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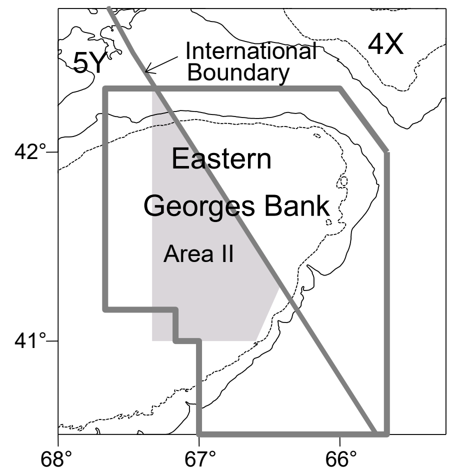
EASTERN GEORGES BANK HADDOCK

[5Zjm; 551,552,561,562]



SUMMARY

- Combined Canada and United States of America (USA) eastern Georges Bank (EGB) haddock catches in 2022 were 5,477 mt and represented 39% of the combined 14,100 mt quota.
- Spawning stock biomass (SSB) for EGB haddock has declined sharply since 2016. The SSB estimate for 2022 is 26,867 mt, which is above the median SSB of 24,929 mt for the time series (1969–2022).
- Recruitment, while highly variable, tends to be higher when SSB is above 20,000 mt. The EGB haddock stock has produced several exceptionally strong year classes since 2003. The median age-1 recruitment for the time series (1968–2021 year classes) is 8.9 million. The model estimates of the 2020 and 2021 year classes are 109 million and 126 million age-1 fish, respectively.
- The 2020 and 2021 year classes appear to be the largest since 2013 based on estimates from the 2023 base model, the 2022 National Marine Fisheries Service (NMFS) spring and fall surveys, and the 2023 Fisheries and Oceans Canada (DFO) survey.
- With the sharp decrease in biomass in the last few years, slight increases in both EGB haddock length- and weight-at-age have been observed in the fishery and surveys.
- The F_{ref}=0.26, previously adopted by the Transboundary Management Guidance Committee (TMGC), was deemed no longer appropriate as the F_{ref} for EGB haddock. TMGC requested that two options for F_{ref} be explored to provide catch advice for 2024.
- TRAC recommended using the F_{ref}= 0.367 (data inputs from 2017–2021) based on the exploration and simulation testing of this option at the 2022 TRAC meeting.

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- Fishing mortality was estimated to be 0.47 and 0.53 for 2021 and 2022 respectively, which are above both of the fishing mortality reference (F_{ref}) values considered.
- Considering the uncertainties of the natural mortality (M) rate in the near future, projections were conducted at F_{ref}=0.367 under two different M scenarios for EGB haddock. The catch advice provided was to use High M or to use the range of projected catch bounded by the High M and Low M scenarios; however, the TRAC did not agree on which option was more appropriate. TRAC suggested that the Low M catch advice at the low risk of exceeding F_{ref} (25%) should be considered as an upper bound (12,280 mt). The High M catch advice is provided for low (7,960 mt) to neutral (9,740 mt) levels of risk.

FISHERY

Combined Canada and USA catches for eastern Georges Bank (EGB) haddock declined from 6,504 mt in 1991 to a low of 2,150 mt in 1995, varied between 2,865 mt and 4,094 mt until 1999, and increased to 15,248 mt in 2005 (Figure 1; Table A1). From 2006 to 2020, catches varied between 11,735 mt and 19,856 mt apart from a decrease to just above 5,000 mt in 2012 and 2013. The total catch decreased to 7,526 mt in 2021 and then to 5,477 mt in 2022. The total catch in 2022 represented 39% of the combined 14,100 mt quota (a reduction of more than half from 30,000 mt in 2020; Table 1).

Table 1. Catches (mt) of eastern Georges Bank Haddock. A dash (-) indicates not applicable.

		2019	2020	2021	2022	2023	Avg[1]	Min[1]	Max[1]
Canada[2]	**Quota**	15,000	13,800	7,614	7,473	2,320[6]	-	-	-
	Landed	14,156	11,045	6,997	5,143	-	6,576	462	17,595
	Discard	4	7	5	7	-	86	4	186
USA[2]	**Quota[3]**	15,000	16,200	6,486	6,627	1,520[7]	-	-	-
	Catch[3]	715	563	417	260	-	-	-	-
	Landed	544	633	518	327	-	1,769	15	9,081
	Discard	50	50	6	8	-	439	0	7,561
Total[2]	**Quota[4]**	30,000	30,000	14,100	14,100	3,840	-	-	-
	Catch[4]	14,875	11,615	7,418	5,485	-	-	-	-
	Catch[5]	14,754	11,735	7,526	5,477	-	8,801	2,150	23,344

[1] 1969-2022
[2] unless otherwise noted, all values are reported for the calendar year
[3] for fishing year from May 1st–April 30th
[4] for Canadian calendar year and USA fishing year May 1st–April 30th
[5] sum of Canadian landed, Canadian discards, and USA catch (including discards)
[6] Canadian adopted quota for 2023.
[7] USA adopted quota for 2023

The **Canadian catch** decreased from 7,001 mt in 2021 to 5,150 mt in 2022. Discards in the groundfish fishery are considered to be negligible. Discards of haddock by the Canadian sea scallop fishery were 7 mt in 2022, but ranged between 4 mt and 186 mt over the time series. Canada caught 69% of its 7,473 mt allocation.

USA catches decreased from 524 mt in 2021 to 334 mt in 2022. Landings in 2022 were 327 mt and discards were estimated to be 8 mt. The USA caught 4% of its 6,627 mt allocation.

The 2020 year class at age 2 was a major contributor to the 2022 Canadian fishery catch (landings and discards; 55% of the fish by number), followed by the 2018 year class at age 4 (14% by number; Figure 2). In 2022, fish aged 9+ accounted for only 9% of the individuals caught in the Canadian fishery. The **size compositions** of the 2022 Canadian fishery catches were derived from port samples and at-sea samples separated out by quarter for the principal gears. Catches by otter trawl gear in 2022 peaked at 40.5 cm (16 in), a decline in size from the 2021 fishing season (Figure 4). Catches by long line gear peaked at 48.5 cm (19 in), consistent with the 2021 season. Catches of discards (dredge) were variable but peaked at 12.5 cm to 30.5 cm (6 to 12 in).

The USA **fishery age composition** (landings and discards) in 2022 was dominated by the 2013 (age 9+; 41% by number) and 2016 (age 6; 20% by number) year classes (Figure 3). In general, sampling for the USA fishery was poor in both 2021 and 2022. The **size compositions** of the 2022 USA fishery catches were derived from pooled port samples and at-sea samples. Catches by otter trawl gear in 2022 peaked at 42 cm (16 in) and 50 cm (20 in; Figure 4).

HARVEST STRATEGY AND REFERENCE POINTS

The Transboundary Management Guidance Committee (TMGC) has adopted a strategy to maintain a low to neutral risk of exceeding the fishing mortality reference (F_{ref}). When stock conditions are poor, fishing mortality rates should be further reduced to promote rebuilding.

A new assessment model for EGB haddock passed peer review in March 2022. The results of this new model suggested that the F_{ref}=0.26, derived from the 2002 Virtual Population Analysis (VPA) model output and previously adopted by TMGC (TMGC Meeting Summary, Oct. 2, 2003), was no longer appropriate. The new candidate F_{ref} was calculated using $F_{40\%SPR}$ (fishing mortality rate at 40% spawner per recruit) as a proxy for F_{MSY} (fishing mortality rate at maximum sustainable yield). The $F_{40\%SPR}$ associated with the higher natural mortality rate (M) in the 2010–2019 period was extremely high (>3); therefore, the Low M scenario was proposed for the $F_{40\%SPR}$ calculation.

In the 2022 Transboundary Resources Assessment Committee (TRAC) EGB haddock assessment, retrospective forecasting using the OpenMSE framework (Hordyk et al. 2022) was conducted to evaluate the performance of management procedures (MPs) with different time periods (5, 10, 15, and 25 years) for the data used to estimate $F_{40\%SPR}$ and a scheduled update for the $F_{40\%SPR}$ reference point every 2 to 7 years. The TRAC recommended a $F_{40\%SPR}$=0.367 as the F_{ref} which was based on the most recent 5 years of data (2017–2021) and an update to the reference point every 3 years for consideration to the TMGC. This was based on higher yields, intermediate inter-annual variability in yield, and higher biomass outcomes than other MPs. At the TMGC intersessional meeting in spring 2023, TMGC suggested catch advice be provided based on the risks of exceeding two reference points 1) the F_{ref} proposed by TRAC in 2022 where F_{ref}=0.367, and 2) a new F_{ref} based on $F_{40\%SPR}$ calculated using the most recent 5 years of data and model results (2018–2022).

STATE OF RESOURCE

The state of the resource is based on the EGB haddock model developed at the haddock Research Track Assessment (Base model with data from 1969–2019; Wang et al. 2022; see *Special Considerations* section). In the current model, M is fixed at 0.2 from 1969 to 2009 and M is estimated in the model as a single value for the period 2010 to 2022. Alternative configurations of the model were examined, but the state of the resource is based on the Base model updated with data through 2022 (Tables A2 and A3).

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 year classes have been poor at contributing to the fishery. Density-dependent changes in growth have occurred and, presently, the contribution of the large 2013 year class to the stock has greatly diminished. As a consequence, overall stock size has been reduced. There is some preliminary evidence of relatively strong 2020 and 2021 year classes (Figures 2 and 5), which are expected to begin to recruit to the fishery in 2023 and 2024.

Improved recruitment since 1990, lower exploitation, and reduced capture of small fish in the fisheries all contributed to the **spawning stock biomass** (**SSB)** estimate increasing to 52,000 mt in 2003. A subsequent increase to 85,000 mt in 2009 was largely due to the strong 2003 year class, estimated at 205 million age-1 fish. The biomass sharply decreased after the 2009 high, and in 2012 the SSB was estimated at 25,000 mt. When the strong 2010 and 2013 year classes became sexually mature, the estimated SSB increased to 83,000 mt in 2016, followed by a sharp and continued decline in the subsequent years. Despite the recruitment being much higher in the 2010 and 2013 year classes compared to the 2003 year class, the SSB did not increase as much, hypothesized to be due to the increased M beginning in 2010. The current SSB estimate for 2022 is 26,867 mt, which is above the median SSB of 24,929 mt for the time series (1969–2022; Figure 5; Table A4).

Recruitment at age 1 has fluctuated between 1.7 and 67 million since 1990, except for the strong year classes. The 2003, 2010, and 2013 year classes were estimated at 205, 351, and 914 million, respectively. The model estimates of the 2020 and 2021 year classes are 109 and 126 million age-1 fish. The median recruitment for the time series (1968–2021 year class) is 8.9 million (Figure 5; Table A5).

Fully recruited **fishing mortality** varied throughout the time series, fluctuating between 0.19 in 2008 to 0.91 during the mid-2000s (Figure 6). Fishing mortality was estimated to be 0.47 and 0.53 for 2021 and 2022, respectively, which are above both of the F_{ref} values considered.

The **swept area biomass indices** in the NMFS fall and DFO survey are consistent and track each other well (Figure 7). There has been a sharp increase and then a decline in the last decade for both DFO and NMFS fall surveys. Despite some year effects, all three surveys show the recovery from the mid-1990s followed by a steady increase due to better recruitment since the 2000s. In 2022, the survey swept area biomass decreased from 2021 for the NMFS spring survey, and increased for the NMFS fall survey. The average swept area biomass was 19,341 mt for 2022 for both USA surveys, a decline from 2021 (currently excludes the DFO 2022 survey that was conducted using new gear configurations, on a new vessel; Table A6). In 2023, the DFO survey swept area biomass estimate was 56,922 mt; this was driven by one large tow in stratum 5Z1.

Productivity

Recruitment, **natural mortality**, **growth**, **age structure** and **spatial distribution** generally reflect changes in the productive potential of the stock. Recruitment has been highly variable. Higher recruitment tends to occur when SSB is above 20,000 mt (Figure 8). This stock has produced three exceptional and five strong year classes in the last 22 years. However, the Base model estimates a substantial increase in M from the historical assumed level of 0.2 to a 13 year time block where M is estimated at 0.493. Estimated total mortality (Z), based on survey estimates of fully recruited age groups and relative F (catch/survey), was examined for changes in M. Both varied among years and missing survey data made comparison of trends difficult (Figures A1 and A2).

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 abundance 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 in both the fishery and survey data, although the length- and weight-at-age are within the range observed during 2010–2019 for most ages (Figure 9). Fish condition has been elevated in the most recent three years, but missing survey values make interpretation of this pattern challenging (Figure 10).

Due to both high M and F in the most recent years, the contribution of the exceptionally strong 2013 year class to the SSB and the 2024 fishery is expected to be small (Figure 11). The age distribution of the catch in 2024 is predicted to be primarily comprised of recruits from the 2020 and 2021 year classes (Figure 11), which is consistent with the catch composition of the surveys (Figure 12 and Tables A7-A9). The length frequency of the survey catch for the 2022 NMFS spring survey peaked at 20 cm (8 in), the 2022 NMFS fall survey catch peaked at 30 cm (12 in), and the 2023 DFO survey peaked at 32 cm (13 in; Figure 13). The spatial distribution patterns observed during these bottom trawl surveys are generally similar to the average patterns over the previous ten years (Figures A3-A5).

This outlook is provided with respect to the proposed F_{ref} =0.367 for catch advice in 2024. In addition, $F_{40\%SPR}$ was estimated using the most recent 5 years of data inputs and model results (2018-2022) and catch projections with respect to the resulting F_{ref} value (F_{ref} =0.380; Table A10).

The full quota for EGB haddock has not been utilized since 2004, when the TMGC began setting the Total Allowable Catch (TAC). In the past 10 years, between 27–53% of the TAC was utilized. This is largely driven by lower USA catches relative to the USA allocation (TRAC 2021) and the Canadian fleet-share arrangements. Based on the lower quota for 2023 and the recent history of USA catches, 3,000 mt was assumed to be the most appropriate estimate for the 2023 catch in the projections. This value was based on the Canadian fleet catching all of their 2,320 mt quota and a USA catch consistent with the average of the last 4 years (approximately 550 mt).

At the 2022 TRAC meeting, two projection scenarios (Low M and High M) and risk evaluation with different assumptions on future M were reviewed. The Low M scenario assumed a return to M=0.2 and the High M (M derived from the model) scenario assumed that future M would remain the same as 2010–2022. Catch advice is provided herein for 2024 for both F_{ref} values as requested by the TMGC. A comparison of projection inputs for 2023 and 2024 are summarized in Table A11.

Low M scenario

A Low M scenario is used to provide an upper bound on catch advice.

Catch Advice based on F_{ref} = 0.367

Assuming a return to historical Low M=0.2 in 2023–2025, Table 2 shows the median estimates of biomass, SSB, and F in 2023 based on 2,000 realizations of terminal year population sizes and an assumed 2023 catch of 3,000 mt. For 2024, the median biomass, SSB, and catch estimates are obtained by applying an F=0.367 to each realization conditional on an assumed catch of 3,000 mt in 2023. The risk analysis in Figure 14 applies a similar logic to estimate the probability of exceeding F=0.367 in 2024 (by assuming a 2023 catch of 3,000 mt) given various catch levels ranging from 0 mt to 30,000 mt in steps of 2,000 mt. The levels of catch associated with 25%, 50%, and 75% of risk are estimated by linear interpolation such that the catch associated with the 50% probability of exceeding F_{ref} =0.367 (15,030 mt) in Figure 14 differs slightly from the equivalent median catch for 2024 (14,980 mt) reported in Table 2.

The median SSB is projected to increase from 41,336 mt in 2023 to 66,543 mt in 2024, and to 74,746 mt in 2025. In 2023, fishing mortality (F) is estimated to be 0.144 assuming a catch of 3,000 mt (Table 2). The median catch at the proposed F_{ref} =0.367 in 2024 is 14,980 mt. The stock biomass is projected to increase in both 2024 and 2025. The assumed higher survival of recruits in the projections (from 0.493 in model years to 0.2 in projection years) is responsible for the increase. The 2020 year class at age 4 and the 2021 year class at age 3 are projected to be the dominant contributors to fishery catch in 2024 due to the lack of older fish in the population and low selectivity of younger age groups (Figure 11).

Catch Advice based on F_{ref} = 0.380

Assuming a return to historical Low M=0.2 in 2023–2025, Table 2 shows the median estimates of biomass, SSB, and F in 2023 based on 2,000 realizations of terminal year population sizes and an assumed 2023 catch of 3,000 mt. For 2024, the median biomass, SSB, and catch estimates are obtained by applying an F=0.380 to each realization conditional on an assumed catch of 3,000 mt in 2023. The risk analysis in Figure 14 applies a similar logic to estimate the probability of exceeding F=0.380 in 2024 (by assuming a 2023 catch of 3,000 mt) given various catch levels ranging from 0 mt to 30,000 mt in steps of 2,000 mt. The levels of catch associated with 25%, 50%, and 75% of risk are estimated by linear interpolation such that the catch associated with the 50% probability of exceeding F_{ref} =0.380 (15,460 mt) in Figure 14 differs slightly from the equivalent median catch for 2024 (15,447 mt) reported in Table 2.

The median SSB is projected to increase from 41,336 mt in 2023 to 66,543 mt in 2024, and to 74,339 mt in 2025. In 2023, F is estimated to be 0.144 assuming a catch of 3,000 mt (Table 2). The median catch at the proposed F_{ref} =0.380 in 2024 is 15,447 mt. The stock biomass is projected to increase in both 2024 and 2025 based on the Base model estimates when M is reduced to 0.2. The 2020 and 2021 year classes are projected to be the dominant contributors to fishery catch in 2024 due to the lack of older fish in the population and low selectivity of younger age groups.

