. Recruitment was generated from a lognormal distribution with a mean recruitment and lognormal deviations from the historical recruitment estimates. Model-estimated selectivity, maturity-at-age, weight-at-age, and M were used in the projections based on the average of the last 3 years (Table A3). Assuming the M continues to be 0.502 (estimated by the model) in 2025–2027, Table 2 shows the median estimates of biomass, SSB, and F in 2025 based on 2,000 realizations of terminal year population sizes and an assumed 2025 catch of 7,410 mt. For 2026, the median biomass, SSB, and catch estimates were obtained by applying F_{ref}=0.339 to each realization. The risk analysis in Figure 20 followed a similar logic to estimate the probability of exceeding F_{ref} in 2026 given various magnitudes of catch ranging from 0 mt to 30,000 mt in steps of 2,000 mt. The catches associated with 25%, 50%, and 75% risk were estimated by linear interpolation such that the catch associated with the 50% probability of exceeding F_{ref}=0.339 (3,170 mt) in Figure 20 differs slightly from the equivalent median catch for 2026 (2,990 mt) reported in Table 2.

The median SSB was projected to decrease from 23,713 mt in 2025 to 15,180 mt in 2026 and 13,963 mt in 2027 (Table 2). For 2025, F was estimated to be 0.534 assuming a catch of 7,410 mt (Table 2). The median catch at F_{ref}=0.339 in 2026 was 2,990 mt. The stock biomass was projected to decrease in 2026 with a minimal increase in 2027. The 2020 year-class at age 6 and the 2021 year-class at age 5 were projected to be the dominant contributors to fishery catch for 2026 due to the lack of older fish in the population and low selectivity of younger age groups (Figure 21).

SOURCES OF UNCERTAINTY

Natural mortality remains a major uncertainty for the EGB Haddock stock. In the Research Track framework, the incorporation of a change in M in two time-blocks was used to address the hypothesis of high density-dependence. The selection of a change point year of 2010 for the change in M from 0.2 to a higher model-estimated M was evaluated at the Research Track peer review (Kronlund et al. 2023) and corresponded with good performance seen in the past Virtual Population Analysis (VPA) model prior to 2010. The expectation was that with the exit of the 2013 year-class and the reduction in overall stock biomass, the model-estimated M would decrease. Contrary to expectations, model-estimated M remains high. However, our understanding of the factors leading to high M in recent years is incomplete. The high M in recent years likely reflects potential changes in additional factors including migrations, catch reporting errors, ageing errors, and misspecification of selectivity. In 2025, a sensitivity analysis was conducted to profile the model AICs over a range of M values for the recent time period (2020–2024), which identified a model with high M (0.6) with the lowest AIC (Table 3) and best diagnostics for the most recent time period. Given that stock size has declined, this higher estimate for M may reflect misspecification due to movement out of the area, instead of an increase in natural mortality.

Survey indices have declined in recent years and may be attributed to changes in the spatial distribution of Haddock (e.g., moving to deeper waters) and changes to the timing of surveys as populations may shift distributions in response to seasonal temperature changes. Haddock distribution has been known to vary throughout the year, although the degree of movement across management areas is unknown. Coincidence of these factors may lead to changes in relative abundance indices independent of actual changes in abundance. Since 2010, the DFO Winter RV Survey started to extend their sampling into a deeper water survey stratum (5Z9), that straddles the boundary of the EGB Haddock stock and the 4X5Y Haddock management unit. As a result of the continued elevated M estimated in the base model, the inclusion of the 5Z9 DFO Winter RV Survey data from 2010–2024 was used as an alternative model to explore the hypothesis of movement of Haddock into deeper waters in the spring. Overall, the estimate of M for the 2010–2024 time-period declined (0.513 to 0.502) and the magnitude of the retrospective pattern decreased with the addition of stratum 5Z9 in the assessment. There was a minimal increase in SSB (approximately 2%) compared to the base model and fully-selected fishing mortality rate was reduced by 8–21% over the last 4 years. Recruitment at age-1 was substantially lower in the model with stratum 5Z9 for 2023 (16%) and 2024 (43%) compared to the base model, but the numbers of older fish (5+) increased by 17–18%.

CATCH ADVICE

The recommended approach from the peer-review meeting was to use the assessment model with the addition of stratum 5Z9 for the DFO Winter RV Survey and to assume full utilization of the 2025 TAC for the projections. Catch advice for the 2026 fishing year ranged from 2,480–3,850 mt based on the 25–75% risk of exceeding F_{ref} (Table 4). The probabilities that the 2027 SSB will be above the LRP ranged from 68–75% and above the USR ranged from 28–30%.

STOCK STATUS

In May 2023, biomass-based reference points were developed domestically for EGB Haddock (DFO 2024) using the new assessment model. The limit reference point (LRP) was defined as the lowest model-estimated SSB in the time series that resulted in sustained recovery ($B_{recover}$, 1991–1996) and an upper stock reference (USR) defined based on the Rago-Razor method was proposed (DFO 2024). Due to the inclusion of stratum 5Z9 in the assessment model, reference points were re-calculated following the same approach as Wang and Carruthers (2025).

Based on the 2024 SSB estimate of 27,343 mt, stock status is considered healthy. There is a 100% probability of being above the LRP and a 70% probability of being above the USR (Figure 22).

RESEARCH RECOMMENDATIONS

Genetic studies on stock structure are limited for Haddock and could help explain observed differences in growth among populations, and to estimate the amount of movement across stock boundaries.

Higher natural mortality, reduced growth, and poor condition of Haddock in recent years have been attributed to higher densities, but even with the large reduction of the 2013 cohort from the population, these patterns persist. Ecosystem changes, alongside density dependence, could be a contributing factor. Examining shifts in ecosystem indicators and prey availability, may help explain these patterns.

Haddock movement has been thought to be limited on Georges Bank; however, Haddock are known to change their spatial distribution based on temperature. More work is required on the inclusion of deeper water strata (e.g., 5Z9) and may improve our understanding of elevated M predicted in the model and improve model diagnostics by including older fish that may not be captured in the survey indices.

CONCLUSIONS

During the peer-review meeting, the alternative assessment model was chosen as the best option for catch advice for 2026. Poor model diagnostics led to the base model being adjusted to include the 5Z9 stratum data. This was an interim decision to address the concerns identified in the model, including the magnitude of retrospective patterns in F and recruitment. This decision will be re-evaluated during subsequent assessments until a new assessment framework can be developed.

Additional uncertainties highlighted during the peer-review and identified since the model development continue to include potential misspecification of survey and fishery selectivity, the inability for the model to react to the reduction in density-dependence with the exit of the 2013 year-class from catch and survey age-composition, and the disconnect between the M used in the F_{ref} calculation and M assumed in the projections. These uncertainties, and the new concerns with model diagnostics, highlight the importance of developing a new assessment framework to evaluate the EGB Haddock stock in the near future.

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DFO. 2025 Calibration of Bottom Trawl Survey Vessels: Results of Comparative Fishing Between the CCGS Teleost and CCGS John Cabot/ CCGS Captain Jacques Cartier on the Scotian Shelf and Bay of Fundy in 2022 and 2023. DFO Can. Sci. Advis. Sec. Res. Doc. 2025/025. iv + 236 p.

FIGURES

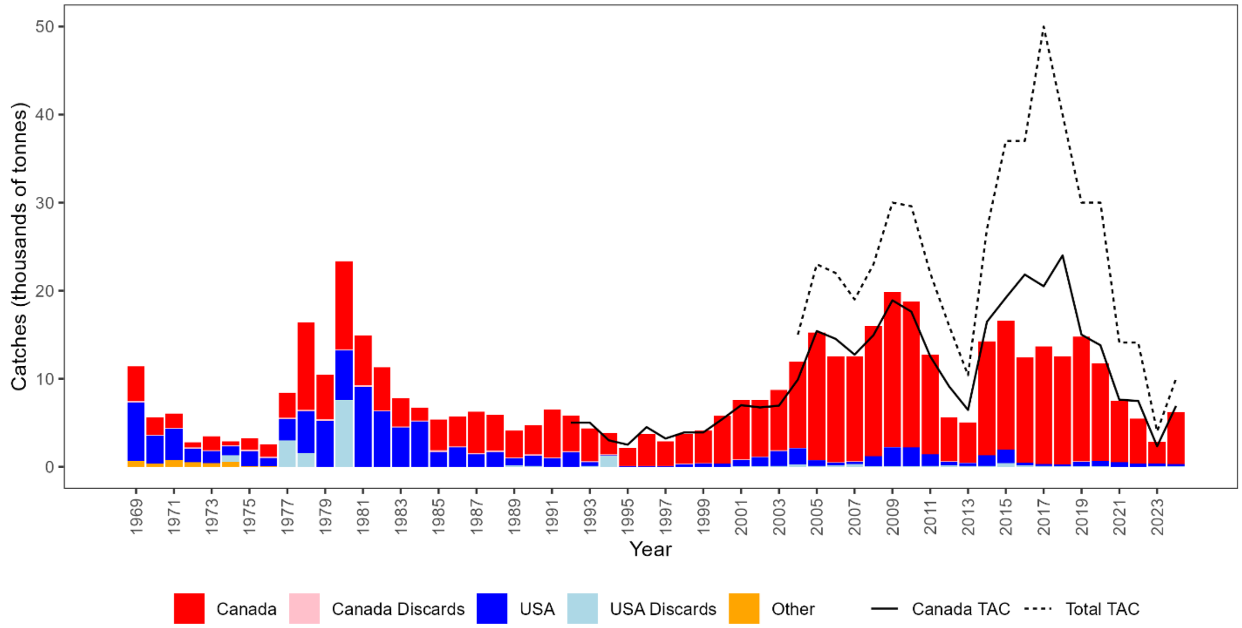

Figure 1. Annual catches and total allowable catch (TAC) of eastern Georges Bank Haddock from 1969–2024.

