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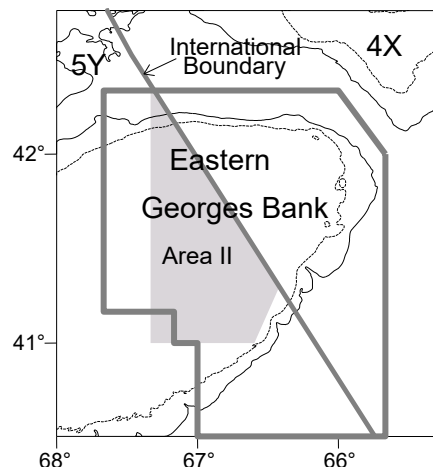NATIONAL MARINE FISHERIES SERVICE

Transboundary Resources Assessment Committee

Status Report 2022/03

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 2021 were 7,526 mt and represented 53% of the combined 14,100 mt quota.

- The state of the EGB Haddock resource is based on a model for the period 1969 to 2019 approved by the Haddock Research Track Assessment peer review held in March 2022.

- Spawning Stock Biomass (SSB) for EGB Haddock has declined sharply since 2016. The current SSB estimate for 2021 is 15,351 mt, which is below the median SSB of 25,235 mt for the time series (1969–2021).

- Recruitment, while highly variable, tends to occur when SSB is above 20,000 mt. The EGB Haddock stock has produced several exceptionally strong year classes since 2003. The median recruitment for the time series (1968–2020 year class) is 8.8 million. The preliminary estimate of the 2020 year class is 111 million.

- The 2021 National Marine Fisheries Service (NMFS) fall survey, and the 2022 DFO and NMFS spring surveys suggest that the EGB Haddock 2021 year class is the largest since 2013.

- Fully-selected fishing mortality (F) is estimated at 0.79 and 0.76 for 2020 and 2021, respectively. These are the highest values since 2007.

- 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 survey.

- The fishing mortality reference (F_{ref})=0.26, derived from the 2002 Virtual Population Analysis model output and adopted by the Transboundary Management Guidance Committee (TMGC), is no longer appropriate as F_{ref} for EGB Haddock. The Transboundary Resource Assessment Committee (TRAC) suggests F=0.367 as the new fishing reference point for TMGC discussion.

- Considering the uncertainties of natural mortality (M) in the near future, projections were conducted under two different M scenarios for EGB Haddock. The two options discussed were to use a catch based on the projections from the High M only scenario or to use the range of projected catch bounded by the High M and Low M scenarios. The TRAC did not reach consensus on which scenario is more likely; however, the TRAC does agree that a decrease in catch advice is necessary. Rationale for both approaches are presented in this document.

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). 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. In 2021, the total catch decreased to 7,526 mt and represented 53% 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.

		2018	**2019**	**2020**	**2021**	**2022**	**Avg[1]**	**Min[1]**	**Max[1]**
Canada[2]	**Quota**	24,000	15,000	13,800	7,614	7,473			
	Landed	12,216	14,156	11,045	6,997		6,603	462	17,595
	Discard	5	4	7	5		87	4	186
USA[2]	**Quota[3]**	16,000	15,000	16,200	6,486	6,627			
	Catch[3]	623	715	563	417				
	Landed	253	544	633	518		1,796	15	9,081
	Discard	20	50	50	6		450	0	7,561
Total[2]	**Quota[4]**	40,000	30,000	30,000	14,100	14,100			
	Catch[4]	12,844	14,875	11,615	7,418				
	Catch[5]	12,495	14,754	11,735	7,526		8,864	2,150	23,344

[1] 1969-2021
[2] unless otherwise notes, 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)

The **Canadian catch** decreased from 11,052 mt in 2020 to 7,001 mt in 2021. Discards in the groundfish fishery are considered to be negligible. Discards of Haddock by the Canadian sea scallop fishery were 5 mt in 2021, but ranged between 4 mt and 186 mt over the time series. Canada caught 92% of its 7,614 mt allocation

USA catches decreased from 683 mt in 2020 to 524 mt in 2021. Landings in 2021 were 518 mt and discards were estimated to be 6 mt. The USA caught 8% of its 6,486 mt allocation.

The combined Canada and USA **fishery age composition** (landings + discards) in 2021 was dominated by the 2013 (age 8) and 2018 (age 3) year classes by numbers and weight. The Canadian fishery was adequately sampled to determine length composition of the catch. In general, sampling for the USA fishery was very poor in both 2020 and 2021, with incomplete

data for 2021 as Q4 was not available in time for the Transboundary Resource Assessment Committee (TRAC) meeting.

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

A retrospective forecasting within the OpenMSE framework (Hordyk et al. 2022) was conducted to evaluate the performance of Management Procedures (MPs) with different options for the interval to update the $F_{40\%spr}$ reference point and the number of years of data used to calculate the $F_{40\%spr}$ reference point. The MP approach was judged to be a more appropriate basis for F_{ref}. The $F_{40\%spr}$=0.367 updated every 3 years and calculated with the data from the last 5 years (U3M5) outperforms longer period average MPs with higher yields, intermediate variability, and higher biomass outcomes (Figure 2). The 3-year update reflects perceptions of the resolution of fishery changes, and it does not require updating on a regular basis (one or two year update). The TRAC suggests this value for TMGC discussion. This proposed F_{ref} would not be appropriate to compare to estimated fishing mortality in years before the most recent three years, as changes in selectivity, weights, and maturity at age would lead to a different F_{ref}.

