STOCK ASSESSMENT OF NORTHERN COD (NAFO DIVISIONS 2J3KL) IN 2018

Image: Atlantic Cod (Gadus morhua).

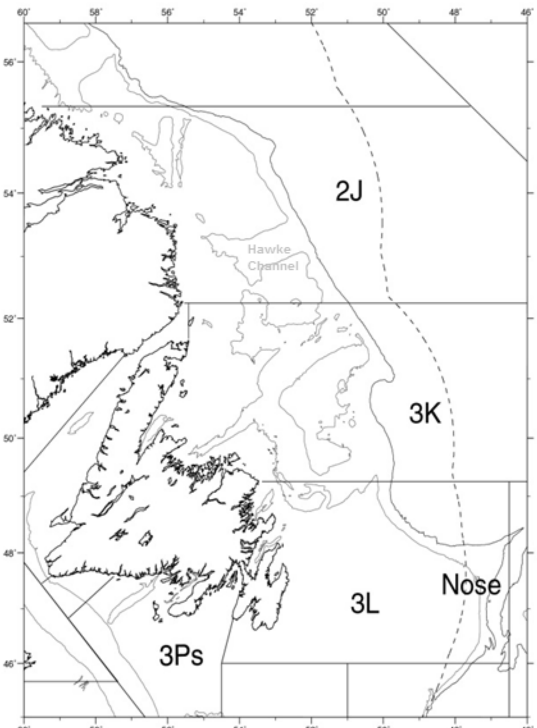

Figure 1: Stock area of Northern (2J3KL) cod. The dashed line indicates Canada's 200 nautical mile Exclusive Economic Zone (EEZ).

Context:

A conservation limit reference point (LRP) was established for Northern cod in 2010 (DFO 2010) and 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. The upper stock reference has not yet been defined. The previous full assessment (March 2016) concluded that the spawning stock biomass (SSB) index in 2015 was 34% of the LRP as estimated from the Northern Cod Assessment Model (NCAM). A subsequent stock update (March 2017) indicated that the total biomass index had continued to grow based on the survey results from the fall research vessel (RV) survey in 2016. Despite these increases, the stock remains in the lower half of the critical zone, below B_{lim}. At these levels the stock is considered to have suffered serious harm and the ability to produce good recruitment is seriously impaired. The scientific advice from the most recent full assessment (DFO 2016b) and subsequent stock update (DFO 2017) 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.

Canada

The Northern cod stock has been subjected to ongoing stewardship and recreational fisheries in the inshore since 2006. In the 2016 and 2017 stewardship fishery, each harvester was allowed weekly landing limits during an extended season. In the 2017 recreational fishery, a maximum catch of 15 fish per boat per day was permitted over a 46 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 19-22, 2018 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 catch-at-age model (NCAM), which allows quantification of uncertainty in estimated and projected stock status.
- Spawning Stock Biomass (SSB) remains in the critical zone in 2018, at 37% of the Limit Reference Point (LRP) (95% CI, 27-51%), down from 52% in 2017 and returning to the level of 2015. This represents an increase from the current estimate of the 2005 level of 3% of B_{lim}.
- SSB was 423 Kt in 2017, and 315 Kt (95% CI, 224-445 Kt) in 2018. This decline results mainly from an increase in estimated natural mortality rate from 0.39 in 2016 to 0.74 (48% annual survival) in 2017 (averaged over ages 5-14).
- The estimated fishing mortality rate from all sources has increased from 0.014 in 2015 to 0.021 in 2016 and 0.025 in 2017 (averaged over ages 5-14).
- Recruitment (age 2) increased from lowest estimated levels of 36 million fish in 1995 to an average of 251 million in 2011-15. This recent average is 19% of the pre-collapse period of the 1980s.
- 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 remain at low levels to at least 2019. This is expected to negatively impact cod productivity.
- In the 2016 assessment, a series of projections under various assumptions about fishery removals in 2016 and 2017 indicated median 2018 SSB would range from 0.6-0.66 (95% CI, 0.32-1.17) of the B_{lim} level. In the current assessment, median 2018 SSB is estimated to be 0.37 (95% CI, 0.27-0.51) of B_{lim}. This difference is driven by 2017 estimates of M that are 2 to 3 times higher than those assumed in the 2016 projections. This increase in M is consistent with ecosystem-wide information that is not directly used in the estimation.
- Natural mortality (M) plays an important role in projections for this stock. A key determinant of the projected 2019 SSB is natural mortality. If natural mortality rates in 2018 are appreciably different than those used, projected outcomes will differ from values reported above. Medium and long term projections were not carried out due to uncertainty about the level of future natural mortality.
- Projections carried out for one year indicated the probability of SSB in 2019 declining below current SSB (2018) with assumed catches of 80% to 120% of the estimated catch in 2017 (15, 054 t) ranged from 0.71 to 0.73. The probability of SSB reaching B_{lim} by 2019 is very low (<0.01) for all the above catch levels. A projection with no fishing indicated a probability

of 0.66 of SSB in 2019 declining below current levels, and a probability <0.01 of reaching B_{lim} by 2019.

- 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.

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).

