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Newfoundland and Labrador Region

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Science Advisory Report 2019/050

STOCK ASSESSMENT OF NORTHERN COD (NAFO DIVISIONS 2J3KL) IN 2019

Image: Atlantic Cod (Gadus morhua).

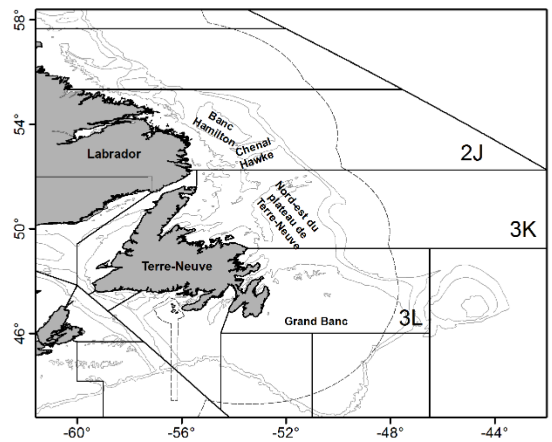

Figure 1. Stock area of Northern (2J3KL) cod. The dashed line indicates Canada's 200 nautical mile Exclusive Economic Zone (EEZ).

Context:

A conservation limit reference point (LRP) for Northern (Div. 2J3KL, Fig. 1) cod (DFO 2010; DFO 2019) is defined as the average spawning stock biomass (SSB) during the 1980s. This reference point defines the boundary between the critical and cautious zones within the Precautionary Approach (PA) framework (DFO 2009) and defines the stock level below which serious harm is occurring. At these levels the stock is considered to have suffered serious harm and the ability to produce good recruitment is seriously impaired. Stock status from the last full assessment (DFO 2018) indicated that the SSB was at 37% (95% CI = 27 – 51%) of B_{lim} and scientific advice stated that removals must be kept to the lowest possible level until the stock has cleared the critical zone. No specific timelines for rebuilding have been identified by management, although a rebuilding plan is currently being developed.

The Northern cod stock has been subjected to ongoing stewardship and recreational fisheries in the inshore since 2006. In the 2018 stewardship fishery, each harvester was allowed weekly landing limits to an overall maximum harvest amount of 9,500 t. In the 2018 recreational fishery, a maximum catch of 15 fish per boat per day was permitted over a 39 day period.

In 2017, the Minister of Fisheries and Oceans Canada announced that Northern cod would be assessed annually starting in 2018. A full stock assessment, in accordance with the Sustainable Fisheries Framework, was requested by Fisheries Management to provide the Minister with advice on the status of the stock covering the period April 1, 2018 to March 31, 2020. This Science Advisory Report (SAR) is from the March 26-28, 2019 Stock Assessment of Northern Cod (Divisions 2J3KL). Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- The stock is being assessed using an integrated model (NCAM), which allows quantification of uncertainty in estimated and projected stock status.
- In the current assessment, the estimate of SSB in 2018 has been revised upward from 315 (95% CI = 223-444) to 383 (304-481) Kt. This resulted from a revision of the estimate of natural mortality (M) for 2017 from 0.74 (95% CI = 0.47-1.17) in the previous assessment, to the current estimate for 2017 of 0.53 (95% CI = 0.35-0.78).
- Spawning Stock Biomass (SSB) remains in the critical zone in 2019, at 48% of the Limit Reference Point (LRP) (95% CI = 37-63%). SSB was 398 Kt in 2019 (95% CI = 306-518 Kt).
- Estimated SSB in 2019 is greater than that projected in the previous assessment, resulting from a lower estimate of M in 2017.
- Natural mortality estimated from NCAM for ages 5+ for 2018 was 0.39 (95% CI = 0.24-0.65), which is a return to the levels for 2012-2016 (average 0.32).
- The estimated fishing mortality rate remains low, with an average value of 0.02 over the last 5 years.
- Recruitment (age 2) increased from lowest estimated levels of 36 million fish in 1995 to an average of 265 million in 2012-16. This recent average is 20% of the pre-collapse period of the 1980s.
- Three-year projections with catch ranging from zero to 1.3 times the model estimated catch for 2018 (13,796 t) indicated that the probability that SSB will reach the LRP by 2022 ranges between 6-9%. The probability of the stock in 2022 being greater than 2019 ranged from 63% to 73%.
- Ecosystem conditions are indicative of an overall low productivity state including low levels of phytoplankton and zooplankton, and low abundance of key forage species such as capelin and shrimp. These conditions may negatively impact cod productivity.
- Consistency with the DFO decision-making framework incorporating the precautionary approach requires that removals from all sources must be kept at the lowest possible level until the stock clears the critical zone.
- Predation by seals was not found to be a significant source of Northern cod mortality in the period 1985-2007. There is no indication that the impact of seal predation has changed since this time.

INTRODUCTION

History of the Fishery

Catches of Northern cod increased during the 1960s to a peak of over 800,000 t in 1968, declined steadily to a low of 140,000 t in 1978, increased to about 240,000 t through much of the 1980s, and then declined rapidly in the early-1990s in advance of a moratorium on directed fishing in 1992 (Fig. 2).