State of Resource

The state of the resource is based on the EGB Haddock model developed in the Haddock Research Track (Base model with data from 1969–2019) and recommended by the peer review panel to be used by the TRAC for catch advice for EGB Haddock (see *Special Considerations* section). In this model, M is fixed at 0.2 for 1969 to 2009; M is estimated in the model as a single value for the period 2010 to 2021 (Wang et al. 2022). Alternative configurations of the model were examined, but the state of resource is based on the Base model updated with data through 2021. Evaluation of model performance metrics suggest it is sufficient to characterize stock status.

Significant changes in the resource have been a function of large year classes, with the 2013 year class sustaining the fishery since it recruited. Since then, 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 is greatly diminished. As a consequence, overall stock size has been reduced. There is some evidence of a better than average 2020 year class, which is expected to recruit to the fishery in 2023.

Improved recruitment since 1990, lower exploitation, and reduced capture of small fish in the fisheries all contributed to the **SSB** increasing to 52,000 mt in 2003. A subsequent increase to 87,000 mt in 2009 was largely due to the strong 2003 year class estimated at 208 million age-1 fish. The biomass sharply decreased after the 2009 high and, in 2012, the SSB was 26,000 mt. When the strong 2010 and 2013 year classes joined the SSB group, SSB increased to 82,000 mt in 2016, followed by a sharp and continued decline in the subsequent years. The

current SSB estimate for 2021 is 15,351 mt, which is below the median SSB of 25,235 mt for the time series (1969–2021).

Recruitment at age 1 has fluctuated between 1.6 and 69 million since 1990, except for the strong year classes. The 2003, 2010, and 2013 year classes were estimated at 209, 379, and 956 million. The preliminary estimate of the 2020 year class is 111 million. The median recruitment for the time series (1968–2020 year class) is 8.8 million (Figure 3).

Fully recruited **fishing mortality** fluctuated between 0.27 and 0.49 during the 1980s (Figure 4). After reaching a high of 0.59 in 1993, it decreased to 0.29 in 1995, stayed low until 2004–2006 when it increased to around 0.8, followed by a decline to 0.19 in 2008. Fishing mortality increased to higher levels between 0.33 and 0.73 from 2010–2019, and was estimated at 0.79 and 0.76 for 2020 and 2021, respectively. These are the highest values since 2006.

Productivity

Recruitment, **natural mortality**, **growth**, **age structure** and **spatial distribution** generally reflect changes in the productive potential. Recruitment has been highly variable. Higher recruitment tends to occur when SSB is above 20,000 mt (Figure 5). This stock has produced three exceptional and five strong year classes in the last 21 years. However, the Base model estimates a substantial increase in natural mortality from the historical assumed level of 0.2 to 0.516 over the last 12 years. The stock is leaving a period of unprecedented high biomass where density-dependent natural mortality rate may have been exceptionally high and would not necessarily continue given a return to biomass levels more consistent with the historical average.

Both fishery and survey average lengths- and weights-at-age have declined considerably since 2000 with an increase in biomass. With density-dependent effects, changes in growth in response to changes in stock abundance and episodes of very strong recruitments have been observed throughout the history of this stock. With the sharp decrease in biomass in the last few years, some improvements of both Haddock length- and weight-at-age have been observed in fishery and survey data, although the length- and weight-at-age are within the range observed during 2010–2019 (the High M period) for most ages. Despite different trends across seasons, there have been improvements in fish condition in the last three years for all three surveys.

Due to both high natural and fishing mortality in most recent years, the contribution of the exceptionally strong 2013 year class to the SSB and the 2023 fishery is expected to be very small (Figure 6). The 2021 DFO spring survey and the 2022 NMFS spring survey indicate that the EGB Haddock stock is mostly composed of younger and not fully mature fish in 2022. The spatial distribution patterns observed during these bottom trawl surveys are generally similar to the average patterns over the previous ten years. The 2021 NMFS fall survey was an exception to this, as age-0 and age-1 Haddock were mostly observed on the northern part of eastern Georges Bank.

The updated calculation of $F_{40\%spr}$ using the Base model output suggests that the current F_{ref}=0.26 is not appropriate as a fishing reference point for EGB Haddock. The TRAC proposes $F_{40\%spr}$=0.367 as a candidate fishing reference point for consideration by the TMGC. This outlook is provided in terms of consequences with respect to the proposed F_{ref}=0.367 for catch advice in 2023.

The full quota for EGB Haddock has never been utilized in any year since 2004, when the TMGC began setting the Total Allowable Catch (TAC). In the past 10 years, between 27–53% of the TAC was realized. This is largely driven by lower USA catches (TRAC 2021) and the Canadian fleet-share arrangements. Considering the impact of the assumed 2022 EGB

Haddock catch on 2023 catch advice at the proposed F_{ref}=0.367, the TRAC agreed to use 7,526 mt as the assumed 2022 catch in the projection. This 7,526 mt is the same as the 2021 catch and 53% of 2022 TAC.