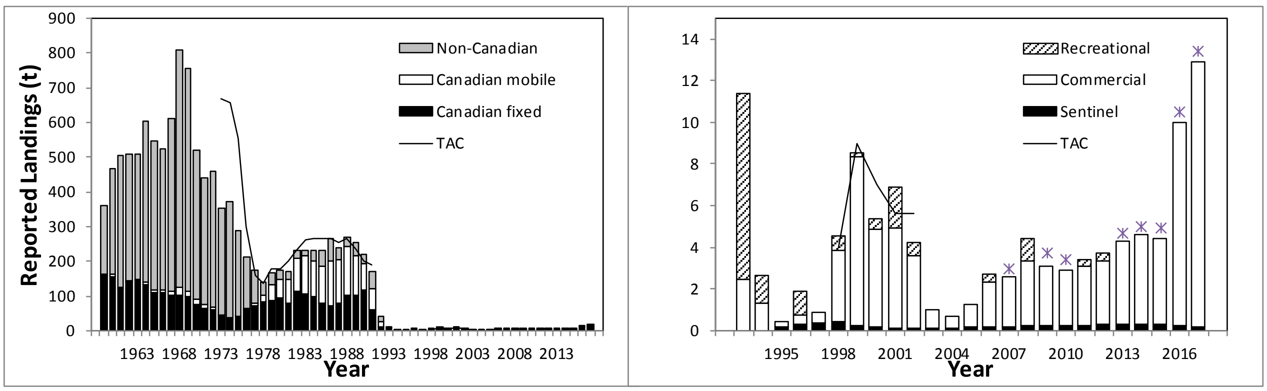

Figure 2: Total Allowable Catches (TACs) and landings (thousands of tons) from 1959-2017. The right panel is expanded to show trends from 1993 onwards. Asterisks indicate that recreational catches in 2007, 2009-10, and 2013-17 were not directly estimated.

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 fishery and a recreational fishery for cod were re-opened in the inshore in 2006 and continued in 2007-17. Commercial fishers were permitted a fixed annual allowance per license holder. The previous multi-year management plan (2013-15) for the stewardship fishery was an individual quota (IQ) based plan, whereby each harvester was permitted an annual allowance of 2.3 t (=5,000 lbs). The management approach changed in 2016 from an IQ for the stewardship fishery to weekly landing limits per fisher (2,000 lbs from August 15 to September 4 then 3,000 lbs from September 4 to December 16), and the requirement that fish could be caught only within the fisher's home bay was removed. The recreational fishing season was extended in 2016, with recreational fishers being allowed to fish on weekends, including both the Canada Day and Labour Day holidays, in addition to the two week season in summer and fall. This was an increase of 14 days from 2015 to 2016 (total 124 days). Recreational fishers were permitted a maximum catch of five fish per day per person, or 15 fish per boat per trip when three or more people were fishing together.

In 2017, the management approach for the stewardship fishery was similar to 2016, with an extended season (149 days), weekly landing limits and a 1 year management plan. There were some changes, however, including:

1. the removal of the requirement to fish within Canada’s Territorial Sea (beyond the 12 nautical mile limit); and
2. the season was extended to include June 12-30 and July 30-November 30.

Reported landings in 2017 were 12,707 t from the stewardship fishery, 173 t in the sentinel surveys, 102 t taken as by-catch (Canadian and non-Canadian) but excluded recreational removals. There are no direct estimates of recreational landings for six of the past 10 years; therefore reported landings are less than total catch in those years. Evidence from tagging data shows that the removals by the recreational fishery are substantial (average of 30% of the total fishery landings) during 2006-17.

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 2000-17 (provisional value of 41 t in 2017).

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 7 in 2016 and age 8 in 2017.

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 in the inshore in Div. 3L and southern Div. 3K. These inshore components appeared to be more productive during the 1990s than those in the offshore. Inshore components were small relative to the components that historically migrated into the inshore from the offshore during spring/summer.

Tagging studies revealed that during the late 1990s to the mid-2000s the inshore of Divs. 3KL was inhabited by at least two groups of cod:

1. a resident coastal group that inhabited an area from eastern Trinity Bay northward to western Notre Dame Bay; and
2. a migrant group that over-wintered in inshore and offshore areas of Subdiv. 3Ps, moved into southern Div. 3L during late spring and summer, and returned to Subdiv. 3Ps in the autumn.

Tagging studies also indicated considerable movement of cod among Trinity Bay, Bonavista Bay, and Notre Dame Bay.

The status of cod in the offshore has improved considerably and the shoreward seasonal migration pattern observed prior to the moratorium did take place in recent years. Overwintering inshore aggregations, such as those observed in Smith Sound, Trinity Bay, have diminished and most of the stock now appears to overwinter in the offshore, similar to the pre-moratorium period. 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 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 for 23 years since 1995. Stronger than average abundances of pre-recruits have been observed during each of the past three years (2015-17) compared to the long term mean in this survey, indicating stability of pre-recruit abundances among the 2015-17 cohorts.

Small cod tend to feed on small crustaceans; medium-sized cod feed on larger crustaceans and small fish; and large cod feed on medium-sized fish and crabs. Capelin (*Mallotus villosus*) in particular has historically been an important part of the annual diet.

Regulation of Northern Cod Dynamics

Studies have shown that dynamics of the Northern cod stock are driven by an interplay between fisheries removals and bottom-up forcers, such as availability of food; in particular, capelin (Drinkwater 2005, Halliday and Pinhorn 2009, Shelton et al. 2006, Buren et al. 2014, Morgan et al. 2017, Sherwood et al. 2007, Rose and O'Driscoll 2002).

ECOSYSTEM INFORMATION

Physical Environment

The marine environment off Labrador and eastern Newfoundland experienced considerable variability 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.

Ocean temperatures have been above normal for the past decade, reaching highs in 2006, declining to more normal values in 2007-09, then increasing to record highs in 2011, before trending lower through until 2017. The cold-intermediate layer (CIL; volume of <0°C) in both 2014 and 2015 was at its highest level since 1985 on the Grand Bank during the spring, and remained significantly above normal during the spring of 2017. A standardized climate index derived from 28 meteorological, ice, water mass areas, and ocean temperature and salinity time-series has been trending downward since the near-record highs of 2010 and 2011 to mostly below normal values (cold/fresh) during the past four years. The 2015 value was the 7th lowest in 68 years of observations and the lowest value since 1993, while the 2017 value was the 15th lowest.