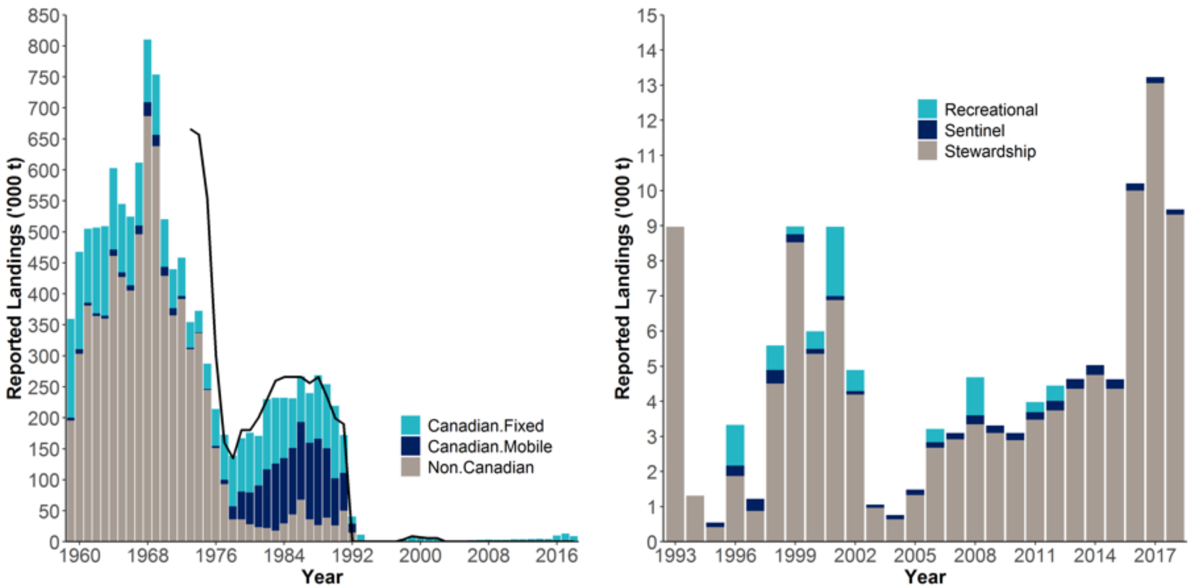

Figure 2. Total Allowable Catches (TACs) and landings (thousands of tons) from 1959-2018. The right panel is expanded to show trends from 1993 onwards. Estimates of recreational catches are only available for 2006, 2008, and 2011-12 in the past 15 years.

Landings during 1993-97 came from by-catches, food/recreational fisheries, and DFO-industry sentinel surveys that started in 1995. In addition, landings from 1998 to 2002 also came from a limited index/commercial inshore fishery restricted to fixed gear and small vessels (<65 ft). The directed commercial and recreational fisheries were closed in April 2003; most of the landings in 2003 came from an unusual mortality event in Smith Sound, Trinity Bay. During 2004 and 2005, substantial by-catches (>600 t) of cod were taken in the inshore, mostly in Divs. 3KL, in the Winter Flounder (blackback; *Pseudopleuronectes americanus*) fishery.

A directed inshore fixed gear Stewardship fishery and a recreational fishery for cod were re-opened in the inshore in 2006 and continue to present. Beginning in 2016, the 2J3KL Northern cod Stewardship Fishery has been managed using variable weekly catch limits. For the 2018 season, a maximum authorized harvest amount of 9,500 t was introduced. This corresponded to a 25% reduction from the 2017 removals. The Recreational Groundfish Fishery season was open for 39 days in 2018. This was a reduction of seven days from the 2017 season. Recreational fishers were limited to five groundfish per day (including cod). The maximum boat limit when three or more people were fishing was 15 groundfish.

Reported landings in 2018 were 9, 269 t from the stewardship fishery, 148 t in the sentinel surveys, and 63 t taken as by-catch (mostly from the redfish (*Sebastes*) and turbot (*Reinhardtius hippoglossoides*) fisheries). The Scientific Council of the Northwest Atlantic Fisheries Organization (NAFO) reported that the annual catches of cod by non-Canadian fleets outside the 200 nautical mile limit on the Nose of the Grand Bank (Div. 3L) were 300 t or less during 2000-18 (provisional value of 16 t in 2018).

There are no direct estimates of recreational landings for eight of the past 10 years; therefore reported landings are less than total catch in those years. Evidence from tagging data shows that although removals by the recreational fishery have been substantial in some years since 1997, they have been about 25% of the commercial catch in the last three years (2016-18).

Catch at Age

The age structure of cod captured in recent inshore fisheries (stewardship, recreational and sentinel) showed an age range dominated by fish aged 6-9, which is typical of a fishery where gillnets are the main gear used (5½” and 6” mesh). The relatively strong 2009 year class was apparent in the commercial catch as age 8 in 2017 and age 9 in 2018.

Species Biology

Historically, much of the Northern cod stock was highly migratory. They over-wintered near the edge of the continental shelf and migrated in spring/summer to shallow waters along the coast and onto the plateau of Grand Bank. By the mid-1990s these offshore over-wintering components were barely detectable, but at the same time, there were aggregations of cod over-wintering in the inshore in Div. 3L and southern Div. 3K. These resident inshore components appeared to be more productive during the 1990s than those in the offshore.

In recent years, the status of cod in the offshore has improved considerably and the shoreward seasonal migration pattern observed prior to the moratorium has likely resumed. Over-wintering inshore aggregations, such as those observed in Smith Sound, Trinity Bay, have since diminished. The offshore biomass of cod has increased in most of the stock area in the past decade, except in southern Div. 3L. The current contribution of offshore cod to the inshore biomass during summer is likely substantial.

Cod off Labrador and eastern Newfoundland grow slowly and are less productive compared with populations in the eastern Atlantic, the Flemish Cap (Div. 3M), and further south in the western Atlantic. Since the late-1980s females have been maturing at about age 5, which is younger than in previous years.

Coastal production of pre-recruit cod (age 0 and age 1 juveniles) has been monitored in Newman Sound, Bonavista Bay, continuously since 1995. Results indicated that the 2016 and 2017 cohorts were strong relative to those observed across the past 23 years. The 2018 cohort, however, was well below the mean and will likely be a weak cohort. Pre-recruits are correlated with numbers of age 2 and 3 fish estimated by NCAM but this needs to be explored further. Such explorations would improve our understanding of the links between the early life stages in the inshore and the subsequent recruitment of these cohorts to the spawning biomass.

Studies have shown that the dynamics of the Northern cod stock are driven by an interplay between fisheries removals and bottom-up forces, such as availability of food, especially capelin (*Mallotus villosus*) (Rose and O’Driscoll 2002, Drinkwater 2005, Shelton et al. 2006, Sherwood et al. 2007, Halliday and Pinhorn 2009, Buren et al. 2014, Morgan et al. 2017). Shrimp are also an important prey species for cod and given the importance of prey for growth and survival, simultaneous low availabilities of two major forage species in the ecosystem could compromise the recovery of cod in particular, and the groundfish community in general.

Top-down forces, such as predation of cod by seals, may be another factor limiting the recovery of cod. However, there is currently no evidence that seals are a major driver of the cod population. Most notably, the Northern cod population has increased at a time when the seal population has remained stable at a time-series high of > 7 million.

