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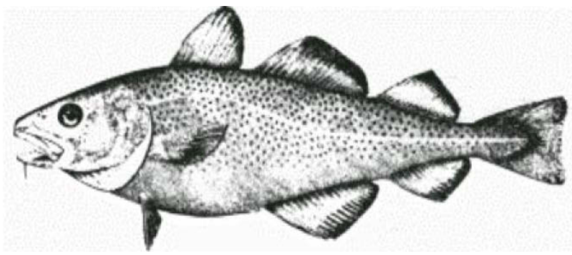
Newfoundland and Labrador Region

Canadian Science Advisory Secretariat
Science Advisory Report 2016/026

STOCK ASSESSMENT OF NORTHERN COD (NAFO DIVS. 2J3KL) IN 2016



Atlantic Cod (Gadus morhua)

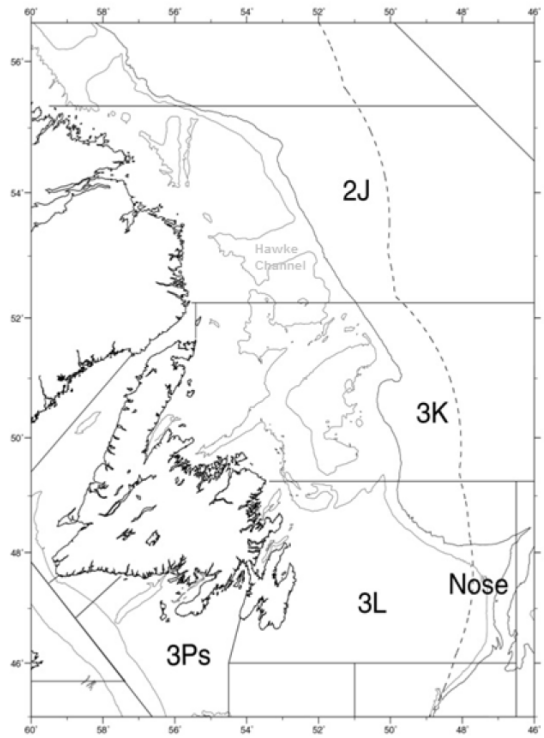


Figure 1. Stock area of Northern (2J3KL) cod. The dashed line indicates Canada's 200 nautical mile Exclusive Economic Zone (EEZ).

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 2013) concluded that the three-year average (2010-12) spawning stock biomass (SSB) index was 15% of the LRP. Subsequent stock updates (March 2014 and March 2015) indicated the three-year average SSB index increased to 18% and 26%, respectively, of the LRP; 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 2013) and subsequent stock updates (DFO 2014, DFO 2015) 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.

The Northern cod stock has been subjected to ongoing stewardship and recreational fisheries in the inshore since 2006. In the 2015 stewardship fishery, each harvester was permitted an annual allowance of 2.3 t (= 5,000 lb). In the 2015 recreational fishery, a maximum catch of 15 fish per boat per day was permitted over a 32 day period.

The current three year management plan ended on 31 March 2016. 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 1 April 2016 – 31 March 2019. This Science Advisory Report (SAR) results from a Regional Peer Review meeting conducted during March 21-24 and 30-31, 2016. A Regional Peer Review Process (Northern Cod Framework Meeting) was also held November 30 – December 4, 2015 to review multiple models of population dynamics, and to discuss the utility of various data sets available for assessing this stock (DFO in press).

SUMMARY

- The stock is being assessed using an integrated catch-at-age model for the first time, which allows quantification of uncertainty.
- The stock has increased considerably over the past decade, but remains within the critical zone. Spawning Stock Biomass (SSB) in 2015 was 34% of the Limit Reference Point (LRP) (95% CI, 28-40%).
- SSB was estimated to be 300,000 tonnes (95% CI, 246,000-362,000 t) in 2015. The increase in SSB was the result of improved recruitment and reduced mortality rates. The increase is observed in 2J, 3K and northern 3L.
- The average fishing mortality rate from all sources was low in 2015 (0.014 for ages 5-14).
- The average natural mortality rate in 2015 was 0.28, a decline from 0.70 in 2010 (ages 5-14).
- Three-year projections with catch ranging from zero to five times the estimated catch in 2015 (6,900t) indicated a low risk (< 4%) of SSB declining below the 2015 value; projections also indicate a low probability (5-8%) of reaching the LRP by 2018.
- 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.
- Overall biomass of groundfish species increased during 2005 to 2012, but has since remained stable below pre-collapse levels.
- Availability of capelin, a key prey species, has improved since the very low levels of the 1990s, but is still well below pre-collapse values.
- Predation by seals was not found to be a significant driver of Northern cod 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).