The impact of these oceanographic changes on cod population dynamics is difficult to determine. Cod in this area can be more productive when water temperatures are towards the warm end of the regional norm. Cod somatic growth values were among the highest in the time series in Divs. 3KL when temperatures were approaching the peak of 2011-12 and the most recent downturn in ocean temperatures has coincided with a recent decrease in the numbers of cod available to the trawl surveys.

Ocean Productivity

Seasonal surveys along the standard sections across Divs. 2J3KL indicate reduction in inventories of macronutrients in 2017 and recent years. The reduction in available macronutrient pools coincided with a reduction in phytoplankton biomass along all standard sections from Div. 2J to 3L during the same time period. In line with this reduction in nutrient inventories and associated biomass of phytoplankton, a general reduction in zooplankton biomass was observed across Divs. 2J3KL. This reduction in zooplankton biomass is linked to a shift in its community composition with increased abundances of smaller taxa, and declines of large taxa. Substantial increases in abundance of a keystone calanoid copepod (*Pseudocalanus* spp.), and other small warm and coldwater copepods along with benthic invertebrates and gelatinous zooplankton have been observed across the standard sections. On the other hand, the abundance of the large energy-rich calanoid copepod (*Calanus finmarchicus*) has declined. These changes observed in lower trophic levels and community composition of zooplankton indicate reduced primary and secondary inputs that may impact transfer of energy to higher trophic levels in recent years.

Marine Community

During the late-1980s and early-1990s the marine community in the Newfoundland and Labrador bioregion collapsed. This collapse can be associated to a combination of historical overfishing, and a regime shift. Changes were more dramatic in the northern regions and involved commercial and non-commercial species, including capelin, the keystone forage fish in this large marine ecosystem. It was also during this period, that increases in shellfish species (e.g. Northern Shrimp, *Pandalus borealis*) took place.

During 2004 to 2010 there was an increasing trend in the finfish biomass in Divs. 2J3KL; with many components of the community (e.g.: piscivores such as Atlantic Cod, Greenland Halibut *Reinhardtius hippoglossoides*, and Atlantic Halibut *Hippoglossus hippoglossus*; large benthivores like American Plaice *Hippoglossoides platessoides*; and plank-piscivores like redfish *Sebastes* spp) showing positive signals. These were the first significant increases observed in the finfish component of this marine community since the collapse, and coincided with an improvement in capelin biomass during this period. While finfish was building-up, total shellfish biomass started to decline in 2007-08. Total finfish biomass remained fairly stable during the early-2010s, but still well below pre-collapse levels. By 2013-14, the entire community started to show declining signals which became clear by 2016-17. This may be linked to reductions in capelin and shrimp availability as well as other changes in ecosystem conditions (e.g. declines in primary production and some zooplankton groups in recent years) which indicate reduced ecosystem productivity. Given the general productivity state of the ecosystem and the role of capelin as a cod driver, further exemplified by the relationship between cod per capita net production rate and capelin availability, current capelin levels also indicate low productivity conditions for the Northern cod stock.

Prey

Both capelin and *Pandalus* shrimp have been key prey for cod based on analysis of cod stomachs sampled during autumn research vessel (RV) surveys. During the 1980s and early-1990s capelin was the main prey in the autumn diet of cod. After the cod collapse, *Pandalus* shrimp became a key prey, increasing its contribution to the diet of cod over time. This trend started in the late-1980s, but became more important in the mid-1990s; coinciding with the increase of *Pandalus* shrimp in the environment. The RV biomass index of *Pandalus* shrimp increased significantly from the mid-1990s until the mid-2000s, but has declined since and it is currently at its lowest level since the mid-1990s.

An index of offshore capelin abundance, based on a spring Div. 3L hydro-acoustic survey, indicates that capelin abundance was high in the late-1980s, but dropped dramatically in the early-1990s and has remained low relative to the late-1980s. The general pattern of changes in capelin abundance appears to be reflected in cod diets. Although the Div. 3L hydro-acoustic survey indicated an increase in capelin abundance in 2007-09 relative to the levels observed during the 1990s and early-2000s, their abundance was still far below the levels of the late-1980s; nonetheless, the timing of this improvement in capelin coincided with increases observed in the biomass of cod in portions of the offshore, and with an increase in the fraction of capelin in cod diets. The 2013-15 period saw a further increase in capelin abundance with capelin reaching their highest levels since the 1990s (approximately 20% of the pre-collapse levels), while shrimp declined to their lowest levels since the mid-1990s. Capelin abundance declined substantially in 2016 and 2017, and combined with already low shrimp biomass resulted in low levels of capelin and shrimp in cod diets.

From 1985-2007, capelin availability was found to be a significant driver of Northern cod biomass dynamics and the trends in cod and capelin biomass, and cod diet composition in recent years further support the importance of capelin availability to rebuilding cod.

Shrimp and capelin are both important prey for cod and other groundfish species. Simultaneous low availabilities of two major forage species in the ecosystem could compromise the potential for the recovery of cod in particular, and the groundfish community in general.

Given the poor recruitment of capelin observed in the last four years and the declining trends in zooplankton biomass observed in the recent time period (which are an important food source for capelin) there are causes for concern about the short-term prospects of this key forage species.