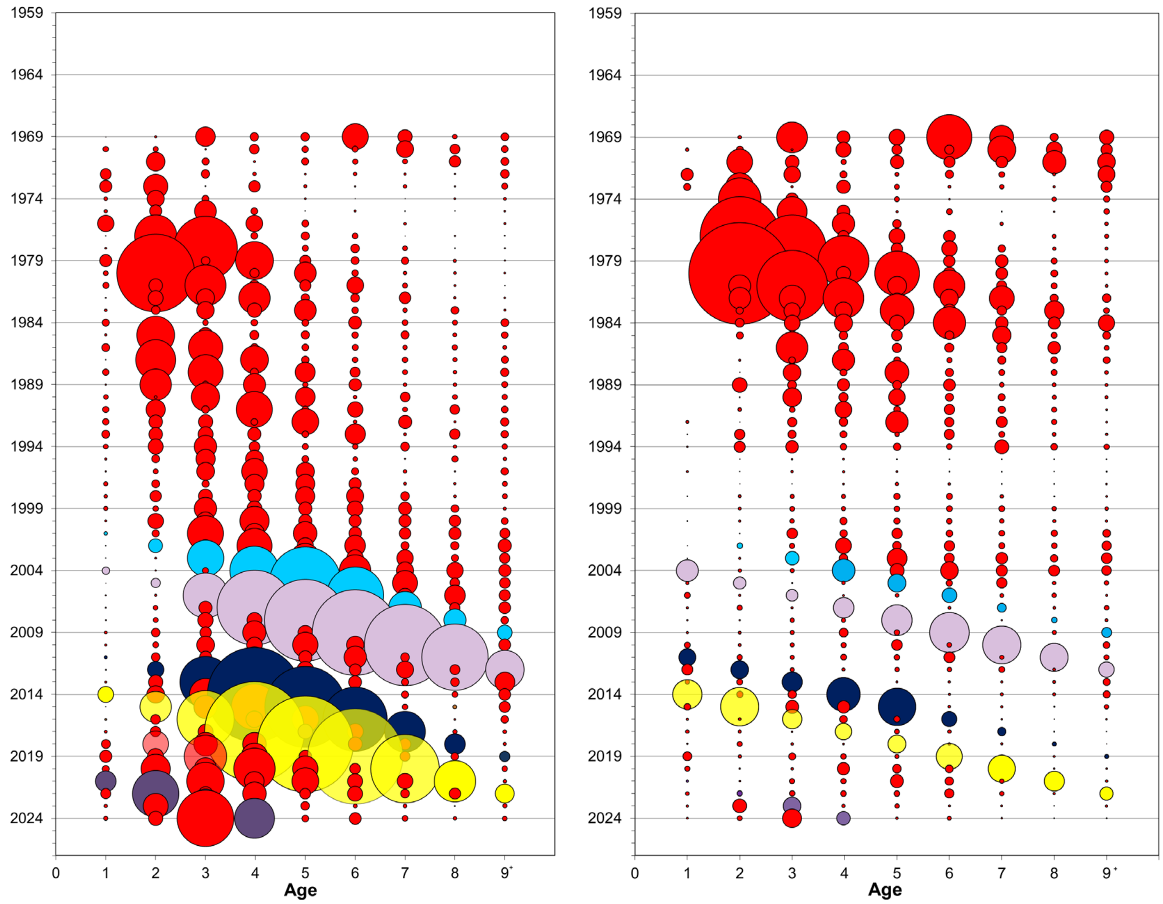

Figure 2. Commercial catch-at-age (numbers) of eastern Georges Bank Haddock from 1969–2024 for Canada (left) and U.S. (right). The 2000, 2003, 2010, 2013, and 2020 year-classes are indicated in light blue, light purple, dark blue, yellow, and dark purple, respectively. The bubble area is proportional to catch magnitude. This includes both landings and discards.

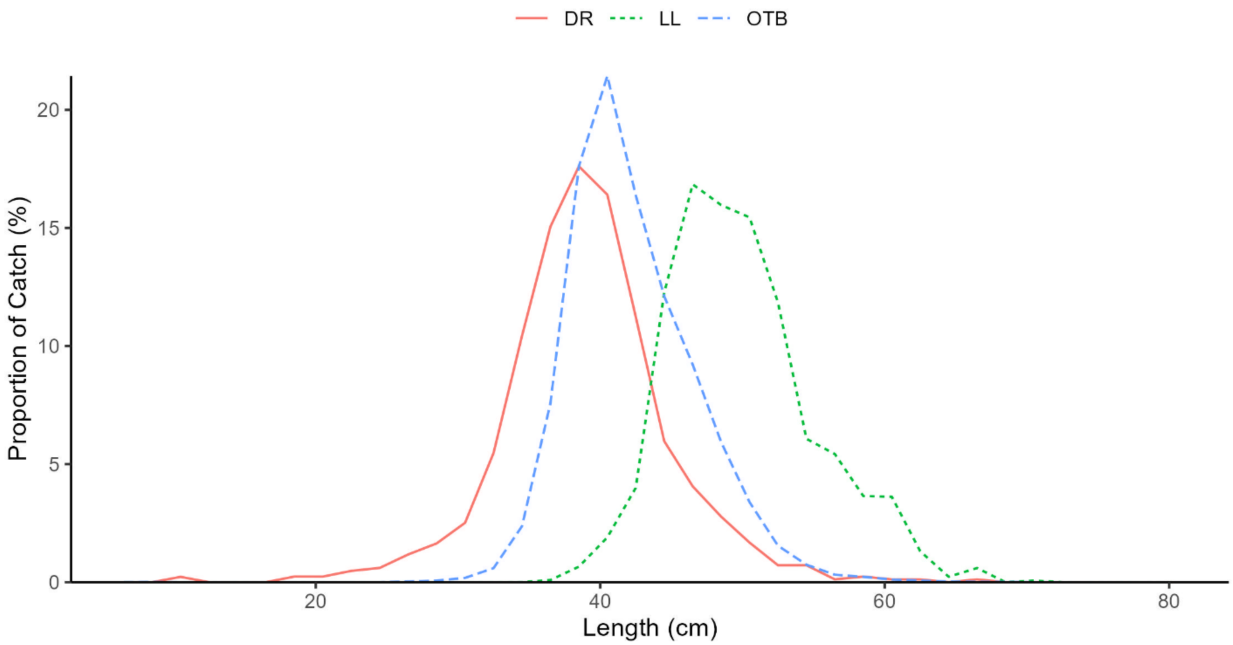

Figure 3. Canadian eastern Georges Bank Haddock fishery catch-at-size as a proportion by gear for 2024. OTB=otter trawl bottom, LL=longline, DR=scallop dredge.

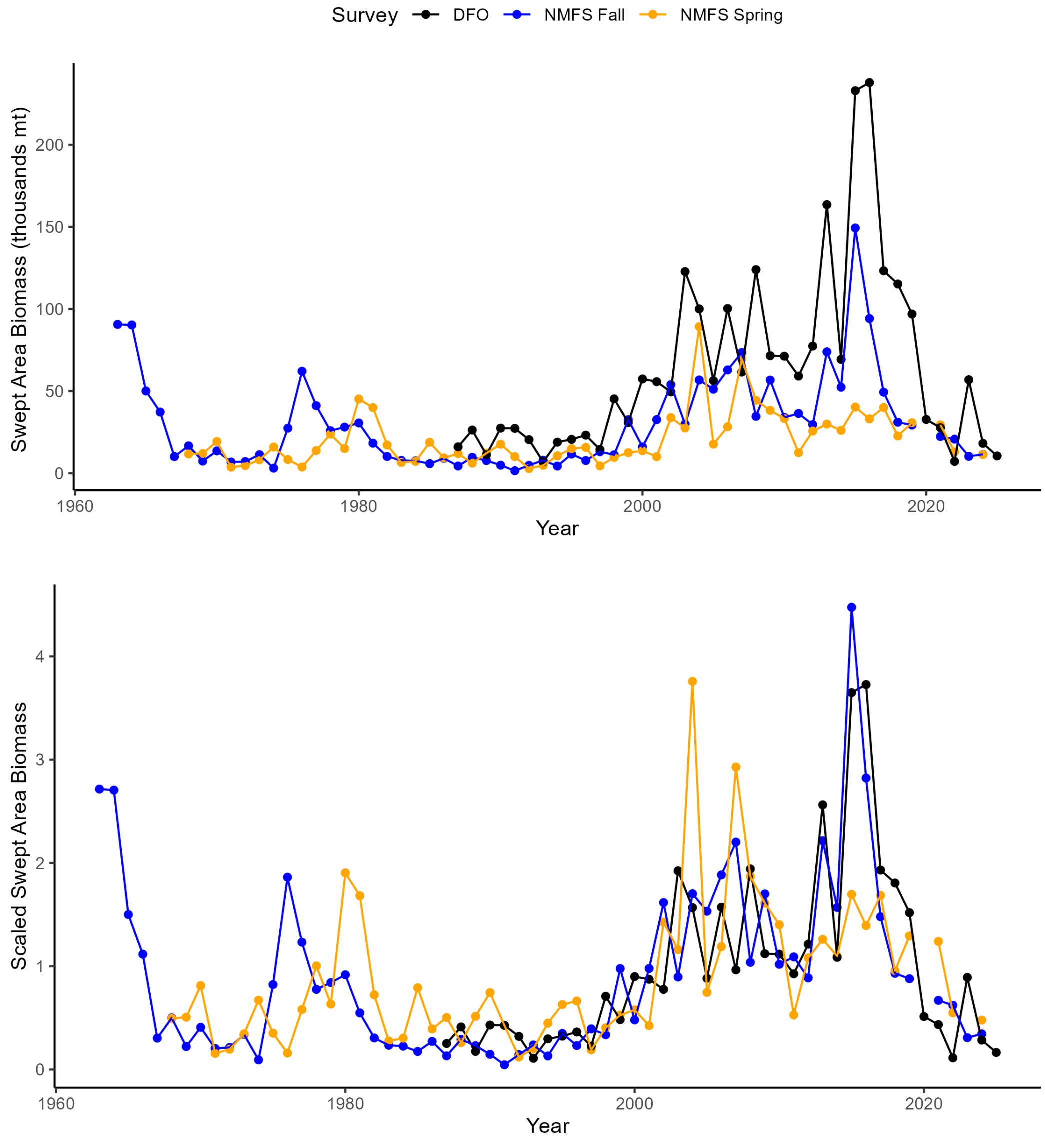

Figure 4. Raw (top panel) and standardized (bottom panel) survey swept-area biomass indices from National Marine Fisheries Service (NMFS) Fall (1963–2024), NMFS Spring (1968–2024), and Fisheries and Oceans Canada (DFO; 1987–2025) Winter Ecosystem Research Vessel surveys for eastern Georges Bank. Biomass conversion coefficients have been applied to the NMFS surveys to adjust for changes in door type (BMV vs Polyvalent; 1968–1984), vessel (Delaware II vs. Albatross IV; 1968–2008), and vessel/net (Albatross IV vs. Henry B. Bigelow; Yankee 36 vs. 4 seam-3 bridle; 2009–2023). Biomass conversion coefficients have been applied to the DFO Winter RV survey for 2022 and 2025 (Cartier vs. Teleost; Western IIA vs. NEST). The NMFS Spring and Fall survey in 2020 were cancelled due to Covid-19 restrictions. The 2023 NMFS Spring survey was not included because of a change of survey protocol. The model only uses survey data up to 2024 and excludes the 2025 survey.

