Fisheries and Oceans Canada
Pêches et Océans Canada

Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

Newfoundland and Labrador Region

Canadian Science Advisory Secretariat
Science Advisory Report 2023/007

REVIEW OF REBUILDING PLAN SIMULATIONS FOR NORTHWEST ATLANTIC FISHERIES ORGANIZATION (NAFO) SUBDIVISION 3Ps ATLANTIC COD

Image: Atlantic Cod Gadus morhua.

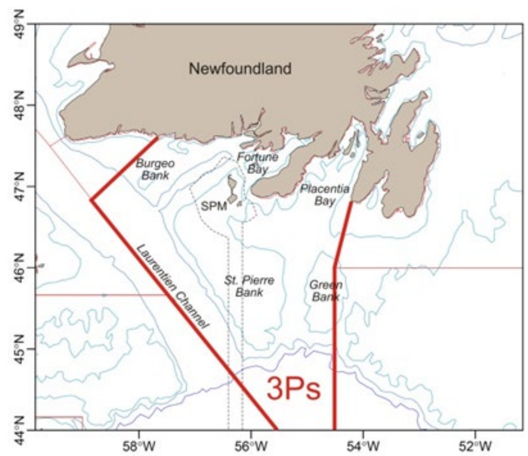

Figure 1: Subdivision 3Ps Atlantic cod stock area.

Context:

3Ps Atlantic cod is one of 30 major stocks that are subject to the Fish Stock Provisions that came into force through regulations on April 4, 2022. As 3Ps Atlantic cod is below its Limit Reference Point (DFO 2022a), Fisheries and Oceans Canada (DFO) has a legal requirement to develop a Rebuilding Plan for this stock that meets the requirements of the Fish Stock Provisions (DFO 2021, 2022b). The Department has committed to developing a Rebuilding Plan for 3Ps Atlantic cod to inform the 2023 management decision. As part of this process, measurable objectives, a rebuilding target and timeline, and performance metrics have been developed for the 3Ps Atlantic Cod Rebuilding Plan. Operating models, with various scenarios of recruitment and natural mortality, have been developed to simulate stock dynamics to help evaluate the performance of management procedures in meeting the measurable objectives.

This meeting was requested by DFO Science to conduct an independent review of the modelling and simulation work that has been done to support the development of the 3Ps Atlantic Cod Rebuilding Plan. Examples of management procedures have been provided to facilitate the review of the robustness of this modelling and simulation work. The outputs of the Regional Peer Review will be utilized to inform the development and evaluation of candidate management procedures for the 3Ps Atlantic Cod Rebuilding Plan.

This Regional Science Advisory Report (SAR) is from the November 28–30, 2022 Regional Peer Review Meeting Review of Rebuilding Plan Simulations for Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps Atlantic Cod, and summarizes the main scientific advice from this meeting. A number of data sources and analyses were explored over the course of the meeting. These, as well as further details on analyses contained herein can be found in the Canadian Science Advisory Secretariat (CSAS) Research Document Series and Proceedings. These additional publications will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Atlantic cod *Gadus morhua* in NAFO Subdivision 3Ps remains well within the critical zone of Canada's Precautionary Approach (PA) Framework, and was at 48% of the Limit Reference Point (LRP) in 2021. Fisheries and Oceans Canada (DFO) has a legal requirement to develop a Rebuilding Plan for this stock. The 3Ps Atlantic cod stock is co-managed by Canada and France.
- ”MSE-lite” is a framework that uses closed-loop simulations of the assessment model to project the stock trajectory under a range of recruitment (R) and natural mortality (M) scenarios, and with the application of various management procedures. This framework is considered to be scientifically sound, and is adequate for assessing the rebuilding potential of Atlantic Cod in 3Ps in support of the development of a Rebuilding Plan for this stock.
- Scenarios of R and M tested within MSE-lite all fall within the conditions previously experienced by the stock. In a changing ocean climate these conditions may not adequately capture future conditions, and biological evidence suggests M is more likely to increase than decrease.
- The prevailing conditions defined for R and M are appropriate for calculating minimum time to rebuild to the proposed target in the absence of fishing (T_{min}). The stock is expected to reach the proposed rebuilding target (above the LRP with a 75% probability) in 2036.

INTRODUCTION

Summary of 3Ps Atlantic Cod Stock Status

The most recent assessment of the 3Ps Atlantic cod *Gadus morhua* stock (DFO 2022a) indicated the stock remains well within the critical zone (48% of the LRP) of Canada's Precautionary Approach (PA) Framework (DFO 2009). The stock is assessed using an integrated state-space model (Hybrid model; Varkey et al. 2022). Increased natural mortality and low recruitment are limiting the growth of this stock. Poor fish condition is one of the major factors impacting increased natural mortality levels (estimated at 0.34 in 2021 for fish aged 5–8). Fishing mortality is currently low (0.03, ages 5–8). The 2011 cohort has been supporting the stock (29% of SSB in 2021) and fishery (45% in 2020) over the last few years. However, recruitment since the 2011 cohort reached historically low levels, with very few fish entering the population in any year since then. The advice from the most recent stock assessment was: “Consistency with the PA Framework would require that removals from all sources must be kept at the lowest possible level while the stock is in the critical zone.”