Table 2. Projection under Low M scenario with an assumed 2023 fishery catch of 3,000 mt of eastern Georges Bank Haddock (median value across 2,000 simulations). SSB=spawning stock biomass. A dash (-) indicates not applicable.

Year	Recruitment	Biomass (mt)	SSB (mt)	Catch (mt)	Fishing Mortality (F)
Option 1: F_{ref}= 0.367					
2023	33,633	58,429	41,336	3,000	0.144
2024	21,155	79,680	66,543	14,980	0.367
2025	-	85,096	74,746	-	-
Option 2: F_{ref}=0.380					
2023	33,633	58,429	41,336	3,000	0.144
2024	21,155	79,680	65,543	15,447	0.380
2025	-	84,752	74,339	-	-

High M scenario

The High M scenario is based on consistency with the Base model.

Catch Advice based on F_{ref} =0.367

Assuming the M continues to be 0.493 (as estimated by the model) in 2023–2025, Table 3 shows the median estimates of biomass, SSB, and F in 2023 based on 2,000 realizations of terminal year population sizes and an assumed 2023 catch of 3,000 mt. For 2024, the median biomass, SSB, and catch estimates are obtained by applying an F=0.367 to each realization conditional on an assumed catch of 3,000 mt in 2023. The risk analysis in Figure 15 applies a similar logic to estimate the probability of exceeding F=0.367 in 2024 (by assuming a 2023 catch of 3,000 mt) given various catch levels ranging from 0 mt to 30,000 mt in steps of 2,000 mt. The levels of catch associated with 25%, 50%, and 75% of risk are estimated by linear interpolation such that the catch associated with the 50% probability of exceeding F_{ref}=0.367 (9,740 mt) in Figure 15 differs slightly from the equivalent median catch for 2024 (9,763 mt) reported in Table 3.

The median SSB is projected to increase from 41,336 mt in 2023 to 49,580 mt in 2024 and decrease to 42,984 mt in 2025. The median catch at the proposed F_{ref} =0.367 in 2024 is 9,763 mt. In 2023, F is estimated to be 0.166 assuming a catch of 3,000 mt (Table 3). Similar to the Low M scenario, the 2020 and 2021 year classes are projected to be the dominant contributors to fishery catch in 2024 due to the lack of older fish in the population and small partial recruitment of younger age groups (Figure 11).

Catch Advice based on F_{ref} =0.380

Assuming the M continues to be 0.493 (as estimated by the model) in 2023–2025, Table 3 shows the median estimates of biomass, SSB, and F in 2023 based on 2,000 realizations of terminal year population sizes and an assumed 2023 catch of 3,000 mt. For 2024, the median biomass, SSB, and catch estimates are obtained by applying an F=0.380 to each realization conditional on an assumed catch of 3,000 mt in 2023. The risk analysis in Figure 15 applies a similar logic to estimate the probability of exceeding F=0.380 in 2024 (by assuming a 2023 catch of 3,000 mt) given various catch levels ranging from 0 mt to 30,000 mt in steps of 2,000 mt. The levels of catch associated with 25%, 50%, and 75% of risk are estimated by linear interpolation such that the catch associated with the 50% probability of exceeding F_{ref} =0.380 (10,100 mt) in Figure 15 differs slightly from the equivalent median catch for 2024 (10,071 mt) reported in Table 3.

The median SSB is projected to increase from 41,336 mt in 2023 to 49,850 mt in 2024 and decrease to 42,719 mt in 2025. The median catch at the proposed F_{ref} = 0.380 in 2024 is 10,071 mt. In 2023, F is estimated to be 0.166 assuming a catch of 3,000 mt (Table 3). Similar to the Low M scenario, the 2020 and 2021 year classes are projected to be the dominant contributors to fishery catch in 2024 due to the lack of older fish in the population and low selectivity of younger age groups.

Table 3. Projection under High M scenario with an assumed 2023 fishery catch of 3,000 mt of Eastern Georges Bank haddock (median value across 2,000 simulations). SSB=spawning stock biomass. A dash (-) indicates not applicable.

Year	Recruitment	Biomass (mt)	SSB (mt)	Catch (mt)	Fishing Mortality (F)
Option 1: F_{ref} = 0.367					
2023	33,633	58,429	41,336	3,000	0.166
2024	21,155	60,654	49,580	9,763	0.367
2025	-	51,517	42,984	-	-
Option 2: F_{ref} =0.380					
2023	33,633	58,429	41,336	3,000	0.166
2024	21,155	60,654	49,850	10,071	0.380
2025	-	51,266	42,719	-	-

TRAC ADVICE

Considering the uncertainties of M in the near future, projections were conducted under two different M scenarios similar to TRAC 2022. The options discussed were to use High M or to use the range of projected catch bounded by the High M and Low M scenarios (Table 4); however, the TRAC did not agree on which option was more appropriate. The TRAC did not expect that M will be reduced to 0.2 in the projected period (2023–2025). TRAC suggested that 12,280 mt, the Low M catch advice at the low risk of exceeding F_{ref} (25%), should be considered as an upper bound. The High M catch advice is provided for low (7,960 mt) to neutral (9,740 mt) levels of risk. The range of advice (7,960 mt–12,280 mt) was provided to address the hypothesis that M has decreased in recent years from the high M time block. The rationales for both approaches are presented below.

Catch advice was provided using the two F_{ref} values requested by TMGC. The TRAC recommended using the F_{ref} =0.367 that uses data from 2017–2021. The justification for this recommendation was that this method was thoroughly explored at TRAC 2022 and included simulation testing. It was discussed that inputs such as selectivity and weight at age are variable among years and will ultimately impact the estimated value of F_{ref} and the catch advice generated from the projections (Table A11).

Rationale for catch advice based on projection using High M only scenario

1. The High M only scenario provides consistency between the Base model estimation period and the two year projection period. The addition of two years of data led to a 9% increase in the estimated M for the period 2010–2021 (0.516) compared to 2010–2019 (0.473), despite expectations at the haddock Research Track review that the estimate of M would decrease with two more years of data. In 2022, with the addition of one year of data, the M from the model remains high (0.493). This result does not support an expectation that M will immediately drop in 2023.
2. Alternative models where M was fixed at 0.2 or separately estimated in the last three years did not fit the data as well as the Base model based on Akaike Information Criteria (AIC) and Mohn's rho. This result supports the current estimate of M remaining high.
3. Density dependence is hypothesized to be the cause of the increased M. Population biomass and SSB have been declining since 2015–2016, with a slight increase in 2022. Yet, in spite of the approximate reduction of 75% in population density between 2016 and 2021 (Figure 5; Table A4), the model estimated that M increased with three additional years of data, suggesting that factors other than density-dependence may be contributing to reduced apparent survival. This result does not support the assumption that M will be lower than 0.493 in 2023 simply because density will be lower.
4. The most recent three years of observed length- and weight-at-age for most ages are still in the range of values observed in the 2010–2019 period, demonstrating that density-dependent effects have not instantaneously dissipated. This result suggests that expectations for release from density-dependent mortality will also not be immediate.
5. Using a High M in the model and then immediately reducing M in the projections may lead to an overestimate of biomass and available yield.

Rationale for catch advice based on range of projections using High M and Low M as bounds

The TRAC did not believe that M will be reduced to 0.2 in the projected period. Therefore, the scenario only considered the Low M projection as an upper bound for the range of catch advice. The uncertainty about the exact level of M within the available range (0.2–0.493) was mitigated by suggesting the use of the low risk (25%) of exceeding F_{ref}.

1. A generalized additive model (GAM) presented at the haddock Research Track showed evidence of density-dependent impacts on M for recent years (TRAC 2021; EGB Haddock Research Track Working Group Report, Kronlund et al. 2023), and formed the basis for allowing M to be estimated in blocks for the EGB Base model presented here.
2. A set of alternative M configuration and sensitivity runs were compared to characterize the uncertainties of M in 2020–2022. The constraint on a fixed M for the 2010 to 2022 period was relaxed. Although these models had less support on the basis of AIC estimates, they showed evidence of a decline in M to 0.32–0.34 in the terminal years for 2022, though not as low as M=0.2. Last year this estimate was 0.32–0.43, suggesting a lower M may be more appropriate.
3. The Base model estimated M for 2010–2022 was 0.493 (95% confidence interval [CI] of 0.453–0.537) which was a decrease from the estimated M of 0.516 (95% CI of 0.474–0.563) for 2010–2021 but above the estimated M of 0.473 (95% CI of 0.431–0.527) for 2010–2019.
4. The projections assume either a continued high level of M (0.493, High M Scenario) or a return to a pre-2010 level of M (0.2, Low M Scenario). Given the uncertainty about the plausible annual rate of change in M, the Low M scenario posits an instantaneous shift from an M=0.493 to 0.2 in one year. Empirical and life-history evidence suggest such a shift is improbable. However, the model configuration upon which the High M estimate is derived posits an equally sharp change from 0.2 to 0.493 in 2010. Although a change in M from 0.493 to 0.2 over one year is improbable, the Low M scenario is reflecting a return in M to historic levels and is consistent with the level of M used in Georges Bank haddock and other stocks around the world.
5. The High M projection scenario posits that the terminal year biomasses are a function of M=0.493, but applies an F_{ref}=0.367 based on M=0.2. Using F_{ref}=0.367 with the selectivity, maturation and average weight parameters from the High M model implies an $F_{71\%SPR}$ rather than the nominal $F_{40\%SPR}$.
6. Improvements of growth, condition and higher survival are expected with the exit of the 2013 year-class from the catch. Based on current projections, the 2013 year class is expected to have low contribution to the catch and improvements in condition and growth were noted from recent survey data (Figure 10; Figure A6).

Table 4. Catch advice for eastern Georges Bank haddock for 2024 based on the probabilities of exceeding the F_{ref} values. The "High M Only" is based on a M=0.493 in the projections and the " Low M" is based on M=0.2 in the projections. The "High M to Low M range" uses a bound of the High M for the lower bound and the Low M as the upper bound. The highlighted cells in grey were not recommended by TRAC as appropriate catch advice.

Probability of exceeding F_{ref}	25%	50%	75%
F_{ref} = 0.367			
2024 Catch (High M Only)	7,960 mt	9,740 mt	12,410 mt
2024 Catch (High M to Low M range)	7,960 - 12,280 mt	9,740 – 15,030 mt	12,410- 19,040 mt
F_{ref} = 0.380			
2024 Catch (High M Only)	8,210 mt	10,100 mt	12,870 mt
2024 Catch (High M to Low M range)	8,210 – 12,610 mt	10,100 – 15,460 mt	12,870 – 19,630 mt

SOURCES OF UNCERTAINTY

1. Mohn's rho is used as one of the measures of model performance. The 7-year peel Mohn's rho of SSB, F, and recruitment are smaller than 0.2; however, it was noted that fluctuations in rho of F may be equally informative about poor model performance and unresolved nonstationary processes within the model (Figure A7).
2. The selection of a change point year (i.e., 2010) for M has important implications. The basis for this selection was described in the haddock Research Track stock assessment (Kronlund et al. 2023). The good performance of the past VPA model with constant M=0.2 in pre-2010 also supports 2010 as a change point year.
3. Inconsistencies in the average weights-at-age in the stock and in the fishery need further investigation. Initial review suggested problems in average weights for fish aged 6 and older due to limited samples and ageing challenges.
4. Density dependence is suggested as a basis for an increase in M. The demise of the 2013 year class has led to rapid reduction in overall stock biomass. However, it was reported by fishermen that major ecosystem changes are underway and a bilateral group, the Canada-US Ecosystem Science (CAUSES) working group, has been investigating other factors that may be responsible for such changes in M. Our understanding of the factors leading to high M in recent years is incomplete.
5. Small changes in timing of surveys may be important in recent years as populations shift distributions in response to seasonal temperature changes. Coincidence of these factors may lead to changes in relative abundance indices independent of actual changes in abundance.
6. Estimates of time varying M in the state-space model reflect potential changes in multiple factors including migrations, catch reporting errors, ageing error, misspecification of selectivity, and so forth. Hence one cannot simply assume that all of the putative changes in estimated M are associated with true changes in natural mortality.

7. The F_{ref}=0.367 proposed by TRAC is estimated by using M=0.2 while using the estimated selectivity patterns from the Base model that assumes M=0.493. It is unknown how the selectivity pattern in the Base model with a freely estimated value of M would have changed under the assumption that M was fixed at 0.2. The consistency of this derivation should be reviewed.

SPECIAL CONSIDERATIONS

Due to the exit of the 2013 year class from the stock and fishery, density-dependent factors influencing EGB haddock maturity, growth, and associated changes in fishery selectivity will be reduced.

As the Base model has its time period of M increase hard-wired into the model, a number of models with alternative M configurations were examined for the updated year (2022). Despite the uncertainties of M in recent years, SSB estimated from all models shows a consistent trend over time.

The 2020 and 2021 year classes appear to be the largest since 2013 based on estimates from the 2023 base model, the 2022 National Marine Fisheries Service (NMFS) spring and fall surveys, and the 2023 Fisheries and Oceans Canada (DFO) survey (Figure 12).

The 2023 NMFS spring survey experienced vessel delays and a change in survey protocols by only sampling during daylight hours. Analyses will need to be conducted in the future to determine whether data from this survey are appropriate to use.

The Base model used in this analysis was not supported by all members of the haddock Research Track working group in 2022 (Kronlund et al. 2023). The TRAC also recognized that the EGB and Georges Bank haddock models developed in the haddock Research Track are not consistent with each other and, as recommended by the peer review panel, future work to harmonize the models would be useful. The TRAC strongly recommends that the TMGC consider a priority to develop a strategy, including guiding principles, that both countries can agree on to ensure a clear direction for TRAC's scientific work on eastern Georges Bank haddock.

RESEARCH RECOMMENDATIONS

Several recommendations were made at the TRAC meeting for the future improvement of the haddock stock assessment. It was acknowledged that the current selection of the model configuration, based on changes in M, requires a more rigorous method of choosing the best fit model on an annual basis. Currently the base model is directly compared to a “M recent” model where M is re-estimated in the model from 2020 to the terminal year and a “M recent 0.2” model where M is defined as a step down to historical M=0.2 from 2020 to the terminal year. The choice of the model is based on AICs but the reviewers suggested alternative diagnostics, such as, retrospective patterns, one step ahead residuals, mean absolute scaled errors (MASE), and simulation self-testing, may be considered as additional measures of goodness of fit.

Based on the annual fluctuations in biological and selectivity parameters, alternative approaches to defining the inputs used in the projections should be considered, other than an average of the last 3 historical years. These approaches could include model growth, weight at age, and selectivity.

Following completion of calibration experiments by DFO, the 2022 DFO survey should be updated and included in the model. Similarly, the 2023 NMFS spring survey should be reviewed to determine the utility of the daytime only sampling and reduced strata coverage as a comparable index of relative abundance.

Trade-off analyses should include a one year update interval when the fishing reference point is next updated.

The reduction in port sampling in the USA for individual lengths and age structures is problematic for stock assessments. If it is not feasible for port sampling effort to be returned to pre-2019 levels, efforts to increase catch sampling by observers (either at sea monitoring or Northeast Fisheries Observer Program) would help offset the loss of these data (Merrick et al 2022).

SOURCE DOCUMENTS

Hordyk, A.H., Carruthers, T.C., Huyhn, Q. 2022. OpenMSE: open source tools for fisheries management strategy evaluation and risk assessment. Retrieved from: https://github.com/Blue-Matter/openMSE [July 2022].

Kronlund, A., R. Merrick, J. Powers, A. Nielson, and K. Stokes. 2023. Research Track Stock Assessment Report of the Georges Bank and eastern Georges Bank Haddock 2022

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ten Brink, T. and McIntyre, T. editors. 2022. Proceedings of the Transboundary Resources Assessment Committee (TRAC): Eastern Georges Bank Cod and Haddock, and Georges Bank Yellowtail Flounder: Report of Meeting held July 12–14, 2022. TRAC Proceedings 2022/01.

TRAC. 2021. Eastern Georges Bank Haddock. TRAC Status Report 2021/02

Wang Y., C. Regnier-McKellar and K. Kraska. 2022. Assessment of Haddock on Eastern Georges Bank for 2022. TRAC Reference Document 2022/02.

CORRECT CITATION

TRAC. 2023. Eastern Georges Bank Haddock. TRAC Status Report 2023/01.