Two scenarios of projection and risk evaluation with different assumptions on future M were reviewed at the 2022 TRAC meeting, Low M and High M. The Low M scenario assumes a return to M=0.2 in 2022–2023. The High M (M=0.516) scenario assumes that future (2022-2023) M will stay the same as 2010-2021.

Low M scenario

Assuming a resumption to historical Low M=0.2 in 2022–2024, Table 2 shows the median estimates of biomass, SSB, and F in 2022 based on 2,000 realizations of terminal year population sizes and an assumed catch of 7,526 mt. For 2023, the median biomass, SSB, and catch estimates are obtained by applying an F=0.367 to each realization conditional on an assumed catch of 7,526 mt in 2022. The risk analysis in Figure 7 applies a similar logic to estimate the probability of exceeding F=0.367 in 2023 given various catch levels ranging from 0 mt to 16,000 mt in steps of 1,000 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 overfishing (approximate value of 4,620 mt) in Figure 7 differs slightly (0.5%) from the equivalent median catch for 2023 (4,601 mt) reported in Table 2.

The median SSB will increase from approximately 16,000 mt in 2022 to 29,000 mt in 2023, and to approximately 38,000 mt in 2024. In 2022, F=1.019 from a catch of 7,526 mt (Table 2). The median catch at the proposed F_{ref}=0.367 in 2023 is 4,601 mt. Population biomass is projected to increase in both 2023 and 2024 based on the Base model estimates when M is reduced to 0.2. The assumed higher survival of recruits in the projections (from 0.516 in model years to 0.2 in projection years) is largely responsible for the increase. The 2020 year class is projected to make the dominant contribution to fishery catch in 2023 due to the lack of older fish in the population and small partial recruitment of younger age groups (Figure 6).

Table 2. Projection under Low M scenario with an assumption of 2022 fishery catch of 7,526 mt of Eastern Georges Bank Haddock (median value of 2000 simulations). The 0.5 mt difference of the 2022 median catch with the input Total Allowable Catch (TAC) of 7,526 mt is caused by the tolerance in openMSE to determine when the catch equals the TAC when solving for F in the simulations. This difference does not impact 2023 catch advice.

Year	Recruitment	Biomass(mt)	SSB (mt)	Catch (mt)	F
2022	29,674	32,321	16,603	7,525.5	1.019
2023	20,334	43,997	28,840	4,601	0.367
2024		53,306	38,334		

A Low M scenario is used to provide a lower bound on M.

High M scenario

Assuming the M continues to be as high as 0.516 in 2022–2024, Table 3 shows the median estimates of biomass, SSB and F in 2022 based on 2,000 realizations of terminal year population sizes and an assumed catch of 7,526 mt. For 2023, the median biomass, SSB, and catch estimates are obtained by applying an F=0.367 to each realization conditional on an assumed catch of 7,526 mt in 2022. The risk analysis in Figure 8 applies a similar logic to estimate the probability of exceeding F=0.367 in 2023 given various catch levels ranging from 0 mt to 16,000 mt in steps of 1,000 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 overfishing (approximate value of 2,820 mt) in Figure 8 differs slightly (1.2%) from the equivalent median catch for 2023 (2,784 mt) reported in Table 3.

The median SSB will increase from approximately 15,000 mt in 2022 to 19,000 mt in 2023 and to approximately 19,000 mt in 2024. The median catch at the proposed F_{ref}= 0.367 in 2023 is 2,784 mt. Fishing mortality in 2022 would be 1.213 from a catch of 7,526 mt (Table 3). Similar to the Low M scenario, the 2020 year class is projected to make the dominant contribution to fishery catch in 2023 due to the lack of older fish in the population and small partial recruitment of younger age groups (Figure 6).

Table 3. Projection under High M scenario with an assumption of 2022 fishery catch of 7,526 mt of Eastern Georges Bank Haddock. The 0.5 mt difference of the 2022 median catch with the input Total Allowable Catch (TAC) of 7,526 mt is caused by the tolerance in openMSE to determine when the catch equals the TAC when solving for F in the simulations. This difference does not impact 2023 catch advice.

Year	Recruitment	Biomass(mt)	SSB (mt)	Catch (mt)	F
2022	29,674	32,321	15,097	7,525.5	1.213
2023	20,334	32,440	19,048	2,784	0.367
2024		31,318	19,297		

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

TRAC Advice

Considering the uncertainties of M in the near future, projections were conducted under two different M scenarios. There was consensus not to use the Low M scenario for EGB Haddock catch advice in the short term. 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. The TRAC did not reach consensus on which scenario is more likely; however, the TRAC does agree that a decrease in catch advice is necessary. Therefore, rationales for both approaches are presented below.

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. Addition of two years of data led to a 9% increase in the estimated M for the period 2010–2021 (0.516) compared to the period 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. This result does not support an expectation that M will immediately drop in 2022.

2. Alternative models where M was fixed at 0.2 or separately estimated in the last two years did not fit the data as well as the Base model. 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 and both are currently estimated to be at levels similar to those prior to the large 2003 year class. Yet, in spite of the approximate reduction of 75% in population density between 2015 and 2019 (Figure 3), the model estimated that M increased with two 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 0.516 in 2022 simply because density will be lower.