Predators

Cod are preyed upon by a changing suite of predators at various stages in their life history, from egg through to mature adults. Juvenile cod are eaten by squid and many species of groundfish (including larger cod), seals, and some species of birds. Large cod probably have few natural predators. The potential contribution of harp seal predation to the dynamics of the Northern cod stock during the period 1985-2007 was assessed in 2014, and was found not to be an important driver of the stock. There is no indication that the impact of seal predation has changed since it was assessed.

Although some information is available, consumption levels of cod and key prey by other predators such as other fish species and sea birds still remains uncertain.

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 autumn offshore bottom-trawl survey (ages 2-14, 1983-2017), inshore Sentinel 5½” mesh gillnet index (combined Divs. 2J3KL; ages 3-10, 1995-2017), inshore acoustic biomass estimates (1995-2009), fishery catch age-composition information (1983-2017), partial fishery landings information (1983-2017), and tagging information (1983-2017) including reporting rates (see below).

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.

Stock Trends

Bottom-trawl survey indices

The abundance and biomass indices from the autumn DFO research vessel (RV) surveys have been low since the start of the moratorium in 1992 (Figs. 3 and 4). From 2011-16, both abundance and biomass indices increased, but in 2017 decreased to levels of 2014. Most of the abundance and biomass (>80%) is located in the northern portion of the stock area (Divs. 2J and 3K). The three-year average (2015-17) for both abundance and biomass indices is approximately 30% of the average during the 1980s.

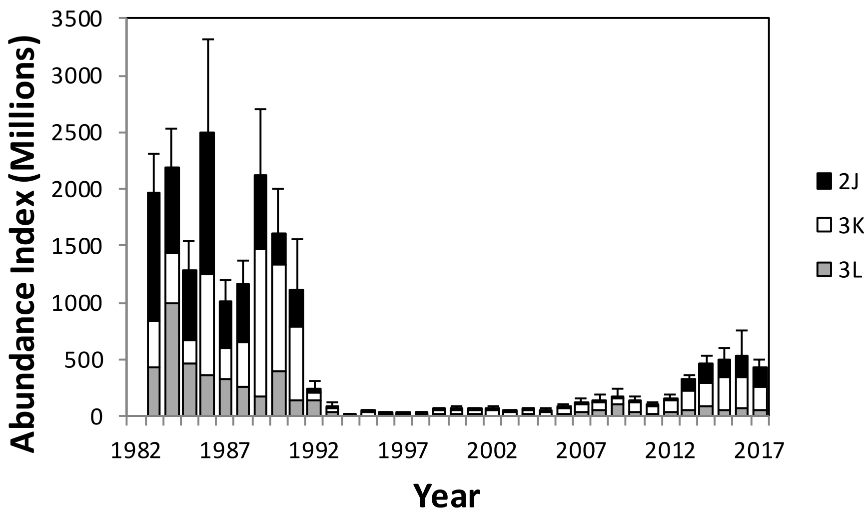

Figure 3: Offshore abundance index (+ 2 standard errors) from autumn RV surveys in NAFO Divs. 2J3KL.

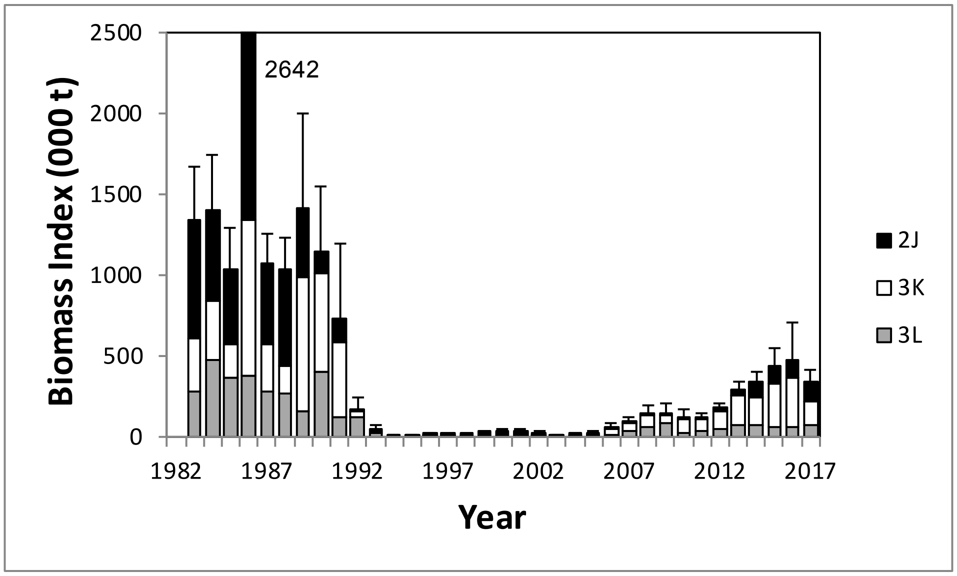

Figure 4: Offshore biomass index (+2 standard errors) from autumn RV surveys in NAFO Divs. 2J3KL.

Increased numbers of small cod (≤ age 4) have been observed since 2012.. The age structure of the RV survey indicated fewer fish at older ages (> 7 years old) than was seen in the previous two years.

Model results

The following results were obtained from the state-space Northern Cod Assessment Model (NCAM) formulation that was identical to the formulation used in the 2016 assessment.

The abundance (2+ years) of Northern cod has remained low after the collapse and moratorium in 1992, but has increased in the past decade from 227 million in 2005 to 795 million (95% CI, 559-1131 million) in 2017 (Fig. 5, left panel). Abundance reached a recent peak value of 880 million fish in 2015 and has since declined. Biomass of fish aged 2+ shows a similar trend to abundance and has increased from 86 kt in 2005 to 639 kt in 2017, down to 467 kt in 2018 (95% CI, 343-635 kt; Fig 5, right panel). Spawning stock biomass increased from 26 kt in 2005 to 441 kt in 2017, but decreased to 315 kt (95% CI, 224-445 kt) in 2018.

