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Newfoundland and Labrador Region

Canadian Science Advisory Secretariat
Science Advisory Report 2024/049

NAFO DIVISIONS 2J3KL NORTHERN COD (*GADUS MORHUA*) STOCK ASSESSMENT TO 2024

CONTEXT

The Fisheries Management Branch of Fisheries and Oceans Canada (DFO) has requested that the Northwest Atlantic Fisheries Organization (NAFO) Divisions (Div.) 2J3KL Atlantic cod stock (Integrated Fisheries Management Plan; IFMP) be assessed relative to reference points that are consistent with the DFO Precautionary Approach (PA) and that harvest advice be provided for this stock. This Science Advisory Report is from the March 18–21, 2024 regional peer review on the Stock Assessment of Northern Cod in 2J3KL. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

This is the first assessment of this stock to use the updated assessment model and Limit Reference Point (LRP) defined at the October 2023 Framework process (DFO 2024b). The assessment model was extended back to 1954 (previously starting at 1983) through the inclusion of additional data, and the longer-term perspective provided by this model informed a revision of the LRP. While estimates of stock size since 1983 were largely the same, the previous LRP was roughly 40% higher than the current LRP. Following this revision, the stock was determined to be out of the Critical Zone since 2016.

SCIENCE ADVICE

Status

- The 2024 Spawning Stock Biomass (SSB) is 1.2 (95% Confidence Interval [CI] = 0.7–2.1) times the Limit Reference Point (LRP). There is an estimated 22% probability that the stock is in the Critical Zone.
- An upper stock reference has not been defined, however given the proximity to the LRP the stock is considered to be in the Cautious Zone.

Trends

- Following a period of growth from 2010 to 2016, SSB has remained unchanged. SSB in 2024 is estimated at 342 Kt (95% CI = 246–475 Kt).
- Estimated numbers of recruits (age 0) have remained unchanged since the mid-2010s, corresponding to about 80% of pre-collapse (1954–90) levels.
- Natural mortality ($\mathbf{M}$, ages 5+) has varied between 0.29 and 0.90 since 1995 (mean = 0.47) and in 2023 was above average [0.59 (95% CI = 0.32–1.12)].
- Fishing mortality ($\mathbf{F}$, ages 5+) has been below 0.05 since 2004 and in 2023 was 0.02 (95% CI = 0.01–0.03).

Ecosystem and Climate Change Considerations

- The Newfoundland and Labrador (NL) ocean climate varies on near-decadal timescales with cooling and warming phases known to impact ecosystem productivity. The ongoing warming phase since about 2020 has likely contributed to improved conditions observed at the lower trophic levels (i.e., phytoplankton, zooplankton).
- The NL bioregion continues to experience overall low productivity as measured by the DFO research vessel (RV) survey, with biomass indices well below pre-collapse levels. While groundfish rebuilding has been observed since the mid-2000s, this process has not been continuous, with declines in the late-2010s. Trends over the last five years show improvements from recent lows.
- Northern cod productivity is linked to Capelin availability. Capelin collapsed in 1991 and has yet to recover, with the current stock size around 10% of pre-collapse levels. Capelin is expected to remain at current levels in the short term, impeding cod stock growth.

Stock Advice

- SSB projections to 2027 with zero to two times the model estimated total removals for 2023 of 13,517 t show the probability of the stock declining into the Critical Zone increases from 42% with zero removals to 52% if removals are doubled.
- With total removal levels examined here (0 to 27,033 t) the risk of stock decline from 2024 to 2027 is moderately high to high, ranging from 62% to 76%. There is no level of removals that gives a neutral to high (≥50%) probability of stock growth.
- Under current ecosystem conditions and total removals the stock has not grown since 2016 and short-term prospects for stock growth are limited even under zero removals. Although primarily driven by ecosystem factors and natural mortality, increases in removals further add to the risk of stock decline into the Critical Zone.