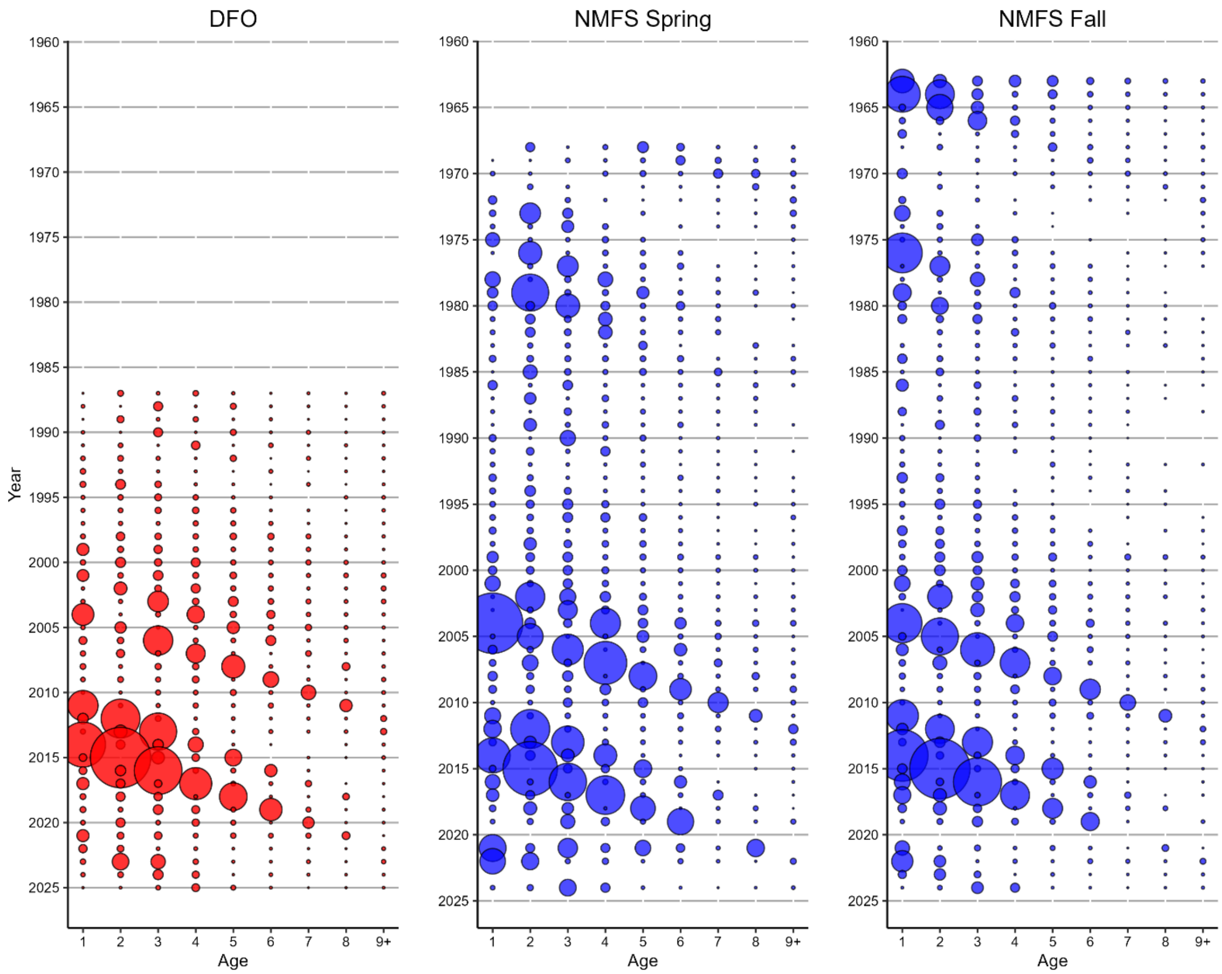

Figure 5. Survey catch-at-age (in numbers) for the Fisheries and Oceans Canada (DFO) Winter Ecosystem Research Vessel survey for 1986 to 2025, the National Marine Fisheries Service (NMFS) Spring survey for 1968 to 2024, and the NMFS Fall survey for 1963 to 2024. Bubble area is proportional to magnitude. Conversion factors to adjust for changes in door type and survey vessel were applied to the NMFS surveys and the DFO Winter RV survey for 2022 and 2025. The NMFS Spring and Fall surveys in 2020 were cancelled due to Covid-19 restrictions and the 2023 NMFS Spring survey was not included because of a change of survey protocol.

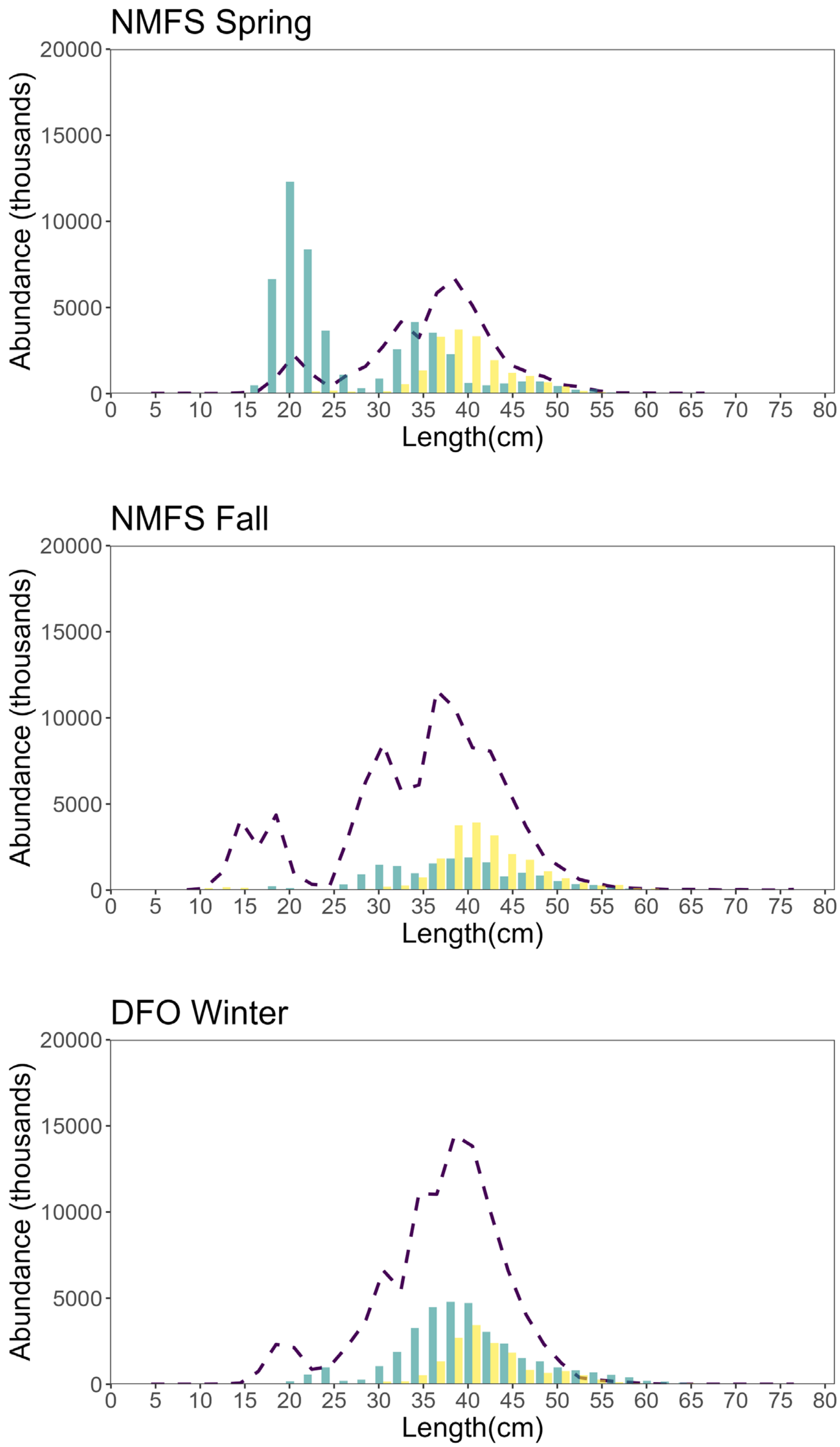

Figure 6. Length-frequency distribution of the National Marine Fisheries Service (NMFS) Spring (2022 and 2024) and NMFS Fall (2023 and 2024) surveys and the Fisheries and Oceans Canada (DFO) Winter Ecosystem Research Vessel survey (2024 and 2025). Bars represent the most recent two years (yellow= most recent year and blue=previous year) and the dashed purple line shows the median abundance from the previous ten years with data.

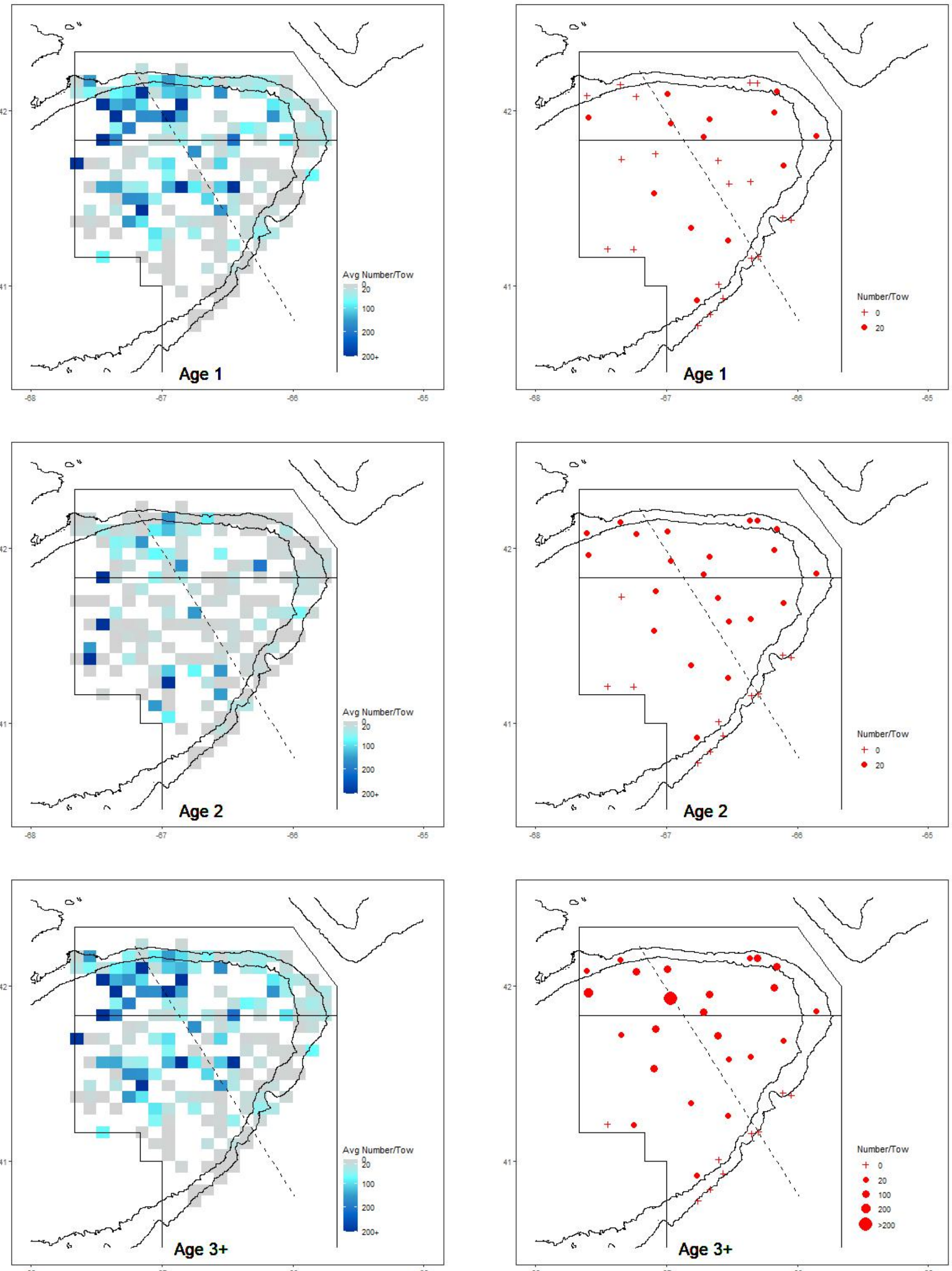

Figure 7. Distribution of eastern Georges Bank Haddock abundance (number/tow) as observed from the National Marine Fisheries Service Spring survey for ages 1, 2, and 3+. The squares (left panels) are shaded relative to the average survey catch for 2012 to 2022 (no survey was conducted in 2020 and the 2023 survey was excluded). The expanding symbols (right panels) represent the 2024 survey catches. Length-based conversion coefficients have been applied since the 2009 survey to make them comparable to surveys undertaken by the Albatross IV. The dashed line marks the international boundary, Hague Line.