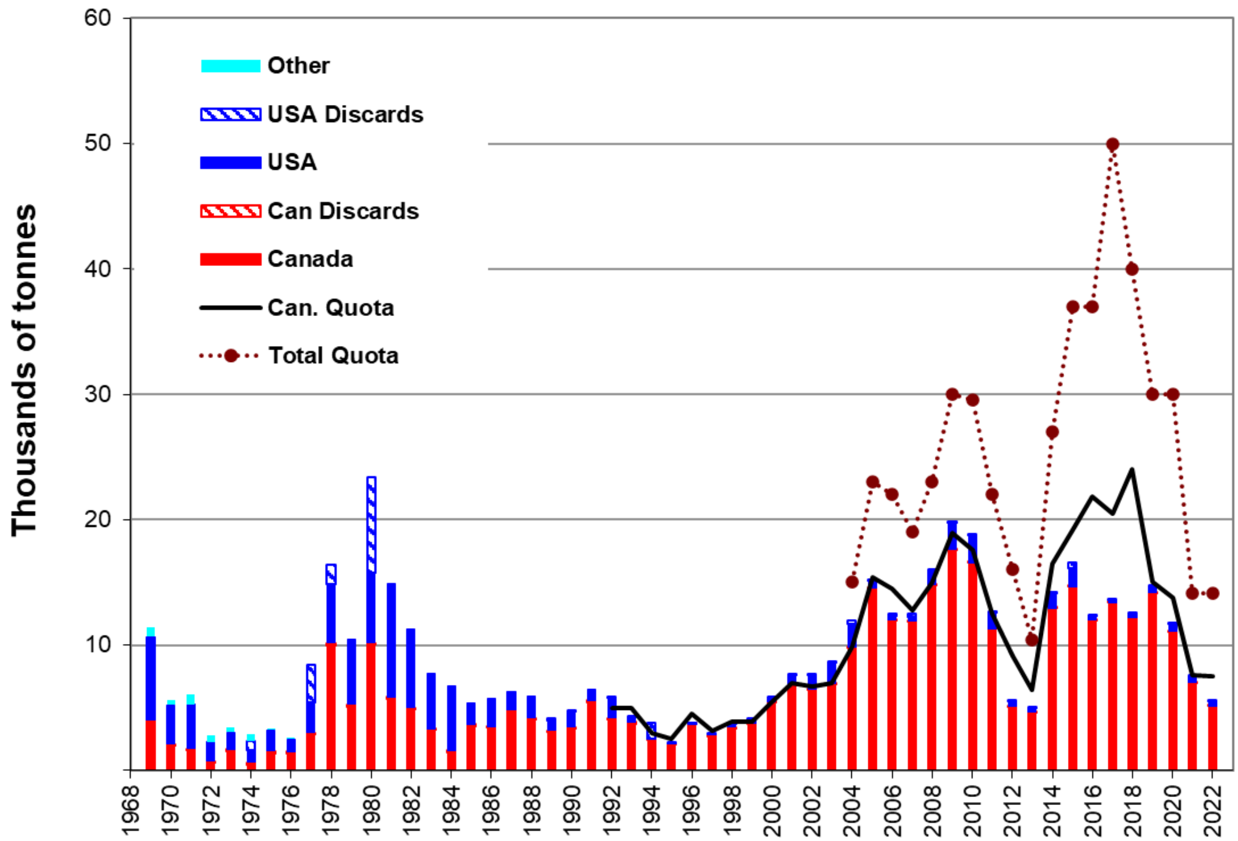


Figure 1. Annual catches of eastern Georges Bank haddock from 1969–2022.

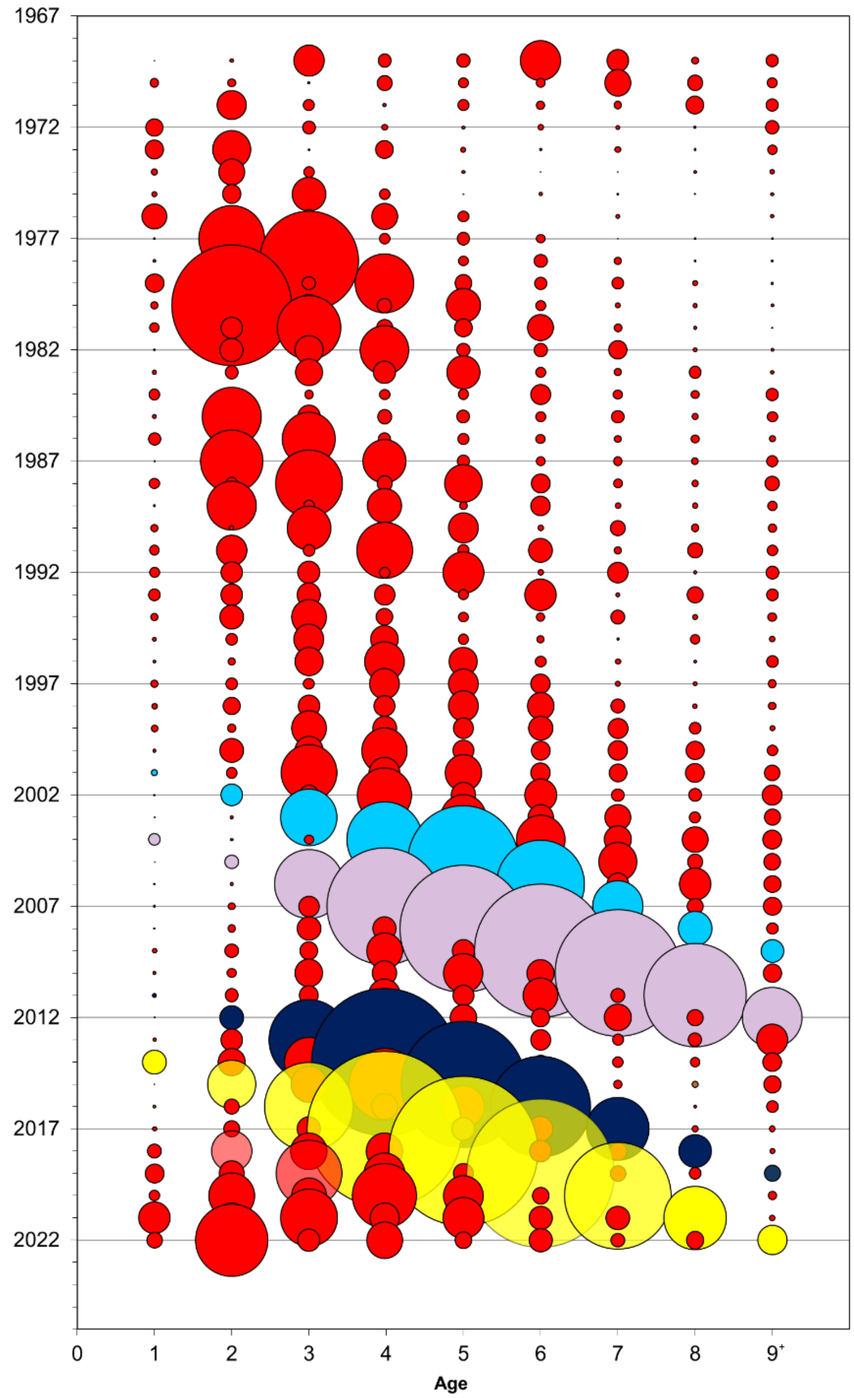


Figure 2. Canadian commercial catch at age (numbers) of eastern Georges Bank haddock from 1969–2022. The 2000, 2003, 2010, and 2013 year classes are indicated in light blue, purple, dark blue, and yellow respectively. The bubble area is proportional to catch magnitude.

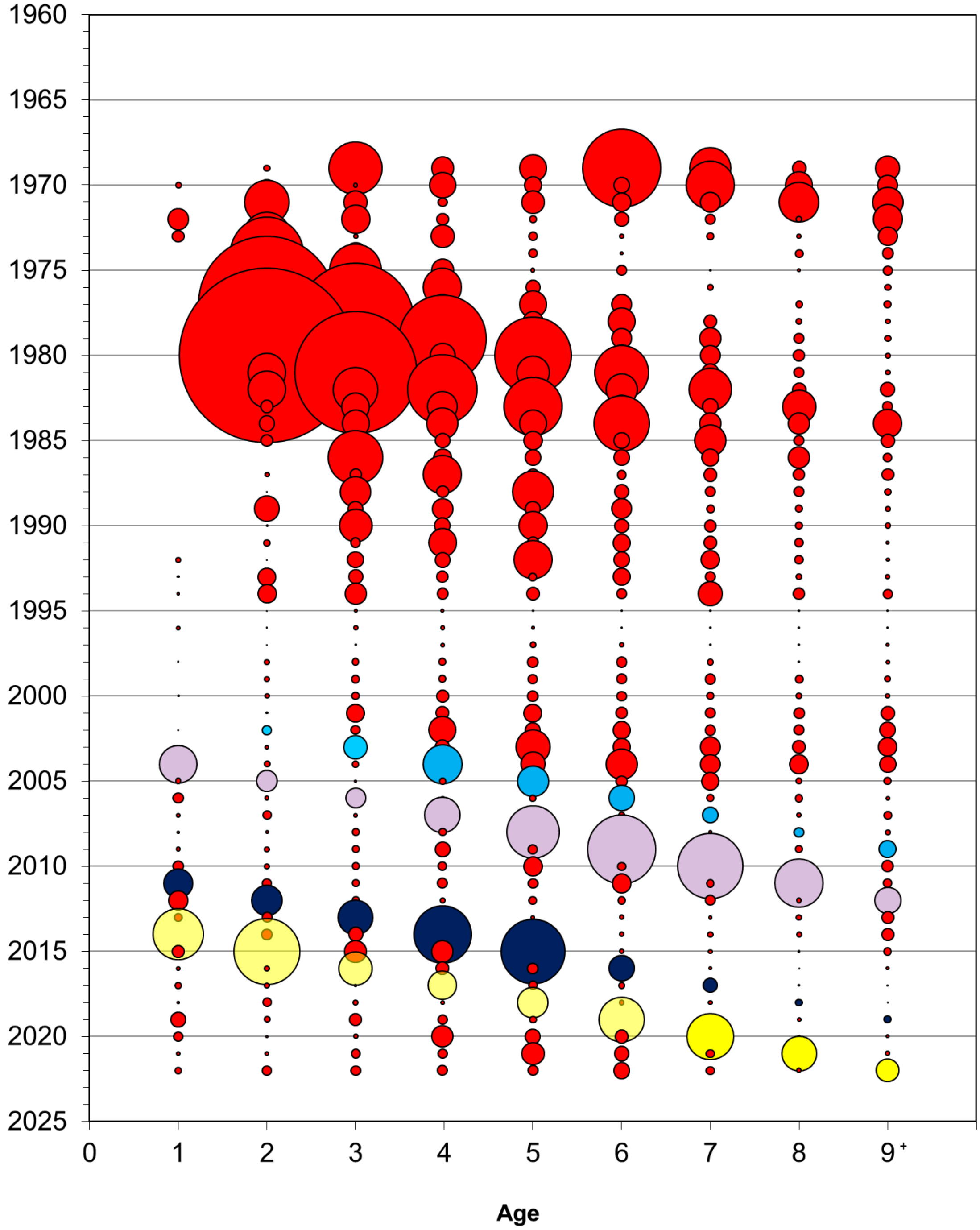


Figure 3. United States of America commercial catch at age (numbers) of eastern Georges Bank haddock from 1969–2022. The 2000, 2003, 2010, and 2013 year classes are indicated in light blue, purple, dark blue, and yellow respectively. The bubble area is proportional to catch magnitude.

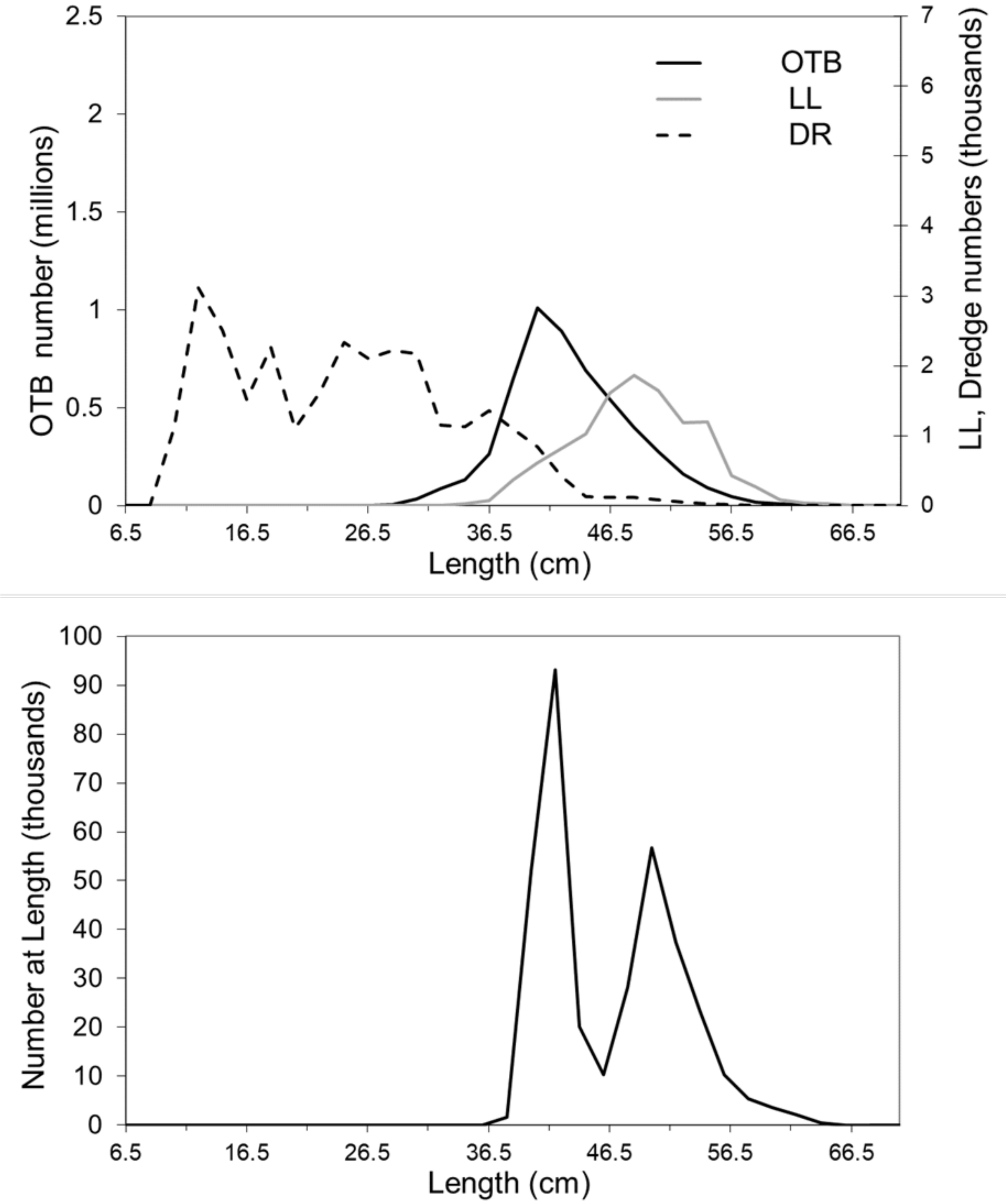


Figure 4. Canadian eastern Georges Bank haddock fishery catch at size in numbers by gear for 2022 (above) and United States of America eastern Georges Bank haddock fishery catch at size in numbers for 2022 (below) OTB=otter trawl bottom, LL=longline, DR=scallop dredge.

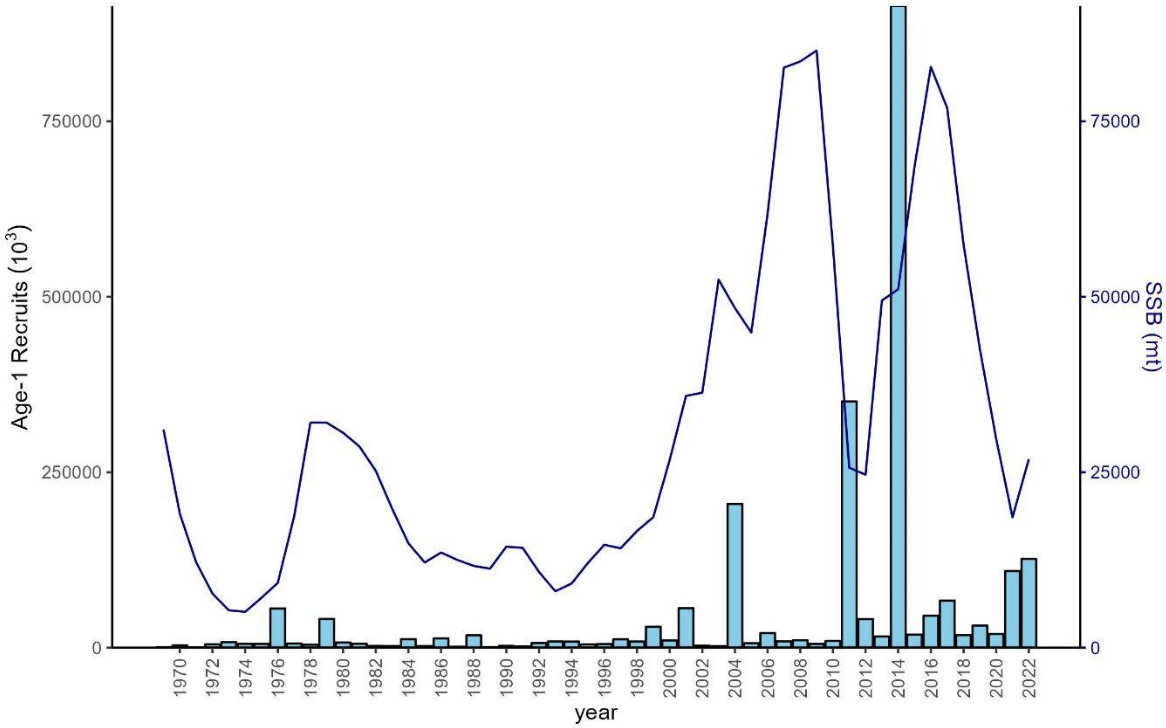


Figure 5. Spawning stock biomass (SSB; line) and Recruitment at age-1 (bars) estimated from the Base model for haddock on eastern Georges Bank.