4. The most recent two years of observed length- and weight-at-age are still in the range of values observed in the 2010–2019 High M 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.

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

The TRAC recognizes that it may take a long time before M returns to historical low levels; therefore, the Low M (M=0.2 for 2022–2023, the same as pre-2010) projection scenario can be used as an unlikely upper bound for 2023 catch advice. With evidence of density-dependence on M and projected low biomass, the High M scenario is considered a lower bound for the catch advice. This approach is thought to encompass the uncertainty around the future levels of M.

1. A LOESS smooth of total mortality (Z) estimates based on survey estimates of fully recruited age groups indicated a slight decrease (7%) in recent years for the DFO survey. Comparison of trends in Z with trends in relative F (catch/survey, 100% increase) suggests a possible decrease in M in recent years.

2. The GAM analysis, based on assessment model-independent data, showed evidence of density-dependent impact on M for recent years (TRAC. 2021; Haddock Research Track Working Group Report, *in prep*), and formed the basis for allowing M to be estimated in blocks for the EGB Base model presented here.

3. A set of alternative M configuration sensitivity runs were compared to characterize the uncertainties of M in 2020–2021. The constraint on a fixed M for the 2010 to 2021 period was relaxed. Although these models had less support on the basis of Akaike Information Criteria (AIC) estimates, they showed evidence of a decline in M to 0.32–0.43 in the terminal years, though not as low as M=0.2.

4. The projections assume either a continued high level of M (0.516, 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=0.516 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 0.516 in 2010. Although a change in M from 0.516 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 GB Haddock and other stocks around the world.

5. In the absence of confirmatory evidence of above average recruitment, EGB Haddock biomass is expected to remain low during the projection period, suggesting that density-dependent pressures on M may continue to decrease.

6. The High M projection scenario posits that the terminal year biomasses are a function of M=0.516, 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 $F_{40\%spr}$.

7. Observed changes in growth, condition, and maturation of EGB Haddock have been attributed to high density, but the role of other factors cannot be excluded. Declines in growth rates appear to have attenuated, but a return to high growth rates is not expected to occur immediately in the short-term projection period. A similar lag in a change in M is expected.

Special Considerations

The stock abundance is expected to decrease from historical high in the next few years due to the exit of the strong 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 years (2020–2021). Despite the uncertainties of M in recent years, SSB estimated from all models shows a consistent trend over time with low values in 2021.

The 2021 NMFS fall survey and the 2022 DFO and NMFS spring surveys all suggest that the 2021 year class is the largest since 2013 (Figure 9).

The Base model used in this analysis was not supported by all members of the Haddock Research Track working group; see the Haddock Research Track Working Group report (*in prep*), or the Haddock Research Track Update by Brian Linton during TRAC 2022 (ten Brink and McIntyre 2022), for more details on points of non-consensus. 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 Haddock Research Track peer review panel, future work to harmonize the models would be useful.

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 fluctuating, but large, changes in rho of F may be equally informative about poor model performance and unresolved nonstationary processes within the model.

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 RTA. 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 M.

7. The TRAC proposed F_{ref}=0.367 is obtained by setting M=0.2 while using the estimated selectivity patterns from the Base model, that has an M=0.516. 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.

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].

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. 2022. Eastern Georges Bank Haddock. TRAC Status Report 2022/03
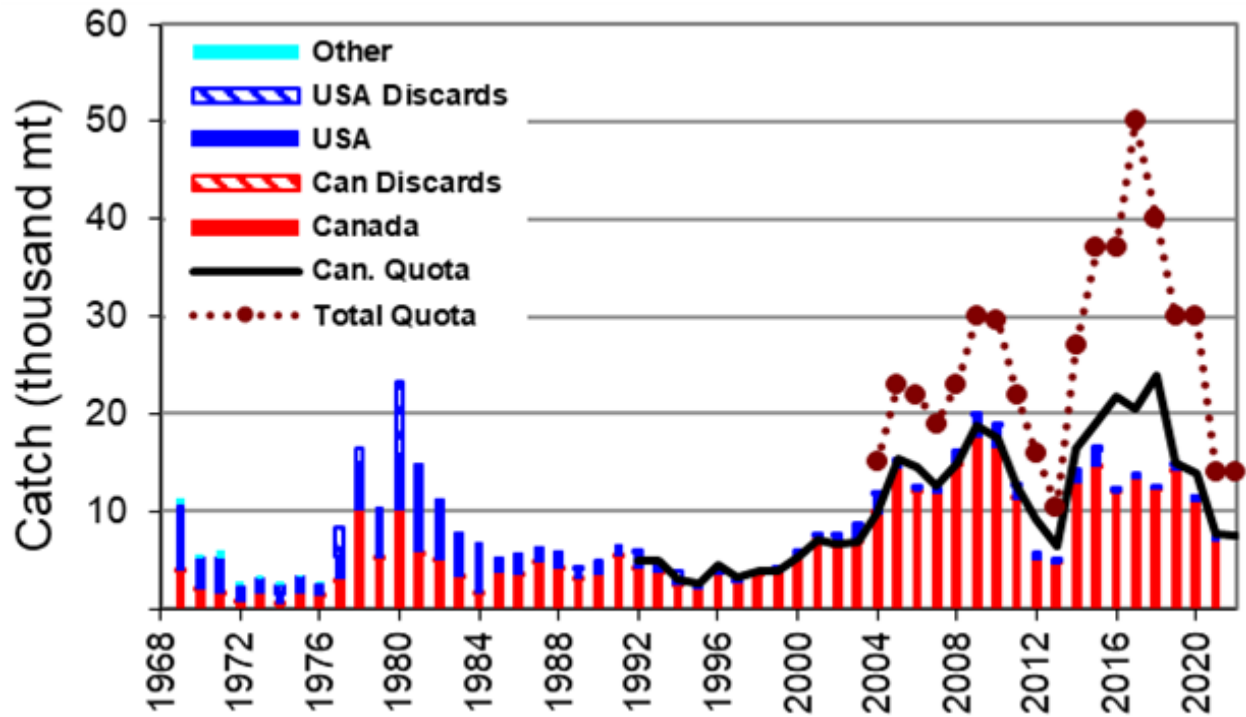
FIGURES