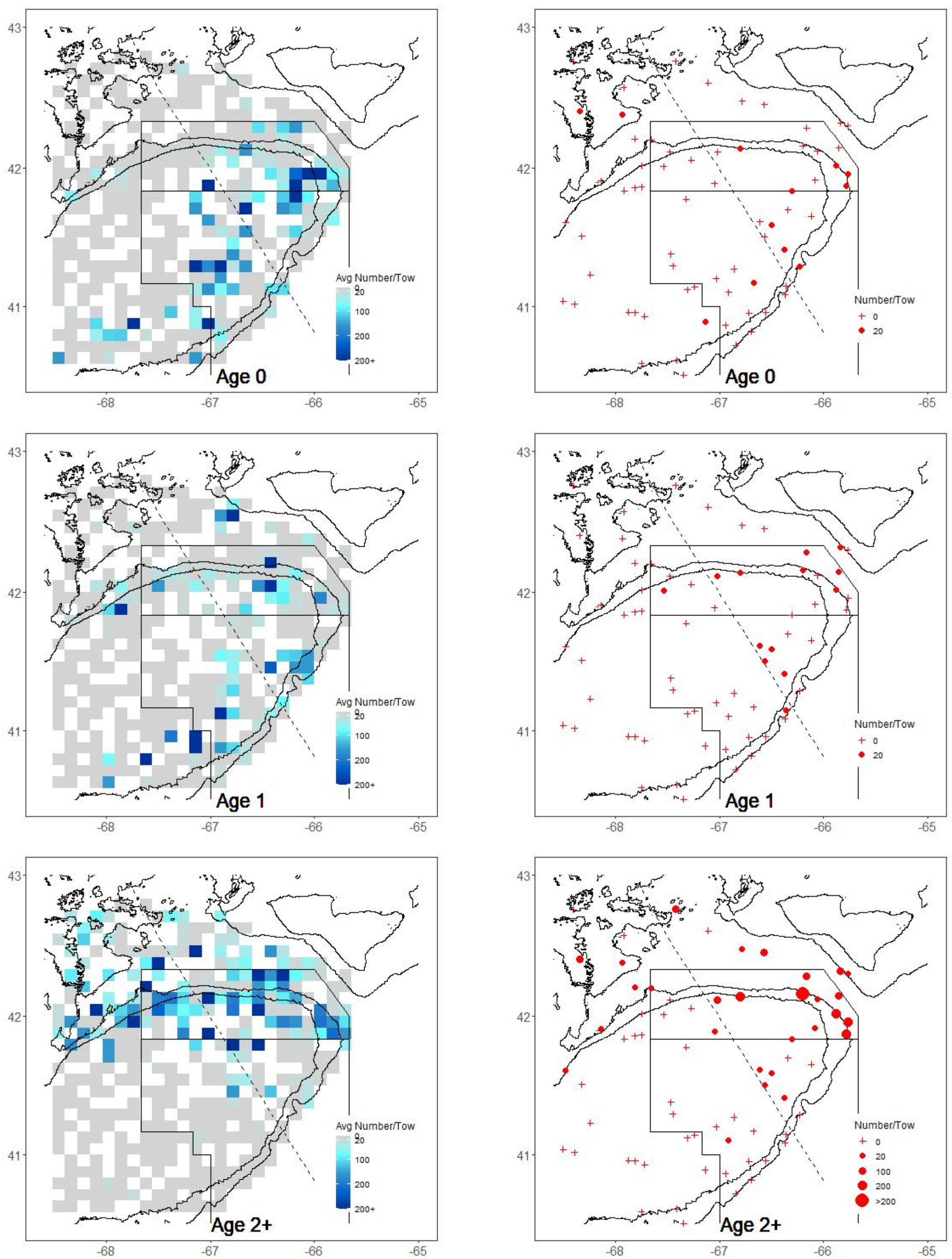

Figure 8. Distribution of eastern Georges Bank Haddock abundance (number/tow) as observed from the National Marine Fisheries Service Fall survey for ages 0, 1, and 2+. The squares (left panels) are shaded relative to the average survey catch for 2013 to 2023 (no survey was conducted in 2020). The expanding symbols (right panels) represent the 2024 survey catches. Length-based conversion coefficients have been applied since the 2009 survey to make them comparable to surveys undertaken by the Albatross IV. The dashed line marks the international boundary, Hague Line.

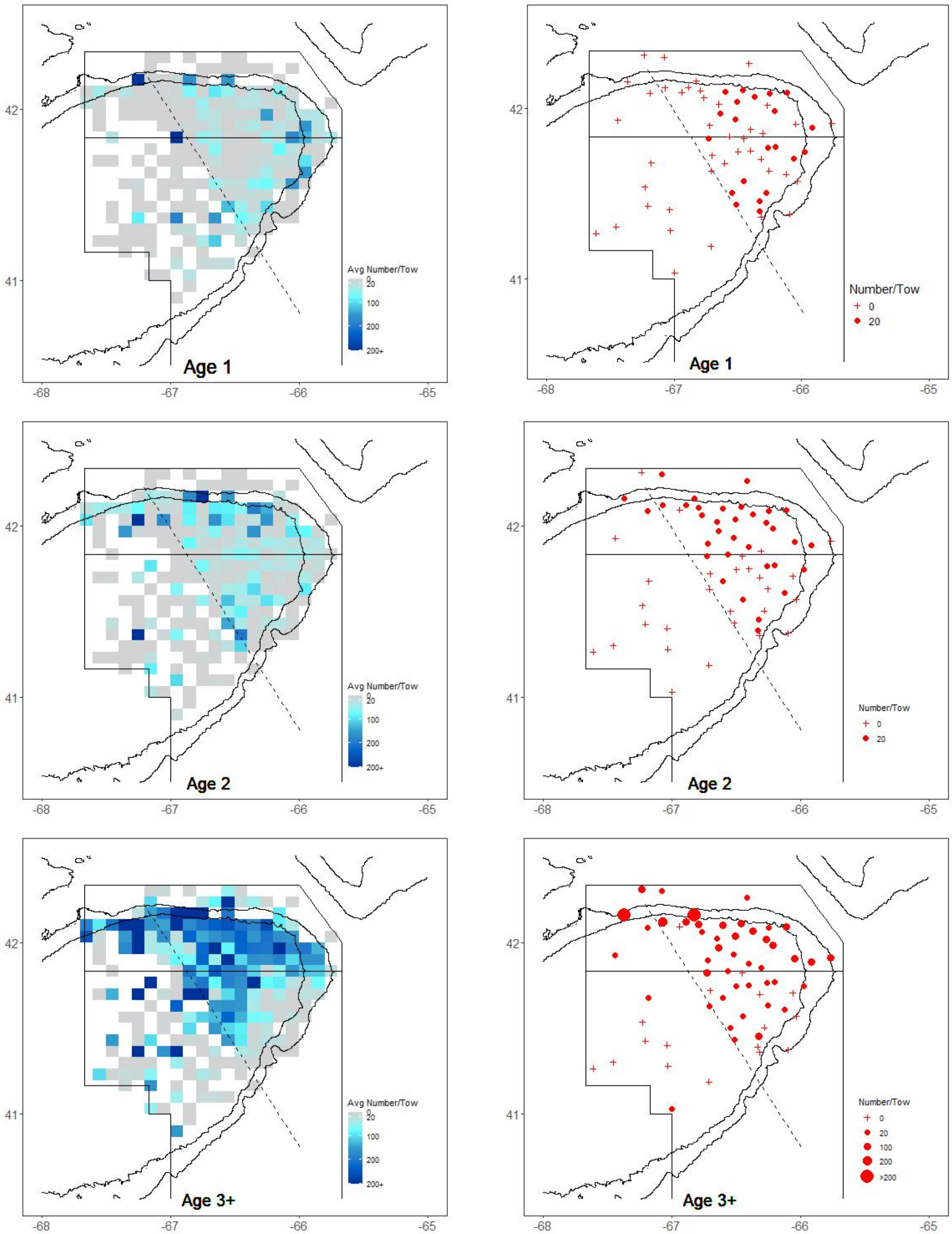

Figure 9. Distribution of eastern Georges Bank Haddock abundance (number/tow) as observed from the Fisheries and Oceans Canada Winter Ecosystem Research Vessel survey. The squares (left panel) are shaded relative to the average survey catch for 2013 to 2024. The expanding symbols (right panel) represent the 2025 survey catches. The dashed line marks the international boundary, Hague Line.

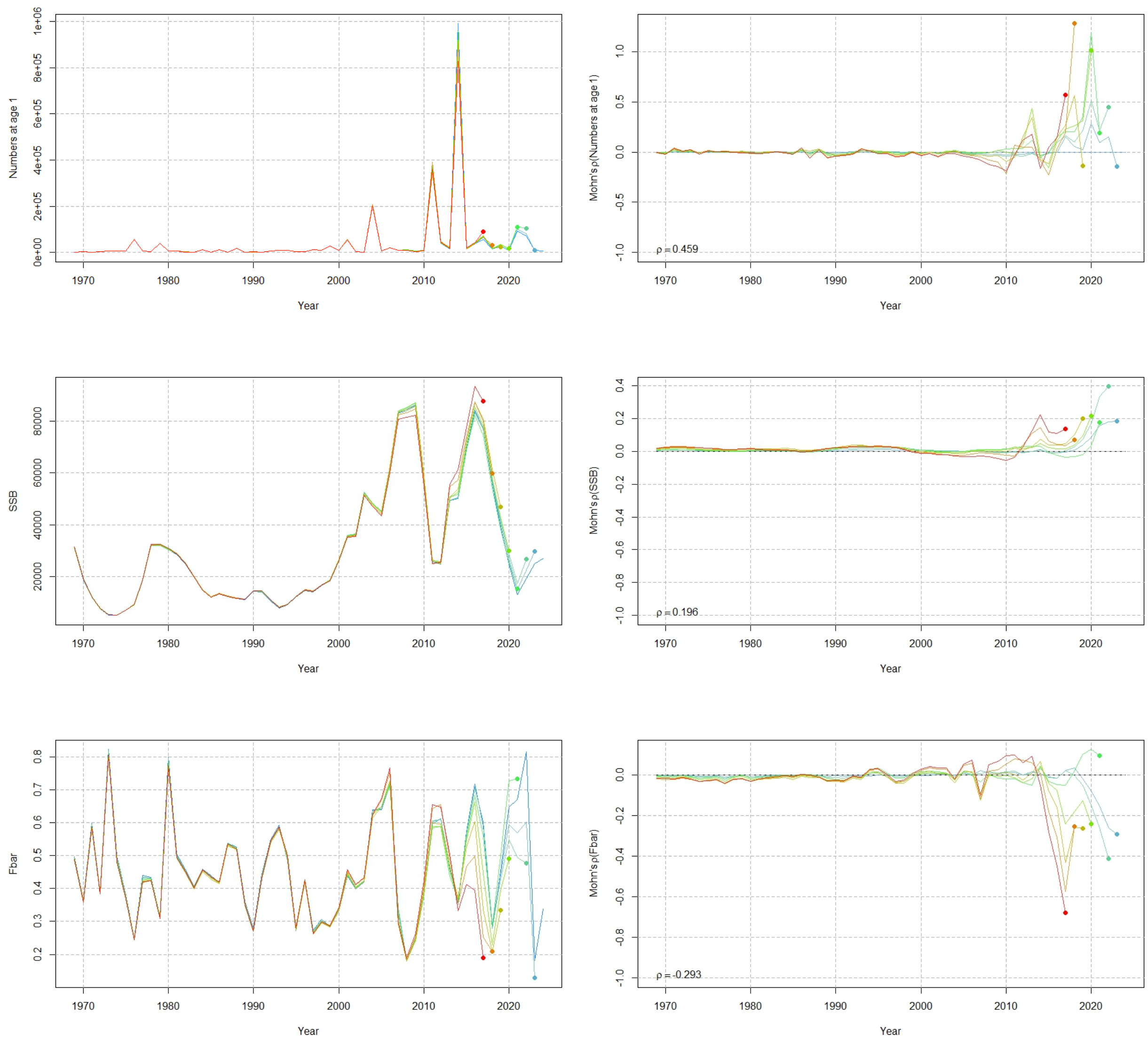

Figure 10. Retrospective analysis of recruitment (numbers-at-age-1), spawning stock biomass (SSB), and mean fishing mortality rate (F_{bar}) of the Base model. Absolute magnitude (left panel) and Mohn's rho (right panel).