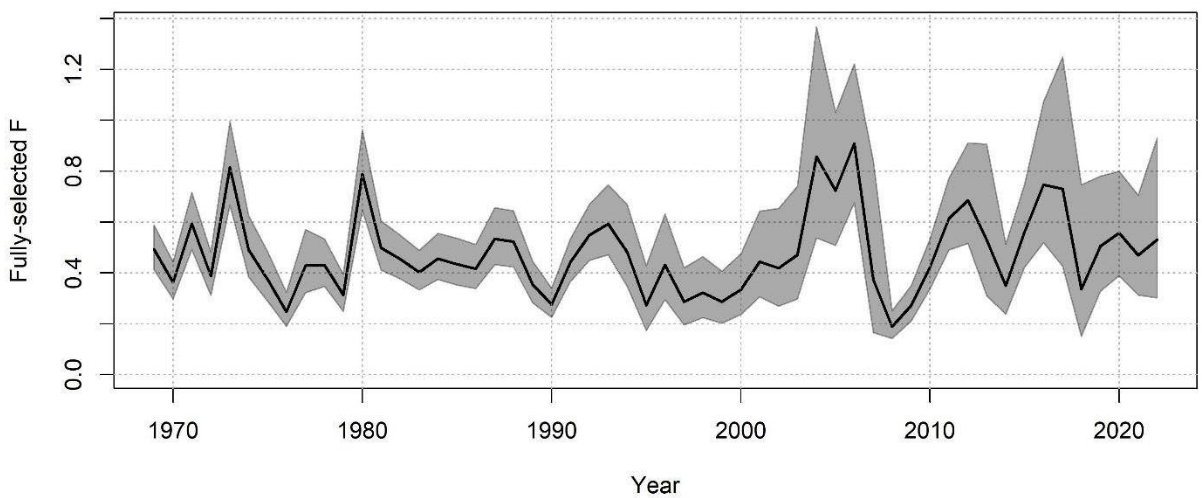
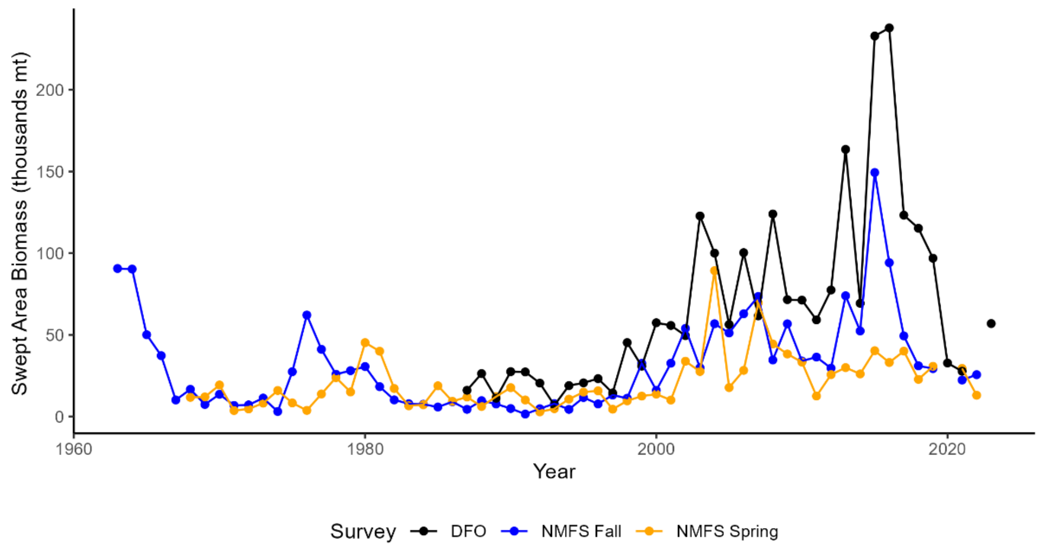


Figure 6. Fully selected fishing mortality (F) estimated from the Base model for haddock on eastern Georges Bank. The black line is the maximum likelihood estimate, the gray shaded area represents the 95% confidence interval. Note that M=0.2 for 1969–2009; M=0.493 for 2010–2022.



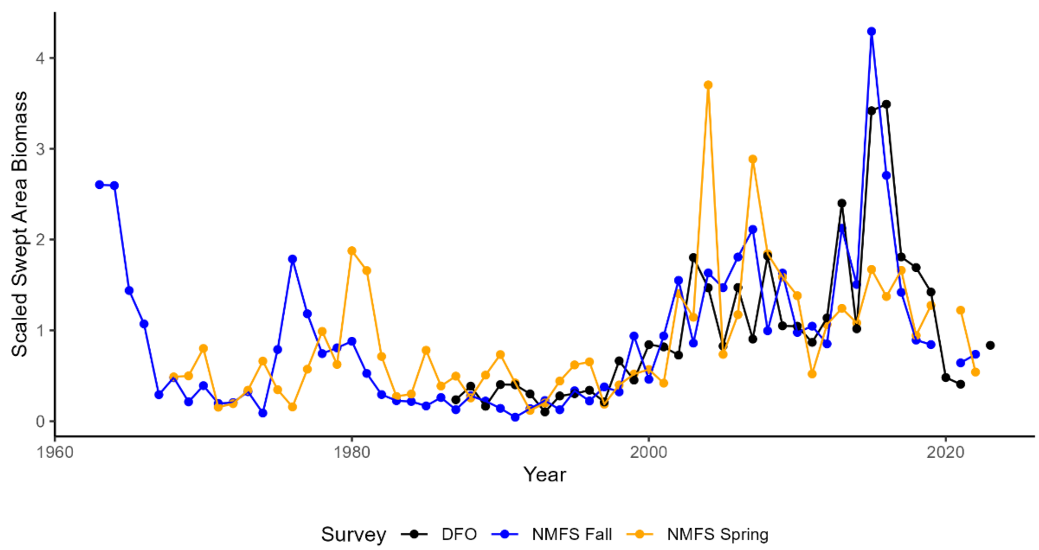


Figure 7. Raw (above) and standardized (below) survey swept area biomass from National Marine Fisheries Service (NMFS) fall (1963–2022), NMFS spring (1968–2022) and Fisheries and Oceans Canada (DFO; 1987–2021 and 2023) research surveys for eastern Georges Bank. Biomass conversion coefficients have been 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; 2009–2022). The NMFS spring and fall survey in 2020 were cancelled due to Covid-19 restrictions and the 2022 DFO survey was excluded until calibration factors for the new vessel are available. The model only uses survey data up to 2022 and excludes the 2023 survey.

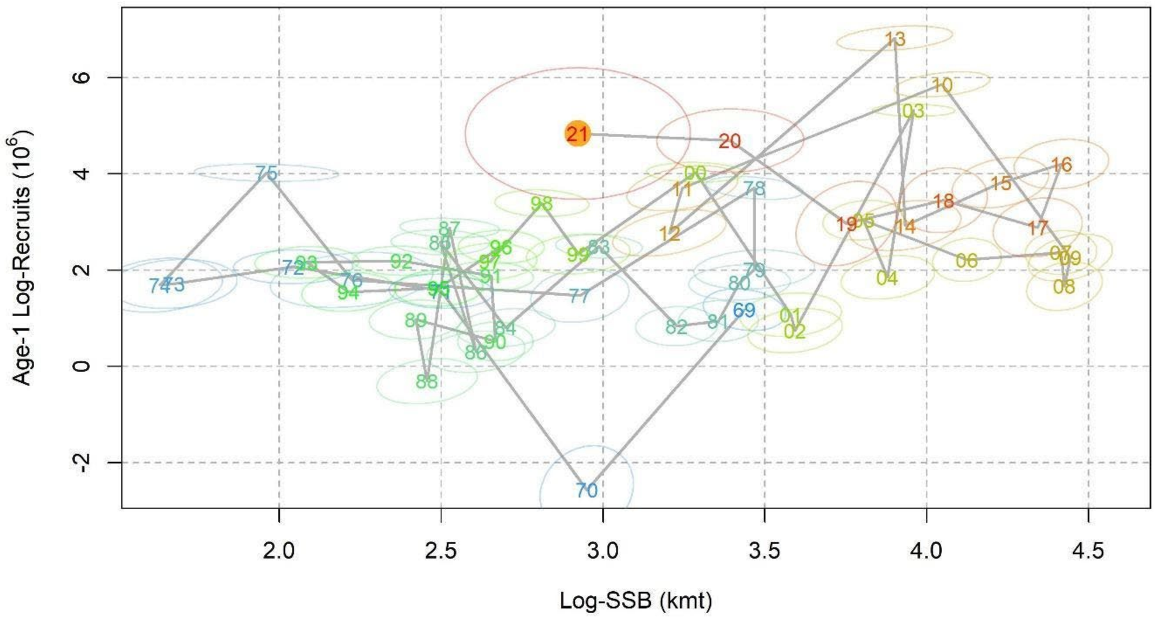


Figure 8. Log-scale of spawning stock biomass (SSB) and recruitment estimated from the Base model for haddock on eastern Georges Bank. The ellipse is a 95% confidence region in estimate based on the joint distribution of log recruitment and log SSB. The data labels are the year classes associated with the age-1 recruitment estimates.

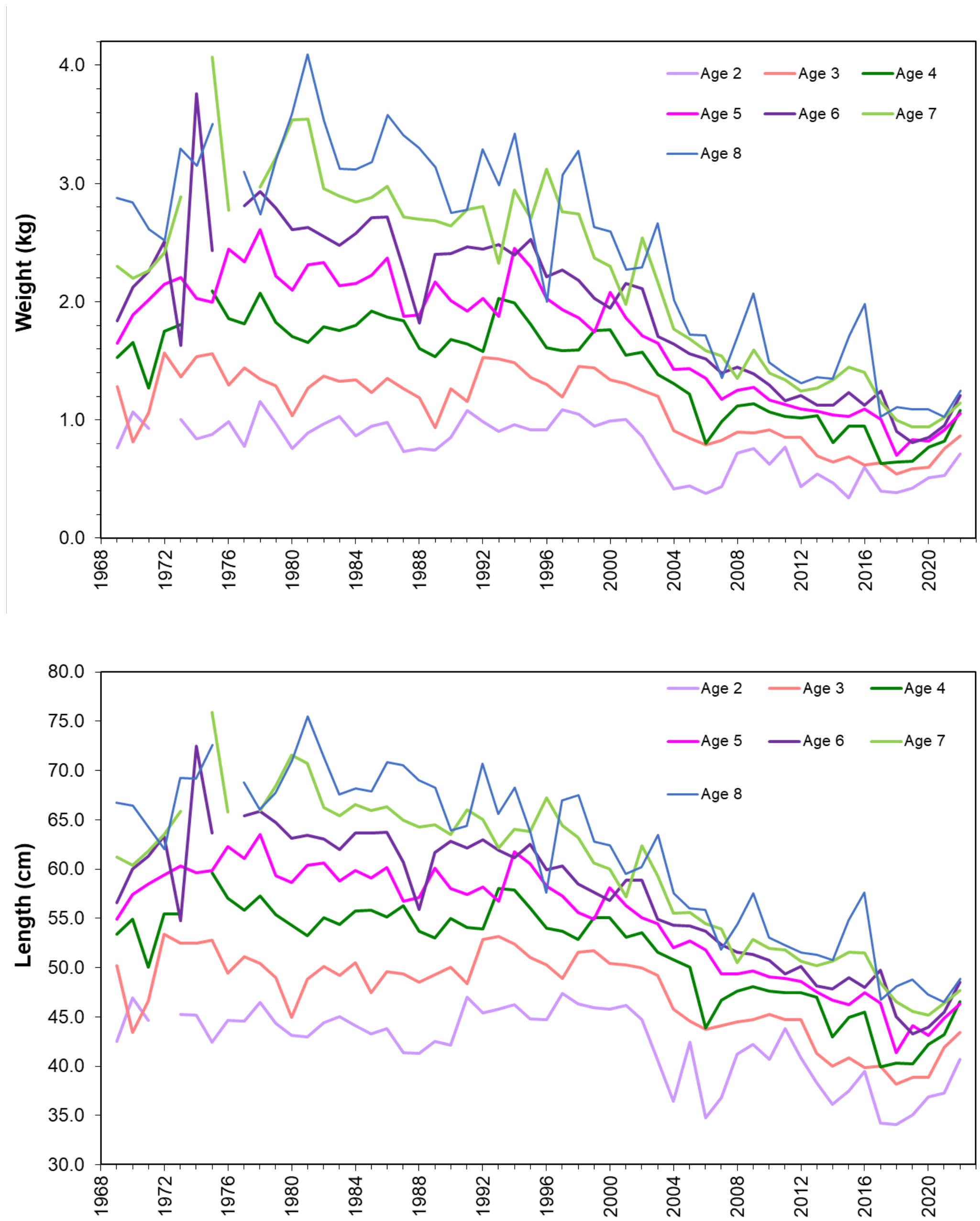


Figure 9. Average weights-at-age (upper panel) and lengths-at-age (lower panel) for eastern Georges Bank haddock from the combined Canadian and United States of America commercial groundfish fishery for 1969–2022.

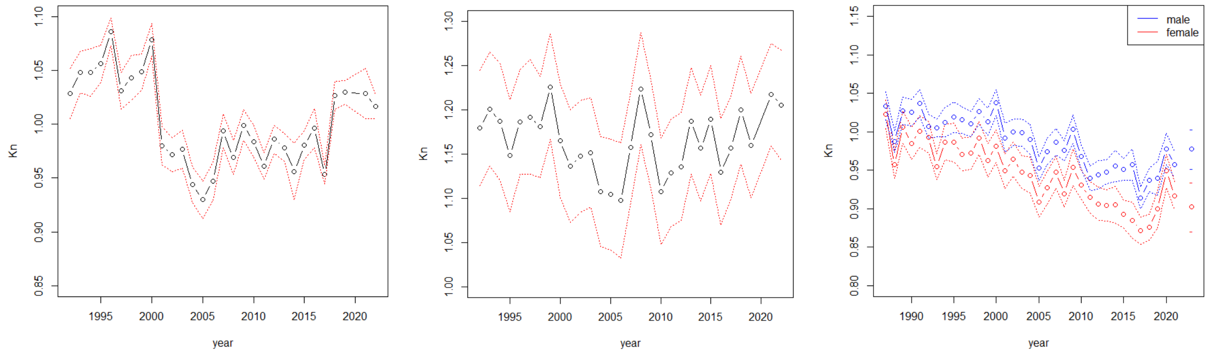


Figure 10. Relative condition factors of National Marine Fisheries Service (NMFS) spring survey for 1993–2022 (left panel), NMFS fall survey for 1993–2022 (middle panel) and the Fisheries and Oceans Canada (DFO) spring survey for 1987–2023 (right panel). The dotted line is +/- 2 standard errors.

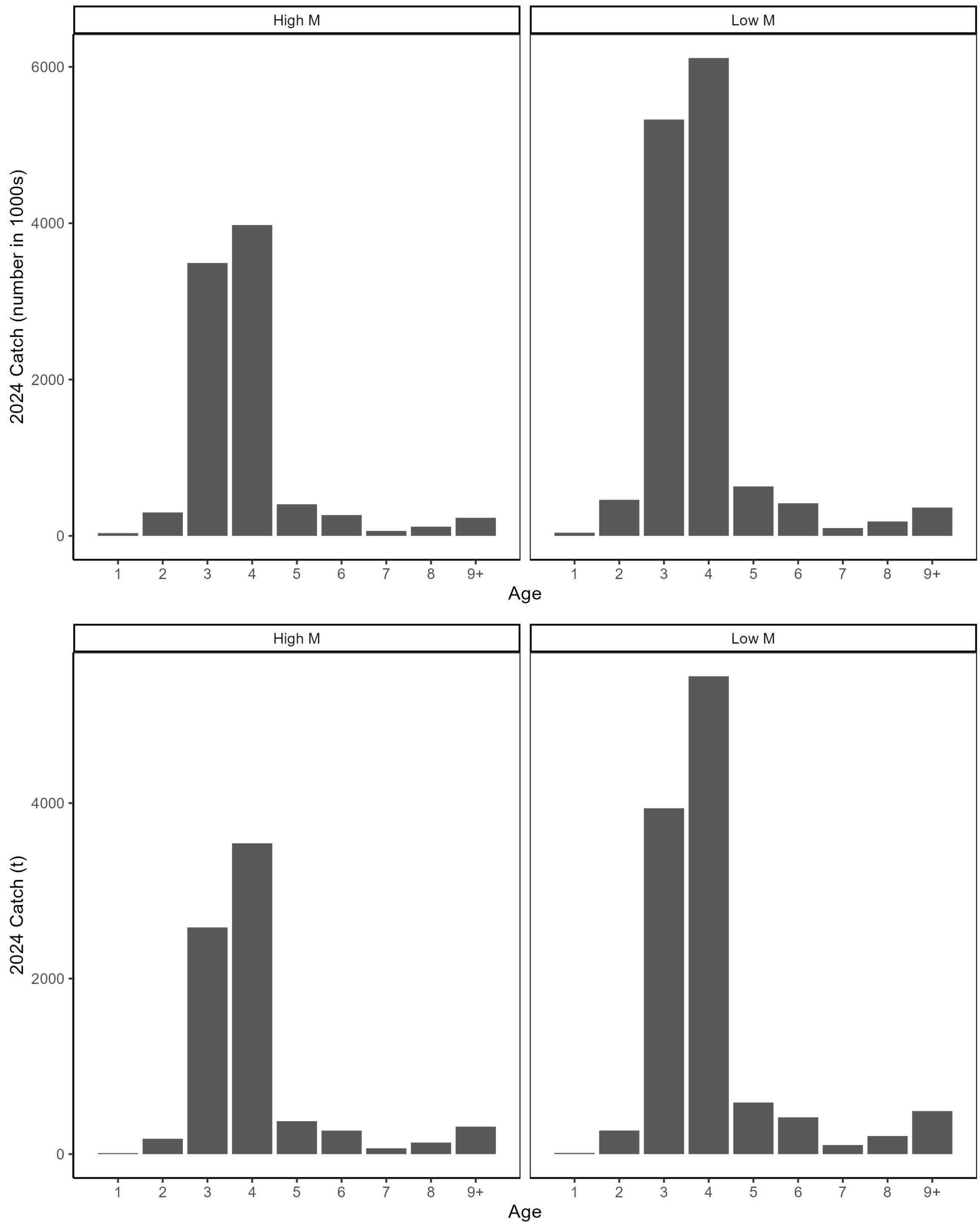


Figure 11. Projected fishery catch-at-age in numbers (top) and biomass (bottom) in 2024 under High M and Low M scenarios with an assumed 2023 fishery catch of 3,000 mt for haddock on eastern Georges Bank (using F_{ref} =0.367 calculated with data from 2017–2021).