Figure 1. Nominal catches of eastern Georges Bank Haddock during 1969–2021.
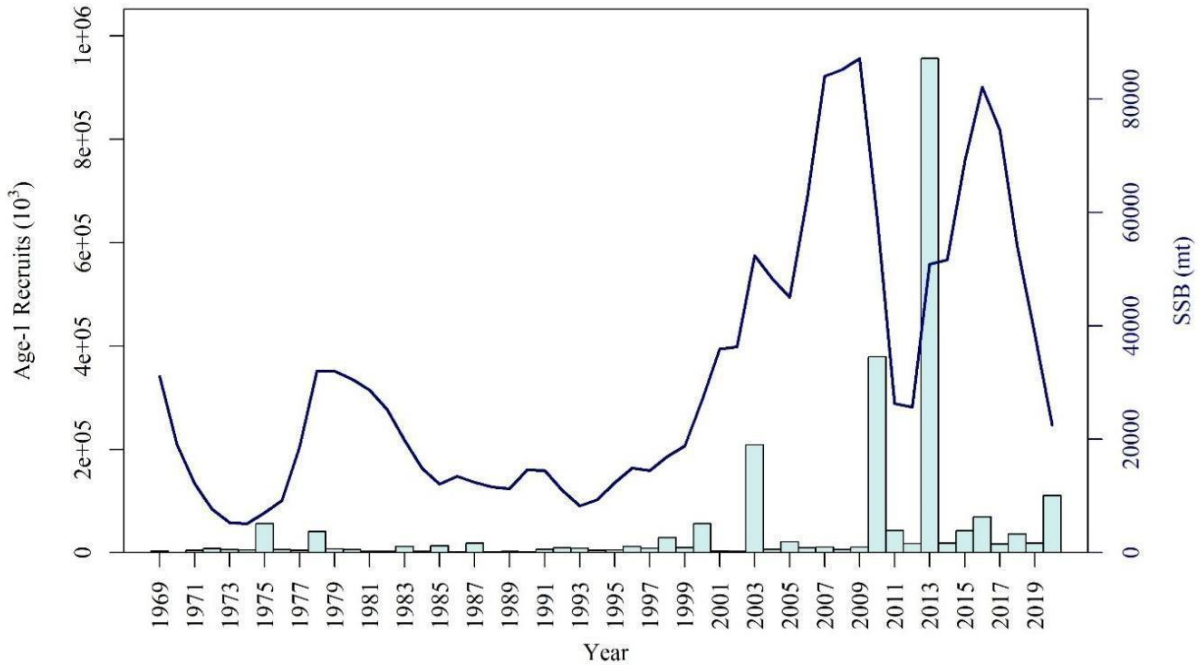
Figure 2. The performance of different Management Procedures (MPs) in terms of trade-offs between annual mean catch, spawning stock biomass in 2021, and average annual variability in catch from a retrospective forecasting. The MPs are different in terms of update interval (U) and number of recent years of data (M) used to calculate the $F_{40\%spr}$ reference point . For example, U3M5 is an MP fishing at $F_{40\%spr}$ updated every 3 years and calculated with data of the last 5 years.