ECOSYSTEM INFORMATION

Physical Environment

The marine environment off Labrador and eastern Newfoundland has varied considerably since the start of standardized measurements in the mid-1940s. A general warming phase reached its maximum by the mid-1960s. Beginning in the early 1970s there was a general downward trend in ocean temperatures, with particularly cold periods in the early-1970s, early to mid-1980s and early-1990s.

In 2018, the annual sea surface temperatures were colder than normal in offshore regions around Newfoundland and Labrador, a tendency observed since 2015. The cold intermediate layer core temperature (defined as the minimum temperature within the monthly average profile) was about normal, but has demonstrated a cooling trend since about 2012. This recent cooling was preceded by a warming period that started after the cold conditions between the mid-1980s to the mid-1990s and driven by the winter North Atlantic Oscillation (NAO). For some aspects of the large-scale forcing (e.g., winter NAO trends, convection in the Labrador Sea and their impacts on sea surface temperature and cold intermediate layer metrics), the cooling observed in recent years shares some similarities with the cooling period that occurred in the late-1980s and early-1990s (Yashayev and Loder 2016). Bottom temperatures in 3KLNOPs (spring) and 2J3KLNO (fall) were slightly above normal. At coastal Station 27 (off St. John's, Newfoundland, in Div. 3L), average temperature over the water column (0-176 m) was normal, but the salinity exhibited its largest negative (fresh) anomaly since the beginning of the time series in 1948.

The impact of these oceanographic changes on cod population dynamics is difficult to determine but, in general, Northern cod tend to be more productive when water temperatures are warmer than average.

Ocean Productivity

In 2018, the biomass of chlorophyll-a in the first 100 m of the water column was above normal levels across the Newfoundland and Labrador shelves for the first time since 1999. Positive chlorophyll-a anomalies were associated with an increase in recent years of nitrate concentration in the deeper layers (50-150 m) of the ocean. However, low concentrations of deep nitrate observed across the shelf in 2018 may negatively affect chlorophyll biomass in the water column in 2019. Spring bloom indices derived from satellite data indicate that surface phytoplankton production in 2018 was below normal across the study region for a 4th consecutive year, with near normal conditions of bloom peak timing and duration. Zooplankton biomass remained mostly below normal 2018 despite a notable increase after three consecutive time series record lows, whereas zooplankton abundance anomalies were among the highest in 20 years. Changes in zooplankton community size-structure observed in recent years are driven by a low abundance of large, energy-rich, copepods (*Calanus finmarchicus*) concurrent with an important increase in the abundance of small copepod taxa (*Pseudocalanus* spp. and *Oithona* spp.) in the fall. The direct link of this reduced productivity to higher trophic levels (i.e. cod) is not well understood.

Overall, primary and secondary production indices indicate limited productivity at lower trophic levels on the Newfoundland and Labrador shelves with potential negative impacts on energy transfer to higher trophic levels including commercial fish stocks such as Atlantic Cod.

ASSESSMENT

Sources of Data

This assessment is based on the Northern Cod Assessment Model (NCAM), an integrated state-space model developed specifically for Northern cod that utilizes much of the existing information on the productivity of this stock. The model uses age-disaggregated information from the DFO fall offshore bottom-trawl survey (ages 2-14, 1983-2018), inshore Sentinel 5½" mesh gillnet index (combined Divs. 2J3KL; ages 3-10, 1995-2018), inshore acoustic biomass estimates (1995-2009), fishery catch age-composition information (1983-2018), partial fishery landings information (1983-2018), and tagging information (1983-2018).

Traditional stock assessment models such as virtual population analysis (VPA) require that catch is known without error and also typically assume a value for the level of natural mortality (M). Key features of the NCAM model are that it provides annual estimates of natural mortality (M) and fishing mortality (F) along with measures of uncertainty (see Cadigan 2015, 2016 for details). In addition, the model estimates the catch, rather than assuming that reported landings are an exact measure. The model requires an interval identifying a likely range of catch (lower and upper bounds) and these were determined during discussions with stakeholders present at the assessment meeting in 2016 and 2017 and presumed to be similar in 2018.

Stock Trends

Bottom-trawl survey indices

The abundance and biomass indices from the fall DFO research vessel (RV) surveys have been low since the start of the moratorium in 1992 (Figs. 3 and 4). Levels of both abundance and biomass have been at higher levels from 2012-18 compared to the previous twenty-five years. The three-year average (2016-18) for both abundance and biomass indices is approximately 30% of the average during the 1980s.

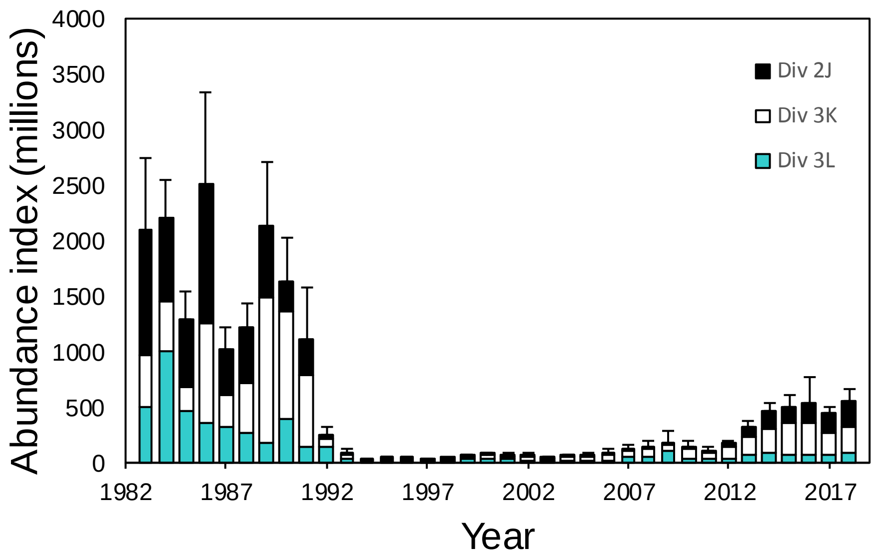

Figure 3. Offshore abundance index for cod (+ 2 standard errors) from fall RV surveys in NAFO Divs. 2J3KL.