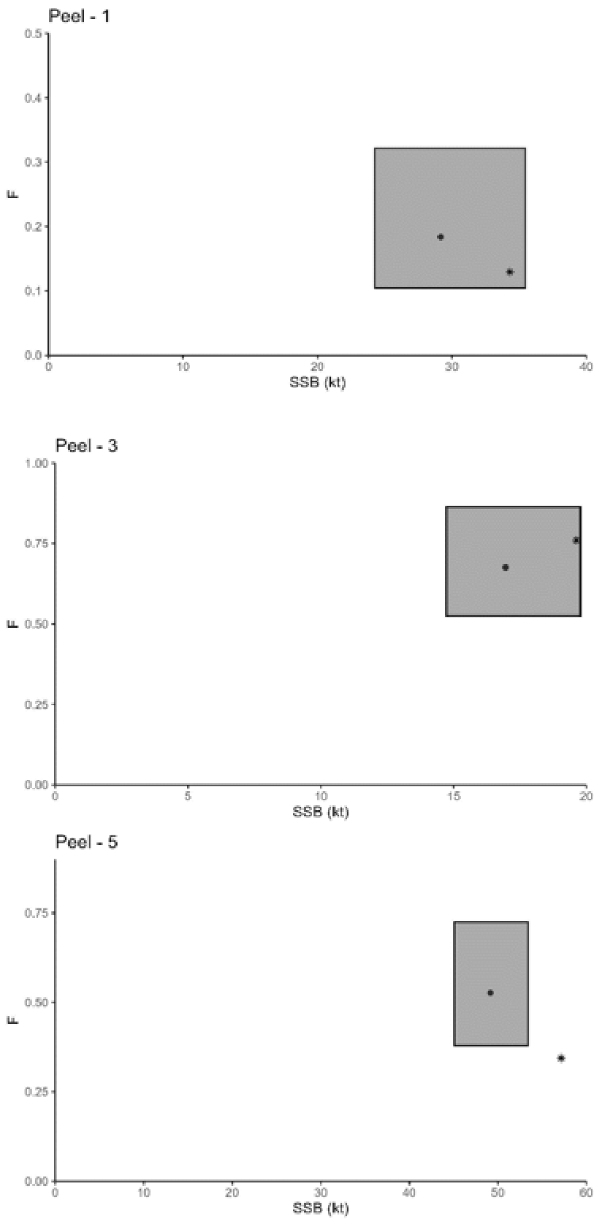

*Figure 11. Retrospective analysis of spawning stock biomass (SSB), and fishing mortality rate (F) of the Base model for five peels. The grey box indicates the 90% confidence intervals for the point estimates from the model (solid point) and the * indicates the point estimates in each year (peel).*

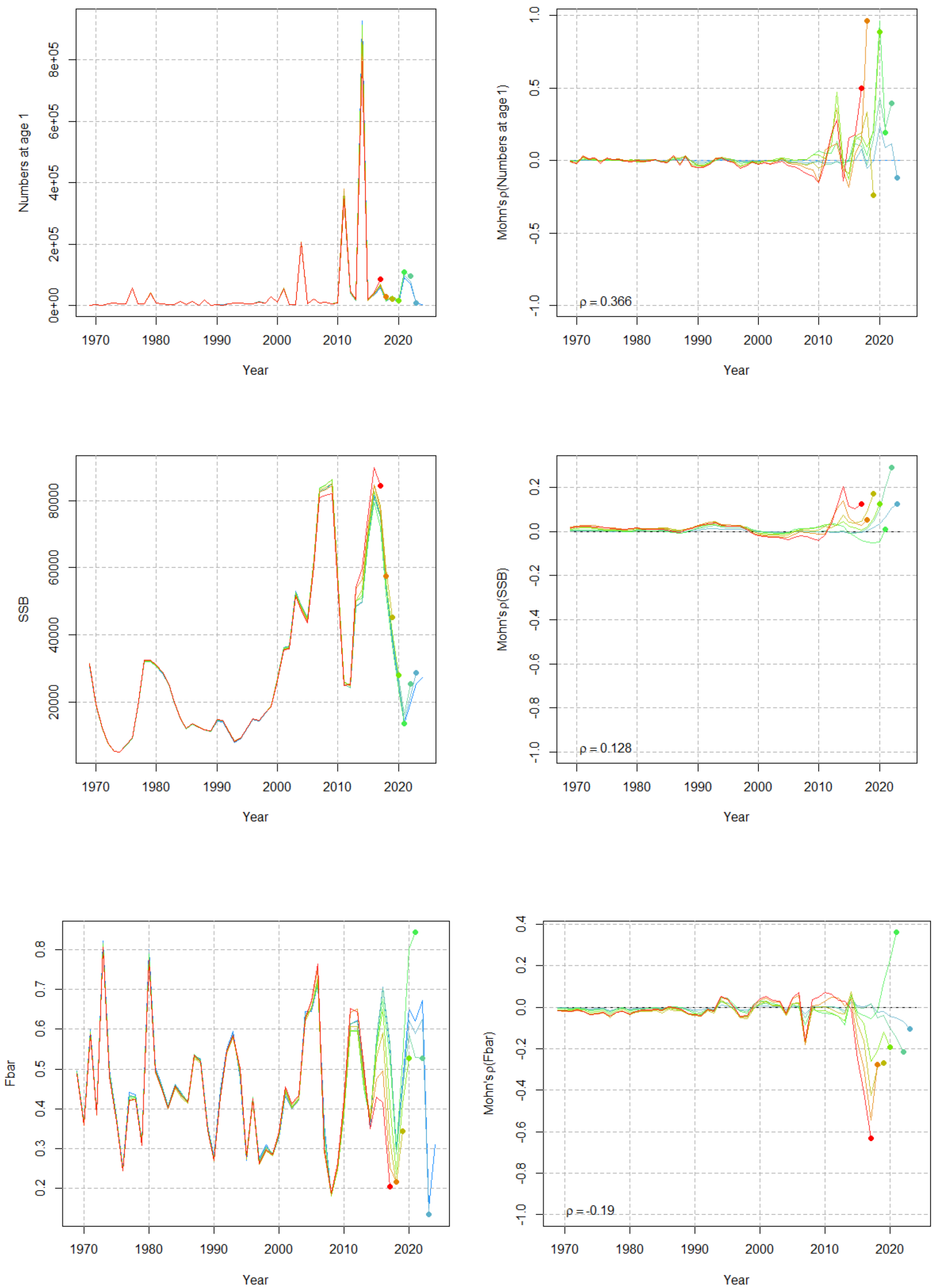

Figure 12. Retrospective analysis of recruitment (numbers at age-1), spawning stock biomass (SSB), and mean fishing mortality rate (F_{bar}) of the chosen assessment model (inclusion of stratum 5Z9). Absolute magnitude (left panel) and Mohn's rho (right panel).

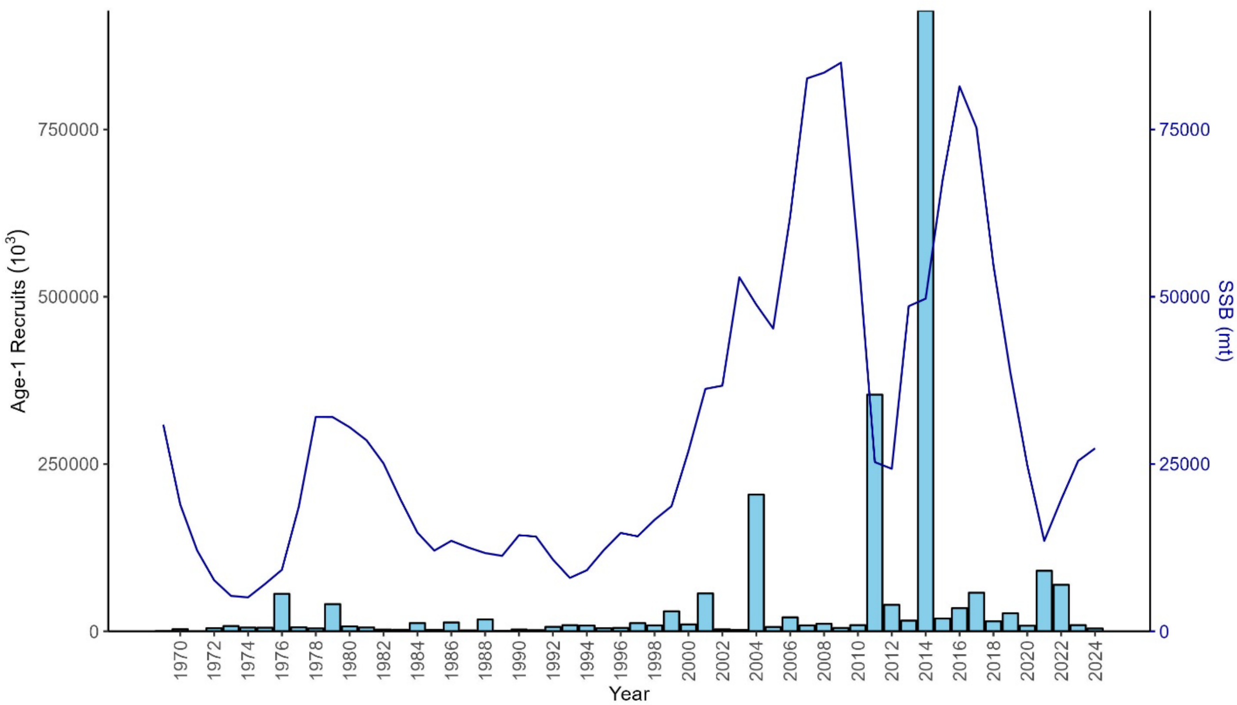

Figure 13. Recruitment at age-1 (bars) and spawning stock biomass (SSB; line) estimated from the model for Haddock on eastern Georges Bank.