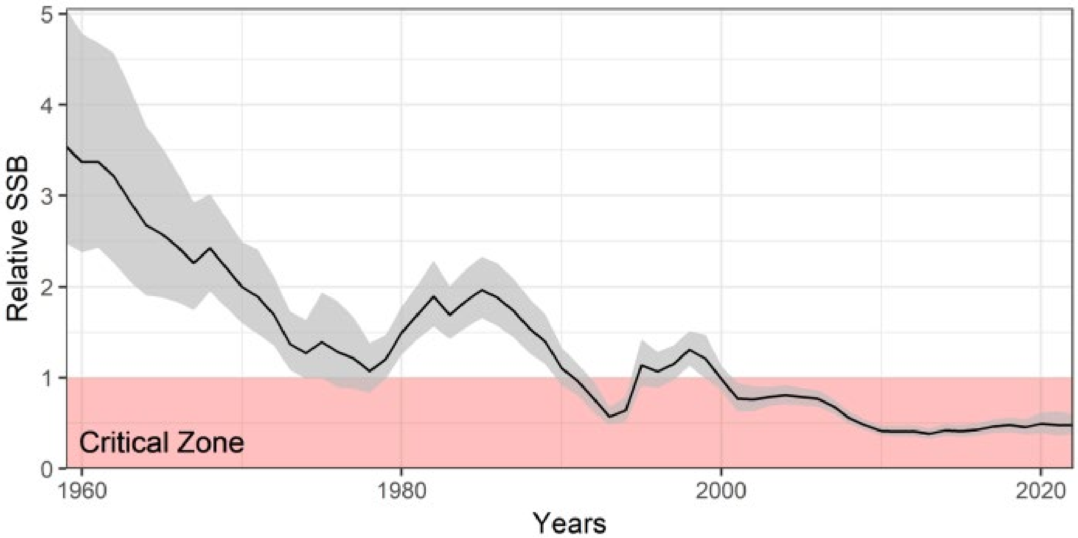

Figure 2: Estimates of SSB (black line = median estimate with grey area = 95% confidence interval) for the period 1959–2022, relative to the Limit Reference Point (LRP = 66 kt SSB). This reference point represents the boundary between the Critical (red shaded area) and Cautious zones of DFO's Precautionary Approach framework.

Rebuilding Objectives and Performance Metrics

3Ps Atlantic cod is one of 30 major stocks that are subject to the Fish Stock Provisions that came into force through regulations on April 4, 2022. As 3Ps Atlantic cod is below its LRP (DFO 2022a), DFO has a legal requirement to develop a Rebuilding Plan for this stock that meets the requirements of the Fish Stock Provisions (DFO 2021). The Department has committed to developing a Rebuilding Plan for 3Ps Atlantic cod to inform the 2023 management decision.

As part of this process, measurable objectives, a rebuilding target and timeline, and performance metrics have been proposed for the 3Ps Atlantic Cod Rebuilding Plan through a working group process with participation from DFO and various external stakeholder groups and organizations. The Working Group (WG) developed several objectives for the Rebuilding Plan which includes a milestone that tracks the trajectory of the population over the next 5 years, and sets objectives for SSB in the short term. Performance metrics (PMs) were also developed based on the WG objectives (Table 1). PMs consider both the trajectory and status of the stock, as well as fishery yield and variation in annual removal levels.

The PMs are considered adequate to track whether future stock levels and fishery yields calculated under various proposed management procedures achieve the objectives as defined by the WG.

Table 1: Summary of proposed rebuilding plan objectives and performance statistics and metrics developed by the Rebuilding Plan Working Group. Prop is proportion, med is median, and CI is confidence interval.

-	Rebuilding plan objective	Performance statistic	Metric
Milestone	1. Achieve a positive stock growth trajectory with a 75% probability over the 5-year timeframe	$SSB_{2027} > SSB_{2022}$	Prop ≥ 0.75
Short term objectives	2. Increase SSB above 75% of the LRP within 15 years with a 75% probability.	$SSB_{2037} > 0.75LRP$	Prop ≥ 0.75
	3. Increase the SSB above the LRP within 25 years (2.5 generation time) with a 75% probability.	$SSB_{2047} > LRP$	Prop ≥ 0.75
Catch-based performance metrics	4. Maximize yield in the short term	Average Catch: 2023–2027	med(80%CI)
	5. Maximize yield in the long term	Average Catch: 2023–2047	med(80%CI)
	6. Keep variation in inter-annual total allowable removals below an established threshold	Average annual variation (aav): 2023–2047	med aav ≤ 0.20

ANALYSIS

MSE Lite Framework

A simplified Management Strategy Evaluation (MSE-lite) modelling framework, based on the current integrated state-space model for this stock (Hybrid; Varkey et al. 2022), was developed to support closed loop simulations for analysis of different management procedures to support the development of a rebuilding plan for Atlantic cod in Subdivision 3Ps. An operating model (OM) based on the SAM model fit previously for this stock was explored by the WG, and in that forum the behavior of both models was deemed consistent. As such, we focus here on simulations based on the Hybrid OM.

The Hybrid OM has the following main features:

1. includes all the available surveys (Canadian Research Vessel survey, French ERHAPS [Evaluation des Ressources Halieutiques de la région 3Ps] survey, industry trawl survey, and gillnet and linetrawl sentinel surveys),
2. two types of commercial data—fisheries catch-at-age where the age composition is fit using continuation ratio logits, and the fisheries landings which are fit using a censored likelihood,
3. Multivariate normal (MVN) random walk for fishing mortality rate (F) with age 2 decoupled from the MVN correlation and with a discontinuity in the random walk at the moratorium,
4. time-varying natural mortality rate (M) based on a condition-based index of mortality and
5. the model starts in 1959 which is the first year for which landings data are available. All model details and descriptions are found in Varkey et al. (2022).

Projections are run for 50 years – from 2021 to 2070 – for each combination of recruitment (R) and M, and each management procedure (MP) which are detailed below. Each projection is considered 1 thread (iteration) of the simulation. Projections were carried out for 10,000 threads for the results presented in this document. Stock values (Spawning Stock Biomass, Yield and F) and PMs are calculated at the end of each simulation set and stored. At the end of a simulation set, the MSE-lite derives PMs which are described as distributions or probability thresholds (e.g., quantiles or confidence intervals) of performance metrics.

Given considerable uncertainty in the full projection timeframe, simulation output is presented here only for 25 years (to 2047), which coincides with the Rebuilding Target timeline outlined in the proposed objectives.

Productivity Scenarios

Much of the uncertainty in future population size is driven by future ecosystem conditions and stock productivity – including M and R for which we test various scenarios here. We have not explicitly accounted for other potential changes within the stock including, but not limited to, changes in growth, distribution, movements, and mixing with adjacent stocks. Notably, our current R and M scenarios – detailed below – all fall within the conditions previously experienced by the stock. In a changing ocean climate these conditions may not accurately capture future conditions.

Recruitment

Recruitment (defined for this stock as abundance at age 2) success has varied throughout the available time series (Figure 2) and predicting future recruitment is highly uncertain. Three recruitment scenarios are examined in the MSE-lite framework: 'low', 'Partial BH', and 'Sigmoid BH'.