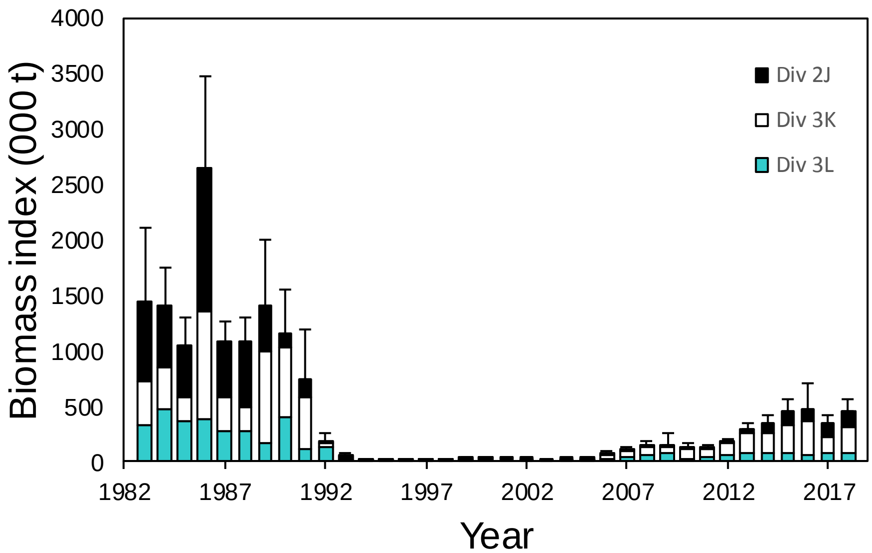

Figure 4. Offshore biomass index for cod (+2 standard errors) from fall RV surveys in NAFO Divs. 2J3KL.

Increased numbers of small cod (≤ age 4) have been observed since 2012. There were fewer fish at older ages (> 7 years old) observed in 2017 in the RV survey but increased again in 2018 (>8 years old).

Tagging

Information from recaptures of cod tagged during 1983-2018 was integrated in the assessment model, and these data are particularly important for estimating F and M. The tagging data used comprised 165,812 releases and 17,239 recaptures and the analysis incorporates methods to estimate the ages of tagged cod and adjustments for initial tagging mortality, tag loss and reporting rates. The tagging data were also used to provide information on the magnitude of recent recreational fisheries and for setting catch bounds for the period 2006-18.

The reporting rate for tags (commercial and recreational combined) during 2018 was 49%, up slightly since 2015, and has been stable around this value for the past few years.

From 2006-18, recreational fishers were responsible for a substantial percentage of the total number of tags returned (average 31%) after numbers were adjusted by respective tag reporting rates. The number of tags returned by recreational versus commercial fishers as a percent of the total has averaged 0.43 (range 0.22 to 0.83) during the past 13 years (2006-18), but in the past three years this number has been lower (0.23), likely due to increases in the commercial harvest. Overall the results indicate that recreational landings contribute to removals and that total removals are higher than reported landings.

An independent Brownie analysis (Brownie 1985) of the tagging data indicated that trends in estimates of natural mortality were similar to those estimated by NCAM.

Model results

The abundance (2+ years) of Northern cod has remained low after the collapse and moratorium in 1992, but has increased from 233 million in 2005 to 954 million (95% CI, 564-1614 million) in 2019 (Fig. 5, left panel). Biomass of fish aged 2+ shows a similar trend to abundance and has increased from 87 kt in 2005 to 588 kt in 2019 (95% CI, 457-756 kt; Fig 5, right panel). Spawning stock biomass increased from 22 kt in 2005 to 398 kt (95% CI, 306-518 kt) in 2019.

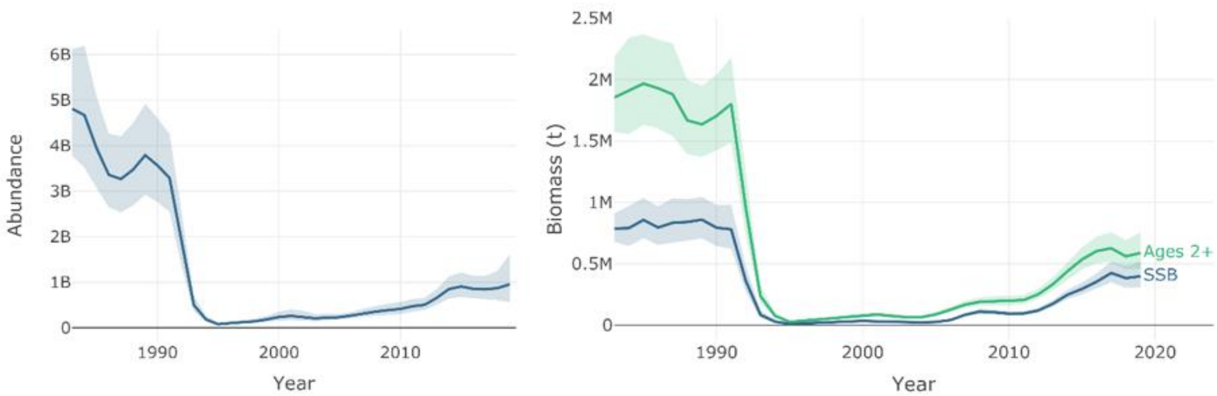

Figure 5. Trends in Northern cod abundance and biomass from 1983-2019. Shaded areas are 95% confidence intervals.

Fishing mortality (F) has been variable during 1983-2018 (Fig. 6, left panel). Average F's for ages 5-14 were around 0.22 during most of the 1980s, and declined after the moratorium was imposed in 1992. Directed inshore fisheries for cod have continued throughout most of the post-moratorium period. Fishing mortality (ages 5-14) was low (0.06) during 1995-97 when inshore fishing was highly restricted, but increased rapidly, reaching close to pre-moratorium values (F=0.13 to 0.22) when a directed inshore fishery for cod was reopened in 1998-2002. Closure of the directed inshore fishery in 2003-05 resulted in a substantial reduction in F to 0.04. More recently, F has been low but has doubled, from 0.01 in 2015 to 0.02 in 2018 due to increased inshore catches during the ongoing directed inshore commercial and recreational fisheries (see Fig. 2).