BASIS FOR ASSESSMENT

Assessment Details

Year Assessment Approach was Approved

2023 (DFO 2024b)

Assessment Type

Full Assessment

Most Recent Assessment Date

1. Last Full Assessment: 2021 (DFO 2022)
2. Last Interim Year Update: 2020 (DFO 2021)

Assessment Approach

1. Broad category: Ecosystem-informed stock assessment model
2. Specific category: State-space age-structured assessment model with censored landings and Capelin-informed mortality rates

The assessment model for Northern cod combines cod data from trawl, acoustic, and juvenile surveys; catch records; tagging; and an acoustic survey of Capelin. This allows for an estimation of stock size back to 1954, a stock-recruit relationship, and time-varying rates of $\mathbf{F}$ and $\mathbf{M}$. By censoring landings, the model accounts for bias introduced by partial reporting of total removals from all sources. Data for Capelin, a key prey species, are used to improve predictions of $\mathbf{M}$ and aid forecasts of cod productivity. The model is used to assess the impact of proposed fisheries catches under varying levels of Capelin availability.

Stock Structure Assumption

Northern cod was first considered to occupy NAFO Div. 2+3KL (Templeman 1962); however, cod along the coast of northern Labrador (NAFO Div. 2GH) is managed separately from the 2J3KL stock complex (DFO 1996). Core areas of productivity and discrete components of the Northern cod stock complex are not well defined in 2J3KL. While there is likely some mixing of cod in 2GH with cod in adjacent areas, levels of mixing are assumed to be negligible and the cod stock in NAFO Div. 2J3KL is managed collectively with one LRP.

Reference Points

- Limit Reference Point (LRP): 40% spawning stock biomass at maximum sustainable yield (B_{MSY}; DFO 2024b)
- Upper Stock Reference (USR): N/A; not defined
- Removal Reference (RR): N/A; not defined
- Target Reference Point (TRP): N/A; not defined

The LRP was defined in accordance with Precautionary Approach (PA) guidelines (DFO 2009). An USR, RR, and TRP have yet to be defined for this stock. These reference points are to be developed by Fisheries Management in consultation with fishery and other interests, with advice and input from DFO Science.

Data

- DFO Multispecies research vessel trawl surveys*
- Inshore sentinel survey*
- Acoustic estimates of cod biomass in Smith Sound*
- Inshore juvenile indices from the Fleming and Newman Sound surveys*
- Fishery landings and catch age composition*
- Tagging information*
- DFO Capelin acoustic survey* and forecasts
- Newfoundland and Labrador Climate Index
- Atlantic Zonal Monitoring Program biogeochemical and plankton data
- Newfoundland & Labrador comparative fishing data

** include data used directly in the assessment model.*

Results from comparative fishing experiments indicated no conversion factor is required for Atlantic cod indices in the DFO multispecies trawl survey between the outgoing vessels (Canadian Coast Guard Ship [CCGS] *Teleost* and CCGS *Alfred Needler*) and new Offshore Fishery Science Vessels CCGS *Capt. Jacques Cartier* and CCGS *John Cabot* (DFO 2024a).