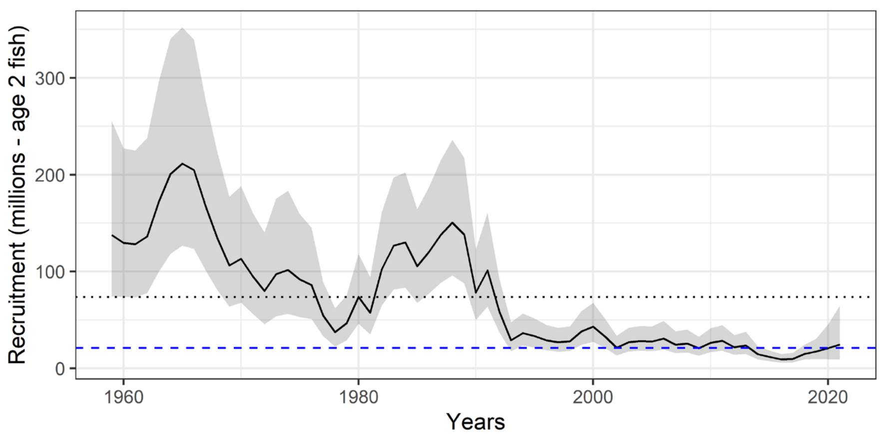

Figure 3: Model estimated recruitment (abundance at age 2) from 1959 to 2021. Dotted black line indicates the time series mean, and the dashed blue line shows the level of the low recruitment scenario.

The low recruitment scenario is defined as the average of the recruitment from years 2019 to 2021. This scenario simulates a constant mean recruitment (individual threads include uncertainty) into the future.

A Sigmoidal Beverton-Holt (SigBH) stock-recruit relationship (as in Perälä et al. 2022) was modelled using the full available time series (1959–2021). An upper bound on recruitment, defined as the recruitment for the timeseries-high SSB, was added to avoid recruitment from reaching unrealistically large values at high SSB levels in the simulation.

The estimated recruitment trend from the assessment model shows that since 1993, recruitment levels have been below the long term mean of historical recruitment. A Beverton-Holt stock recruit relationship (Partial-BH) was therefore fit to the data from 1993 onwards in order to generate a stock recruit relationship that represented the data from a more recent period.

Comparison of the SigBH and the Partial-BH curves (Figure 4) show substantial differences in magnitude in the long term, with predicted recruitment estimates deviating considerably at SSB levels higher than around 50 kt (higher when the full time series is used, i.e., with the SigBH curve). The level of SSB (around 50 kt) where the two functions diverge is at a critical point just below the LRP (66 kt); this deviation between the two recruitment functions is important to consider when evaluating mid- to long-term projections.

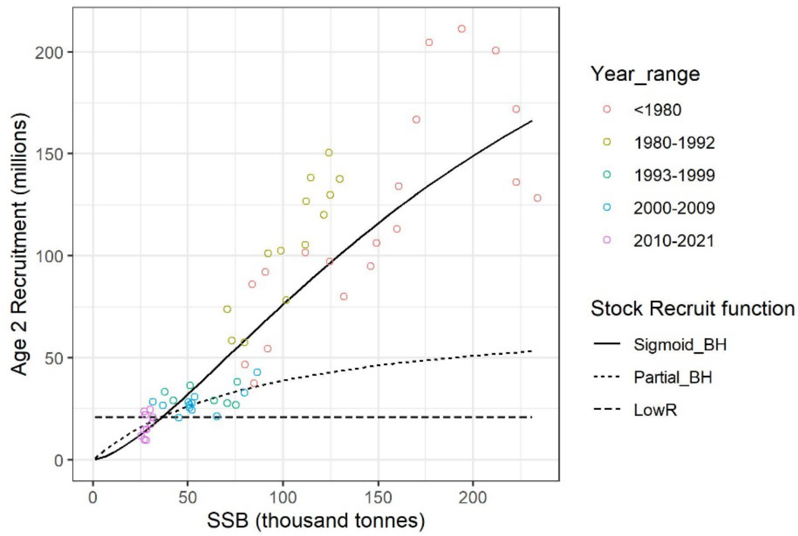

Figure 4: Fitted stock recruit relationships used in MSE-lite simulations. Dotted line shows the Partial Beverton-Holt Relationship fit to model derived stock and recruitment estimates from 1993 to 2021, solid line the Sigmoid Beverton-Holt fit to stock and recruitment estimates from 1959 to 2021. Horizontal dashed line shows the level of the low R scenario (average 2019–2021).

Natural Mortality

Figure 5 shows the time series of average natural mortality from the most recent stock assessment (DFO 2022a). Three alternate scenarios for future M levels are identified based on low and high levels reached in the historical M trend from the assessment. M was low (0.27) during the period from 1996–2005 and high (0.37) from 2015–21. M in 2021 (terminal M) was estimated to be 0.34.

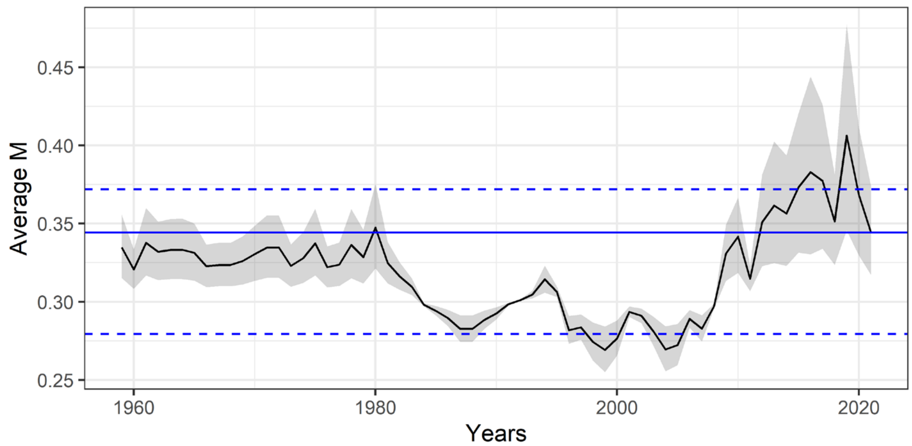

Figure 5: Natural mortality trend from the most recent assessment (DFO 2022). Blue horizontal lines show the M scenarios levels overlaid on the historical trend (prevailing: solid line, dashed lines show the low and high values).