The rate of natural mortality (M) has also been variable during 1983-2018 (Fig. 6, right panel), ranging from 0.3 to 0.4 in the early to mid-1980s, increasing rapidly to a peak of 2.6 during 1992-1994, then declining to approximately 0.37 during 1995-1999. Additional periods of high M are evident in 2000-03 (M = 0.7 to 0.9) and 2008-2010 (M = 0.6). Recent values of M had declined since then; however M increased from 0.38 (equivalent to an annual survival of 68%) in 2016 to a higher level of 0.53 (59% annual survival) in 2017. Natural mortality has decreased again in 2018, to 0.39 (68% annual survival).

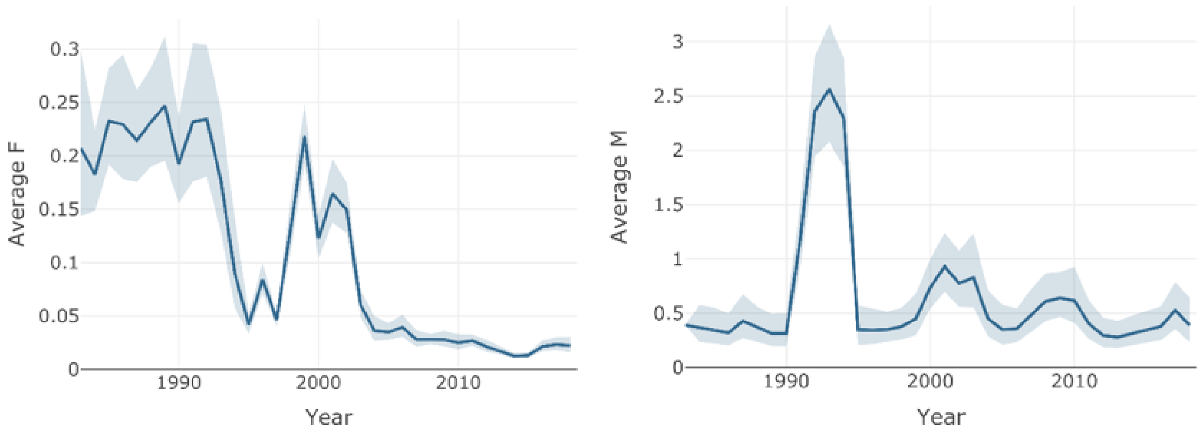

Figure 6. Trends in population-weighted fishing mortality rates (F, left panel) and natural mortality rates (M, right panel). Solid lines are the age-aggregated model estimates (ages 5-14) and shaded areas are 95% confidence intervals.

These results on the relative magnitudes of F and M around the time of the moratorium are different from published studies (e.g. Hutchings and Myers 1994, Myers et al. 1996) on the causes of the stock collapse. In the NCAM model the rate of natural mortality is estimated and information from tagging is integrated directly into the model, whereas in previous population dynamics models of Northern cod M was an assumed constant value (typically M=0.2) and tagging data were analyzed separately. The current model can assign the sudden disappearance of cod from the DFO RV survey to either F or M, but, to be consistent with the existing tagging data, the model assigns much of the mortality to M. However, if there was unreported catch by Canadian and/or non-Canadian fleets, and tags from these fish were not returned, then a portion of the M estimated in the current analysis would actually be F. Investigations on the relative size of F versus M leading up to the moratorium and the current period are continuing.

Recruitment (age 2) increased from lowest estimated levels of approximately 36 million fish in 1995 to an average of 265 million in 2012-2016 (more recent age class estimates are less precise) (Fig. 7). This recent average is 20% of the pre-collapse period of the 1980s.

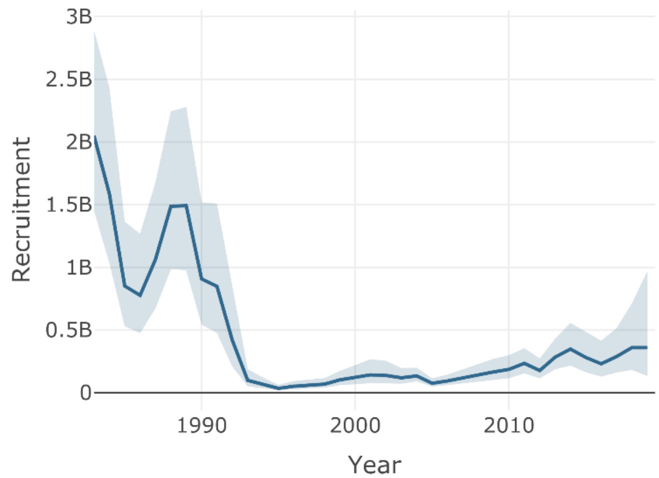

Figure 7. Trends in Northern cod recruitment (number at age 2). Solid line is the model estimate, and shaded areas are 95% confidence intervals.

Spawning Stock Biomass (SSB) remains in the critical zone in 2019, at 48% of the Limit Reference Point (LRP) (95% CI, 37-63%) (Fig. 8). This represents an increase from the estimate of the 2005 level of 3% of B_{lim}.