ASSESSMENT

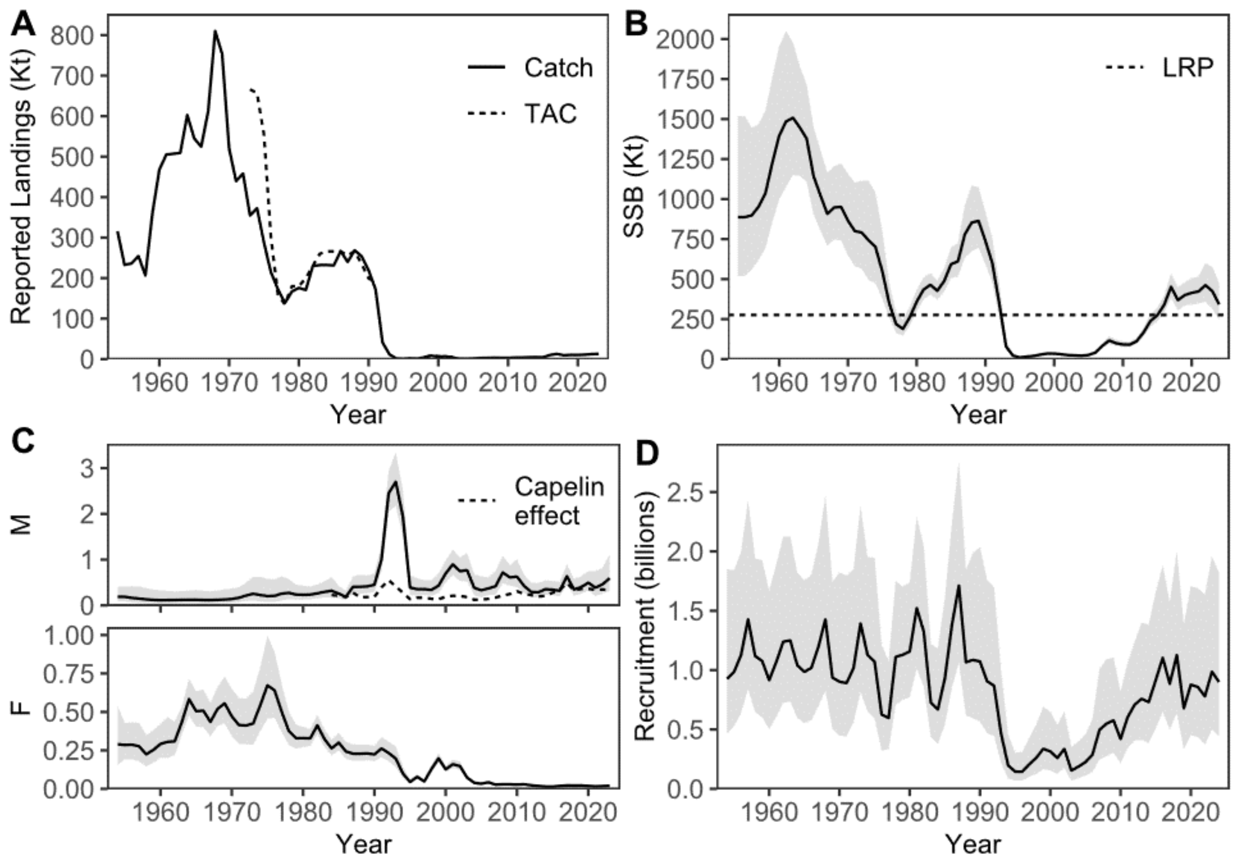

Figure 1. A) Reported annual landings (solid) and Total Allowable Catch (TAC) (dashed). B) Estimates of SSB (black line = median estimate; grey area = 95% confidence interval) relative to the LRP (dashed line). C) Average Natural mortality (M; Top) including the effect of Capelin availability (dotted line), and Fishing mortality (F; Bottom) estimates for ages 5+ with 95% confidence intervals (grey area). D) Estimated recruitment (median estimate of age-0 abundance, with 95% confidence interval [grey area]).