Figure 3. Spawning Stock Biomass (SSB; line) and Recruitment at age 1 (bars) estimated from the Base model for Haddock on eastern Georges Bank.
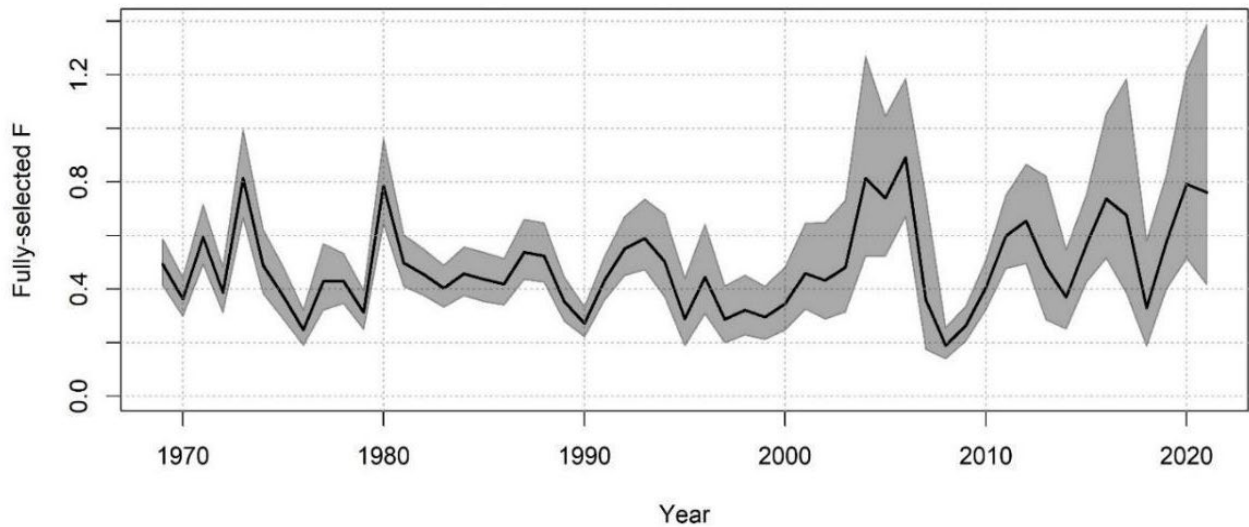
Figure 4. Fully selected fishing mortality (F) estimated from the Base model for Haddock on eastern Georges Bank. The black line is the maximum likelihood estimate, the gray shaded area represents the 95% confidence interval. Note that M=0.2 for 1969–2009; M=0.516 for 2010—2021.
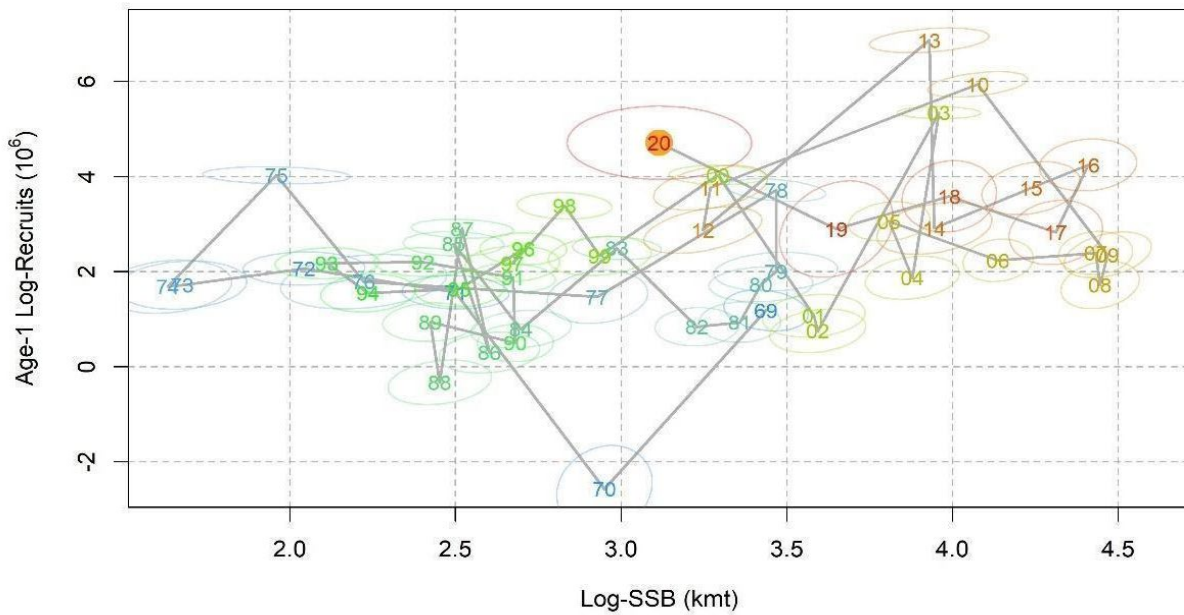
Figure 5. Log-scale of Spawning Stock Biomass (SSB) and Recruitment estimated from the Base model for Haddock on eastern Georges Bank. The ellipse is a 95% confidence region in estimate based on the joint distribution of log recruitment and log SSB.