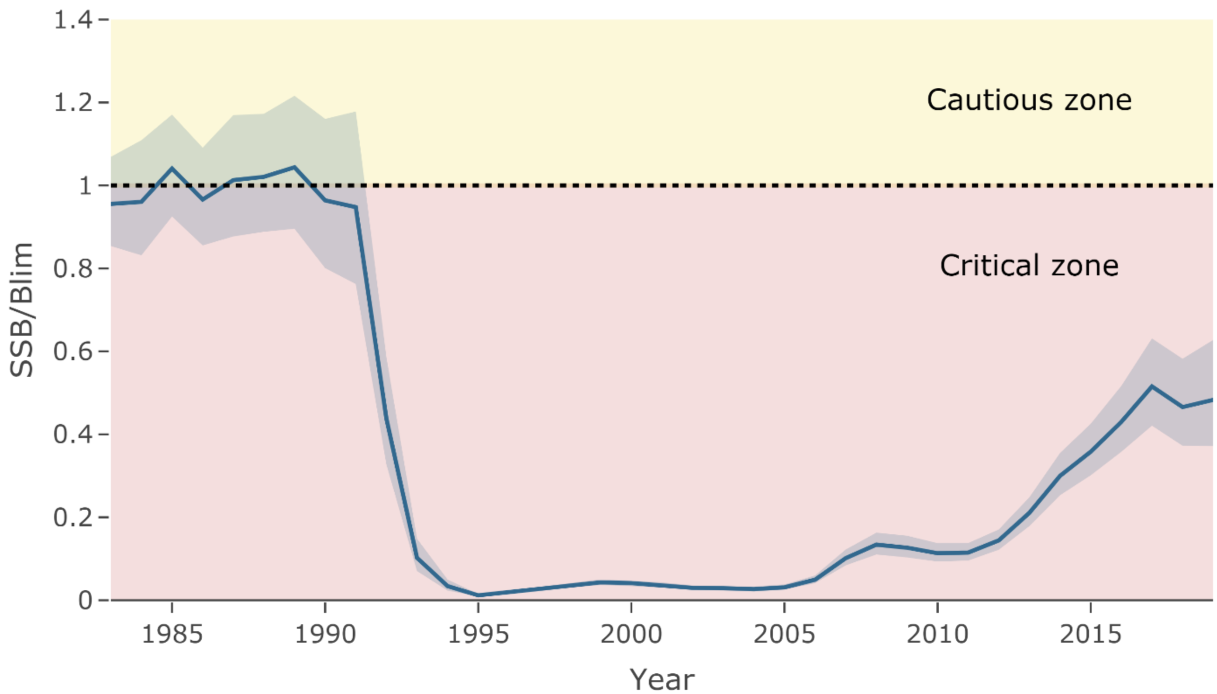

Figure 8. Trends in Northern cod SSB relative to the limit reference point B_{lim}, where B_{lim} (dashed line) is defined as the average SSB during the 1980s. Solid line is the model estimate and shaded areas are 95% confidence intervals.

In the 2018 assessment model, the estimate of natural mortality (M) in 2017 was 0.74 [95% confidence intervals: 0.47 – 1.17]; in the current assessment (2019) M in 2017 was estimated lower at 0.53 [95% confidence intervals: 0.35 – 0.78]. Though this appears to be a large revision, it is important to note that these values are not exact and the 95% confidence intervals from both estimates overlap. Like recruitment, estimates of M have large uncertainty and change from year to year as more information becomes available. In particular, the most recent estimate (the terminal value) of M is prone to annual changes until a number of years are available to observe the survivors and, in turn, improve estimates of M.

The abovementioned revision to the estimate of M was primarily driven by observations of older cod (> 7 years) in the RV survey. Specifically, the number of cod aged 7 years and older sharply declined during the 2017 RV survey and this was interpreted as natural mortality by NCAM. The magnitude of this decline has since been tempered because cod aged 7 years and older were better represented in the 2018 RV survey and another year of tagging data did not indicate a large natural mortality event in 2017. The observation of these cod in 2018 suggest that they may not have been available to the RV survey in the previous year. Nonetheless, the latest RV and tagging data series still indicate that M was higher than the long-term average in 2017. It is therefore possible that older cod remained inshore later than average in 2017 and experienced a higher than average rate of M. This ‘year effect’ may be related to the late arrival and low availability of capelin in the inshore in 2017 and the high estimates of M align with observations of a high proportion of cod in poor condition through the spring and summer of 2017.

Explorations of the mortality estimates from NCAM

Estimates of M from the model are highly variable and the relative contribution of each of the following factors to M have yet to be determined. These include losses from: unreported fisheries removals, predation by harp seals, effects of temperature, and starvation from lack of prey. Most of these factors have been explored to varying degrees in the literature (Rose and O’Driscoll 2002, Drinkwater 2005, Shelton et al. 2006, Sherwood et al. 2007, Halliday and Pinhorn 2009, Buren et al. 2014, Morgan et al. 2017). Previous research has indicated that the dynamics of the Northern cod population are driven primarily by fishery removals and prey availability (Buren et al. 2014).

Further exploratory analyses carried out on these factors in this assessment indicate that there is a negative relationship between the number of capelin available per cod and average cod mortality, suggesting that capelin is important to cod survival. Average rates of natural mortality also tend to be higher when a high proportion of cod are observed to be in poor body condition in spring. These preliminary results imply that cod are dying of starvation and support previous research suggesting that prey availability may be a key factor limiting the recovery of cod (e.g. Rose and O’Driscoll 2002, Buren et al. 2014).

Harp seals are known to consume cod and the population of seals has been increasing since the 1980s, but has plateaued in recent years. If predation mortality is a large component of natural mortality (M), then M estimates are expected to increase as the harp seal population increases. However, contrary to expectations, there was no clear relationship between the M (ages 2+) estimates produced by the model and the population estimates of harp seals. While seals consume cod, this and previous work indicates that capelin abundance and fishing pressure are the primary factors influencing the dynamics of cod (Buren et al. 2014).

Projections

Medium (3-year projections, to 2022) were carried out to investigate the potential impact of a range of catch options from zero catch (no fishing) to a 1.3-fold increase in catch. Projections were based on the model estimate of catch for 2018 (13,797 t). The age-pattern in F values was assumed to be the same as in 2018. Projected recruitment, stock weights, and proportions mature were assumed to be equal to the mean of their 2016-18 values. Assumed recruitment (age 2) has zero impact on the projected SSB as these fish do not reach SSB in the time period of projections. There was concern about carrying out medium- term projections due to uncertainty about the level of future natural mortality. However, since it appeared that the higher level of M in 2017 was reduced in 2018, it was decided that three year projections would be carried out, with the caveat that there was a high level of uncertainty and caution should be taken in interpreting the projections.

The projections indicate that the stock will continue to grow over the next three years and that there is between 63 and 73% probability of SSB in 2022 being above the 2019 value, and also a low probability (<10%) of exceeding B_{lim} in 2022 (Table 1). In 2022, under current catch levels, the SSB relative to B_{lim} is projected to be 0.56 with wide confidence intervals of 0.26 to 1.19 (Fig. 9).

Table 1: Results of projections for catch multipliers from 0 (no catch) to 1.3 times the estimated catch in 2018 (13,797 t).