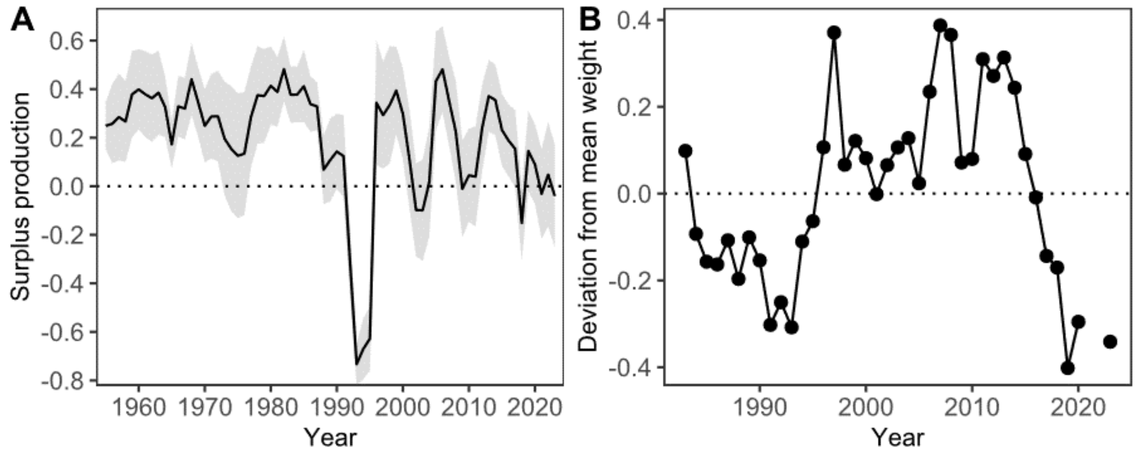

Figure 2. A) Model estimated levels of surplus production (grey area = 95% confidence interval). B) Average deviation from mean weight-at-age for ages 3–7 from the fall multispecies bottom-trawl survey.

Historical and Recent Stock Trajectory and Trends

Table 1. Northern cod SSB, recruitment, and mortality rate estimates over the last five years. Lower and upper 95% confidence intervals indicated in parentheses. Dashes (-) indicate estimate is not yet possible for this year.

Year	SSB (kt)	SSB / LRP	Recruits (age 0; millions)	Average M (ages 5+)	Average F (ages 5+)
2020	414 (340, 505)	1.50 (0.94, 2.39)	877 (451, 1,706)	0.49 (0.33, 0.74)	0.02 (0.01, 0.02)
2021	423 (347, 516)	1.53 (0.95, 2.47)	858 (436, 1,688)	0.39 (0.20, 0.74)	0.02 (0.01, 0.02)
2022	462 (357, 598)	1.67 (1.02, 2.74)	779 (371, 1,636)	0.46 (0.26, 0.82)	0.02 (0.01, 0.02)
2023	425 (314, 575)	1.54 (0.93, 2.56)	987 (498, 1,955)	0.59 (0.32, 1.12)	0.02 (0.01, 0.03)
2024	342 (246, 475)	1.24 (0.72, 2.12)	900 (444, 1,822)	- -	- -

Spawning Stock Biomass

Estimates of SSB increased from the mid-1950s to the early 1960s, after which the stock declined through to the late-1970s. Following a recovery of the stock through the 1980s, SSB rapidly declined in the early-1990s to a time-series low in 1995. SSB remained low through the 1990s, but subsequently increased, especially from 2010–16. Growth in SSB has since stalled and levels in 2024 (342 Kt [95% CI = 246–475 Kt]) are similar those of 2016 (Table 1; Figure 1B). The 2024 Spawning Stock Biomass (SSB) is 1.2 (95% Confidence Interval [CI] = 0.7–2.1) times the Limit Reference Point (LRP).

Recruitment

Levels of recruitment (age 0) fell to their lowest observed levels around 1995, but recruitment has slowly improved and the average number of recruits since the mid-2010s correspond to about 80% of the average numbers of recruits observed prior to 1990 (Figure 1D).

Natural Mortality

Population-weighted average M (ages 5+) increased rapidly from levels below 0.4 to a peak of 2.5 around 1992–94. Average M declined in 1995 and has since varied between 0.29 and 0.90 (mean = 0.47). In 2023, M was above average [0.59 (95% CI = 0.32–1.12)]. Periods of elevated M correspond to declines in the relative abundance of Capelin (Figure 1C). Results indicate that since the collapse of both Capelin and cod in the early 1990s, there has been insufficient growth in the Capelin population to support sustained growth of cod.

Fishing Mortality

Population-weighted average F (ages 5+) exceeded M through most of the 1950s to the 1980s; however, M has exceeded F since the collapse. Average F declined when the moratorium was imposed in 1992 and again when an inshore fishery was closed in 2003. While directed inshore fisheries for cod have continued throughout most of the post-moratorium period, average F has remained below 0.05 since 2004. Average F in 2023 was 0.02 (95% CI = 0.01–0.03) (Figure 1C).