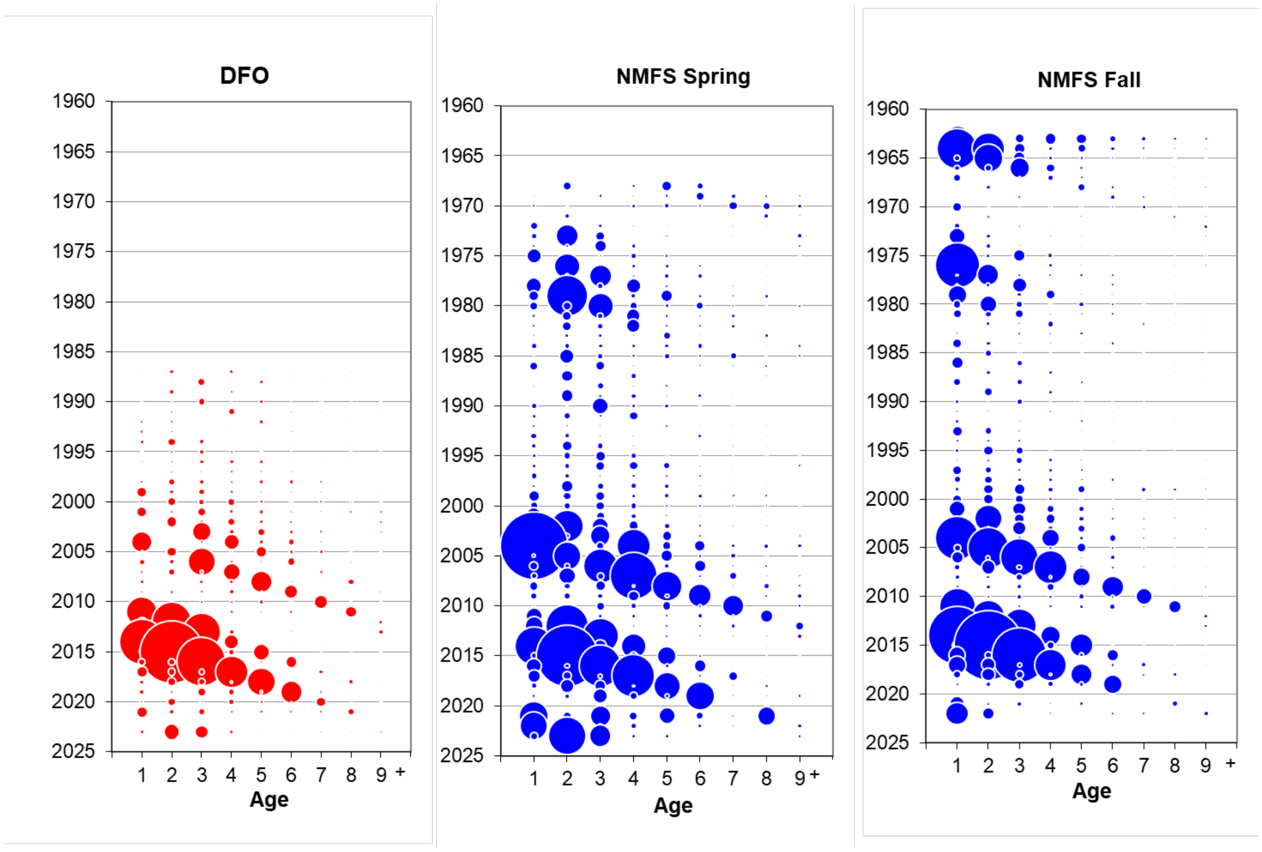


Figure 12. Age-specific mean abundance indices per tow of eastern Georges Bank haddock for the Fisheries and Oceans Canada (DFO) survey for 1986 to 2023, the National Marine Fisheries Service (NMFS) spring survey for 1968 to 2022, and the NMFS fall survey for 1963 to 2022. Bubble area is proportional to magnitude. Conversion factors to adjust for changes in door type and survey vessel were applied to the NMFS surveys. The NMFS spring and fall surveys in 2020 were cancelled due to Covid-19 restrictions and the 2022 DFO survey was excluded until calibration factors for the new vessel are available.

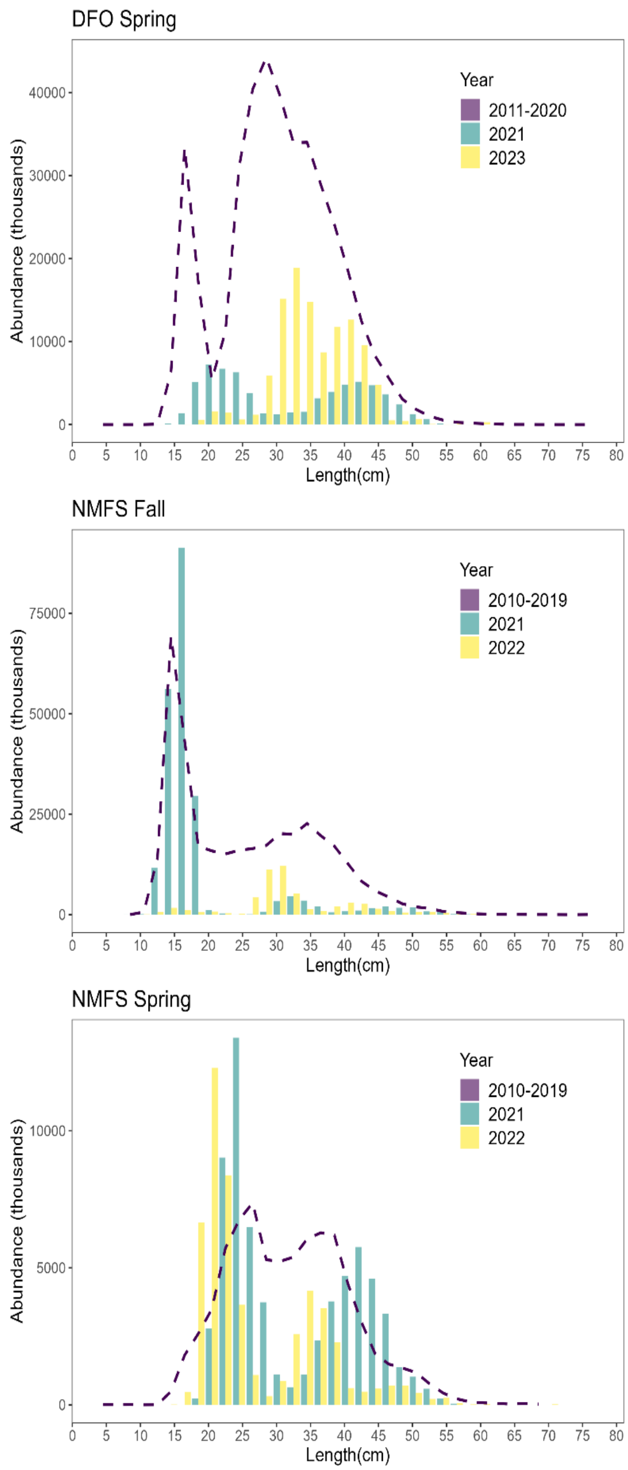


Figure 13. Length frequency distribution of the National Marine Fisheries Service (NMFS) spring (2021 and 2022) and fall (2021 and 2022) surveys and the Fisheries and Oceans Canada (DFO) spring survey (2021 and 2023). Bars represent the most recent two years and the dashed line shows the average distribution from the previous ten years (2010–2019 for NMFS fall and spring; 2011–2020 for DFO). The DFO survey plot compares 2021 and 2023 because the DFO survey in 2022 was excluded until calibration factors for the new vessel are available.

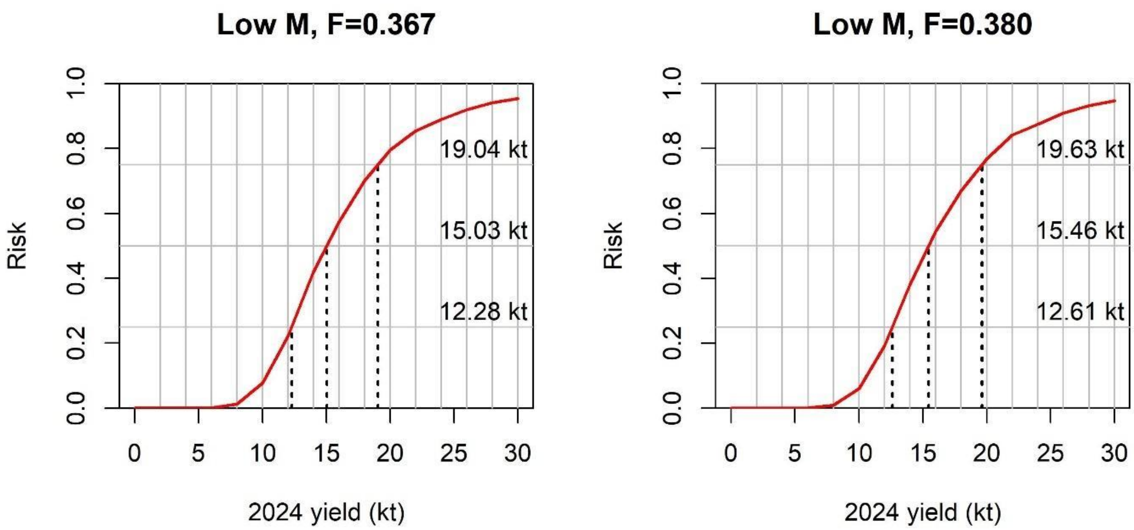


Figure 14. Probability of exceeding the F_{ref} values in 2024 for different fishery catches in the Low M scenario assuming a 2023 fishery catch of 3,000 mt for haddock on eastern Georges Bank. Dashed lines denote the 2024 yield (kt) associated with 25% (12.28–12.61 kt), 50% (15.03–15.46 kt), and 75% (19.04–19.63 kt) probability of exceeding F_{ref}.

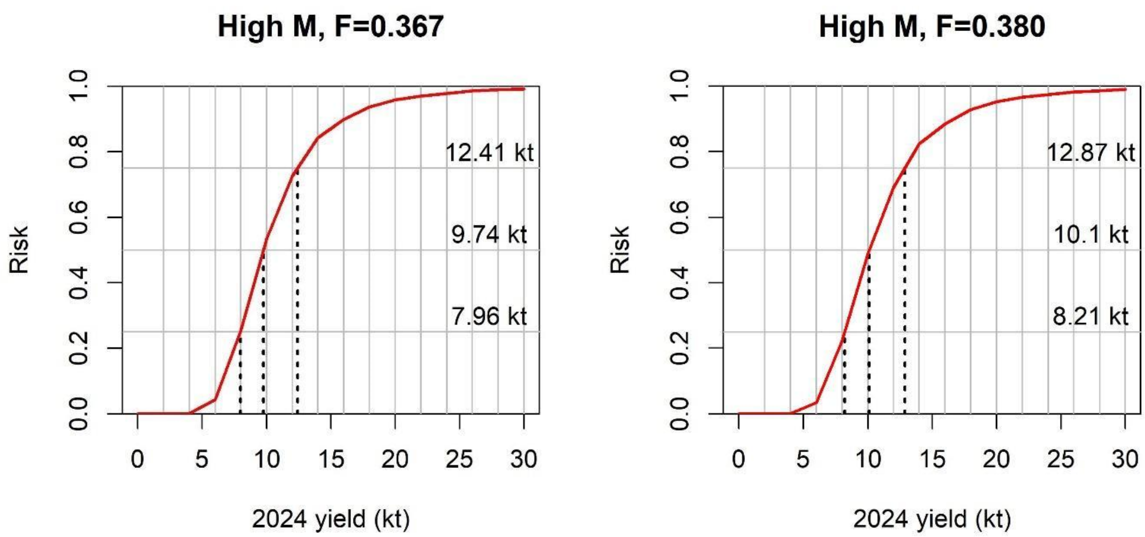


Figure 15. Probability of exceeding the F_{ref} values in 2024 for different fishery catches in the High M scenario assuming a 2023 fishery catch of 3,000 mt for haddock on eastern Georges Bank. Dashed lines denote the 2024 yield (kt) associated with 25% (7.96–8.21 kt), 50% (9.74–10.1 kt), and 75% (12.41–12.87 kt) probability of exceeding F_{ref}..

APPENDIX- FIGURES

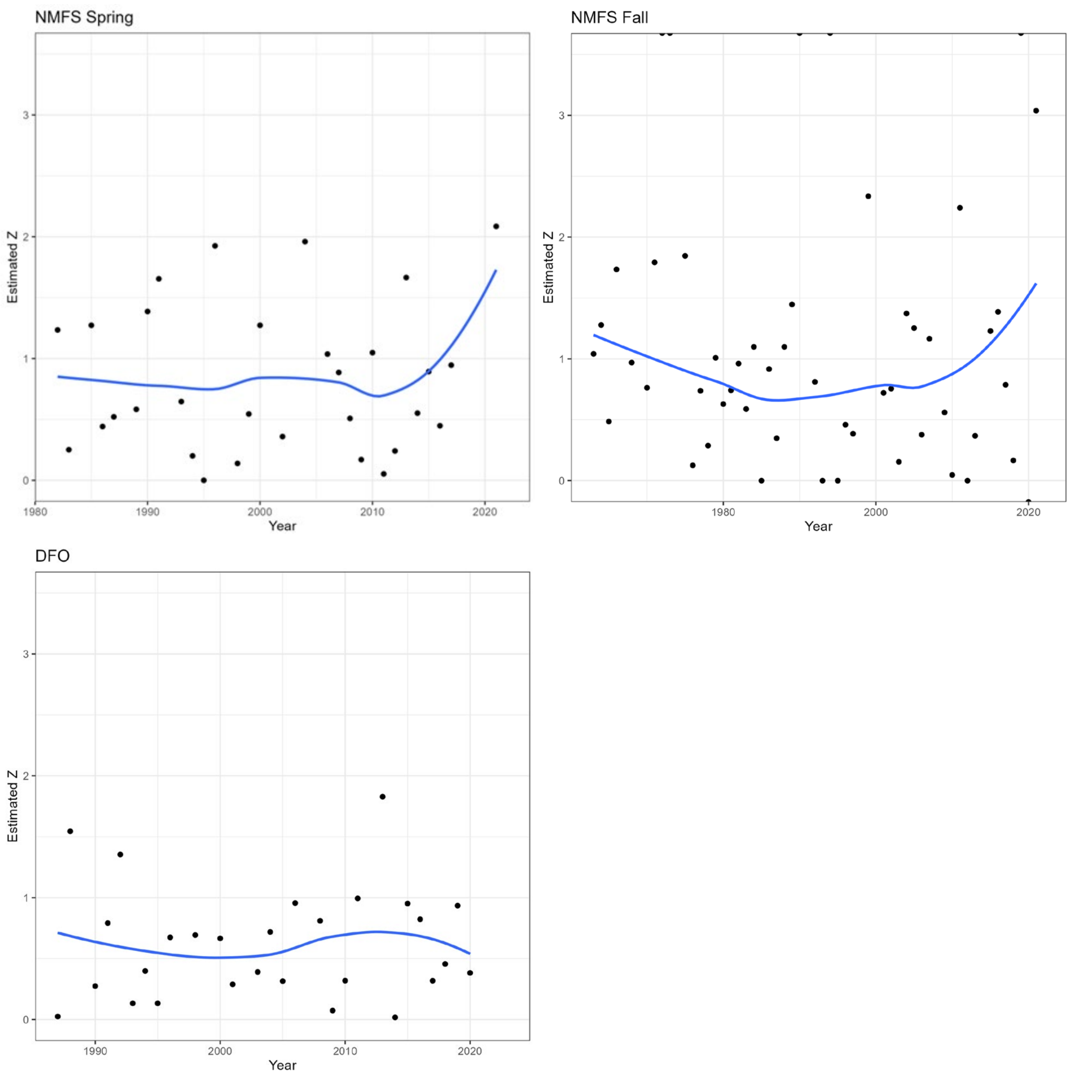


Figure A1. Estimated relative total mortality (Z) (points) of fish aged 3–6 for Fisheries and Oceans Canada (DFO) survey, and fish aged 4–7 for National Marine Fisheries Service (NMFS) spring and fall surveys with a LOESS smoother (blue line; span=0.75).

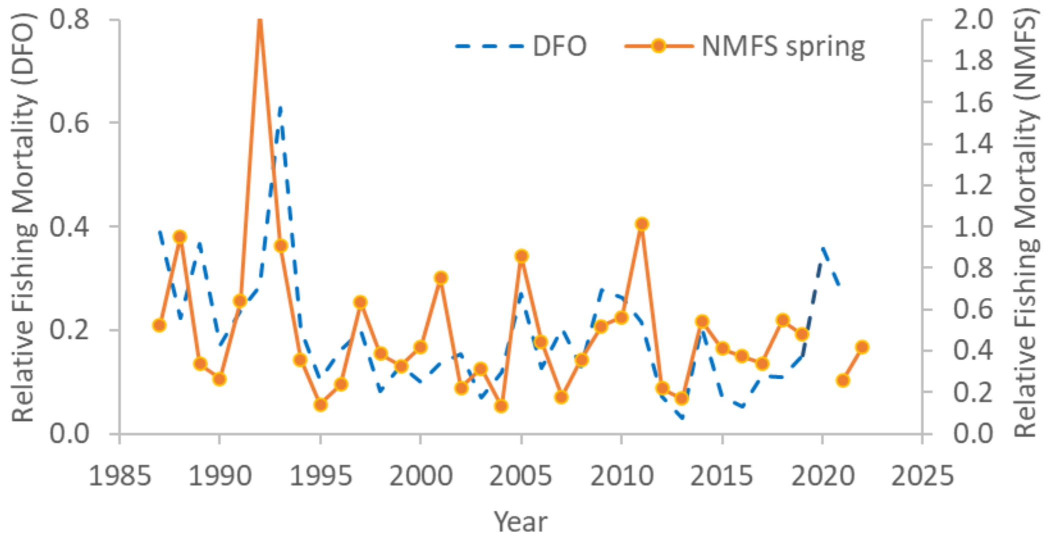


Figure A2. Relative fishing mortality for eastern Georges Bank haddock derived from the ratio of fishery catch to Fisheries and Oceans Canada (DFO; blue) and National Marine Fisheries Service (NMFS) spring survey (orange) biomass.