The M in Hybrid OM is time-varying ($M_{a,y}$), where a trend is based on an index of mortality due to poor fish condition (Regular et al. 2022), and estimation occurs separately for fish ages 2 to 5 and those ages 6+ (Varkey et al. 2022). In all the alternate scenarios of M simulated, the M for younger ages are very close to the base value of 0.3, the variation is only in the M for older ages 6+.

Rebuilding Timeline

There is a need within the Rebuilding Plan process to define "prevailing conditions". Rebuilding plan requirements define that the "timeline to rebuild a stock to its rebuilding target must be between T_{min} and a maximum of two to three times T_{min}, where T_{min} is the time the stock would take to rebuild to that target in the absence of all fishing (F=0) under prevailing productivity conditions" (DFO 2022b). However, no formal definition of prevailing productivity exists.

The WG recommended a stock recruit relationship fit to the entire available time series of SSB and Recruitment (since 1959) to determine prevailing recruitment within the context of the rebuilding plan, which is consistent with the time series used to define the LRP for this stock. The SigBH is used here for this purpose. Prevailing natural mortality is defined as the terminal year estimate of M (2021).

The definition of prevailing proposed by the WG is considered adequate for determining a rebuilding timeline for this stock.

In accordance with the requirements for Rebuilding Plans under the Fish Stock Provisions, an estimated rebuilding timeline is derived from forecasting the population in the absence of fishing (F=0) under prevailing conditions (Figure 6). Projections indicate the stock achieves the proposed rebuilding target (above the LRP with a 75% probability) in 2036, therefore T_{min} = 14 years.

While the Rebuilding Plan guidelines require the definition of a rebuilding timeline under "prevailing conditions", we note here that this timeline is sensitive to the assumptions made about future recruitment and mortality (Table 2). We note that under the low recruitment scenario and at terminal or high mortality, the stock projections do not reach the proposed rebuilding target.

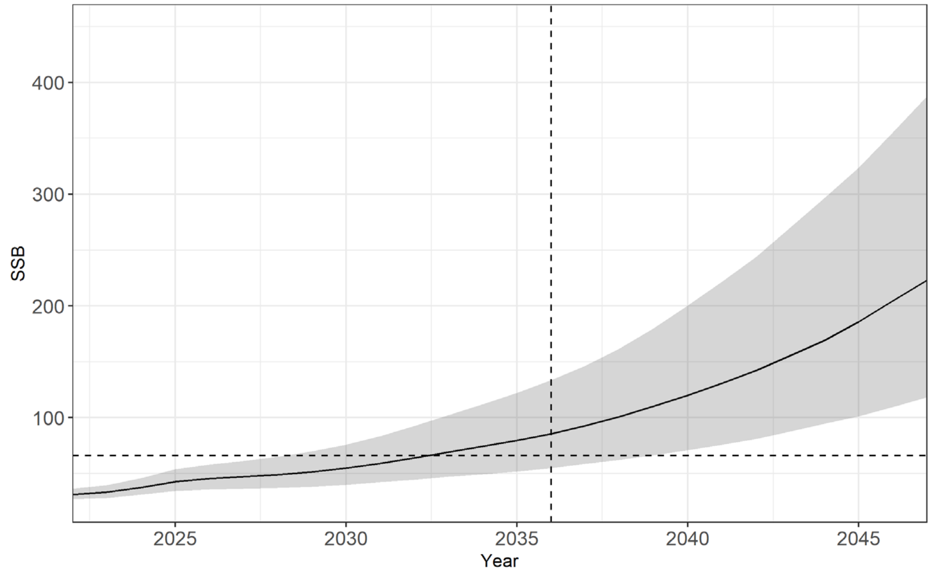

Figure 6: SSB projection with no fishing (F=0) under prevailing M and R conditions. Horizontal dashed line indicates the LRP at 66kt, vertical dashed line shows the year when the stock rebuilds to a level that is above the LRP with a 75% probability (2036).

Table 2: Time to reach the rebuilding target (above the LRP with a 75% probability) under each M and R scenario in the absence of fishing (F=0). Grey cells labelled n/a indicate the stock does not reach the rebuilding target, yellow cell shows prevailing conditions.

	Natural mortality		
Recruitment	**High (2015–2021)**	**Terminal (2021)**	**Low (1996–2003)**
avg3yr	n/a	n/a	2028
Beverton-holt	2049	2040	2029
Sigmoid Beverton-holt	2039	2036	2029

Simulation Output Under Varying Example MPs

Example MPs (Figure 7) were examined during the meeting to consider the most appropriate method to present the modelling and simulation results, and examine the sensitivity of projections to various example MPs. These should not be considered as proposed for implementation. F levels in the example MPs shown here are implemented in the projections as F at the fully selected ages, and F decreases with age based on the average selectivity from 2019–2021.

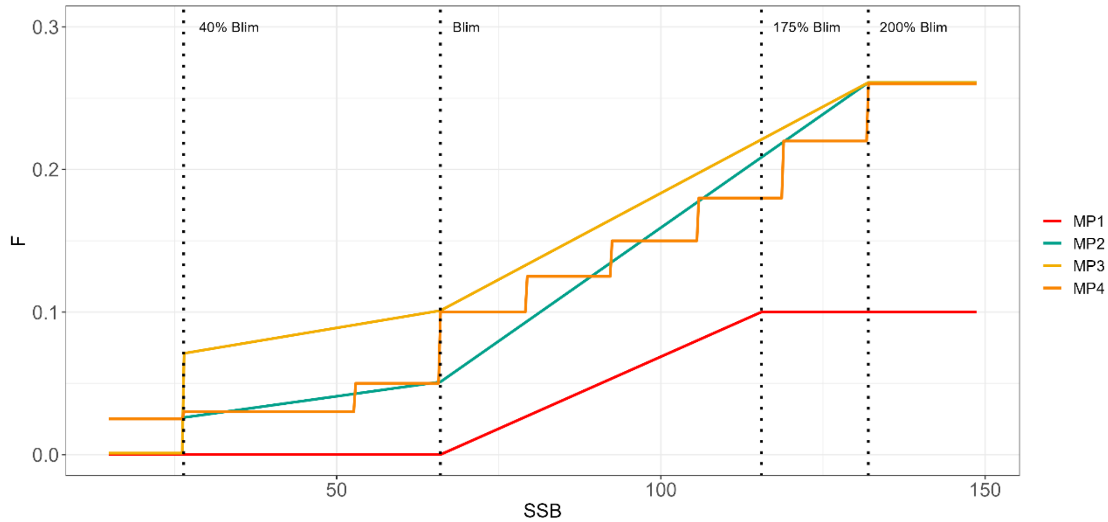

Figure 7: Trends in F with respect to SSB for each example MP. Vertical lines indicate SSB values at which changes in F trends occur at various control points.