Surplus Production

Prior to the collapse, surplus production – the surplus biomass generated by the stock (through growth and recruitment) beyond what is necessary to keep the overall stock biomass constant – remained positive. Following a large decline in surplus production between 1991–95, associated with the collapse of this stock, variability has increased and several periods of negative surplus production have impeded stock growth. Surplus production has been at or near 0 since 2019 (Figure 2A).

Biological Indicators

Mean lengths and weights-at-age, body condition in spring, and age of maturation all declined during the collapse. While there have been some signs of improved body condition over the last two years, mean lengths and weights-at-age (Figure 2B) have declined across all divisions since 2015, especially for ages 3+. Given smaller size-at-age, a higher abundance of fish are removed from the system by any given removal weight.

History of Landings, TAC & Catch Advice

Table 2. Reported landings of Northern cod by NAFO Division and calendar year (t). Provisional catches for current year.

Division	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
2J	119	139	214	313	281	444	1,129	1,314	1,836	2,467
3K	2,326	2,256	5,273	6,335	4,430	4,819	3,767	4,387	5,497	5,598
3L	2,425	2,041	4,618	6,232	4,744	5,241	5,364	5,276	5,143	4,932
Total	4,870	4,436	10,105	12,881	9,456	10,503	10,260	10,977	12,475	12,998

Northern cod once supported one of the largest fisheries in the world which extracted 810 Kt at its peak in 1968 (Figure 1A). The fishery declined through the 1970s, briefly recovered in the 1980s, and collapsed in the 1990s. A moratorium was established in 1992, but an inshore index fishery was opened between 1998–2002 until the moratorium was re-established in 2003. Since 2006, there has been a directed inshore Stewardship Fishery. Additionally, Northern cod is the primary species targeted in the recreational groundfish fishery in NL. The current management approach for the NL recreational groundfish fishery has remained unchanged from 2016 to 2023. The Stewardship Fishery is managed using weekly/bi-weekly limits, gear types, and season dates, and a maximum authorized harvest (MAH). The MAH for the Stewardship Fishery has been 12,999 t since 2021. Recent catches are shown in Table 2.

There is no direct measure of landings from the recreational fishery. Recreational catch was estimated based on mark-recapture tag returns, averaging 2,077 t since 2006, and in 2023 was estimated to be 2,175 t (95% CI = 1,205–3,926 t).

Ecosystem and Climate Change Considerations

The NL ocean climate varies on near-decadal time scales with known impacts on ecosystem productivity. An increase in short-term climate variability has been observed since the mid-2000s, and more extreme fluctuations in ocean conditions are expected with ongoing climate change. The cooler climate conditions observed in the mid-2010s were followed by a warming phase that has been ongoing since about 2020. The last three years (2021–23) were the three warmest years on record for sea surface temperature, with extremes observed across many oceanographic indices.

The ongoing warm phase has likely contributed to the improved conditions observed at the lower trophic levels including increased concentrations of nutrients and chlorophyll-a, earlier phytoplankton blooms, and near-to-above-normal zooplankton abundance and biomass. While some indices suggest good conditions to support higher trophic levels – including a higher abundance of copepod taxa (e.g., *Calanus finmarchicus* and *Pseudocalanus* spp.) important for the diet of juvenile and adult Capelin (Murphy et al. 2018) – direct impacts are not well understood.

A regime shift in the NL bioregion in the early 1990s coincided with the coldest period in seven decades and involved the collapse of the groundfish community and a key forage species, Capelin, and increases in shellfish. However, these shellfish increases did not compensate for the loss of groundfish in terms of total biomass. Within this broader ecosystem change, the collapse of Capelin in the early 1990s was followed by the collapse of cod, after which both populations have slowly increased but have yet to rebuild to pre-collapse levels. Cod dynamics have been linked to Capelin availability (Koen-Alonso et al. 2021; Regular et al. 2022). The Capelin stock in Div. 2J3KL is around 10% of the pre-collapse stock size and is expected to remain at this level in the short term, which suggests limited growth prospects for the cod stock.