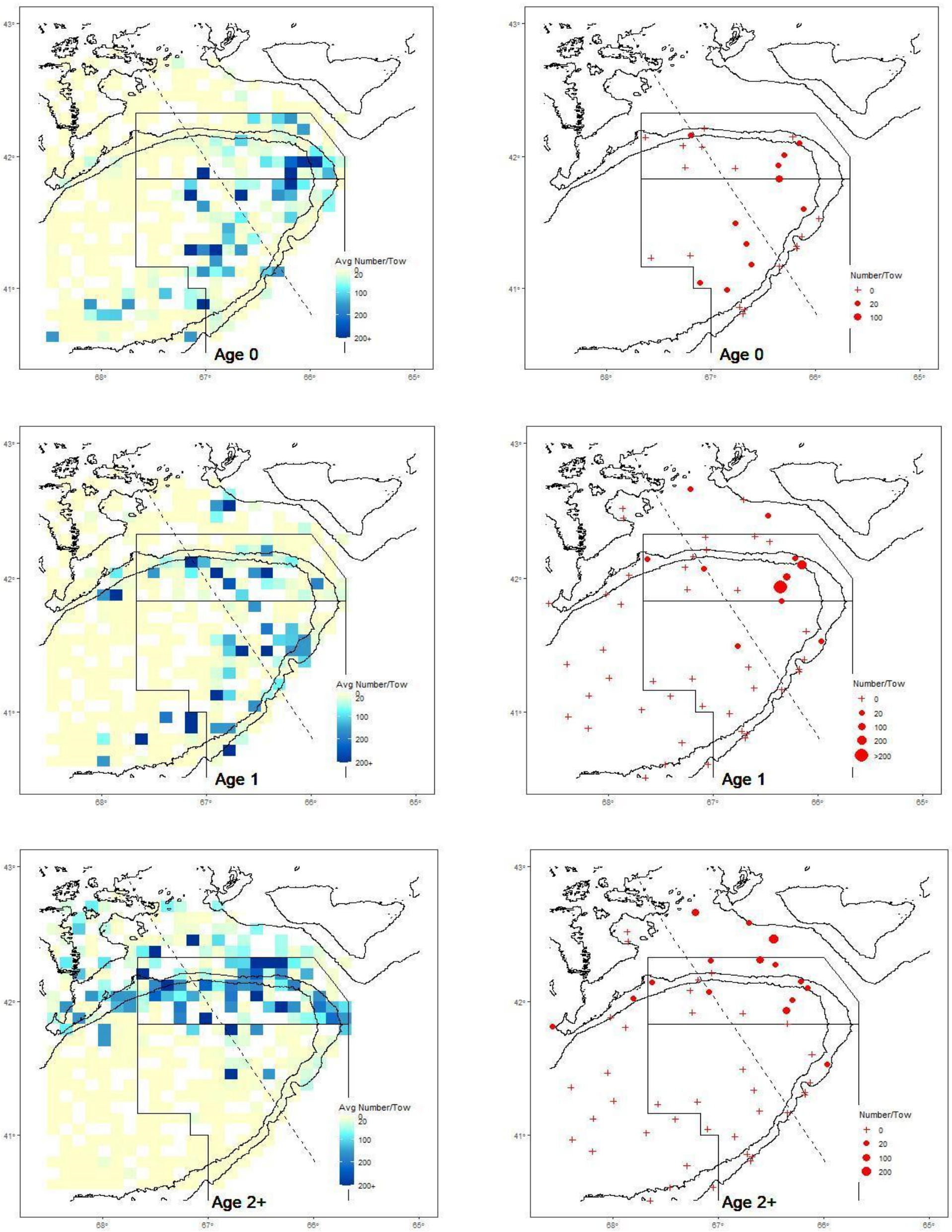


Figure A3. Distribution of eastern Georges Bank haddock abundance (number/tow) as observed from the National Marine Fisheries Service fall survey for ages 0, 1 and 2+. The squares (left panels) are shaded relative to the average survey catch for 2011 to 2021 (No survey was conducted in 2020). The expanding symbols (right panels) represent the 2022 survey catches. Length based conversion coefficients have been applied since the 2009 survey to make them comparable to surveys undertaken by the Albatross IV.

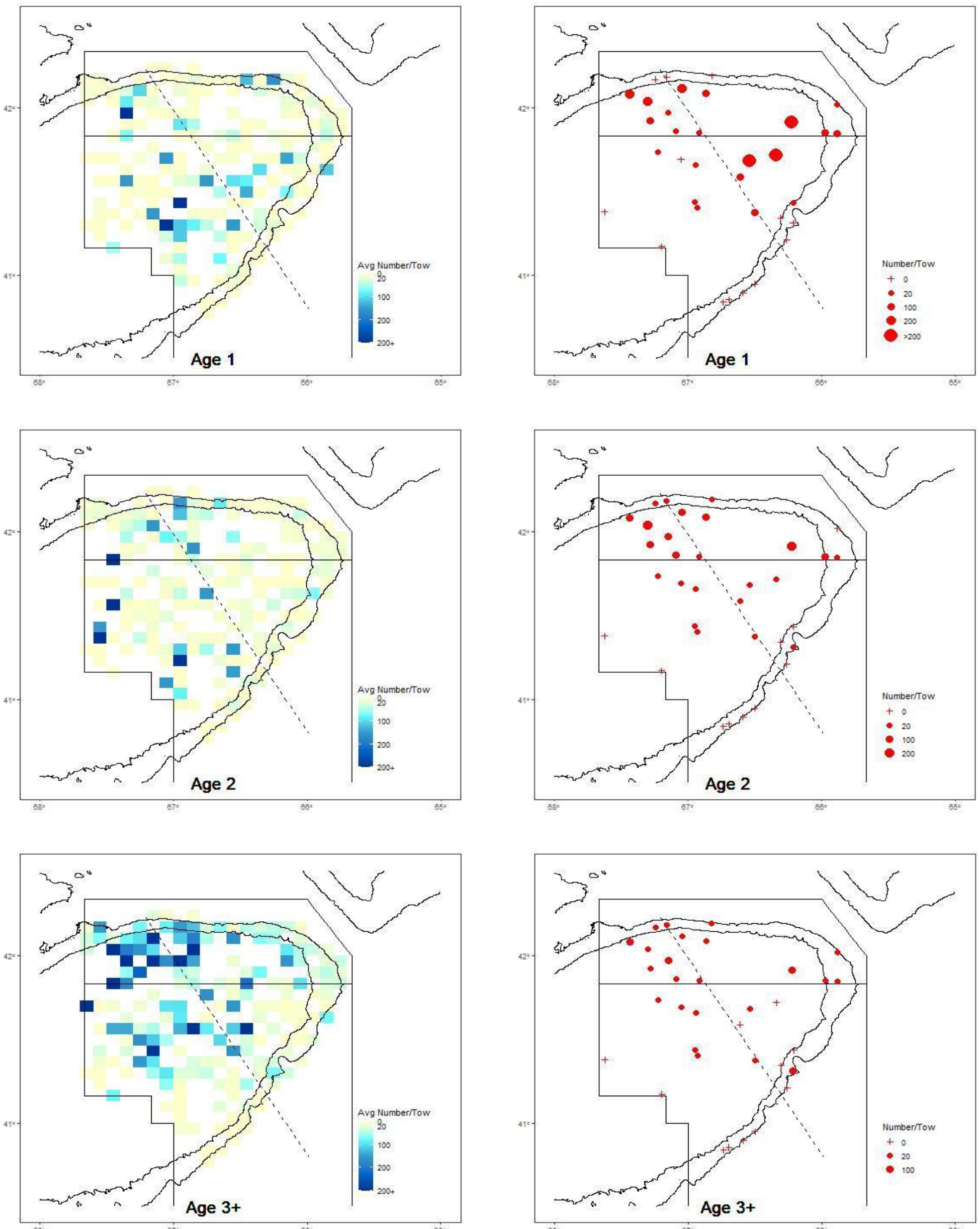


Figure A4. Distribution of eastern Georges Bank haddock abundance (number/tow) as observed from the National Marine Fisheries Service spring survey for ages 1, 2 and 3+. The squares (left panels) are shaded relative to the average survey catch for 2011 to 2021 (No survey was conducted in 2020). The expanding symbols (right panels) represent the 2022 survey catches. Survey data from 2023 were not available. Length-based conversion coefficients have been applied since the 2009 survey to make them comparable to surveys undertaken by the Albatross IV.

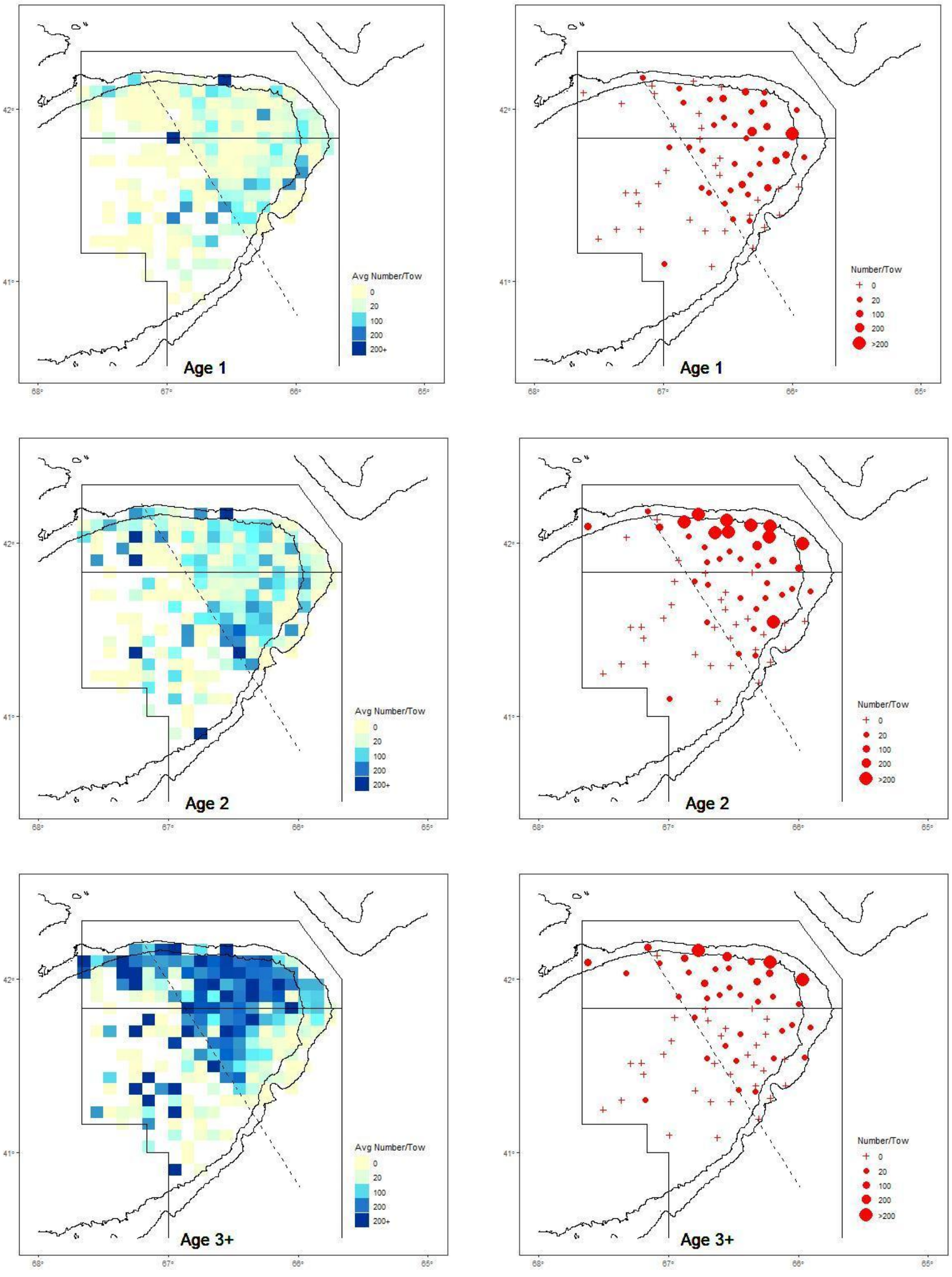


Figure A5. Distribution of eastern Georges Bank haddock abundance (number/tow) as observed from the Fisheries and Oceans Canada spring survey. The squares (left panel) are shaded relative to the average survey catch for 2012 to 2021. The expanding symbols (right panel) represent the 2023 survey catches. Conversion factors have not yet been established for the 2022 spring survey.

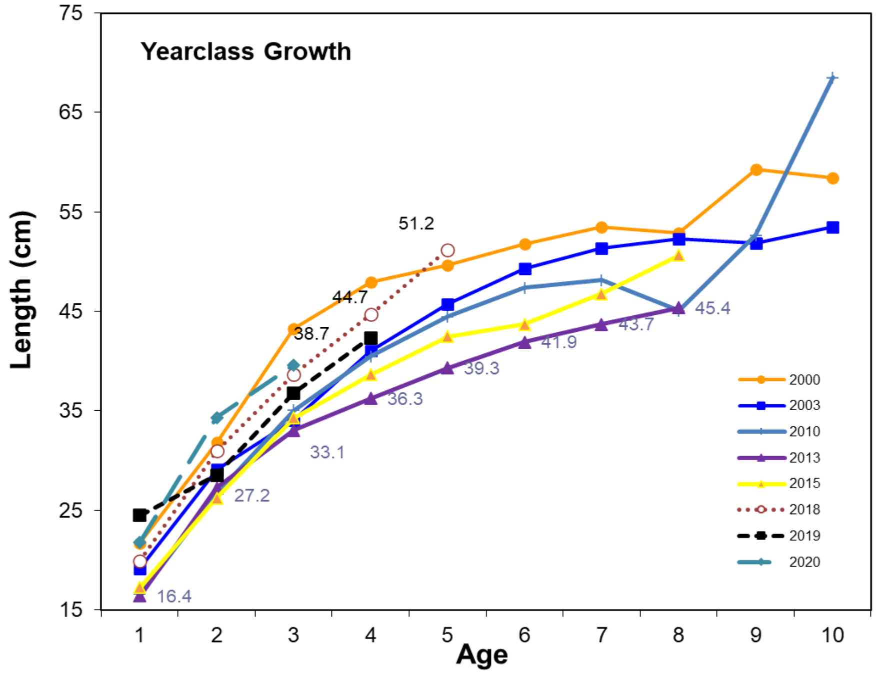


Figure A6. Mean length at age for selected year classes of eastern Georges Bank haddock sampled from the Fisheries and Oceans Canada spring survey. The numbers indicate the mean value of the 2013 year class (purple) for comparison with the 2018 year class (brown).

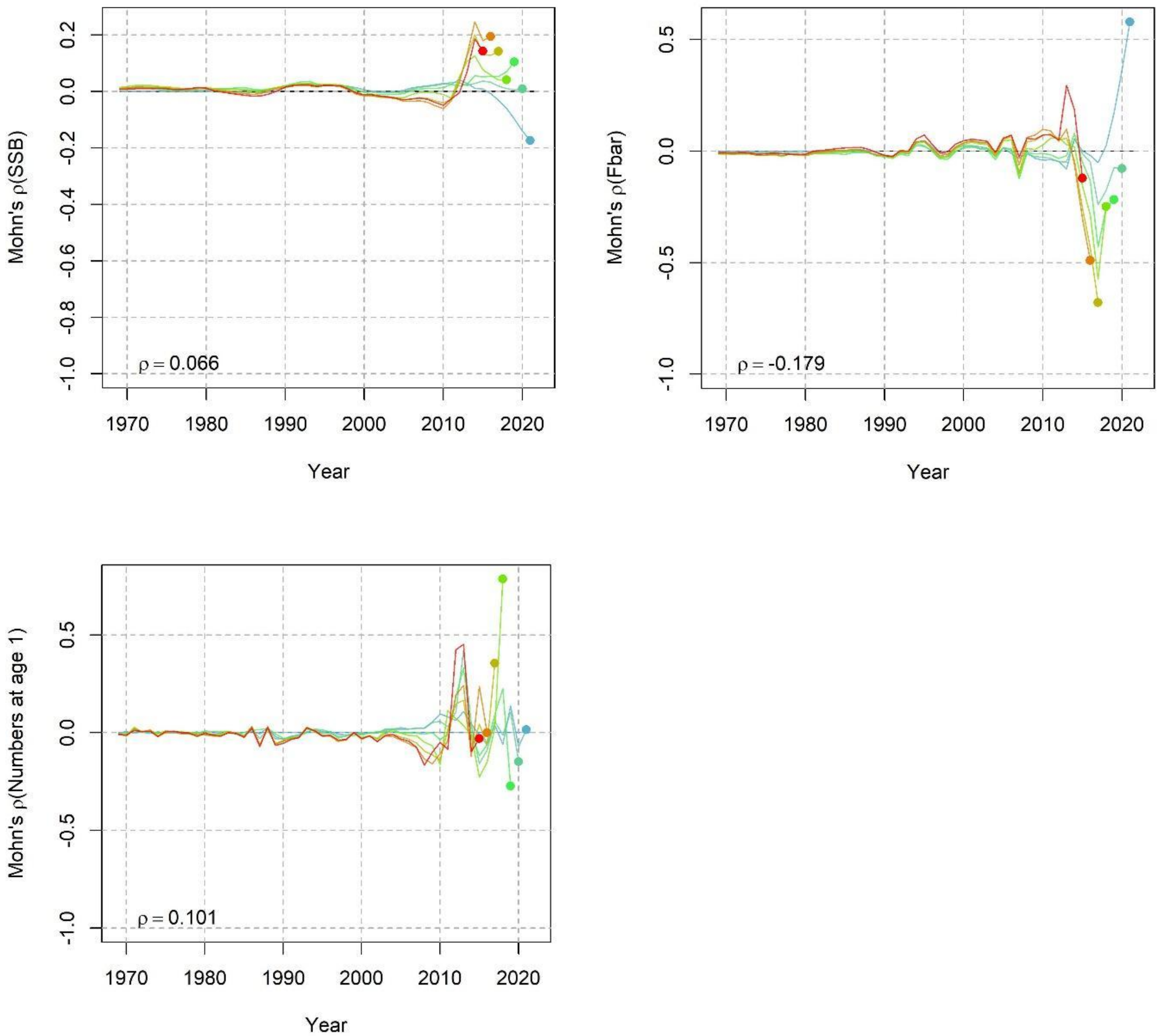


Figure A7. Retrospective analysis of spawning stock biomass (SSB), mean fishing mortality rate (F_{bar}) and recruitment (Numbers at age-1) of the Base model.