In the short term, projections are more sensitive to mortality rates than to recruitment, with higher total mortality leading to slower stock growth. However, in the long term, recruitment drives the stock trajectory (Figure 8).

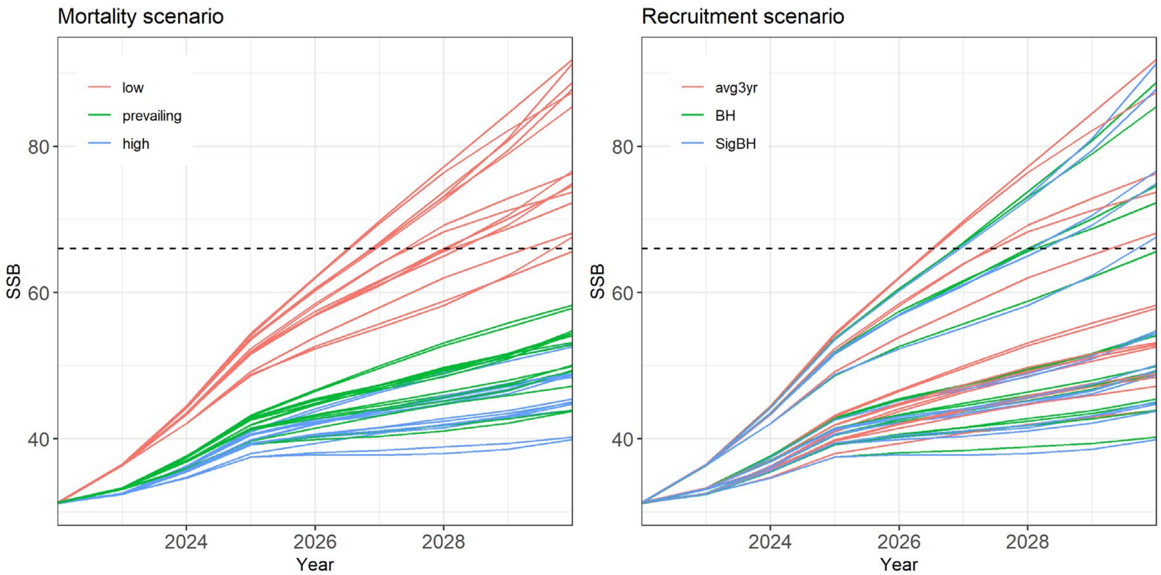

Figure 8: Median SSB projections to 2030. Each line represents a different OM across the example MPs. The panel on the left shows line types by mortality scenario, and on the right lines by recruitment scenario.

Stock trajectories vary greatly between OM scenarios (RxM, 9 tested here), and the stock's ability to achieve the proposed objectives relies heavily on our assumptions about recruitment and natural mortality, and is also influenced by MP structure and scale.

SSB projections are shown here relative to the historic time across three sample OMs (M and R scenarios) (Figure 9).