Projected Catch	Probability of growing out of the critical zone $P(B_y>B_{lim})$			Probability of growth from current levels $P(B_y>B2019)$			SSB_y/B_{lim}		
-	2020	2021	2022	2020	2021	2022	2020	2021	2022
0	0%	2%	9%	65%	70%	73%	51%	55%	60%
0.7*$Catch_{2018}$	0%	2%	7%	59%	64%	68%	50%	53%	57%
0.85 *$Catch_{2018}$	0%	2%	7%	58%	63%	67%	50%	53%	57%
1.0*$Catch_{2018}$	0%	2%	7%	57%	62%	66%	50%	53%	56%
1.15*$Catch_{2018}$	0%	2%	7%	56%	61%	65%	50%	52%	56%
1.3*Catch	0%	2%	6%	54%	59%	63%	50%	52%	55%

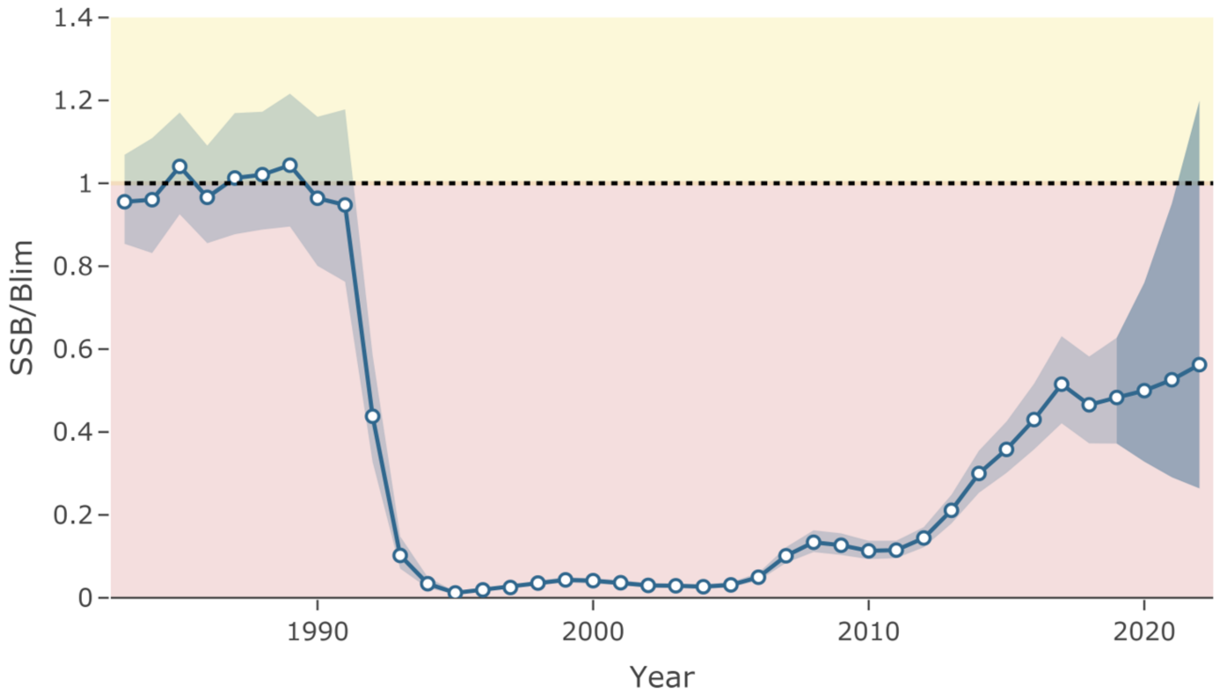

Figure 9. Three year projections (to 2022) of Northern cod Spawning Stock Biomass (SSB) under status quo catch (13, 797 t) relative to the limit reference point B_{lim}, where B_{lim} (horizontal dashed line) is defined as the average SSB during the 1980s. Solid line with circles is the model median estimate and light grey envelope is 95% confidence intervals. Dark grey envelope is 95% confidence intervals for the projection period.

Additional Sources of Information

Other information reviewed at the assessment but not included in this report included the following: biological characteristics (growth, condition, maturity) obtained from analysis of catch rate-at-age in the fall surveys; recaptures of conventionally tagged cod combined with detections of acoustically tagged cod were used to estimate mortality rates and investigate migration patterns; analysis of catch rate trends from DFO-Industry Sentinel survey not used in the state space model (i.e. 3¼ inch mesh gillnet and line-trawls) from three inshore regions; logbooks from commercial vessels for post-moratorium fisheries to investigate area-specific inshore catch rate trends; an annual telephone survey of fish harvesters' observations conducted by the Fish, Food and Allied Workers (FFAW) Union; information on the relative abundance of young cod (ages 0 and 1) from beach seine studies in Newman Sound, Bonavista Bay; information on the size and/or age composition of the catch obtained from lengths and otoliths collected from cod sampled at ports and at sea during stewardship, Sentinel and recreational fisheries. Details of these sources of information may be found on the Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) website in the Research Documents Series when available.

Sources of Uncertainty

The relationship between reported landings and total deaths due to fishing from both commercial and recreational fisheries is highly uncertain. Total deaths due to fishing are estimated by the model based on both the survey and tagging data; therefore the model-estimated catches can be considerably different from reported landings.

There is uncertainty in the range of catch bounds used in the assessment model. The likely range of catch (lower and upper bounds) was determined during discussions that included stakeholders present at assessment meetings.

Since 2005, there are no direct estimates of recreational landings for most years (2006, 2008, 2013-18) and available estimates in other years are uncertain. Removals from all sources should be better accounted for to reduce uncertainty in the assessment model inputs.

Tag reporting rates are determined from returns of low and high reward tags. Low reporting rates lead to less tagging data to work with, which increases the uncertainty in a number of estimates and indices: assessment model estimates, the relative contributions of commercial and recreational harvest, and analyses of movement patterns and stock structure. Harvesters (recreational and commercial) should return all tags in a timely fashion to help reduce this uncertainty.

The catastrophic mortality event in the early-1990s, attributed to natural mortality in the current assessment, is controversial and a major source of uncertainty regarding the dynamics of the stock and impact of the fishery at that time.

Natural mortality (M) plays an important role in projections for this stock. A key determinant of the three-year projected SSB is natural mortality. If natural mortality rates in 2019 are appreciably different than those used, projected outcomes will differ from values reported above. There is a high level of uncertainty in the projections beyond the first year due to the level of future natural mortality.