Table A1. Nominal catches (mt) of haddock from eastern Georges Bank (EGB) from 1969–2022. For "Other" it was assumed that 40% of the total 5Z catch was in EGB. United States of America (USA) landings and 1989 to 2007 USA discards were revised (Van Eeckhaute et al. 2009). Canadian discards are from the scallop fishery and USA discards are from the groundfish fishery. A dash (-) indicates *not applicable.*

	Landings (mt)			Discards (mt)		Totals			Quotas	
Year	Canada	USA	Other	Canada	USA	Canada	USA	Catch	Canadian	USA[2]
1968	-	-	-	-	-	-	-	-	-	-
1969	3,941	6,624	695	123	-	4,064	6,624	11,382	-	-
1970	1,970	3,154	357	116	-	2,086	3,154	5,597	-	-
1971	1,610	3,533	770	111	-	1,721	3,533	6,024	-	-
1972	609	1,551	502	133	-	742	1,551	2,795	-	-
1973	1,565	1,397	396	98	-	1,663	1,397	3,455	-	-
1974	462	955	573	160	757	622	1,712	2,907	-	-
1975	1,353	1,705	29	186	-	1,539	1,705	3,273	-	-
1976	1,355	974	24	160	-	1,515	974	2,513	-	-
1977	2,871	2,428	-	151	2,966	3,022	5,394	8,416	-	-
1978	9,968	4,725	-	177	1,556	10,145	6,281	16,426	-	-
1979	5,080	5,213	-	186	-	5,266	5,213	10,479	-	-
1980	10,017	5,615	-	151	7,561	10,168	13,176	23,344	-	-
1981	5,658	9,081	-	177	-	5,835	9,081	14,916	-	-
1982	4,872	6,286	-	130	-	5,002	6,286	11,287	-	-
1983	3,208	4,453	-	119	-	3,327	4,453	7,780	-	-
1984	1,463	5,121	-	124	-	1,587	5,121	6,708	-	-
1985	3,484	1,684	-	186	-	3,670	1,684	5,354	-	-
1986	3,415	2,201	-	92	-	3,507	2,201	5,708	-	-
1987	4,703	1,418	-	138	-	4,841	1,418	6,259	-	-
1988	4,046[1]	1,694	-	151	-	4,197	1,694	5,891	-	-
1989	3,060	785	-	138	137	3,198	922	4,121	-	-
1990	3,340	1,189	-	128	76	3,468	1,265	4,732	-	-
1991	5,456	931	-	117	0	5,573	931	6,504	-	-
1992	4,058	1,629	-	130	9	4,188	1,638	5,826	5,000	-
1993	3,727	424	-	114	106	3,841	530	4,371	5,000	-
1994	2,411	24	-	114	1,279	2,525	1,302	3,827	3,000	-
1995	2,065	15	-	69	0	2,134	16	2,150	2,500	-
1996	3,663	26	-	52	5	3,715	31	3,746	4,500	-
1997	2,749	55	-	60	1	2,809	56	2,865	3,200	-
1998	3,371	271	-	102	0	3,473	271	3,744	3,900	-
1999	3,681	359	-	49	5	3,729	364	4,093	3,900	-
2000	5,402	340	-	29	3	5,431	343	5,774	5,400	-
2001	6,774	762	-	39	22	6,813	784	7,597	6,989	-
2002	6,488	1,090	-	29	16	6,517	1,106	7,623	6,740	-
2003	6,775	1,677	-	98	96	6,874	1,772	8,646	6,933	-
2004	9,745	1,847	-	93	235	9,838	2,081	11,919	9,900	5,100
2005	14,484	649	-	49	76	14,533	724	15,257	15,410	7,590
2006	11,984	313	-	58	275	12,043	588	12,630	14,520	7,480
2007	11,890	256	-	58	306	11,948	562	12,510	12,730	6,270
2008	14,781	1,138	-	33	52	14,814	1,190	16,003	14,950	8,050
2010	16,578	2,167	-	15	34	16,593	2,201	18,794	17,612	11,988

	Landings (mt)			Discards (mt)		Totals			Quotas	
Year	Canada	USA	Other	Canada	USA	Canada	USA	Catch	Canadian	USA[2]
2011[3]	11,232	1,322	-	16	87	11,248	1,409	12,656	12,540	9,460
2012	5,034	443	-	30	126	5,064	569	5,633	9,120	6,880
2013	4,621	344	-	10	91	4,631	435	5,066	6,448	3,952
2014	12,936	1,182	-	17	108	12,953	1,290	14,243	16,470	10,530
2015	14,631	1,506	-	17	415	14,648	1,921	16,569	19,200	17,800
2016	11,935	341	-	8	125	11,943	466	12,409	21,830	15,170
2017	13,377	214	-	8	81	13,384	295	13,679	20,500	29,500
2018	12,216	253	-	5	21	12,221	274	12,495	24,000	16,000
2019	14,156	544	-	4	50	14,160	594	14,754	15,000	15,000
2020	11,045	633	-	7	50	11,052	683	11,735	13,800	16,200
2021	6,997	518	-	5	6	7,001	524	7,526	7,614	6,486
2022	5,143	327	-	7	8	5,150	334	5,484	7,473	6,627

[1] 1,895 mt excluded because of suspected area misreporting. [2]The USA quota pertains to the USA fishing year of May 1 to April 30 while the USA catches reported in this table pertain to the calendar year. [3]USA landings and discards revised in 2011.

Table A2. Input data for the Base model.

Data	List	Description
Fishery data	annual aggregate catch (biomass, 1 fleet)	1969-2022
	annual CVs for aggregate catch observations	0.1
	annual fishery age composition (numbers)	1969-2022, ages 1-9+
	annual effective samples size for age composition	70
	annual fishery weight at age	1969-2022, ages 1-9+
Survey data	annual aggregate catch for each survey index (mean number/tow)	1969 - 1972,1982 - 2022, NMFS Spring Survey 1969 - 2022, NMFS Fall Survey 1987 – 2021, DFO Spring Survey
	annual CVs for each index's aggregate observations	Calculated for each survey based on survey design
	annual age composition(numbers) for each index	ages 1-9+ for three surveys
	annual effective sample sizes for each index's age composition observations	40 for three surveys
	Survey timing(month)	3 for NMFS spring survey 9 for NMFS fall survey 2 for DFO spring survey
Others	spawning stock weight at age	1969-2022, ages 1-9+
	spawning time	0.25
	maturity at age data	1969-2022, ages 1-9+

Table A3. Configuration of the Base model.

Model feature	Base (Mest) 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 - 2022
Modeled age classes	1 – 9+
Fleet structure	Single aggregate fleet
Fleet selectivity	Two blocks: 1969 - 1991, time-invariant logistic; 1992 - 2022, iid random effects in logistic parameters.
Survey selectivity	Single block, time-invariant, age-specific selectivity for each survey. 1969 - 1972, 1982 - 2022, NMFS Spring Survey 1969 - 2022, NMFS Fall Survey 1987 – 2021, DFO Spring Survey
Stock recruitment model	Mean recruitment with log deviations estimated as fixed effects.
Natural mortality rate	Two blocks: 1969 – 2009, age- and time-invariant M = 0.2 2010 – 2022, 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 A4. Estimated spawning stock biomass (SSB in mt) from Base model.

Year	SSB (mt)
1969	31,082
1970	19,096
1971	12,181
1972	7,708
1973	5,332
1974	5,106
1975	7,100
1976	9,237
1977	18,697
1978	32,066
1979	32,058
1980	30,621
1981	28,674
1982	25,211
1983	19,834
1984	14,874
1985	12,146
1986	13,559
1987	12,504
1988	11,659
1989	11,262
1990	14,400
1991	14,216
1992	10,785
1993	8,039
1994	9,152
1995	12,092
1996	14,663
1997	14,165
1998	16,625
1999	18,599
2000	26,725
2001	35,869
2002	36,344
2003	52,439
2004	48,394
2005	44,916
2006	61,833
2007	82,650
2008	83,538
2009	85,078
2010	57,252
2011	25,648
2012	24,647
2013	49,462
2014	51,079
2015	68,568
2016	82,754
2017	76,893
2018	57,487
2019	42,568
2020	29,745
2021	18,576
2022	26,867

Table A5. Estimated population numbers at age (in 1000s) from the Base model.

Year	1	2	3	4	5	6	7	8	9+
1969	522	187	2,522	1,253	822	8,723	2,220	350	1,080
1970	3,255	424	132	1,318	628	411	4,364	1,110	715
1971	77	2,648	311	78	751	357	234	2,483	1,039
1972	4,772	62	1,812	148	35	340	162	106	1,593
1973	7,923	3,880	45	1,042	83	20	189	90	944
1974	5,554	6,393	2,484	18	379	30	7	68	375
1975	5,408	4,508	4,514	1,301	9	190	15	4	222
1976	55,924	4,398	3,297	2,629	734	5	107	8	127
1977	6,033	45,582	3,341	2,153	1,681	469	3	68	87
1978	4,367	4,901	32,783	1,850	1,150	896	250	2	83
1979	40,825	3,548	3,524	18,144	987	612	477	133	45
1980	7,484	33,236	2,642	2,169	10,870	591	366	286	107
1981	5,700	6,041	21,446	1,055	810	4,045	220	136	146
1982	2,560	4,625	4,254	11,149	526	403	2,011	109	140
1983	2,311	2,079	3,301	2,302	5,804	273	209	1,045	130
1984	12,114	1,878	1,507	1,871	1,261	3,174	149	114	642
1985	2,234	9,837	1,340	814	972	654	1,646	77	392
1986	13,190	1,815	7,063	738	432	515	347	872	249
1987	1,356	10,718	1,310	3,956	399	233	278	187	605
1988	17,762	1,099	7,470	660	1,904	192	112	134	381
1989	736	14,407	769	3,800	321	925	93	54	250
1990	2,650	599	10,597	456	2,185	184	531	53	175
1991	1,684	2,159	451	6,745	283	1,357	114	330	142
1992	6,579	1,367	1,547	247	3,555	149	714	60	248
1993	8,988	5,290	1,005	892	122	1,691	71	338	146
1994	8,698	7,288	4,041	606	429	55	766	32	219
1995	4,697	7,059	5,599	2,531	320	218	28	387	127
1996	5,094	3,834	5,670	4,179	1,677	201	136	17	320
1997	12,010	4,162	3,093	4,250	2,580	918	108	73	180
1998	8,849	9,810	3,368	2,402	2,977	1,649	569	66	155
1999	29,701	7,224	7,918	2,589	1,641	1,841	987	338	131
2000	10,333	24,280	5,844	6,005	1,709	1,020	1,133	606	288
2001	56,386	8,449	19,656	4,405	3,818	1,012	598	664	524
2002	2,926	46,135	6,870	15,072	2,697	2,047	533	314	624
2003	2,102	2,395	37,643	5,464	10,434	1,541	1,110	287	505
2004	204,952	1,720	1,954	30,114	3,938	6,065	806	569	405
2005	6,375	167,574	1,399	1,552	21,648	2,163	2,478	291	340
2006	20,852	5,216	136,626	1,112	1,063	10,592	891	989	250
2007	9,159	17,065	4,258	109,603	805	545	3,902	299	410
2008	10,683	7,496	13,933	3,420	80,865	501	313	2,206	400
2009	5,302	8,744	6,120	11,173	2,545	55,919	341	212	1,767
2010	9,608	4,329	7,079	4,787	8,005	1,666	35,285	213	1,234
2011	350,928	5,842	2,586	3,957	2,311	3,406	677	14,171	579
2012	40,613	213,375	3,450	1,300	1,489	778	1,127	224	4,870
2013	16,001	24,764	129,087	1,997	629	541	248	349	1,567
2014	914,301	9,756	14,988	75,219	1,010	257	200	90	689
2015	18,638	557,181	5,851	8,144	34,461	438	111	86	335
2016	45,505	11,369	336,378	3,223	3,341	12,255	153	39	147
2017	67,062	27,780	6,923	199,463	1,570	1,105	3,601	44	54

Year	1	2	3	4	5	6	7	8	9+
2018	17,909	40,927	16,901	4,133	107,907	640	353	1,075	29
2019	31,598	10,911	24,766	9,980	2,277	53,174	291	156	483
2020	19,461	19,160	6,506	14,039	5,039	986	20,785	109	236
2021	109,295	11,743	11,137	3,360	5,950	1,870	350	7,292	121
2022	126,464	65,909	6,719	5,415	1,379	2,304	716	134	2,830

Table A6. Swept area biomass (mt) of National Marine Fisheries Service (NMFS) fall (1963-2022), NMFS spring (1968-2022) and Fisheries and Oceans Canada (DFO; 1987-2023) research surveys for eastern Georges Bank. Biomass conversion factors 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; 2009-2022). The NMFS spring and fall survey in 2020 were cancelled due to Covid-19 restrictions. The 2022 DFO survey used a new vessel and calibration factors are currently not available (NA). The 2023 spring survey results were not available for TRAC meeting (NA). A dash (-) indicates not applicable.

Year	NMFS Fall	NMFS Spring	DFO	3 survey Average
1963	90,610	-	-	-
1964	90,273	-	-	-
1965	50,070	-	-	-
1966	37,269	-	-	-
1967	10,143	-	-	-
1968	16,694	11,758	-	-
1969	7,412	12,028	-	-
1970	13,633	19,323	-	-
1971	6,819	3,708	-	-
1972	7,135	4,663	-	-
1973	11,326	8,220	-	-
1974	3,118	15,958	-	-
1975	27,451	8,360	-	-
1976	62,128	3,785	-	-
1977	41,153	13,804	-	-
1978	25,900	23,847	-	-
1979	28,097	15,065	-	-
1980	30,616	45,244	-	-
1981	18,305	39,994	-	-
1982	10,197	17,181	-	-
1983	7,848	6,570	-	-
1984	7,549	7,221	-	-
1985	5,838	18,830	-	-
1986	9,077	9,341	-	-
1987	4,418	11,962	16,092	10,824
1988	9,723	6,186	26,310	14,073
1989	7,715	12,235	11,198	10,383
1990	4,917	17,700	27,485	16,701
1991	1,529	10,141	27,323	12,998
1992	4,805	2,867	20,476	9,382
1993	7,926	4,816	6,953	6,565
1994	4,393	10,662	18,947	11,334
1995	11,660	14,949	20,621	15,743
1996	7,743	15,760	23,212	15,572
1997	13,138	4,513	14,455	10,702
1998	11,231	9,623	45,267	22,040
1999	32,626	12,516	30,821	25,321
2000	16,036	13,727	57,411	29,058
2001	32,656	10,106	55,760	32,841
2002	53,952	33,876	49,538	45,789
2003	29,905	27,589	122,786	60,094
2004	56,798	89,287	100,046	82,044
2005	51,154	17,741	56,366	41,754
2006	62,897	28,275	100,307	63,826
2007	73,481	69,583	61,604	68,223
2008	34,640	44,434	123,963	67,679
2009	56,745	38,281	71,560	55,529
2010	34,003	33,322	71,269	46,198
2011	36,404	12,547	59,162	36,038
2012	29,618	25,679	77,447	44,248

Year	NMFS Fall	NMFS Spring	DFO	3 survey Average
2013	73,936	29,966	163,515	89,139
2014	52,378	26,091	69,329	49,266
2015	149,349	40,298	232,895	140,847
2016	94,176	33,108	237,859	121,714
2017	49,357	40,054	123,253	70,888
2018	31,073	22,755	115,240	56,356
2019	29,342	30,748	96,905	52,332
2020	NA	NA	32,765	32,765
2021	22,343	29,465	27,730	26,513
2022	25,638	13,043	NA	19,341
2023	-	NA	56,922	56,922
average (1987-2022)	34,792	24,112	68,133	42,461

Table A7. Age-specific mean abundance indices per tow of eastern Georges Bank haddock from the Fisheries and Oceans Canada (DFO) surveys during 1986–2023. The 2022 survey used a new vessel and calibration factors are currently not available (-).