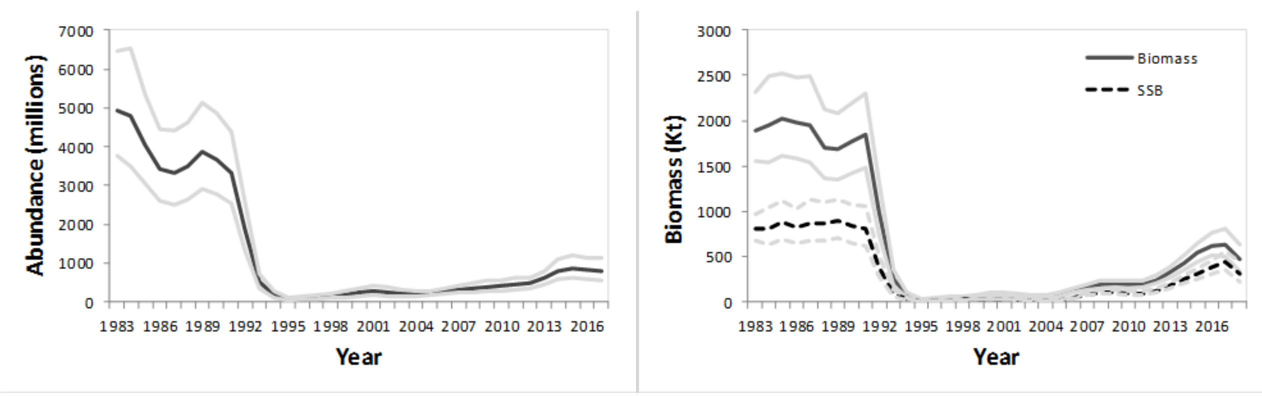

Figure 5: Trends in Northern cod stock size. Black lines are the model estimates, and grey lines are 95% confidence intervals.

Fishing mortality (*F*) has been variable during 1983-2017 (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 (0.05) during 1995-97 when inshore fishing was highly restricted, but increased rapidly reaching close to pre-moratorium values (*F*=0.15 to 0.20) when a directed inshore fishery for cod was reopened in 1998-2002. Closure of the directed inshore fishery in 2003-2005 resulted in a substantial reduction in *F* to 0.04. More recently, *F* has been low but has doubled, from 0.01 on 2015 to 0.02 in 2017 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 1983-2017 (Fig. 6, right panel), ranging from 0.3 to 0.5 in the early to mid-1980s, increasing rapidly to a peak of 2.5 during 1992-1994, then declining to approximately 0.35 during 1995-1999. Additional periods of high *M* are evident in 2000-2003 (*M* = 0.7 to 0.9) and 2009-2010 (*M* = 0.6 to 0.7). Recent values of *M* had declined, from 0.70 (equivalent to an annual reduction of 50%) in 2010 to 0.28 (equivalent to an annual reduction of 24%) in 2015; however *M* increased from 0.36 in 2016 to a higher level of 0.74 (48% annual survival) in 2017.

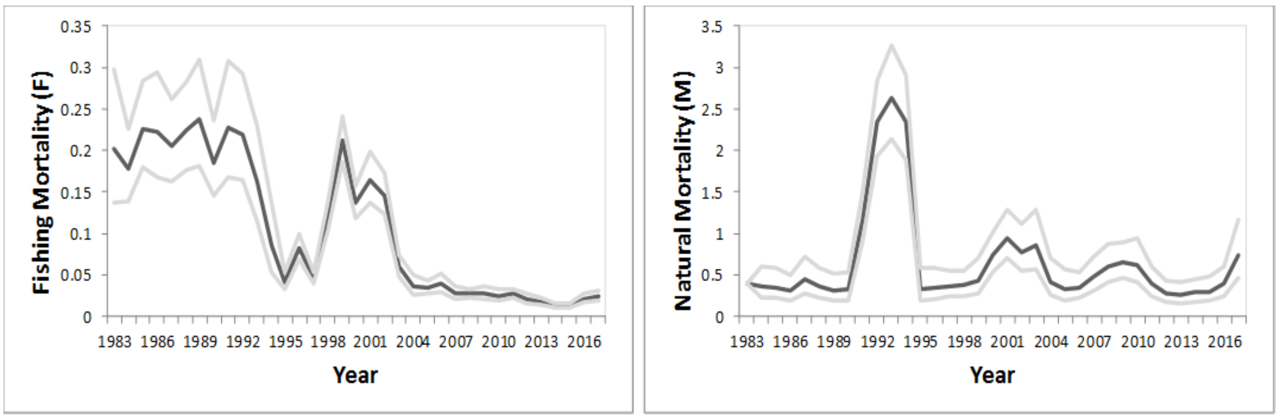

Figure 6: Trends in population-weighted fishing mortality rates (F, left panel) and natural mortality rates (M, right panel). Dark lines are the age-aggregated model estimates (ages 5-14) and grey lines are 95% CI's.

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.

The recent increase in *M* is consistent with ecosystem-wide information that is not directly used in the estimation (e.g. lower levels of capelin, changes in environmental conditions, weight-at-age and lower condition indices of cod in the recent time period, etc.).

Recruitment (age 2) increased from lowest estimated levels of 36 million fish in 1995 to an average of 251 million in 2011-2015 (more recent age classes are less informative) (Fig. 7). This recent average is 19% of the pre-collapse period of the 1980s.