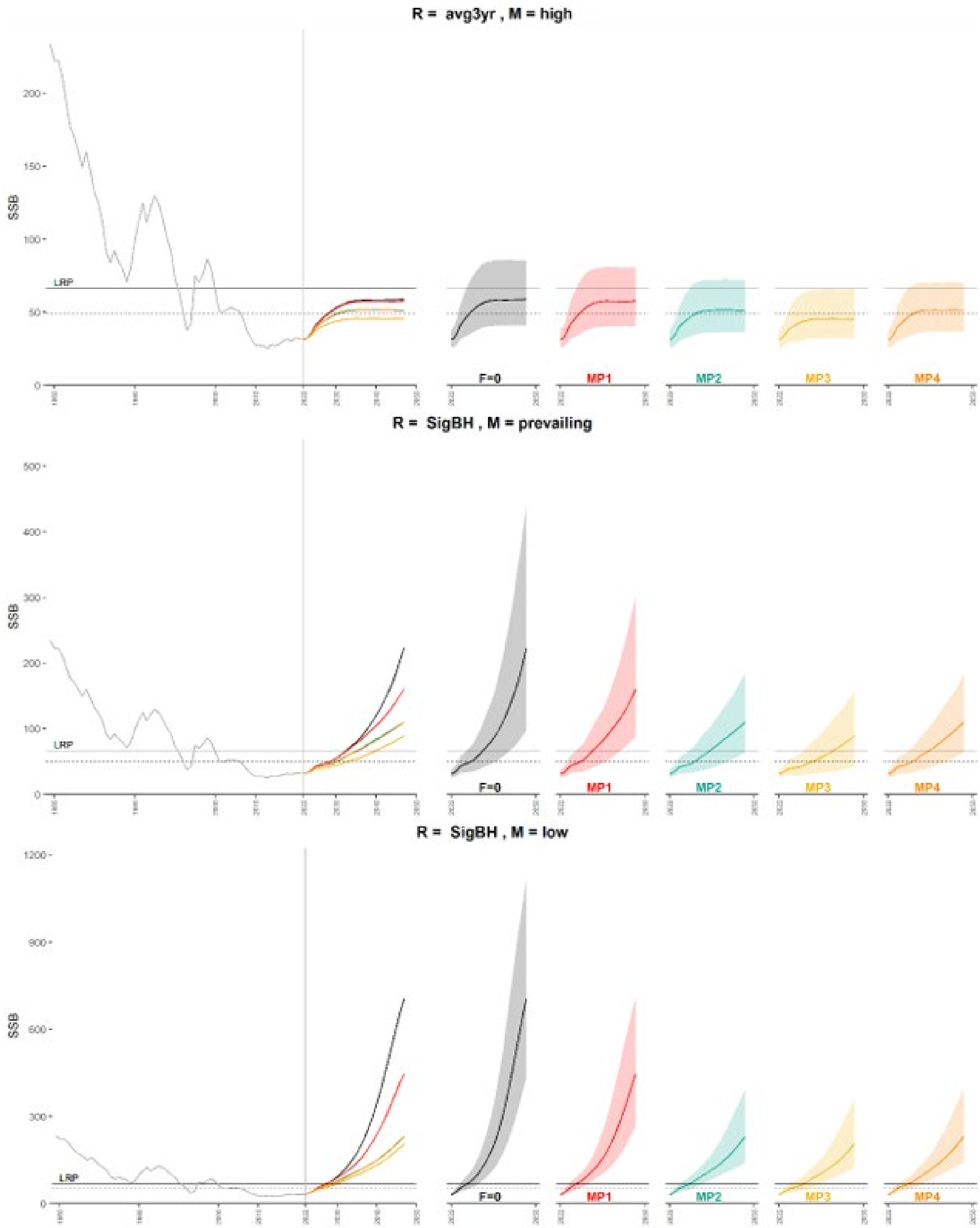

Figure 9: Stock size (SSB) projections compared to historical stock size estimates (1959–2022). The panel on the left shows median estimates, while on the right the projections under each example management procedure are shown with associated 80% CIs. Solid horizontal line at SSB=Blim, dashed horizontal line at SSB = 0.75Blim.

Performance of each example MP under each M and R scenario is examined based on the probability of reaching an objective (Figure 10). Each is then given a score of either 1 (objective achieved) or 0 (objective not achieved) based on the proposed performance metrics (PMs), and the three SSB-based objectives summed to give each example MP a score out of 3 in each scenario combination (Figure 11). The F=0 scenario achieves all proposed rebuilding objectives under prevailing conditions, but does not achieve them all under all M and R scenarios examined.

It is recommended that performance metrics be communicated both in terms of probabilities as well as pass/fail based on defined PM cut offs to best inform decision makers on MP performance. Reporting performance relative to the full suite of M and R conditions examined is important in assessing the robustness of any candidate MP across future productivity scenarios.

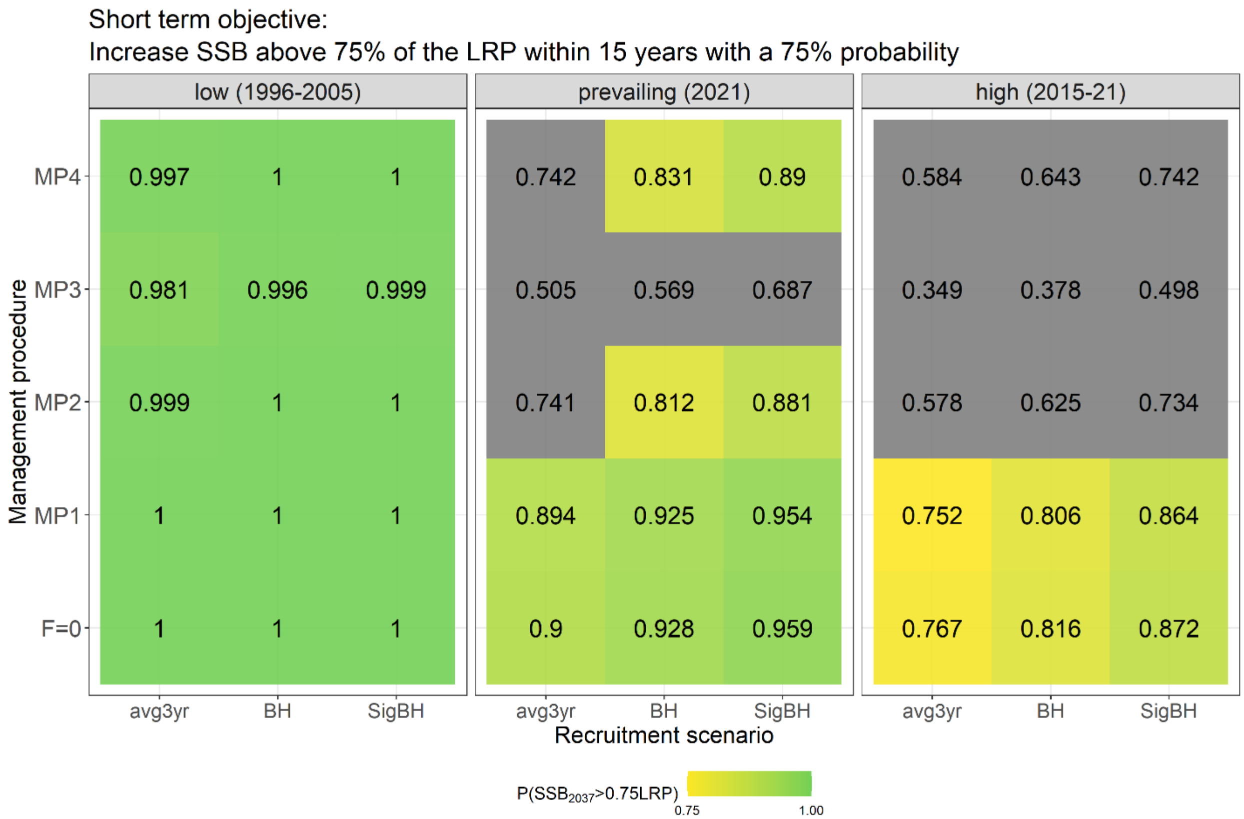

Figure 10: Example of a performance metric summary scorecard. Each cell represents a combination of mortality, recruitment, and example MP scenarios. Values indicate probability. Grey cells do not achieve the PM at the defined probability level (0.75 here)