Year	1	2	3	4	5	6	7	8	9+	1-9+
1987	0.11	10.32	2.24	8.31	1.57	0.20	0.93	0.33	2.73	26.72
1988	2.34	0.12	30.61	0.62	10.46	0.66	0.59	0.31	1.65	47.36
1989	0.12	16.05	2.39	7.01	0.59	1.27	0.10	0.08	0.63	28.23
1990	1.75	0.26	29.61	0.40	10.75	0.72	3.30	0.35	0.94	48.08
1991	0.92	5.21	0.32	26.05	0.27	4.60	0.28	1.22	0.54	39.41
1992	4.61	9.34	3.43	0.53	11.58	0.04	3.07	0.13	1.58	34.31
1993	8.30	4.23	1.31	1.04	0.08	2.86	0.05	0.68	0.35	18.90
1994	10.11	36.51	12.84	1.32	0.76	0.05	2.20	0.04	0.86	64.68
1995	2.96	7.76	15.02	7.31	1.73	0.96	0.00	1.75	2.05	39.54
1996	3.50	5.51	11.52	12.77	7.50	0.73	0.66	0.09	1.65	43.93
1997	2.49	3.73	2.94	6.60	6.16	3.36	0.36	0.16	0.89	26.70
1998	5.73	25.58	12.88	7.68	12.79	12.11	5.41	0.84	1.45	84.46
1999	59.21	11.53	24.24	7.47	4.73	4.53	4.25	1.08	0.42	117.45
2000	7.65	38.20	18.49	29.15	6.98	4.99	6.56	3.83	1.96	117.82
2001	55.44	8.47	35.23	10.25	13.50	4.35	3.43	4.73	5.53	140.94
2002	1.76	67.84	14.39	30.48	7.18	6.37	1.56	1.27	5.83	136.69
2003	4.05	3.62	197.83	13.32	36.37	8.85	5.67	2.66	4.78	277.15
2004	221.14	1.30	6.46	132.14	12.04	23.34	3.98	2.30	1.53	404.23
2005	4.02	50.46	1.28	3.75	61.54	8.19	11.59	2.62	1.32	144.77
2006	21.54	12.97	417.73	6.01	5.30	37.24	1.81	3.88	0.61	507.09
2007	7.35	22.97	7.92	162.07	2.37	0.37	8.63	0.60	1.57	213.85
2008	9.23	2.93	11.19	12.10	250.11	2.42	0.46	20.59	1.74	310.78
2009	4.82	9.58	6.42	14.42	1.57	105.55	1.53	0.30	3.77	147.97
2010	2.09	1.46	7.23	5.62	11.69	3.45	101.86	0.75	2.58	136.73
2011	504.45	4.56	3.97	7.41	3.20	7.16	1.78	70.20	1.29	604.03
2012	48.27	850.15	9.89	1.80	2.56	0.99	1.65	0.97	10.72	926.99
2013	7.19	79.60	772.78	12.81	1.89	3.35	1.41	2.33	13.10	894.47
2014	1,143.45	20.27	42.06	124.84	1.57	0.21	0.07	0.44	1.32	1,334.24
2015	14.93	2,149.12	49.68	20.01	145.61	0.00	0.68	0.13	2.63	2,382.78
2016	23.34	25.32	1,312.15	5.22	5.39	72.51	0.83	0.00	0.79	1,445.55
2017	65.20	31.87	17.41	572.54	5.08	3.12	13.45	0.06	0.33	709.07
2018	11.66	38.69	29.43	3.05	428.55	1.10	0.33	14.77	0.12	527.70
2019	11.59	6.28	40.13	22.10	4.45	265.44	7.42	0.22	0.59	358.22
2020	5.84	34.75	5.37	18.82	6.61	0.79	55.31	0.36	0.72	128.57
2021	67.84	16.74	22.08	6.36	8.60	5.99	7.63	23.76	0.12	159.13
2022	-	-	-	-	-	-	-	-	-	-
2023	9.11	138.05	100.14	7.75	1.09	0.76	3.16	0.33	4.14	264.56

Table A8. Age-specific mean abundance indices per tow of eastern Georges Bank haddock from the National Marine Fisheries Service spring surveys during 1968–2022. Years 1973–1981 are omitted as a 41 Yankee trawl was used those years, while a 36 Yankee trawl was used in other years up to and including 2008. Since 2009 a new net, vessel and protocols were used and conversion factors to equate to Albatross IV catches were applied. The 2020 survey was cancelled due to Covid-19 restrictions (-). The 2023 spring survey results were not available for the Transboundary Resources Assessment Committee meeting (NA).

Year	1	2	3	4	5	6	7	8	9+	1-9+
1968	0.00	5.71	0.12	1.22	8.92	3.69	0.43	0.22	0.42	20.74
1969	0.03	0.06	1.02	0.44	1.13	5.68	2.12	0.90	0.75	12.13
1970	0.92	0.37	0.00	1.26	1.94	0.85	5.93	4.71	1.50	17.49
1971	0.00	1.59	0.38	0.00	0.15	0.18	0.11	2.25	0.49	5.14
1972	4.72	0.00	1.35	0.34	0.05	0.12	0.36	0.04	2.12	9.10
1982	1.05	6.71	2.79	14.51	1.16	0.82	1.26	0.00	0.00	28.31
1983	0.43	1.39	1.31	0.57	4.66	0.06	0.00	1.45	0.10	9.98
1984	2.73	2.61	1.96	1.84	1.76	2.16	0.25	0.14	0.91	14.36
1985	0.07	16.09	2.53	1.22	2.70	1.06	3.61	0.23	0.87	28.39
1986	6.02	0.51	6.50	0.44	0.38	0.60	0.42	1.01	0.29	16.17
1987	0.22	9.89	0.26	2.52	0.28	0.42	0.21	0.67	0.00	14.46
1988	0.55	0.11	3.37	0.42	1.10	0.37	0.39	0.32	0.00	6.64
1989	0.15	12.06	1.12	2.42	0.48	1.43	0.11	0.17	0.09	18.02
1990	3.08	0.13	19.28	1.12	1.94	0.20	0.34	0.00	0.00	26.09
1991	1.34	3.74	0.78	6.10	0.35	0.37	0.12	0.16	0.05	12.98
1992	0.96	0.52	0.37	0.28	1.09	0.06	0.08	0.08	0.00	3.45
1993	3.38	2.02	0.36	0.42	0.35	1.29	0.14	0.06	0.08	8.10
1994	1.98	8.30	2.89	0.52	0.36	0.23	0.54	0.05	0.16	15.02
1995	1.67	4.20	7.60	3.14	0.48	0.28	0.09	0.49	0.39	18.34
1996	1.66	2.48	6.84	5.76	3.44	0.43	0.07	0.00	0.89	21.57
1997	2.95	2.23	0.69	1.08	0.85	0.62	0.04	0.08	0.04	8.58
1998	1.06	11.62	3.86	2.46	2.28	0.58	0.11	0.03	0.23	22.24
1999	9.41	5.17	6.84	1.25	2.04	1.76	0.92	0.86	0.08	28.32
2000	4.86	3.85	6.14	2.93	1.15	1.02	0.79	0.55	0.30	21.60
2001	18.95	2.15	6.01	2.24	0.68	0.54	0.21	0.04	0.04	30.84
2002	0.44	77.76	21.03	7.78	2.87	0.91	0.55	0.44	0.45	112.24
2003	0.23	1.99	30.55	4.06	6.83	0.86	0.36	0.15	0.52	45.54
2004	351.78	8.52	4.77	82.76	6.39	9.49	1.73	2.25	1.52	469.21
2005	0.97	59.48	0.47	1.11	10.53	1.21	2.16	0.43	0.12	76.50
2006	5.36	2.25	88.24	0.38	1.71	12.01	0.59	1.04	0.34	111.93
2007	2.65	20.53	3.71	172.96	0.32	0.80	3.91	0.40	0.56	205.84
2008	6.14	3.01	7.81	0.43	69.57	1.51	0.67	3.14	0.87	93.15
2009	4.01	4.32	2.59	8.48	1.32	40.70	1.02	0.81	2.32	65.56
2010	0.62	1.01	5.48	2.44	6.38	0.87	35.33	0.00	1.06	53.17
2011	21.07	2.14	1.48	1.12	0.90	1.93	0.57	12.48	0.30	42.00
2012	25.64	142.95	2.20	0.60	1.13	1.10	1.54	0.07	6.08	181.33
2013	3.37	11.10	97.08	2.08	0.95	0.67	0.55	0.51	1.92	118.24
2014	114.58	6.66	13.06	46.11	0.47	0.11	0.13	0.09	0.27	181.47
2015	2.69	283.75	5.14	4.56	26.27	0.62	0.00	0.11	0.19	323.33
2016	17.75	1.88	130.93	1.45	1.51	11.37	0.05	0.00	0.16	165.16
2017	12.04	5.55	1.43	139.71	1.16	1.01	7.04	0.06	0.03	168.03
2018	2.60	13.17	10.01	0.27	54.53	0.14	0.48	1.09	0.01	82.32
2019	0.96	2.06	15.86	4.60	1.30	62.06	0.73	0.35	1.20	89.12
2020	-	-	-	-	-	-	-	-	-	-
2021	65.73	3.82	18.30	3.14	11.15	2.64	0.35	14.50	0.00	119.63
2022	58.66	24.72	1.21	2.24	0.40	1.32	0.38	0.06	1.94	90.98
2023	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table A9. Age-specific mean abundance indices per tow of eastern Georges Bank haddock from National Marine Fisheries Service fall surveys during 1963–2022. Since 2009 a new net, vessel and protocols were used and conversion factors to equate to Albatross IV catches were applied. The 2020 survey was cancelled due to Covid-19 restrictions (-).

Year	0	1	2	3	4	5	6	7	8	9+	1–9+
1963	125.63	45.78	12.38	6.26	9.49	7.81	2.84	1.55	0.94	0.68	87.72
1964	2.02	109.71	69.90	8.25	1.53	4.95	1.43	0.74	0.42	0.38	197.30
1965	0.27	2.41	56.70	10.82	1.03	0.90	0.69	0.65	0.25	0.21	73.67
1966	10.15	2.02	3.52	27.03	5.36	1.09	0.33	0.24	0.05	0.12	39.76
1967	0.00	4.41	0.08	0.46	2.82	0.93	0.23	0.12	0.09	0.08	9.22
1968	0.06	0.12	1.36	0.10	0.19	4.41	1.18	0.32	0.12	0.51	8.32
1969	0.10	0.00	0.00	0.62	0.16	0.11	1.42	0.74	0.06	0.18	3.30
1970	0.00	6.74	0.38	0.02	0.46	0.42	0.59	1.10	0.45	0.29	10.45
1971	2.84	0.00	0.94	0.18	0.00	0.46	0.06	0.15	0.81	0.36	2.96
1972	5.03	2.86	0.00	0.56	0.05	0.00	0.12	0.04	0.01	1.20	4.85
1973	1.48	18.48	1.76	0.00	0.32	0.02	0.00	0.04	0.00	0.55	21.17
1974	0.20	0.51	1.70	0.37	0.00	0.01	0.00	0.00	0.00	0.08	2.66
1975	33.10	0.91	1.21	9.86	1.87	0.00	0.05	0.00	0.01	0.53	14.45
1976	0.90	137.13	0.67	0.33	1.40	0.32	0.00	0.05	0.07	0.30	140.26
1977	0.05	0.37	31.15	0.85	0.76	0.97	0.54	0.01	0.01	0.08	34.73
1978	15.43	0.56	1.26	15.00	0.16	0.27	0.70	0.07	0.00	0.00	18.02
1979	1.69	24.95	0.22	1.48	6.58	0.42	0.43	0.06	0.02	0.00	34.15
1980	3.84	4.35	21.86	2.83	0.39	2.08	0.52	0.10	0.12	0.00	32.27
1981	0.63	4.97	2.94	5.19	0.48	0.68	0.85	0.04	0.11	0.08	15.34
1982	2.28	0.00	1.19	0.63	3.07	0.20	0.14	0.67	0.03	0.05	5.98
1983	3.84	0.53	0.32	0.64	0.64	1.12	0.10	0.13	0.42	0.06	3.95
1984	0.05	5.70	1.65	0.55	0.54	0.13	0.91	0.00	0.00	0.14	9.64
1985	12.80	0.40	3.36	0.43	0.12	0.14	0.17	0.19	0.00	0.05	4.85
1986	0.03	10.16	0.17	2.42	0.12	0.23	0.22	0.03	0.02	0.03	13.41
1987	0.54	0.00	1.37	0.21	1.45	0.15	0.11	0.03	0.02	0.00	3.33
1988	0.13	4.20	0.19	2.62	0.22	0.73	0.25	0.25	0.00	0.07	8.53
1989	0.21	0.09	5.07	0.35	1.25	0.16	0.22	0.01	0.00	0.00	7.15
1990	1.28	1.19	0.06	2.32	0.08	0.34	0.06	0.01	0.00	0.00	4.05
1991	0.96	0.51	0.49	0.09	0.54	0.04	0.03	0.00	0.00	0.00	1.69
1992	3.67	1.11	0.39	0.50	0.00	0.93	0.03	0.16	0.05	0.13	3.29
1993	1.16	7.07	3.85	0.66	0.00	0.10	0.29	0.05	0.00	0.00	12.02
1994	0.76	0.86	1.15	1.07	0.22	0.07	0.02	0.31	0.10	0.00	3.79
1995	0.94	1.57	6.40	4.01	0.62	0.03	0.00	0.01	0.07	0.00	12.71
1996	2.06	0.51	0.71	2.95	1.32	0.58	0.00	0.05	0.00	0.02	6.14
1997	0.27	6.17	3.80	0.78	1.27	0.87	0.30	0.00	0.15	0.17	13.50
1998	3.76	3.30	4.89	1.37	0.96	0.72	0.96	0.02	0.00	0.02	12.25
1999	3.70	1.42	6.45	8.28	2.00	3.77	0.39	1.73	0.89	0.50	25.44
2000	1.53	5.83	7.62	4.67	0.93	0.41	0.03	0.21	0.05	0.10	19.83
2001	0.69	18.34	2.48	12.05	4.51	2.42	0.54	0.25	0.13	0.02	40.74
2002	0.19	2.28	49.10	7.10	6.88	2.10	1.05	0.55	0.41	0.08	69.56
2003	210.27	0.08	0.72	13.15	2.68	4.04	0.34	0.41	0.00	0.39	21.81
2004	3.02	133.10	0.49	1.25	23.83	1.60	3.76	0.59	0.55	0.15	165.32
2005	5.34	3.30	118.34	0.44	0.87	6.17	0.61	0.55	0.07	0.14	130.49
2006	1.04	9.93	1.32	97.62	1.43	0.39	1.69	0.09	0.11	0.02	112.58
2007	1.33	2.28	14.16	1.50	74.10	1.20	0.72	0.55	0.04	0.02	94.55
2008	2.00	1.97	1.23	2.81	0.52	23.56	0.00	0.13	0.35	0.25	30.82
2009	1.17	0.77	1.60	1.81	4.73	0.68	33.33	0.13	0.05	0.44	43.55
2010	106.00	1.01	0.76	1.74	0.93	2.55	0.96	18.61	0.00	0.33	26.89
2011	15.49	88.12	0.51	0.64	1.01	1.25	2.38	0.53	11.51	0.26	106.21
2012	2.35	9.03	69.69	0.35	0.21	0.22	0.11	0.21	0.05	1.47	81.34
2013	639.11	3.23	7.40	76.45	0.94	0.18	0.16	0.14	0.31	0.99	89.81
2014	2.43	233.81	3.26	2.57	26.56	0.54	0.28	0.13	0.13	0.05	267.32
2015	25.32	6.05	323.66	2.04	3.99	36.05	0.15	0.04	0.03	0.06	372.06
2016	50.77	19.33	3.27	202.91	1.42	1.23	10.59	0.03	0.00	0.06	238.86
2017	3.65	22.42	12.23	1.37	70.08	0.23	1.13	1.99	0.01	0.06	109.53
2018	11.57	4.58	12.54	4.24	0.31	31.60	0.20	0.73	0.94	0.00	55.14
2019	2.43	0.72	1.73	7.01	2.46	1.33	25.80	0.08	0.00	0.40	39.54
2020	-	-	-	-	-	-	-	-	-	-	-
2021	199.13	15.32	0.77	1.80	0.36	1.06	0.40	0.01	2.49	0.01	22.24
2022	2.21	36.44	9.37	0.22	0.67	0.25	1.05	0.60	0.21	1.68	50.53

Table A10. $F_{40\% SPR}$ (fishing mortality rate at 40% spawner per recruit) calculated using input data over various time periods. The fishing mortality reference (F_{ref}) =0.367 recommended by the Transboundary Resource Assessment Committee was based on the mean $F_{40\%SPR}$ calculated using data inputs from 2017 to 2021. A second F_{ref} was calculated using updated data inputs from 2018–2022. The reference point computations assume that natural mortality (M)=0.2.

	2017–2021	2018–2022
Mean	0.367	0.380
5%	0.320	0.323
25%	0.347	0.354
Median	0.365	0.378
75%	0.386	0.402
95%	0.420	0.443

Table A11. Input data for projections and the risk analysis of the Low M and High M scenarios used to provide 2023 and 2024 catch advice.

	Age Group								
	1	2	3	4	5	6	7	8	9+
Stock Weight at Age (kg)									
2020-2022	0.105	0.293	0.504	0.701	0.781	0.962	0.994	1.026	1.206
2019-2021	0.101	0.242	0.486	0.601	0.728	0.845	0.88	1.201	1.229
Fishery Weight at Age (kg)									
2020-2022	0.331	0.583	0.74	0.891	0.929	1.004	1.037	1.121	1.355
2019-2021	0.297	0.488	0.647	0.748	0.858	0.873	0.969	1.341	1.373
Natural Mortality									
Low M	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
High M (2022)	0.493	0.493	0.493	0.493	0.493	0.493	0.493	0.493	0.493
High M (2021)	0.516	0.516	0.516	0.516	0.516	0.516	0.516	0.516	0.516
Selectivity									
2020-2022	0.018	0.087	0.376	0.789	0.943	0.987	0.997	0.999	1
2019-2021	0.016	0.065	0.231	0.535	0.798	0.93	0.979	0.995	1
Maturity at Age									
2020-2022	0.076	0.64	0.87	1	1	1	1	1	1
2019-2021	0.066	0.506	0.805	0.977	0.996	0.999	1	1	1