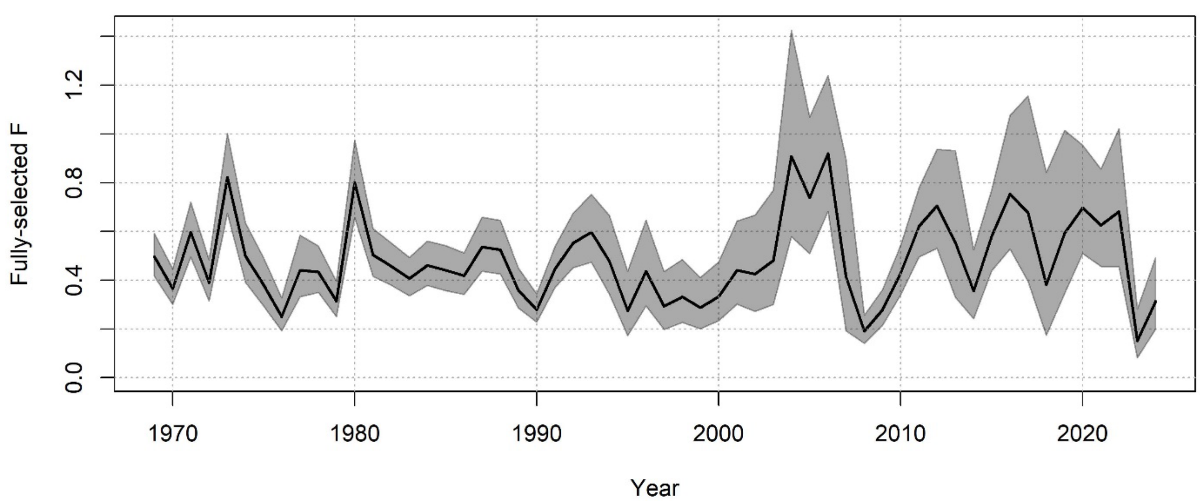

Figure 14. Fully-selected fishing mortality (F) estimated from the model for Haddock on eastern Georges Bank. The black line is the maximum likelihood estimate, the gray shaded area represents the 95% confidence interval. Note that M=0.2 for 1969–2009; M=0.502 for 2010–2024.

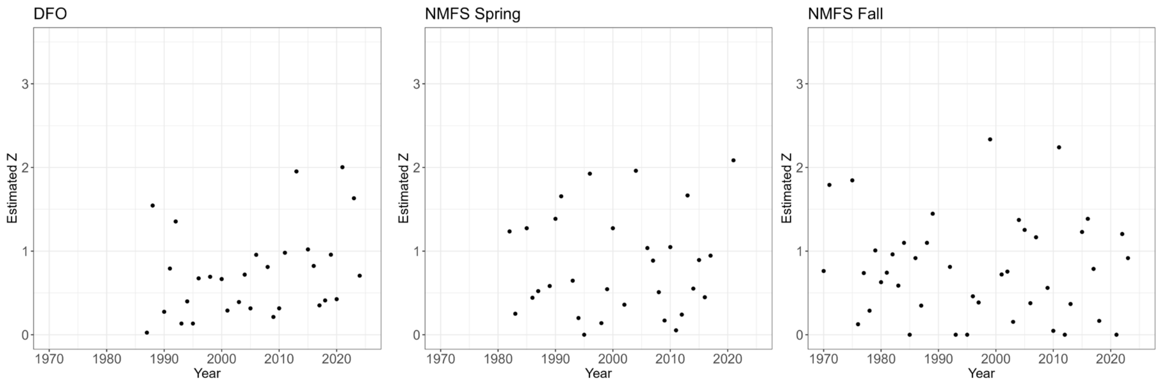

Figure 15. Estimated relative total mortality (Z) (circles) of fish aged 3–6 for Fisheries and Oceans Canada (DFO) Winter Ecosystem Research Vessel survey, and fish aged 4–7 for National Marine Fisheries Service (NMFS) Spring and Fall surveys.

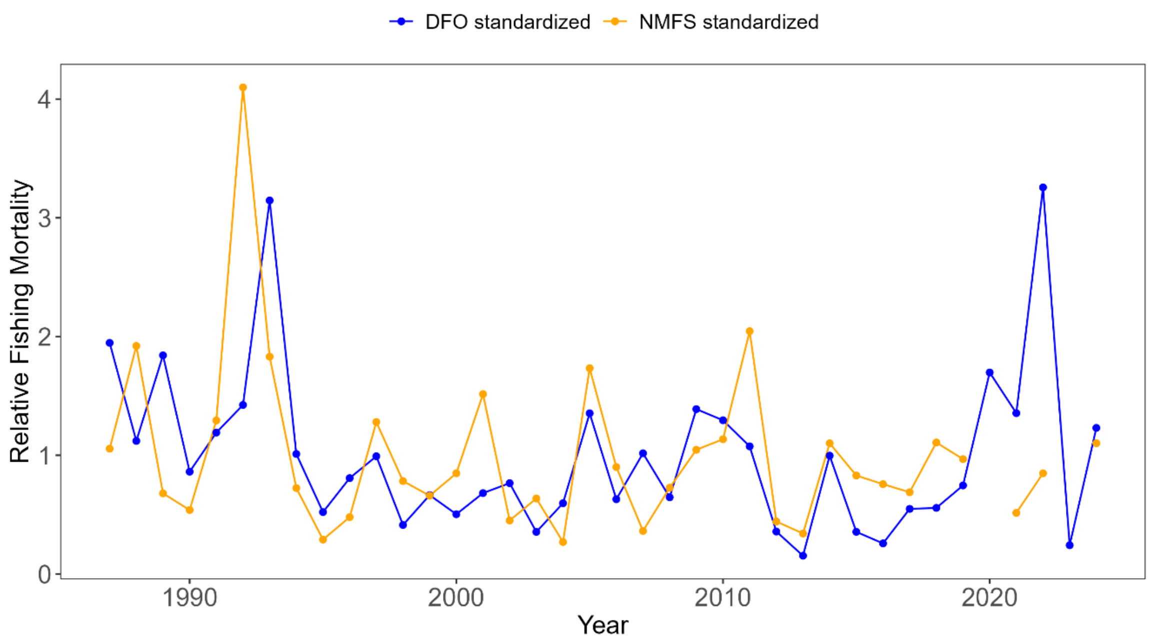

Figure 16. Relative fishing mortality for eastern Georges Bank Haddock derived from the ratio of fishery catch to Fisheries and Oceans Canada (DFO; blue) Winter Ecosystem Research Vessel survey and National Marine Fisheries Service (NMFS) Spring survey (orange) biomass.

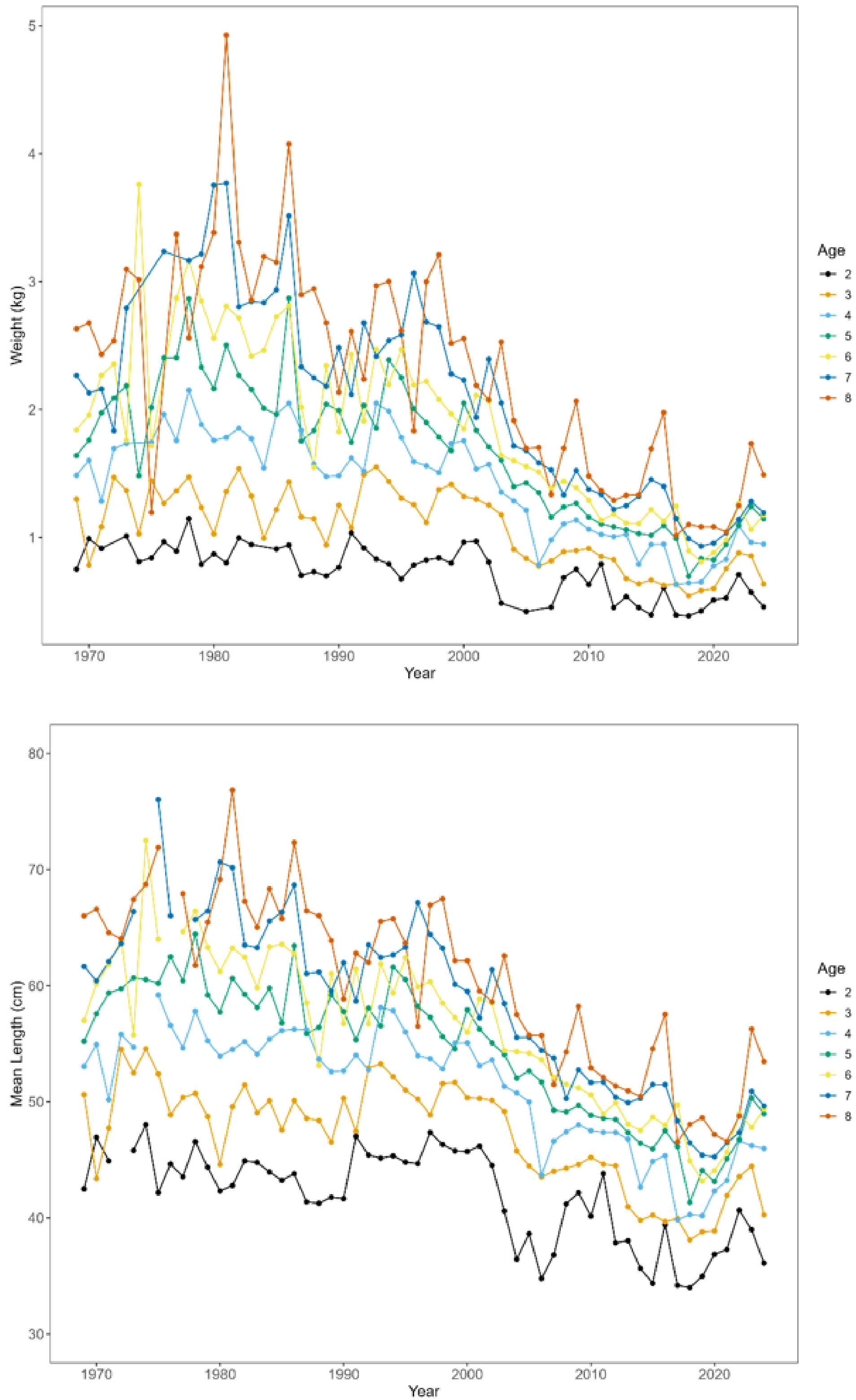

Figure 17. Average weights-at-age (top) and lengths-at-age (bottom) for eastern Georges Bank Haddock from the Canadian commercial groundfish fishery for 1969–2024.