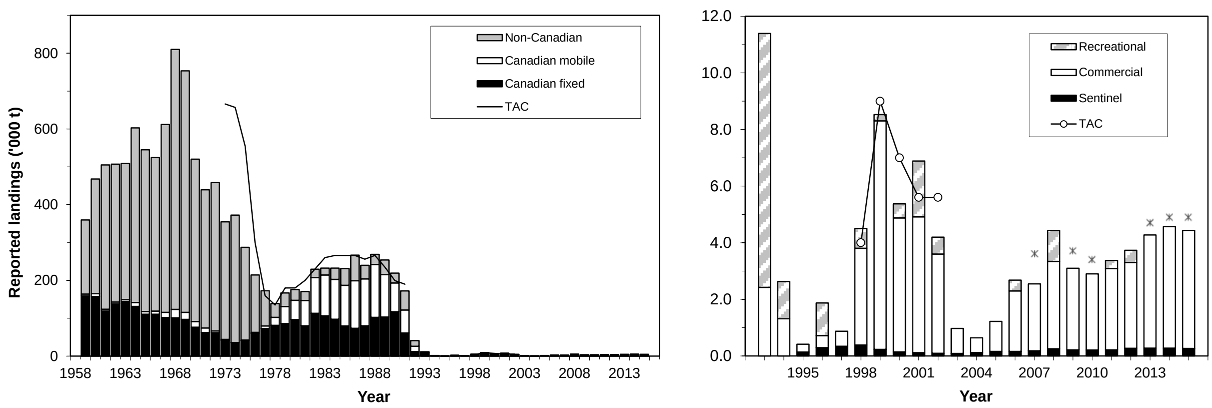


Figure 2. Total Allowable Catches (TACs) and landings (thousands of tonnes) from 1959-2015. The right panel is expanded to show trends from 1993 onwards. Asterisks indicate that recreational catches in 2007, 2009-10, and 2013-15 were not directly estimated.

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 an 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 Div. 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 2007-15. Commercial fishers were permitted an annual allowance of cod per license holder ranging from 1,135 kg to 1,475 kg during 2006-08, 1,700 kg during 2009-12, and 2,270 kg during 2013-15. Reported landings in 2015 were 4,436 t. This included 4,071 t in the stewardship fishery, 268 t in the sentinel surveys, and 97 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 ten years; therefore reported landings are less than total catch in those years. Evidence from tagging data shows that the removals by the recreational fishery were substantial (average of 30% of the stewardship fishery landings) during 2006-15.

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 80 t or less during 2000-09, 61 t for 2010, 292 t for 2011, and ≤ 135 t during 2013-15 (value for 2015 is provisional).

Catch at age

The age structure of cod captured in recent inshore fisheries (stewardship, recreational and sentinel) and in the autumn DFO research vessel (RV) survey are consistent, showing an expansion of age structure, particularly in year-classes produced from 2002 onwards. The fishery catch at age in most years is dominated by fish aged 6-8 which is typical for a fishery where gillnets (5½" and 6" mesh) are the dominant gear.

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 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.

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.

Ecosystem Information

During the late 1980s and early 1990s the fish community in the Newfoundland and Labrador large marine ecosystem 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 the ecosystem. It was also during this period, that increases in shellfish species (e.g., Northern Shrimp, *Pandalus borealis*) took place.

During 2003 to 2007 there was an increasing trend in the fish biomass in Divs. 2J3KL; some components of the fish community (e.g., piscivores such as Atlantic Cod, Greenland Halibut *Reinhardtius hippoglossoides*, and Atlantic Halibut *Hippoglossus hippoglossus*) and large benthivores (e.g., American Plaice *Hippoglossoides platessoides*) showed positive signals. These were the first significant increases observed in the fish component of ecosystem structure since the collapse, and coincided with an improvement in capelin biomass during this period.

The most recent ecosystem information indicates that the overall biomass level of the fish community has shown a decline since 2011, but this overall decline is due to the decrease in shellfish biomass. As a whole, the finfish component of the community has remained fairly stable in 2011-15. The increase in cod observed during this period implies an increased dominance in the overall biomass, but does not reflect the biomass trend of the broader finfish community. Overall, the fish community still remains at a significantly lower level in comparison to the pre-collapse period.

Physical Oceanography

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 2015. The cold-intermediate layer (volume of water < 0°C) in both 2014 and 2015 was at its highest level since 1985 on the Grand Bank during the spring. A standardized climate index derived from 28 meteorological, ice and ocean temperature and salinity time series declined for the 4th consecutive year, reaching the 7th lowest in 66 years and the lowest value since 1993. 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.

Ocean Productivity

Indices of secondary production derived from monthly near-surface plankton sampling and seasonal oceanographic surveys have remained relatively stable during 2010-15 and in some cases have trended upwards (e.g., copepod abundance) that may support feeding of early life stages of northern cod. Long-term changes in primary and secondary producers based on the Continuous Plankton Recorder and Atlantic Zone Monitoring Program data indicate increased standing stocks of zooplankton during recent years although certain cold-water-adapted calanoids (*Calanus glacialis and C. hyperboreus*) have declined on the Grand Bank and northeast Newfoundland Shelf. Zooplankton biomass also shows a significant decline in 2015, likely related to the observed reduction in standing stocks of the arctic calanoid copepods.