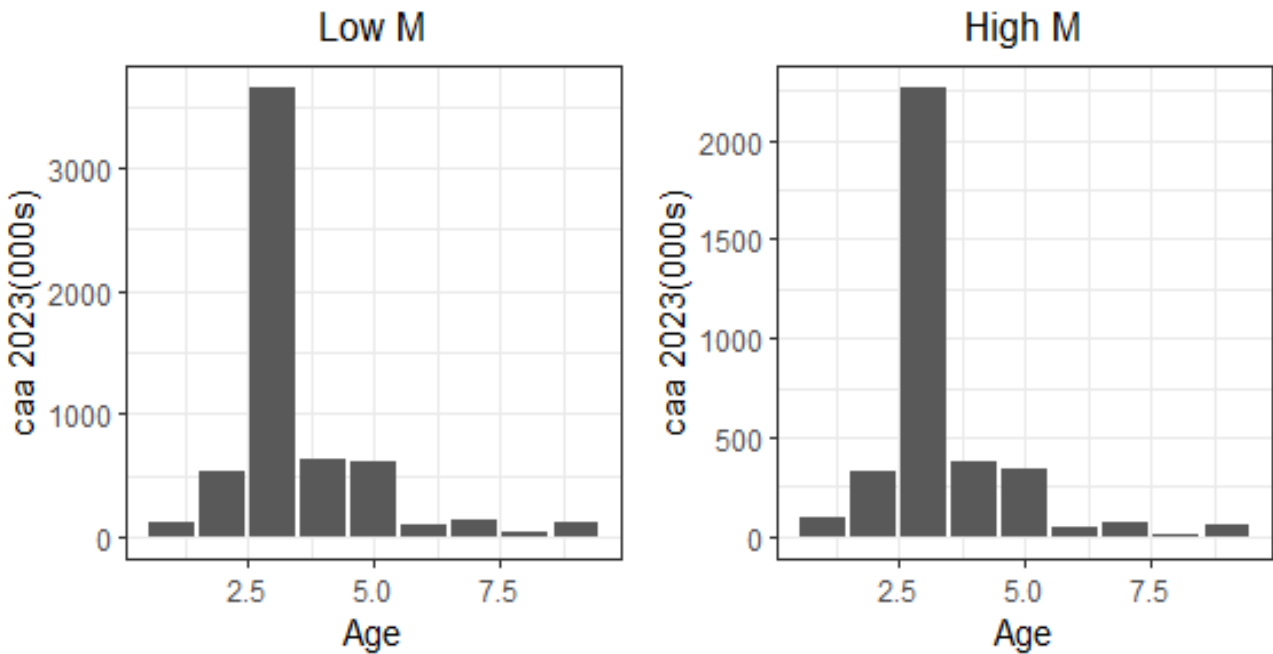
Figure 6. Projected fishery catch-at-age (caa) in 2023 under Low M and High M scenarios with an assumed 2022 fishery catch of 7,525 mt for Haddock on eastern Georges Bank. Note differences in scale between scenarios.
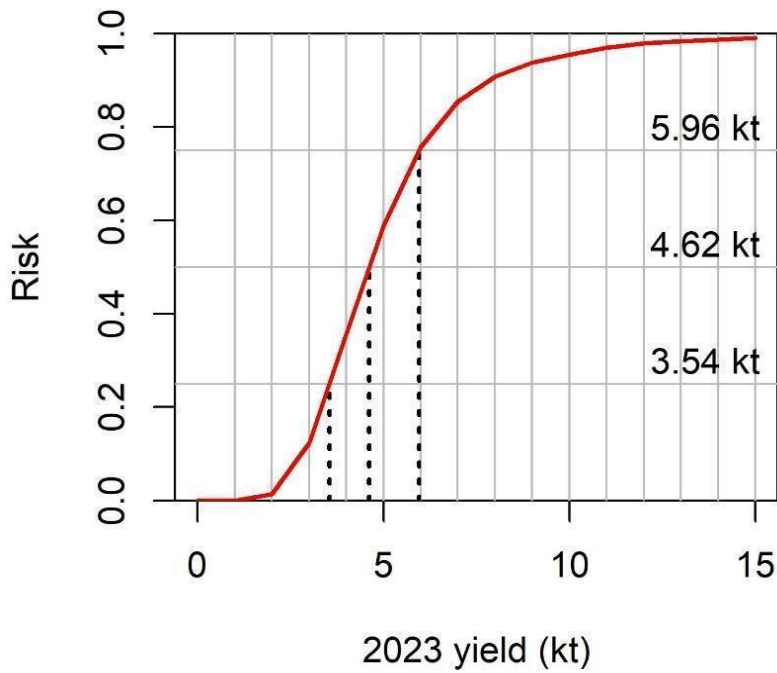
Figure 7. Probability of exceeding the proposed F_{ref}=0.367 in 2023 for different fishery catch in the Low M scenario with an assumption of 2022 fishery catch of 7,526 mt for Haddock on eastern Georges Bank. Dashed lines denote the 2023 yield (kt) associated with 25% (3.54 kt), 50% (4.62 kt), and 75% (5.96 kt) probability of exceeding F_{ref}.
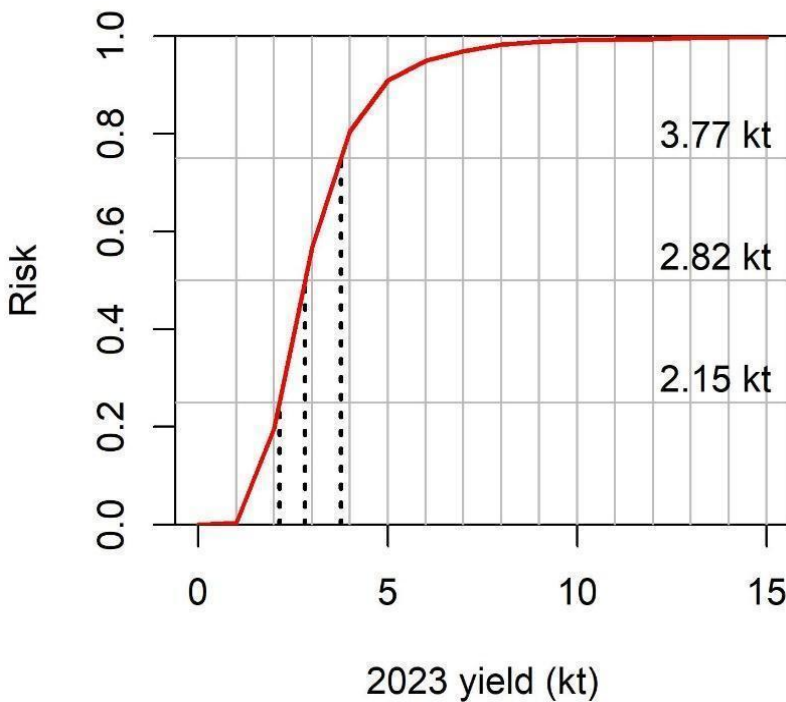