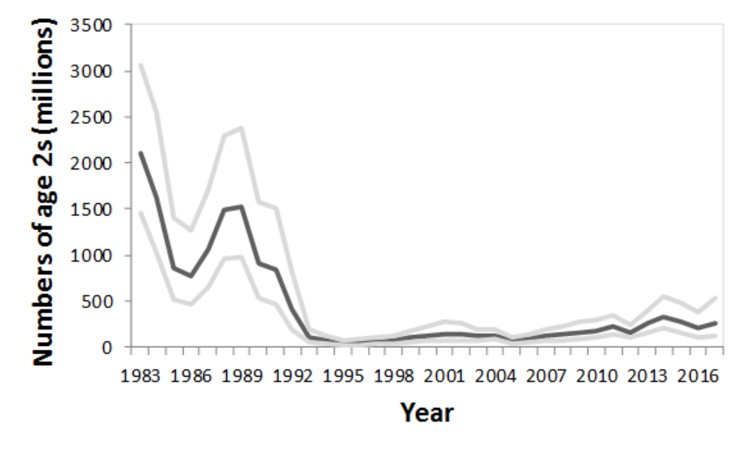

Figure 7: Trends in Northern cod recruitment (number at age 2). Solid black line is the model estimate, and grey lines are 95% confidence intervals.

Spawning Stock Biomass (SSB) remains in the critical zone of the DFO PA framework in 2018, at 37% of the Limit Reference Point (LRP) (95% CI, 27-51%), down from 52% in 2017 and returning to the level of 2015 (Fig. 8). This represents an increase from the current estimate of the 2005 level of 3% of B_{lim} but a decline in SSB from 2017 to 2018 of 30%.

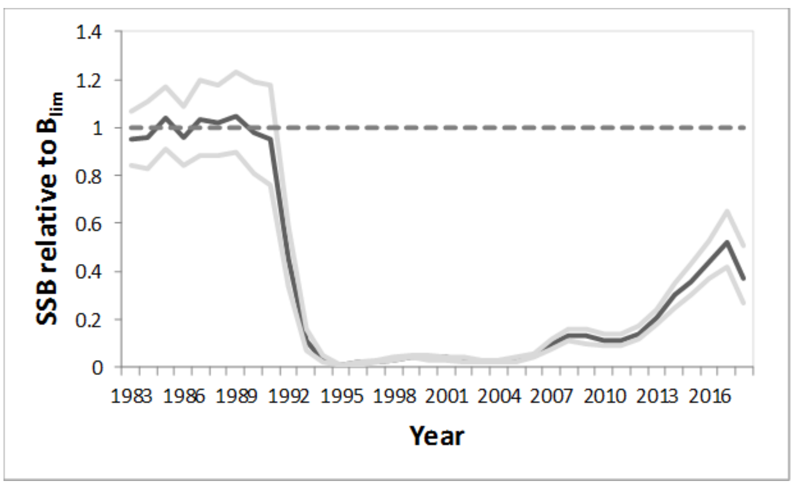

Figure 8: Trends in Northern cod Spawning Stock Biomass (SSB) relative to the limit reference point B_{lim}, where B_{lim} (dashed line) is defined as the average SSB during the 1980s. Solid black line is the model estimate and grey lines are 95% confidence intervals.

Projections

Medium and long term projections were not carried out due to uncertainty about the level of future natural mortality. A one-year projection (to 2019) was conducted to investigate the potential impact of a range of catch options from zero catch (no fishing) to a 1.2-fold increase in catch. Projections were based on the model estimate of catch for 2017 (15,054 t). The age-pattern in *F* values was assumed to be the same as in 2017. Projected recruitment, stock weights, and proportions mature were assumed to be equal to the mean of their 2015-17 values. Assumed recruitment (age 2) has zero impact on the projected SSB.

The projections indicate a risk of between 66 and 73% of SSB in 2019 declining below the 2018 value, and also a very low probability (<0.1%) of exceeding B_{lim} in 2019. The stock is projected to be less than B_{lim} (approximately one-third) and remain in the critical zone in 2019 over the full range of catch options considered, including no fishing (Table 1). In 2019, under current catch levels, the SSB relative to B_{lim} is projected to be 0.32 with wide confidence intervals of 0.18 to 0.59 (Fig. 9).

Table 1: Results of the three-year projections for catch multipliers from 0 (no catch) to 1.2 times the estimated catch in 2017 (15,054 t).

Projections	**Catch multiplier 0**	**Catch multiplier 0.8**	**Catch multiplier 0.9**	**Catch multiplier 1.0**	**Catch multiplier 1.1**	**Catch multiplier 1.2**
Risk (in %) of SSB declining below 2018 value	66	71	71	72	72	73
Probability (in %) of exceeding B_{lim} in 2019	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
SSB in 2019 relative to B_{lim}	0.34	0.33	0.33	0.32	0.32	0.32