The NL shelf continues to experience low productivity conditions, likely driven by bottom-up processes (e.g., food limitation) with indices of total biomass well below pre-collapse levels. The groundfish rebuilding that started in the mid-2000s stalled, and declines were observed in the mid-2010s. Ecosystem trends in recent years (e.g., biomass trends, stomach content weights) indicate improvements from the lows in the late 2010s, but overall biomass has yet to reach the early 2010s level.

Projections

Projections assume status quo levels of Capelin (DFO in press), terminal year selectivity, and average mean weight and proportion mature at age over 2021–23. The stock was projected to 2027 under total removal scenarios of 0 (no fishing), 0.5, 1 (status quo), 1.5, and 2 times current estimated removal levels.

These projections indicated moderately high to high probabilities of decline (62–76%) over the next three years (Table 3). Under the no fishing to 1.5 times current removal scenarios, probabilities of being in the Critical Zone are moderate, ranging from 31–49%, but the probability increases to moderately high (52%) by 2027 if removals are doubled (Table 3). Under status quo model-predicted removals (~13,517 t), SSB relative to the LRP is projected to be 1.06 (95% CI = 0.30–3.80) by 2027 (Figure 3).

Table 3. Probability of SSB declining from 2023 levels and SSB being in the Critical Zone at various catch multipliers over a 3 year projection period.

Catch multiplier	Catch (t)	Probability of decline			Probability of being in the Critical Zone		
		2025	2026	2027	2025	2026	2027
0	0	68%	66%	62%	31%	40%	42%
0.5	6,758	70%	68%	64%	32%	42%	44%
1	13,517	72%	70%	67%	34%	45%	47%
1.5	20,275	74%	73%	69%	36%	47%	49%
2	27,033	76%	75%	71%	38%	49%	52%

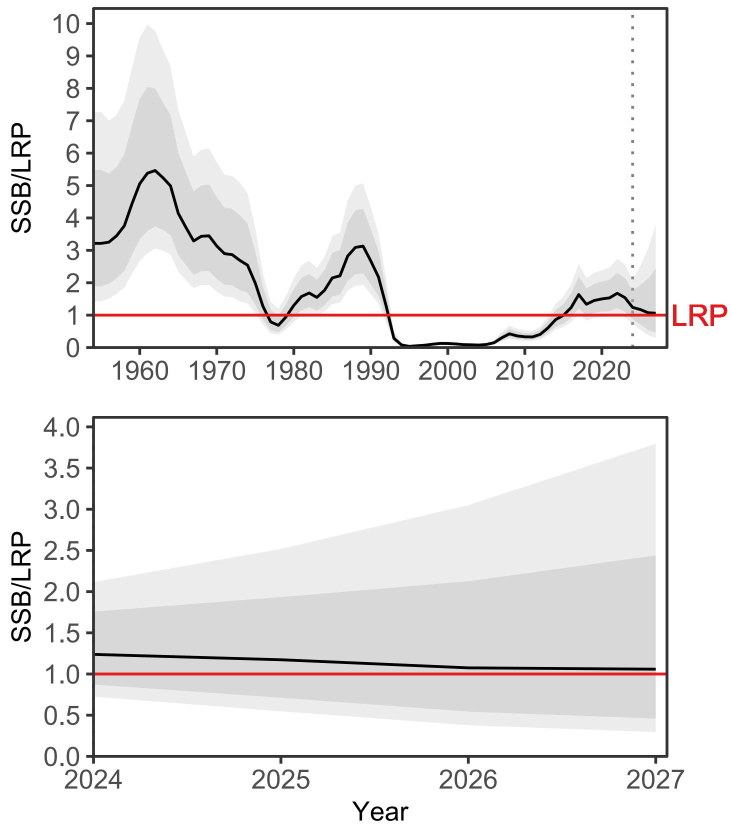

Figure 3. Projected relative SSB (SSB/LRP) assuming status quo levels of Capelin and catch, where LRP (horizontal solid red line) is defined as 40% of B_{MSY}. Solid black line is the model estimate and the grey and dark grey shaded region are 95% and 80% CIs, respectively. The dotted vertical line in the top panel indicates the beginning of the projection period, which is the focal period of the lower panel.