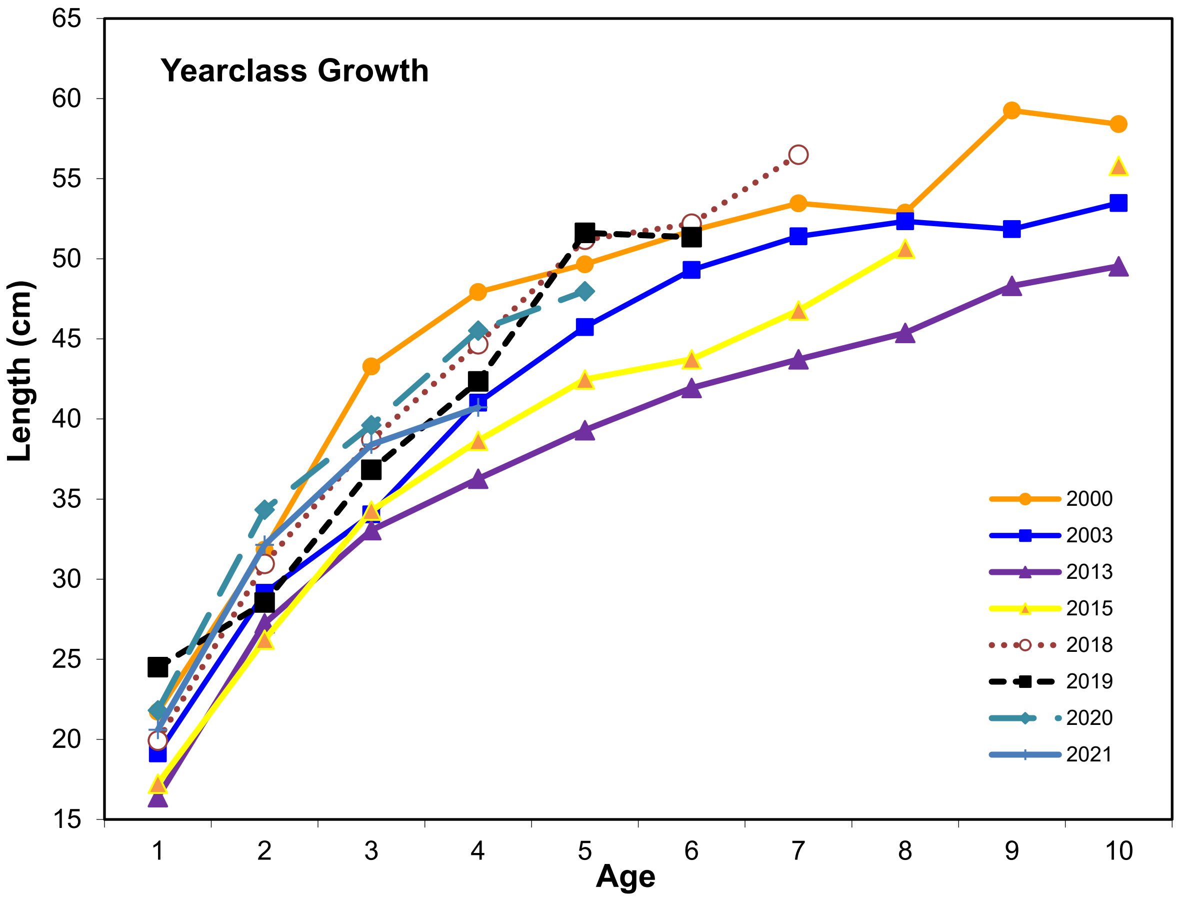

Figure 18. Mean length-at-age for selected year-classes of eastern Georges Bank Haddock sampled from the Fisheries and Oceans Canada Winter Ecosystem Research Vessel survey.

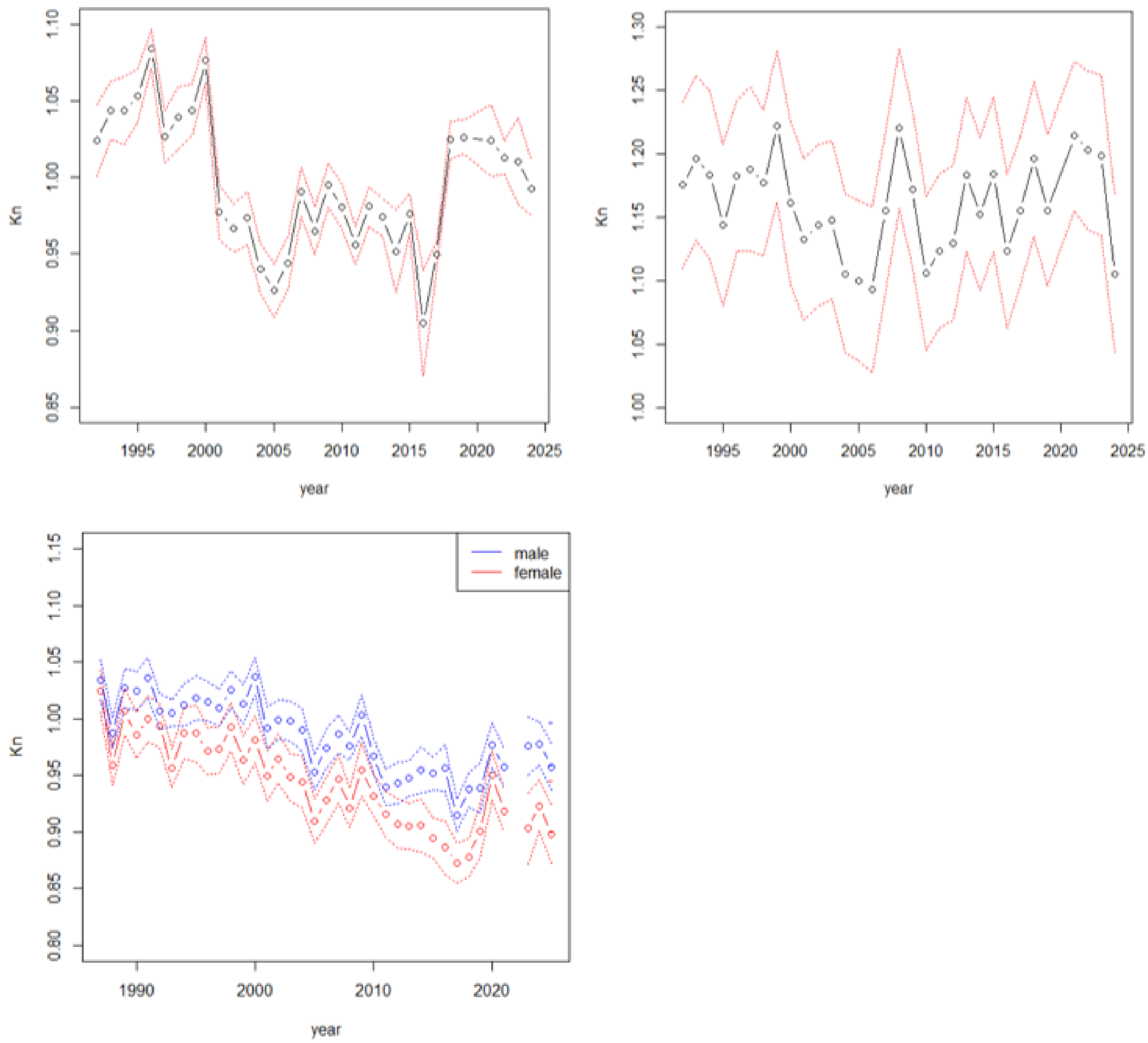

Figure 19. Relative condition factors of National Marine Fisheries Service (NMFS) Spring survey for 1993–2024 (top left panel), NMFS Fall survey for 1993–2024 (top right panel) and the Fisheries and Oceans Canada (DFO) Winter Ecosystem Research Vessel survey for 1987–2025 (bottom left panel). The dotted lines represent the 95% confidence intervals.

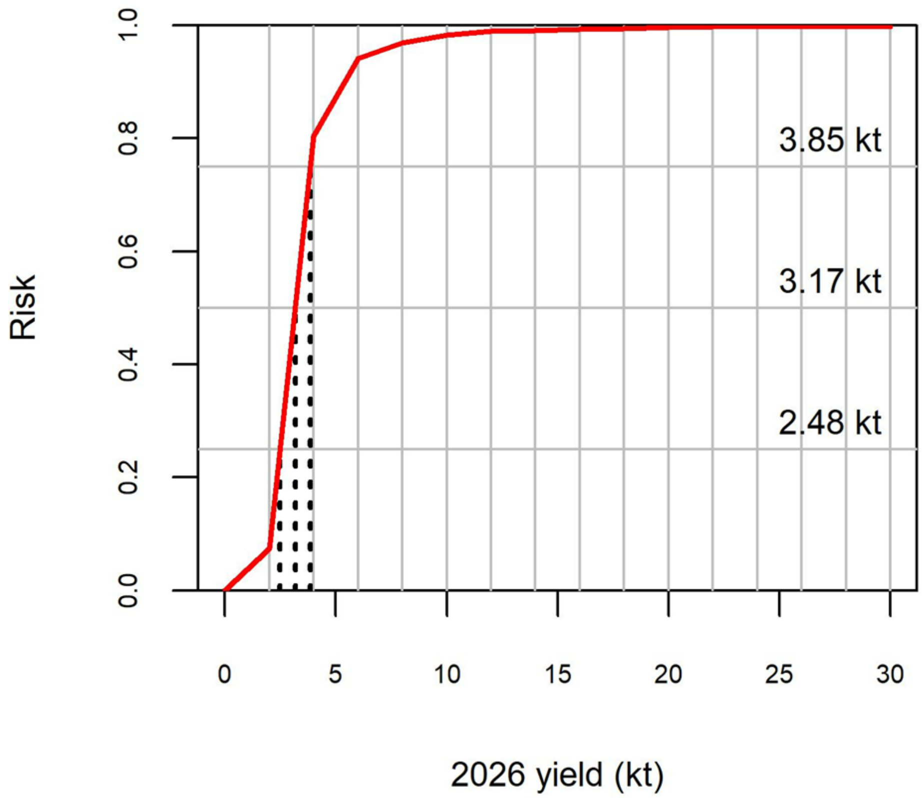

Figure 20. Probability of exceeding the F_{ref} (0.339) in 2026 assuming a 2025 fishery catch of 7,410 mt for Haddock on eastern Georges Bank. Dashed lines denote the 2026 yield (kt) associated with 25%, 50%, and 75% probability of exceeding F_{ref}.

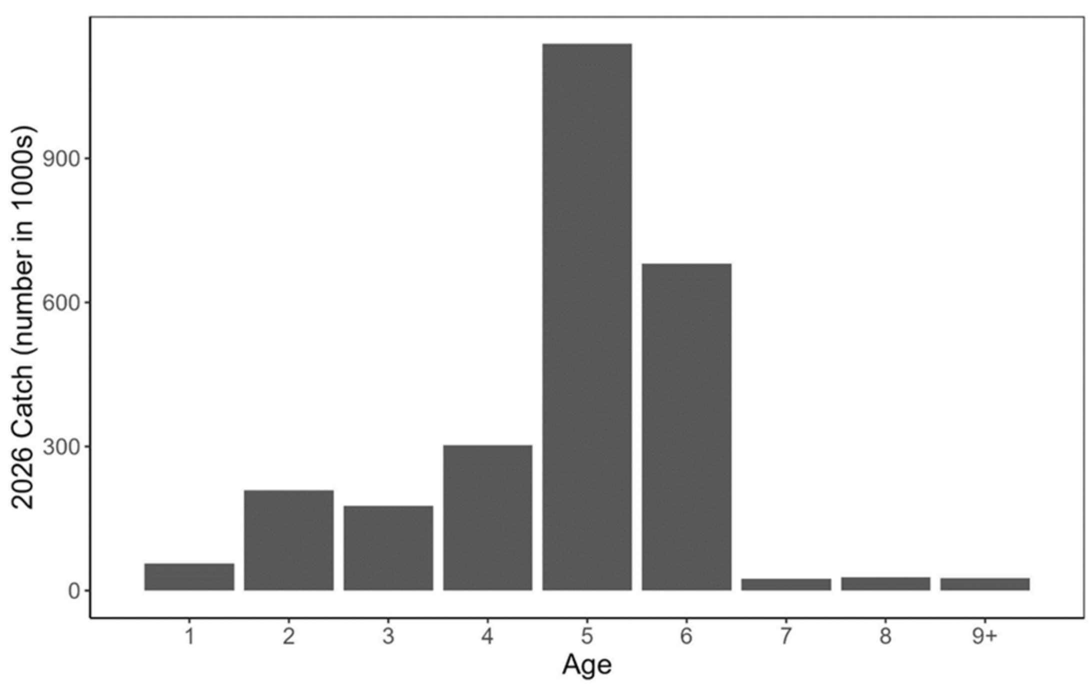

Figure 21. Projected fishery catch-at-age in 2026 for the assessment model with an assumed 2025 fishery catch of 7,410 mt for Haddock on eastern Georges Bank.