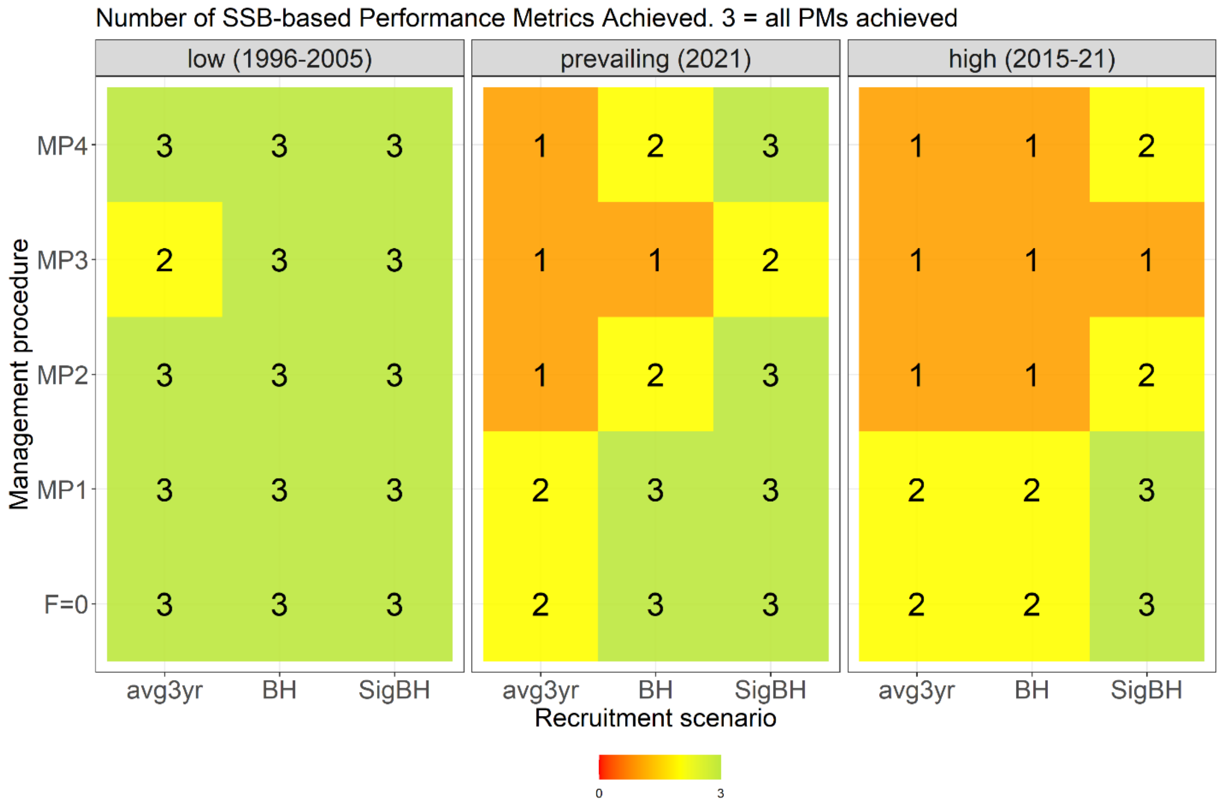

Figure 11: Example of a PM scorecard, where each SSB-based PM is given a score of 1 = passed, or 0 = failed, and values are summed across PMs. Here, values can range from 0 (no objectives achieved) to 3 (all objectives achieved).

Rebuilding in a Changing Ecosystem

In Subdiv. 3Ps, near-bottom temperatures have experienced a general warming trend since 1990 (Cyr et al. 2022), and ocean warming is expected to continue (Bush and Lemmen 2019). Atlantic Cod was the historically dominant species among predatory fishes in this ecosystem unit, but its dominance within this functional group has been markedly reduced since 2010 due to increases in warm water species such as Silver Hake (*Merluccius bilinearis*) (Koen-Alonso and Cuff 2018; NAFO 2021). Important changes have also been noted in nutrient levels, phytoplankton and zooplankton across the Northwest Atlantic, including in Subdiv. 3Ps (Bélanger et al. 2021). The distribution, abundance, and seasonality of predators, of prey, and of competitors can all effect cod growth, survival, and condition. The interaction between these, and other factors and the impacts on cod in a changing 3Ps environment are not well understood. Ongoing warming trends, together with more recent increased dominance of warm water fishes, indicate that the 3Ps ecosystem continues to experience structural changes. In this context, bottom-up effects are contributing to poor fish condition and high natural mortality of cod in this stock (DFO 2022a). Biological evidence suggests M is more likely to increase than decrease, in which case the scenarios presently examined within the MSE-lite framework would underestimate mortality, overestimate stock growth and future stock size, and underestimate the relative impact of fishing mortality. The most recent estimate of M for 3Ps Atlantic cod is 0.34 (2021, ages 5–8), well below M levels reported for adjacent cod stocks, ranging from 0.51 to 1.57 across the Gulf of St. Lawrence, Newfoundland and Labrador Shelf, and the Scotian Shelf (DFO 2019a,b,c; DFO 2022c).

Historical telemetry data (tags deployed between 1993 and 2010; Benoît et al. 2011, Hammill et al. 2017, and references therein) indicated a very small proportion of the Grey Seal (*Halichoerus grypus*) population in Atlantic Canada utilizes Subdiv. 3Ps, primarily during the summer months. Harbour Seals (*Phoca vitulina*) are found in Subdiv. 3Ps throughout the year. Predation by seals is not currently considered to be a major driver of 3Ps Atlantic cod stock trends. However, updated information on seal distribution and use of Subdiv. 3Ps may change the understanding of the relative impact of seals on this cod stock.

Sources of Uncertainty

Projections are run for 50 years – from 2021 to 2070 – for each combination of recruitment (R) and natural mortality (M), and each management procedure (MP). Given considerable uncertainty in the full projection timeframe, simulation output is presented only for 25 years (to 2047), which coincides with the Rebuilding Target timeline outlined in the proposed objectives.

Much of the uncertainty in future population size is driven by future ecosystem conditions and stock productivity – including M and R for which we test various scenarios here. We have not explicitly accounted for other potential changes within the stock including, but not limited to, changes in growth, distribution, movements, and mixing with adjacent stocks.

CONCLUSIONS AND ADVICE

The MSE-lite framework is considered scientifically sound for assessing the rebuilding potential of Atlantic Cod in Subdiv. 3Ps under a range of recruitment (R) and natural mortality (M) scenarios, and with the application of various management procedures. The range of OMs (mortality and recruitment scenarios) are considered appropriate and representative for the current Rebuilding Plan process. In the short term, stock trajectory is more sensitive to mortality rates than to the recruitment used, with higher total mortality leading to slower stock growth. There is considerable uncertainty associated with long term stock projections. Much of this is driven by uncertainty in future ecosystem conditions and stock productivity. Under prevailing conditions of R and M and in the absence of fishing, the stock is expected to reach the proposed rebuilding target (above the LRP with a 75% probability) in 2036.