Figure 8. Probability of exceeding the proposed F_{ref}=0.367 in 2023 for different fishery catch in the High M scenario with an assumption of 2022 fishery catch of 7,526 mt for Haddock on eastern Georges Bank. Dashed lines denote the 2023 yield (kt) associated with 25% (2.15 kt), 50% (2.82 kt), and 75% (3.77 kt) probability of exceeding F_{ref}.
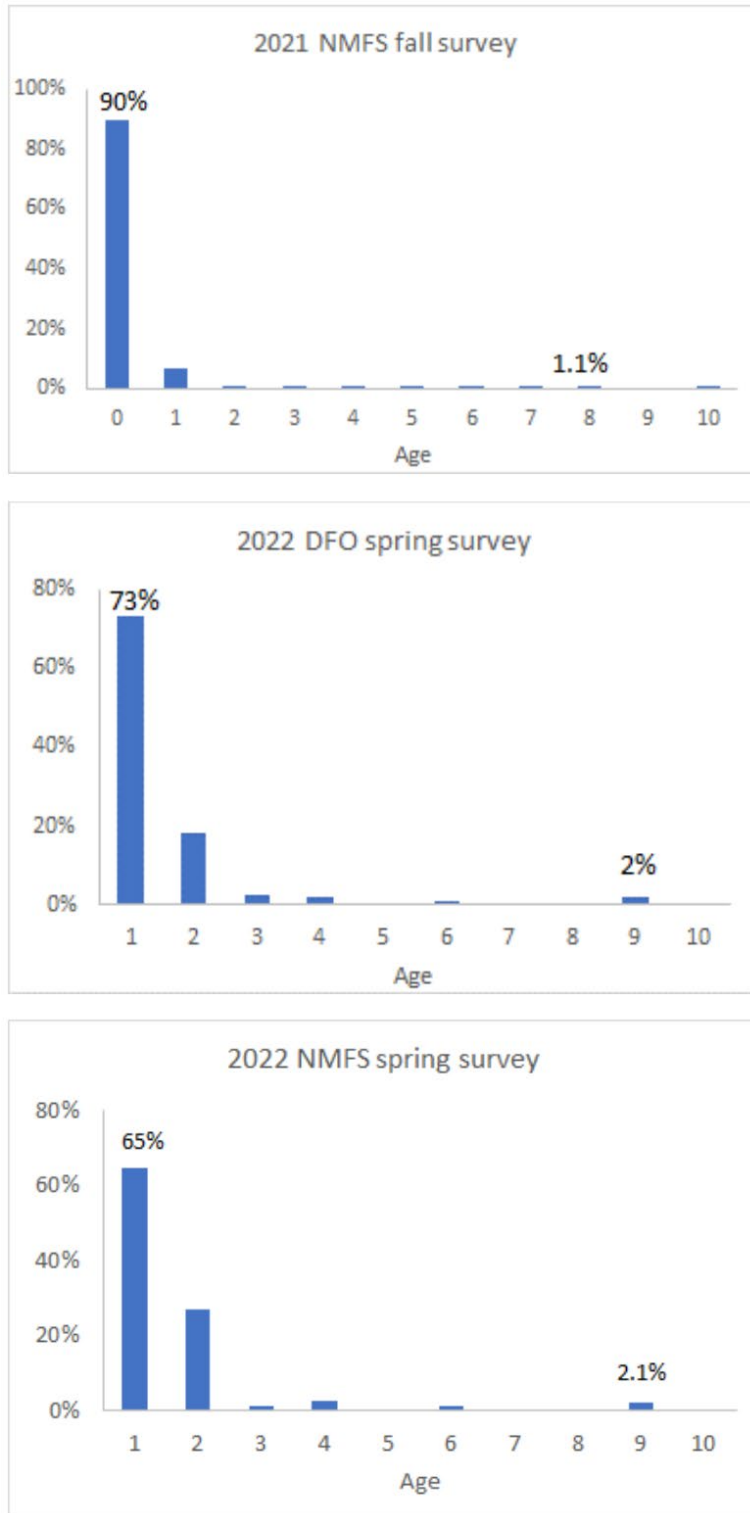
Figure 9. Age composition of eastern Georges Bank Haddock in the 2021 National Marine Fisheries Service (NMFS) fall survey, 2022 Fisheries and Oceans Canada (DFO) spring survey, and the NMFS spring survey. Proportion of the 2021 year class (age 0 in NMFS fall survey, age 1 in 2022 DFO and NMFS spring surveys) and the 2013 year classes (age 8 in NMFS fall survey, age 9 in 2022 DFO and NMFS spring surveys) are shown in the figure.