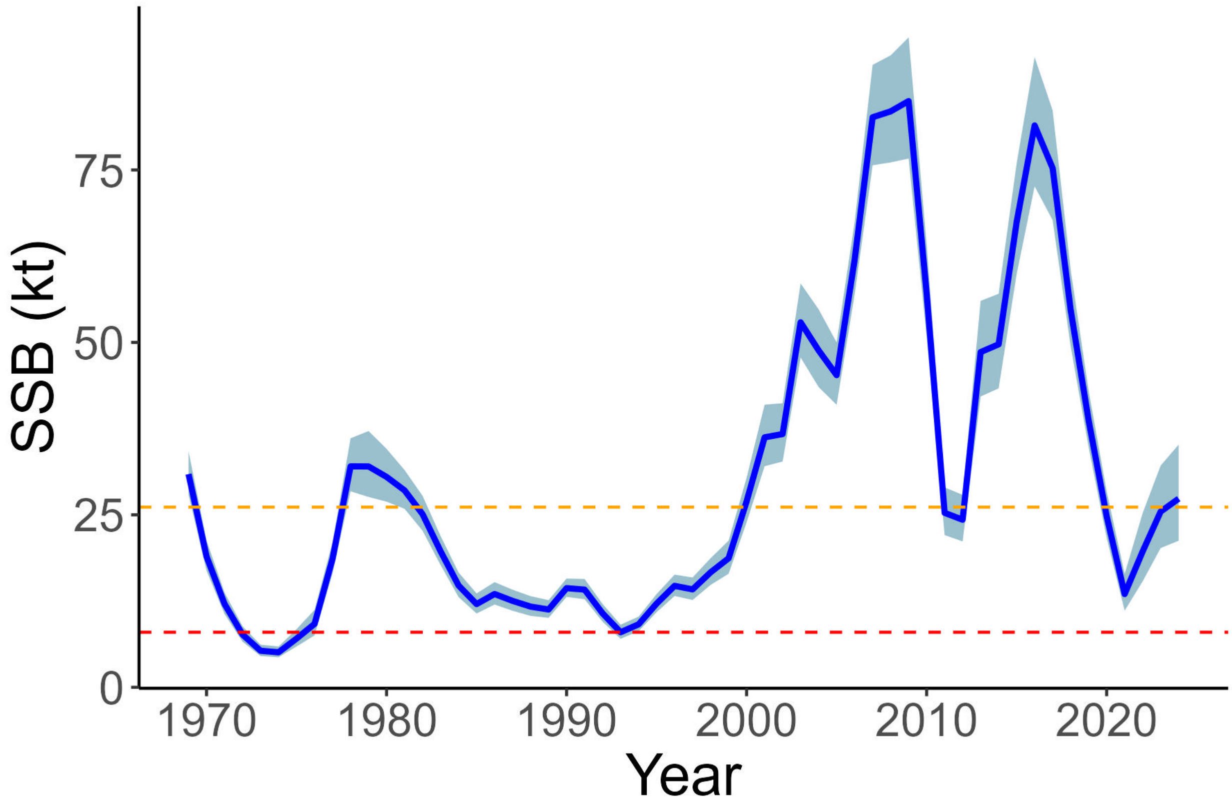

Figure 22. Spawning stock biomass of eastern Georges Bank Haddock relative to the limit reference point (red dashed line) and upper stock reference point (orange dashed line) for the accepted assessment model (including stratum 5Z9 for Fisheries and Oceans (DFO) Winter RV survey).

TABLES

Table 1a. Landings and discards from the Canadian (CAN) eastern Georges Bank Haddock fishery. A dash indicates information is unavailable.

Calendar Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
CAN TAC (mt)	19,200	21,830	20,500	24,000	15,000	13,800	7,614	7,473	2,320	6,900	5,854
CAN Landings (mt)	14,631	11,935	13,377	12,216	14,156	11,045	6,997	5,143	2,499	5,889	-
CAN Discards (mt)	17	8	8	5	4	7	5	7	8	9	-

Table 1b. Landings and discards from the U.S. eastern Georges Bank Haddock fishery. A dash indicates information is unavailable.

Calendar Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
U.S. TAC (mt)	17,800	15,170	29,500	16,000	15,000	16,200	6,486	6,627	1,520	3,100	1,556
U.S. Landings (mt)	1,506	341	214	253	544	633	518	327	299	285	-
U.S. Discards (mt)	415	125	81	21	50	50	6	8	33	26	-

Table 1c. Total landings and discards (Total Catch) from the Canadian and US eastern Georges Bank Haddock fishery. A dash indicates information is unavailable.

Calendar Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
TAC (mt)	37,000	37,000	50,000	40,000	30,000	30,000	14,100	14,100	3,840	10,000	7,410
Total Catch (mt)	16,569	12,409	13,679	12,495	14,735	11,735	7,526	5,485	2,840	6,219	-

Table 2. Projections from the assessment model with an assumed full utilization of the 2025 fishery catch (7,410 mt) of eastern Georges Bank Haddock (median value across 2,000 simulations) and F_{ref}=0.339. SSB=spawning stock biomass. A dash (-) indicates not applicable.

Year	Age 1 Recruitment (000s)	Biomass (mt)	SSB (mt)	Catch (mt)	Fishing Mortality (F)
2025	15,143	26,543	23,713	7,410	0.534
2026	19,397	19,794	15,180	2,990	0.339
2027		20,575	13,963	-	-

Table 3. The diagnostics from sensitivity analyses comparing different M profiles for the most recent time block (2020–2024) in the EGB Haddock assessment model. SSB= spawning stock biomass, Fbar= mean fishing mortality, R= recruitment, rho=Mohn's rho, AIC= Akaike information criterion, dAIC= delta AIC.

Model	Natural mortality (M)	dAIC	AIC	rho_R	rho_SSB	rho_Fbar
M11	0.602	0	-7172.7	0.2711	0.0926	-0.1922
M10	0.557	0.4	-7172.3	0.3585	0.1428	-0.2447
M9	0.513	2.6	-7170.1	0.4589	0.196	-0.2928
M8	0.469	6.5	-7166.2	0.57	0.2509	-0.3362
M7	0.427	11.9	-7160.8	0.6885	0.3065	-0.3745
M6	0.389	18.6	-7154.1	0.8113	0.3617	-0.4081
M5	0.353	26.1	-7146.6	0.9353	0.4157	-0.4371
M4	0.321	34.3	-7138.4	1.0581	0.4677	-0.4622
M3	0.292	43	-7129.7	1.1779	0.5175	-0.4838
M2	0.265	51.8	-7120.9	1.2933	0.5648	-0.5024
M1	0.241	60.8	-7111.9	1.4034	0.6093	-0.5184

Table 4. Catch advice for eastern Georges Bank Haddock for 2026 based on the probabilities of exceeding the F_{ref} value (0.339). SSB= spawning stock biomass, LRP= limit reference point, USR= upper stock reference point.

Probability of exceeding F_{ref}	25%	50%	75%
2026 catch advice	2,480 mt	3,170 mt	3,850 mt
P(SSB_{2027}>LRP)	0.746	0.709	0.679
P(SSB_{2027}>USR)	0.298	0.290	0.281

APPENDIX

Table A1. Input data for the Base model for eastern Georges Bank Haddock.

Data type	List	Description
Fishery	annual aggregate catch (biomass, one fleet)	1969–2024
Fishery	annual CVs for aggregate catch observations	0.1
Fishery	annual fishery age composition (numbers)	1969–2024, ages 1–9+
Fishery	annual effective samples size for age composition	70
Fishery	annual fishery weight at age	1969–2024, ages 1–9+
Survey	annual aggregate catch for NMFS Spring Survey	1969–1972,1982–2024
Survey	annual aggregate catch for NMFS Fall Survey r	1969–2024
Survey	annual aggregate catch for DFO Spring Survey (5Z9 since 2010)	1987–2024, (5Z9 since 2010)
Survey	annual CVs for each index's aggregate observations	Calculated for each survey based on survey design
Survey	annual age composition(numbers) for each index	ages 1–9+ for three surveys
Survey	annual effective sample sizes for each index's age composition observations	40 for three surveys
Survey	Survey timing(month)	3 for NMFS spring survey
Survey	Survey timing(month)	9 for NMFS fall survey
Survey	Survey timing(month)	2 for DFO winter survey
Other	spawning stock weight at age	1969–2024, ages 1–9+
Other	spawning time	0.25
Other	maturity at age data	1969–2024, ages 1–9+

Table A2. Configuration of the Base model for eastern Georges Bank Haddock.

Model feature	**Base configuration**
Modeling/estimation framework	Woods Hole Assessment Model (WHAM, GitHub v1.0.5.9000) (Stock and Miller 2021) using Template Model Builder (TMB v1.7.21) (Kristensen et al. 2016)
Model type	Statistical catch-at-age with random effects for fleet selectivity
Model years	1969–2024
Modeled age classes	1–9+
Fleet structure	Single aggregate fleet
Fleet selectivity	Block 1: 1969–1991, time-invariant logistic
Fleet selectivity	Block 2: 1992–2024, iid random effects in logistic parameters.
Survey selectivity	1969–1972, 1982–2024, NMFS Spring Survey
Survey selectivity	1969–2024, NMFS Fall Survey
Survey selectivity	1987–2024, DFO Winter Survey
Stock recruitment model	Mean recruitment with log deviations estimated as fixed effects.
Natural mortality rate	First Block: 1969–2009, age- and time-invariant M = 0.2
Natural mortality rate	Second Block: 2010–2024, age- and time-invariant, M estimated.
Likelihood function for fishery catch and survey index data	Lognormal
Likelihood function for catch age-composition data	Logistic-normal, ignoring zeros (self-weighted)
Likelihood function for survey age-composition data	Logistic-normal, ignoring zeros (self-weighted)
Process errors (survival deviations) for numbers-at-age	None
Approach to characterizing model uncertainty	Multivariate normal sampling of parameters from the inverse Hessian (variance-covariance matrix)
Reference point calculation and short-term projections	openMSE (Hordyk et al. 2021)

Table A3. Input data for projections used to provide 2026 catch advice for eastern Georges Bank Haddock.

	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9+
Stock Weight at Age (kg) 2022–2024	0.096	0.318	0.561	0.800	1.066	1.165	1.198	1.232	1.455
Fishery Weight at Age (kg) 2022–2024	0.357	0.571	0.781	0.957	1.095	1.104	1.167	1.382	1.359
Natural Mortality 2024	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502	0.502
Selectivity 2022–2024	0.042	0.182	0.527	0.843	0.964	0.992	0.998	1.000	1.000
Maturity at Age 2022–2024	0.076	0.640	0.870	1	1	1	1	1	1