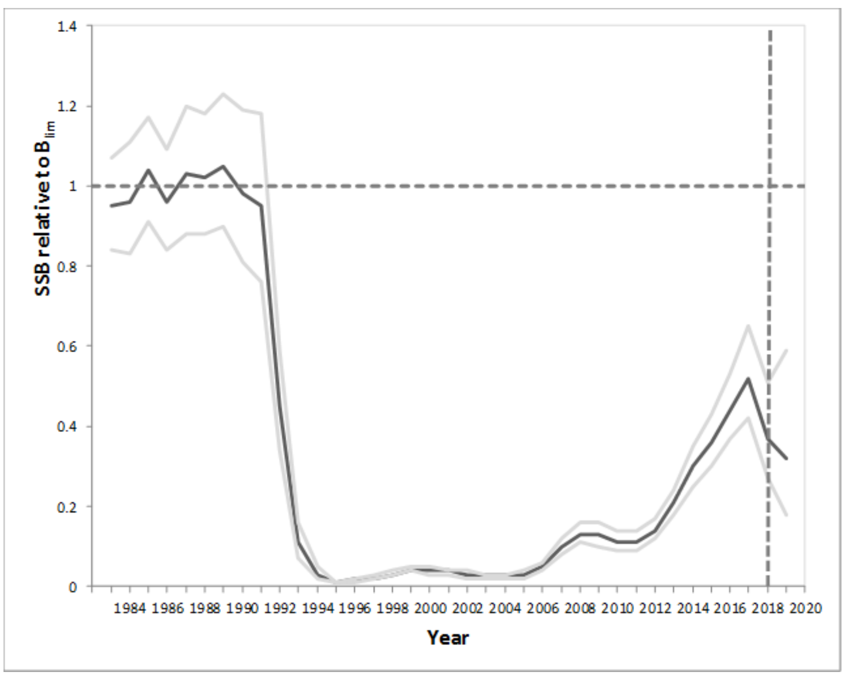

Figure 9: One year projection (to 2019) of Northern cod Spawning Stock Biomass (SSB) relative to the limit reference point B_{lim}, where B_{lim} (horizontal dashed line) is defined as the average SSB during the 1980s. Solid black line is the model estimate and grey lines are 95% confidence intervals. Vertical dashed line indicates projection period.

Tagging

Information from recaptures of cod tagged during 1983-2017 was integrated in the assessment model, and these data are particularly important for estimating *F and M*. The tagging data comprise 116,000 releases and over 11,000 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 2006-17.

A new method was used to estimate tag reporting rates and for the recent period (2010-15) this approach gave lower estimates and a slightly steeper decline in reporting rates compared with previous analysis. The reporting rate for tags (commercial and recreational combined) during 2017 was 49%, up slightly since 2015, but amongst the lowest in the time series.

From 2006-17, recreational fishers were responsible for a substantial percentage of the total number of tags returned (average 30%) after numbers were adjusted by respective tag reporting rates. The ratio of tags returned by recreational versus commercial fishers as a percent of the total has averaged 0.45 (range 0.23 to 0.82) during the past 12 years (2006-17), but in the past two years this number has been lower (0.24) due to increases in the commercial harvest. Overall the results suggest that recreational landings are substantial and that total removals are much higher than reported landings.

Additional Sources of Information

Other information reviewed at the assessment but not included in this report included the following: total mortality, and biological characteristics (growth, condition, maturity) obtained from analysis of catch rate-at-age in the autumn surveys; recaptures of conventionally tagged cod combined with detections of acoustically tagged cod were used to estimate harvest rates and investigate migration patterns; analysis of catch rate trends from DFO-Industry Sentinel survey fixed-gears 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 can estimate catches to 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 the assessment meeting.

There are no direct estimates of recreational landings for some years (2006, 2008, 2013-17) 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 uncertain and difficult to estimate, and this has implications for the perceived size of recreational and commercial catch and assessment model estimates. Harvesters (recreational and commercial) should return all tags to reduce the uncertainty in reporting rates. Low reporting rates also add uncertainty to analyses of movement patterns and stock structure.

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. Additional analysis of tagging data may provide greater insight.

Natural mortality (*M*) plays an important role in projections for this stock. A key determinant of the projected 2019 SSB is natural mortality. If natural mortality rates in 2018 are appreciably different than those used, projected outcomes will differ from values reported above. Medium and long term projections were not carried out due to uncertainty about the level of future natural mortality.

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 remain at low levels to at least 2019. 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 2017, it should be re-iterated 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}) was established for Northern cod in 2010. 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 2018 SSB is 37% of B_{lim} and is therefore in the lower half of 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.

A one-year projection indicated a risk of between 66 and 73% of SSB in 2019 declining below the 2018 value, and also a very low probability (<0.1%) of exceeding B_{lim} in 2019. 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.[1]

SOURCES OF INFORMATION

This Science Advisory Report is from the March 19-22, 2018 Stock Assessment of Northern cod (Divs. 2J3KL). Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Buren, A.D., Koen-Alonso, M. and Stenson, G.B. 2014. The role of harp seals, fisheries and food availability in driving the dynamics of northern cod. Marine Ecology Progress Series, 511: 265-284.

Cadigan, N. G. 2015. A state-space stock assessment model for Northern cod, including under-reported catches and variable natural mortality rates. Can. J. Fish. Aquat. Sci. 73(2): 296-308.

Cadigan, N. 2016. Updates to a Northern cod (*Gadus morhua*) state-space integration assessment model. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/022. v + 58p.

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach.

DFO. 2010. Proceedings of the Newfoundland and Labrador Regional Atlantic Cod Framework Meeting: Reference Points and Projection Methods for Newfoundland cod stocks; November 22-26, 2010. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2010/053.

DFO. 2016a. Proceedings of the Northern cod Framework Review Meeting. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2016/031.

DFO. 2016b. Stock assessment of Northern (2J3KL) cod in 2016. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2016/026.

DFO. 2017. Northern (2J3KL) cod Stock Update. DFO Can. Sci. Advis. Sec. Sci. Resp. 2017/034.

Drinkwater, K.F. 2002. A review of the role of climate variability in the decline of northern cod. In: McGinn, N.A. (Ed.) Fisheries in a changing climate. pp. 113-130. American Fisheries Society, Symposium 32, Bethesda, Maryland.