There is uncertainty over the appropriateness of including the Sentinel survey in NCAM as a data source. A number of exploratory runs were carried out, including one that excluded the Sentinel survey, which yielded improved residual patterns from the RV survey. This is because the Sentinel and RV surveys are showing different trends in recent years, as well as the Sentinel survey showing apparent variation in selectivity over time. The Sentinel survey is a fixed site nearshore survey and is affected by timing of fish arriving inshore (biological) as well as potentially competition with commercial gear in some areas and years. A thorough overview of this data source should be carried out to determine whether the current analysis methods should be revised, and additionally, whether it should continue to be used as a data source in NCAM.

Management Considerations

Accurate monitoring of deaths resulting from both commercial and recreational fisheries should be considered a management priority. Information from tagging indicates that although current levels of fishing mortality are low, the recreational fishery can be a substantial component of total removals. Recreational removals can be an important source of mortality particularly when stock size is low and the stock is not productive. Improving the management of recreational fisheries is strongly recommended so that total removals can be effectively controlled and directly measured.

Ecosystem conditions are indicative of an overall low productivity state including low levels of key forage species such as capelin and shrimp. Capelin is anticipated to decline to low levels in 2020. This is expected to negatively impact cod productivity and could compromise the potential for recovery of cod. Low levels of capelin should signal the need for a more cautious approach with regard to harvesting decisions.

Although the model output indicates that M is the driving factor behind the decline in stock size in recent years, the stock is in the critical zone, and due to low levels of forage prey and low levels of productivity in the system, harvesting decisions must be made with caution.

The NCAM estimates of actual catches can differ substantially from the reported catches and are influenced by the assumed catch bounds. In projections, catch multipliers are applied to the estimated catches from the model, not the reported landings. When setting future harvest levels, it is important to consider the proportion that is expected to be unreported.

Projections and trends in general indicate wide confidence intervals around a point estimate. When making management decisions, it is important to take this uncertainty into account.

CONCLUSIONS AND ADVICE

A conservation LRP (B_{lim}) established for Northern cod in 2010 was re-evaluated in 2019 and considered the average SSB of the 1980s. The estimated SSB has been well below the LRP since the early-1990s. Although the status of the stock is generally improved over the levels of the 2000s, the estimate of 2019 SSB is 48% of B_{lim} (95% CI, 37-63%) and remains in the critical zone. At current levels of SSB the stock is considered to have suffered serious harm and the ability to produce good recruitment is seriously impaired. When the stock is at such a low level, management actions should focus on promoting increases in SSB until the stock is more resilient to the effects of fishing.

Three year projections indicate a low probability (<10%) of reaching B_{lim} under any catch scenario. Consistency with the DFO decision-making framework incorporating the precautionary approach requires that removals from all sources must be kept at the lowest possible level until the stock clears the critical zone.

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This Science Advisory Report is from the March 26-29, 2019 Stock Assessment of Northern Cod (Division 2J3KL). Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDIX I - TABLES

Table A1: Reported landings by management year in NAFO Divs. 2J3KL (nearest thousand metric tons).

Year	62-76 Avg.	77-91 Avg.	98	99	00/01	01/02	02/03	03-06 Avg.	06/07[1]	07/08[1,2]	08/09[1]	09/12[1,2]	12/ 15[1,2]	15/16[1,2]	16/17[1,2]	17/18[1,2]
TAC	N/A	N/A	4	9	7	6	6	0	-	-	-	-	-	-	-	-
Can. Fixed	88	90	5	9	5	7	4	1	3	3	3	3-4	4-5	10	13	9
Can. Mobile	9	84	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	405	38	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals	502	212	5	9	5	7	4	1	3	3	3	3-4	4-5	10	13	9

[1] There is currently no TAC in the Stewardship fishery. Since 2016, the 2J3KL Northern cod Stewardship Fishery has been managed using variable weekly catch limits.

[2] Since 2005, there have only been estimates for Canadian recreational fisheries for 2006, 2008, and 2011-12.

Table A2: Northern cod population size and estimates of F and M from the M-shift formulation of the Northern Cod Assessment Model (NCAM).

Year	2+ pop'n Abundance (millions)	2+ pop'n. Biomass (000's t)	Spawning Stock Biomass SSB (000's t)	Recruits Age 2 (millions)	Average M Age 5-14	Average F Age 5-14
1983	4809	1854	786	2050	0.39	0.21
1984	4669	1909	790	1588	0.37	0.18
1985	3942	1968	857	852	0.35	0.23
1986	3361	1930	795	777	0.32	0.23
1987	3267	1880	834	1064	0.43	0.21
1988	3475	1668	840	1487	0.37	0.23
1989	3792	1636	859	1493	0.31	0.25
1990	3568	1704	793	908	0.31	0.19
1991	3292	1801	780	849	1.19	0.23
1992	1839	954	360	419	2.36	0.23
1993	502	237	84	99	2.56	0.18
1994	185	75	28	65	2.29	0.09
1995	79	26	10	36	0.35	0.04
1996	103	37	16	52	0.34	0.08
1997	122	46	20	60	0.35	0.05
1998	141	58	29	69	0.38	0.13
1999	184	69	36	103	0.45	0.22
2000	237	81	34	127	0.74	0.12
2001	261	86	30	143	0.93	0.17
2002	241	74	25	138	0.78	0.15
2003	207	63	24	119	0.83	0.06
2004	225	63	22	134	0.45	0.04
2005	233	87	26	76	0.35	0.04
2006	272	126	41	95	0.36	0.04
2007	324	166	83	121	0.49	0.03
2008	358	189	110	139	0.61	0.03
2009	388	195	104	166	0.64	0.03
2010	415	194	93	187	0.62	0.03
2011	474	204	95	235	0.40	0.03
2012	506	250	119	178	0.30	0.02
2013	660	332	174	284	0.28	0.02
2014	851	438	247	349	0.32	0.01
2015	908	535	295	282	0.35	0.01
2016	856	603	354	231	0.38	0.02
2017	846	626	424	289	0.53	0.02
2018	872	560	383	361	0.39	0.02
2019	954	588	398	-	-	-

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