LIST OF MEETING PARTICIPANTS

NAME	AFFILIATION
Eugene Lee	DFO-NL – Centre for Science Advice
Laura Wheeland	DFO-NL – Science
Dale Richards	DFO-NL – Centre for Science Advice
Hilary Rockwood	DFO-NL – Centre for Science Advice
Karen Dwyer	DFO-NL – Science
Divya Varkey	DFO-NL – Science
Mark Simpson	DFO-NL – Science
Nick Gullage	DFO-NL – Science
Andrea Perreault	DFO-NL – Science
Aaron Adamack	DFO-NL – Science
Robert Deering	DFO-NL – Science
Paul Regular	DFO-NL – Science
Rajeev Kumar	DFO-NL – Science
Emilie Novaczek	DFO-NL – Science
Katherine Skanes	DFO-NL – Science
Krista Tucker	DFO-NL – Science

NAME	AFFILIATION
Ryan Critch	DFO-NL – Communications
Shelley Dwyer	DFO-NL – Resource Management
Julie Diamond	DFO-NL – Resource Management
Chelsie Triccot	DFO-NL – Resource Management
Jill Duff	DFO-NL – Policy and Economics
Danny Ings	DFO-NCR – Science
Julie Marentette	DFO-FPS-NCR – Science
Jordan Ouellete-Plante	DFO-QUEBEC – Science
Vanessa Byrne	Gov. NL – Fisheries, Farming and Natural Resources
Joel Vigneau	IFREMER
Greg Robertson	ECCC
Todd Broomfield	Nunatsiavut Government
Erin Carruthers	Fish, Food and Allied Workers Union
Kris Vascotto	Atlantic Groundfish Council
Jonathan Babyn	Academia – Dalhousie Grad Student
Tommi Perala	Academia – University of Jyväskylä, Finland
Jack Daly	Oceana Canada
Gemma Rayner	Oceans North

SOURCES OF INFORMATION

This Science Advisory Report is from the November 28–30, 2022 Regional Peer Review of Rebuilding Simulations for Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps Atlantic Cod. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Bélanger, D., Pepin, P., and Maillet, G. 2021. Biogeochemical oceanographic conditions in the Northwest Atlantic (NAFO subareas 2-3-4) during 2020. NAFO SCR Doc. 21/010.

Benoît, H.P., Swain, D.P., Bowen, W.D., Breed, G.A., Hammill, M.O., and Harvey, V. 2011. Evaluating the potential for grey seal predation to explain elevated natural mortality in three fish species in the southern Gulf of St. Lawrence. Mar. Ecol. Prog. Ser. 442: 149–167.

Bush, E., and Lemmen, D.S. (Eds.) 2019. Canada's Changing Climate Report; Government of Canada, Ottawa, ON. 444 p.

Cyr, F., Snook, S., Bishop, C., Galbraith, P.S., Chen, N., and Han, G. 2022. Physical Oceanographic Conditions on the Newfoundland and Labrador Shelf during 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/040. iv + 48 p.

DFO. 2009. A Fishery Decision-Making Framework Incorporating the Precautionary Approach.

DFO. 2019a. Stock Assessment of Atlantic Cod (*Gadus morhua*) in NAFO Divisions 4X5Y. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/015.

DFO. 2019b. Assessment of Atlantic Cod (*Gadus morhua*) in the southern Gulf of St. Lawrence (NAFO Div. 4T-4Vn (Nov. – April)) to 2018. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/021.

DFO. 2019c. Assessment of the Northern Gulf of St. Lawrence (3Pn, 4RS) Atlantic Cod Stock in 2018. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/032.

DFO. 2021. Science guidelines to support development of rebuilding plans for Canadian fish stocks. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/006.

DFO. 2022a. Stock Assessment of NAFO Subdivision 3Ps Cod. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/022.

DFO. 2022b. Guidelines for writing rebuilding plans per the Fish Stocks Provisions and A Fishery Decision-making Framework Incorporating the Precautionary Approach.

DFO. 2022c. Stock assessment of Northern cod (NAFO Divisions 2J3KL) in 2021. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2022/041.

Hammill, M.O., den Heyer, C.E., Bowen, W.D., and Lang, S.L.C. 2017. Grey Seal Population Trends in Canadian Waters, 1960-2016 and harvest advice. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/052. v + 30 p.

Koen-Alonso, M., and Cuff, A. 2018. Status and trends of the fish community in the Newfoundland Shelf (NAFO Div. 2J3K), Grand Bank (NAFO Div. 3LNO) and Southern Newfoundland Shelf (NAFO Div. 3Ps) Ecosystem Production Units. NAFO SCR Doc. 18/070: 1–11.

NAFO. 2021. Report of the Scientific Council Working Group on Ecosystem Science and Assessment,16 - 25 November 2021. Dartmouth, Nova Scotia, Canada. NAFO SCS Doc. 21/21.

Perälä, T., Hutchings, J.A., and Kuparinen, A. 2022. Allee effects and the Allee-effect zone in northwest Atlantic cod. Bio. Lett. 18(2): 20210439.

Regular, P.M., Buren, A.D., Dwyer, K.S., Cadigan, N.G., Gregory, R.S., Koen-Alonso, M., Rideout, R.M., Robertson, G.J., Robertson, M.D., Stenson, G.B., Wheeland, L.J., and Zhang, F. 2022. Indexing starvation mortality to assess its role in the population regulation of Northern cod. Fish. Res. 247: 106180.

Varkey, D.A., Babyn, J., Regular, P., Ings, D.W., Kumar, R., Rogers, B., Champagnat, J., and Morgan, M.J. 2022. A state-space model for stock assessment of cod (*Gadus morhua*) stock in NAFO Subdivision 3Ps. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/022. v + 78 p.

THIS REPORT IS AVAILABLE FROM THE:

Centre for Science Advice (CSA)
Newfoundland and Labrador Region
Fisheries and Oceans Canada
PO Box 5667
St. John's, NL, A1C 5X1

E-Mail: DFONLCentreforScienceAdvice@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087
ISBN 978-0-660-47087-0 N° cat. Fs70-6/2023-007E-PDF

Correct Citation for this Publication:

DFO. 2023. Review of Rebuilding Plan Simulations for Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps Atlantic Cod. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2023/007.

Aussi disponible en français :

MPO. 2023. Examen des simulations du plan de rétablissement de la morue franche de la sous-division 3Ps de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO). Secr. can. des avis sci. du MPO. Avis sci.2023/007.