Drinkwater, K.F. 2005. The response of Atlantic cod (*Gadus morhua*) to future climate change. ICES Journal of Marine Science, 62(7): 1327-1337.

Halliday, R.G. and Pinhorn, A.T. 2009. The roles of fishing and environmental change in the decline of Northwest Atlantic groundfish populations in the early 1990s. Fisheries Research, 97(3): 163-182.

Hutchings, J. A. and Myers, R. A. 1994. What can be learned from the collapse of a renewable resource? Atlantic cod, *Gadus morhua*, of Newfoundland and Labrador. Can. J. Fish. Aquat. Sci. 51: 2126-2146.

[1] Erratum (August 2018).

Morgan, M.J., Koen-Alonso, M., Rideout, R.M., Buren, A.D., and Maddock Parsons, D. Handling editor: Emory Anderson, 2017. Growth and condition in relation to the lack of recovery of Northern cod. ICES Journal of Marine Science, 75(2), pp.631-641.

Myers, R. A., Barrowman, N. J., Hoenig, J. M., and Qu, Z. 1996. The collapse of cod in Eastern Canada: the evidence from tagging data. ICES J. Mar. Sci. 53: 629-640.

Rose, G.A. and O' Driscoll, R. 2002. Capelin are good for cod: can the northern stock rebuild without them? ICES Journal of Marine Science, 59(5), pp.1018-1026.

Shelton, P.A., Sinclair, A.F., Chouinard, G.A., Mohn, R. and Duplisea, D.E. 2006. Fishing under low productivity conditions is further delaying recovery of Northwest Atlantic cod (*Gadus morhua*). Canadian Journal of fisheries and aquatic sciences, 63(2), pp.235-238.

Sherwood, G.D., Rideout, R.M., Fudge, S.B. and Rose, G.A. 2007. Influence of diet on growth, condition and reproductive capacity in Newfoundland and Labrador cod (*Gadus morhua*): Insights from stable carbon isotopes (δ13C). Deep Sea Research Part II: Topical Studies in Oceanography, 54(23-26), pp.2794-2809.

APPENDIX

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]
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
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

[1] There is currently no TAC in the Stewardship fishery. From 2006-15 the fishery was managed by Individual Quotas (I.Qs). These I.Qs were 3,000 lbs in 2006, 2,500 lbs in 2007, 3,750 lbs in 2008-12, and 5,000 lbs from 2013-15. In 2016 the management approach changed from an I.Q. based fishery to one managed by weekly limits and included an extended season. In 2016, weekly limits were 2,000 lbs/week from August 15 to September 4, and 3,000 lbs/week from September 4 to December 16. In 2017 the season was further extended and weekly limits varied based on the month and NAFO area. Division 2J based harvesters had weekly limits of 4,000 lbs/week in June and August and 5,000 lbs/week from September to November. Divisions 3KL based harvesters had weekly limits of 4,000 lbs/week in June, 2,000 lbs/week in August, 3,000 lbs/week in September and 5,000 lbs/week in October and November. Fishing was not authorized in July.

[2] Does not include Canadian recreational fisheries for 2007, 2009-10, and 2013-17 as no direct estimates are available.

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	4928	1893	807	2106	0.39	0.2
1984	4781	1955	815	1620	0.37	0.18
1985	4024	2017	881	853	0.35	0.23
1986	3409	1978	818	767	0.31	0.22
1987	3330	1952	872	1061	0.45	0.21
1988	3501	1709	869	1489	0.37	0.22
1989	3861	1681	893	1526	0.31	0.24
1990	3658	1769	834	918	0.33	0.19
1991	3327	1848	807	840	1.17	0.23
1992	1886	1001	380	408	2.34	0.22
1993	518	252	92	102	2.64	0.16
1994	190	78	29	66	2.34	0.09
1995	79	26	10	36	0.33	0.04
1996	106	38	16	53	0.35	0.08
1997	124	47	21	61	0.37	0.05
1998	141	58	30	69	0.38	0.12
1999	186	70	36	104	0.44	0.21
2000	243	83	35	130	0.74	0.14
2001	270	88	31	148	0.95	0.16
2002	248	75	25	142	0.78	0.15
2003	207	64	24	118	0.86	0.06
2004	216	61	22	128	0.42	0.04
2005	227	86	26	72	0.33	0.03
2006	267	125	42	92	0.34	0.04
2007	325	167	85	122	0.48	0.03
2008	359	192	113	136	0.6	0.03
2009	388	198	107	164	0.65	0.03
2010	408	195	95	181	0.62	0.02
2011	452	201	96	224	0.39	0.03
2012	473	246	120	158	0.27	0.02
2013	614	327	176	259	0.26	0.02
2014	807	434	252	335	0.29	0.01
2015	880	539	307	279	0.3	0.01
2016	828	626	378	205	0.39	0.02
2017	795	639	441	262	0.74	0.02
2018	-	467	315	-	-	-

* Note that the estimates of SSB for recent years may be revised because the mean weights at age and proportions mature at age are estimated each year and can change for unfinished cohorts that are used in the calculation of SSB.

THIS REPORT IS AVAILABLE FROM THE:

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

Telephone: (709) 772-3332
E-Mail: DFONLCentreforScienceAdvice@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2018. Stock assessment of Northern cod (NAFO Divisions 2J3KL) in 2018. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/038. (Erratum: August 2018)

Aussi disponible en français :

MPO. 2018. Évaluation du stock de morue du Nord (divisions 2J3KL de l'OPANO) en 2018. Secr. can. de consult. sci. du MPO, Avis sci. 2018/038. (Erratum : Août 2018)