OTHER MANAGEMENT QUESTIONS

The meeting was requested to provide information on spawning times and locations. Cod in Div. 2J3KL represent a stock complex, with different components spawning in various offshore and nearshore areas throughout the stock area. Recent data and analyses on spawning times and locations are very limited, partially because RV surveys for much of the stock area (Div. 2J3K) do not temporally overlap with the spawning season. The most recent data from ichthyoplankton surveys (1991–92), RV surveys in Div. 3L (1972–2002), inshore sentinel surveys (1995–2018), and acoustic-trawl surveys directed at specific overwintering aggregations (1990–2015) indicated that spawning takes place over a broad range of the shelf area from Hamilton Bank to the northern Grand Bank, as well as inshore areas in all three NAFO Divisions.

Recent data to estimate area-specific spawning times are not available, but there are previous reports of fish spawning as early as March and as late as August. There are also previous reports of offshore spawning times being progressively later from north to south. Any potential contributions from historically reported spawning areas (2GH) north of the stock area are uncertain.

SOURCES OF UNCERTAINTY

Every fall, an unknown proportion of the stock migrates from inshore to offshore areas. The 2023 DFO survey began approximately four weeks earlier than usual in Div. 2J and two weeks earlier in 3K. It is likely that a greater portion of the stock than usual was shoreward of the survey area in 2023. However, the timing and extent of this inshore-offshore movement is not fully understood, and is suspected to vary annually and differ across age. This adds a level of uncertainty to the 2023 survey indices that is not explicitly accounted for in the assessment.

M plays an important role in model projections for this stock and the drivers contributing to large changes in M are not fully understood. The inclusion of Capelin in the model addresses one of the major drivers of cod dynamics within the ecosystem, but does not fully resolve the uncertainties around M.

The accuracy of the catch bounds used in the assessment model is uncertain. The likely range of catch (lower and upper bounds) incorporated into the model was determined during discussions involving stakeholders present at past assessment meetings. However, these discussions primarily focused on the estimated range of catch for the post-1983 period. The current model uses reported landings starting in 1954, and historic stock size estimates may be improved by more accurate catch bounds for this period.

The calculation of B_{MSY} is highly sensitive to levels of M. The model shows a progressive reduction in the LRP as additional data are added, with increases in M leading to a downward revision of B_{MSY}. There is a need to monitor the stock for increases in M as this would tend for the assessment to report a better relative stock status for the same amount of SSB.

There are currently no direct measures of removals from the recreational fishery or monitoring of the length and age distribution of recreational catches. These removals are indirectly accounted for in the assessment model using information from the tag returns; however, tagging is limited to cod larger than 40 cm. Some of the M in the model at younger ages may therefore be unaccounted for F from the recreational fishery.

Research Recommendations

Further exploration that explicitly accounted for spatial variation with sentinel catch data and, more broadly, research on changes to the distribution of the stock are recommended. Additionally, exploration into the potential application of acoustic telemetry and other data sources for estimating cod availability to the sentinel index and the RV survey is warranted.

The inclusion of juvenile cod survey data in the assessment model provides valuable information on ages 0 to 1 cod, has allowed for the direct estimation of a stock-recruit relationship, and subsequent estimation of B_{MSY}. However, there are changes in the juvenile cod indices that are not fully captured by the assessment model. Additional research is needed to better explain changes in juvenile productivity and predict year class strength.

Continued research on the drivers of M is still required to help reduce the uncertainty of this key model parameter, including predation on cod (e.g., Harp seals and fish predators, cannibalism), as well as the impacts of changing environmental and lower trophic levels conditions (e.g., ocean climate, zooplankton availability).

Further exploration of declines in length and weight-at-age are required, including how these declines may be associated with changing age-at-maturity, condition, and productivity, as these relationships can have important implications for the prospects of cod.

Revisit logbook standardization to provide a better description of changes in catch per unit effort, and assess whether changes in catch per unit effort reflect changes in exploitable biomass.

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