Predators

Predation is an important source of natural mortality and cod are preyed upon by a changing suite of predators at various stages in their life history, from egg through to mature adults. Pre-recruit cod are eaten by squid and many species of groundfish, including larger cod, and some species of birds. Larger juveniles are eaten by seals and larger groundfish. Large cod probably have few natural predators.

Consumption by harp seals had been often proposed as an important reason for the non-recovery of the stock during the two decades following the collapse. However, a study of the impact of seal predation, capelin availability and fishery takes on 2J3KL cod found that the stock’s biomass dynamics are driven by food (capelin) availability and fisheries, while harp seal consumption was not a significant driver during 1985-2007. An update of the data used to estimate the harp seal inputs for this study was presented; the estimate of abundance of harp seals is lower than the estimate used in the analysis, and the contribution of Atlantic cod to the diet has remained stable. Therefore, there is no indication that that the impact of seal predation has changed since this time.

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

Prey

Both capelin and Pandalus shrimp have been key prey for cod based on analysis of cod stomachs sampled during autumn 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 early 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 biomass, based on a spring Div. 3L hydro-acoustic survey, indicates that capelin biomass was high in the 1980s, but dropped dramatically in the early 1990s and has remained low. In recent years capelin has increased from the 1990s level, but remains well below the pre-collapse levels. This general pattern of change in capelin abundance appears to be reflected in the cod diet. Although the Div. 3L hydro-acoustic survey indicated a slight increase in offshore capelin biomass in 2007-09 relative to levels during the 1990s and early 2000s, the biomass was still far below levels of the 1980s; nonetheless, the timing of this improvement in capelin coincided with increases observed in biomass of cod in portions of the offshore, and with an increase in the fraction of capelin in the cod diet. The 2013-15 period saw a further increase with capelin reaching the highest biomass levels since the 1990s (approximately 20% of the pre-collapse levels), as well as the lowest shrimp levels. This was also reflected in cod diets, in which the capelin fraction increased further, while the shrimp fraction was reduced. These changes imply an increase in the quality of the diet for cod.

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

The 2015 capelin hydro-acoustic survey biomass was the third highest since the mid-1990s. However, given the poor recruitment observed in the last two years and the declining trends in zooplankton biomass observed in 2014-15 (which are a food source for capelin) there are causes for concern about the short-term prospects of this key forage species.

Both shrimp and capelin are important prey for cod and other groundfish species. A combined low availability of two major forage species in the ecosystem could compromise the potential for recovery of cod in particular, and the groundfish community in general.

ASSESSMENT

Sources of data

This assessment is based on a new 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, 1983-2015), inshore Sentinel 5½" mesh gillnet index (ages 3-10, 1995-2015), inshore acoustic biomass estimates (1995-2009), fishery catch age-composition information (1983-2015), partial fishery landings information (1983-2015), and tagging information (1983-2015) including reporting rates (see below).

Traditional stock assessment models such as virtual population analysis (VPA) require that catch is known without error and also assume a value for the level of natural mortality (*M*). Key features of the new stock assessment model (Northern Cod Assessment Model; NCAM) 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). The abundance index increased during 2005-09 and the biomass index increased during 2005-08; these increasing trends did not persist during 2009-11, but have resumed during 2012-15. In the 2015 survey, most of the abundance (87%) and biomass (84%) is located in the northern portion of the stock area (Divs. 2J and 3K). The recent (2012-15) upward trend in the abundance index is mostly due to increased numbers of small cod (≤ age 4).

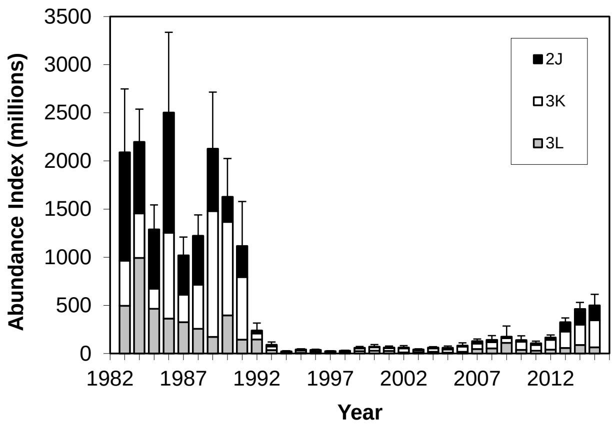


Figure 3. Offshore abundance index (+2 SEs) from autumn RV surveys in NAFO Divs. 2J3KL.

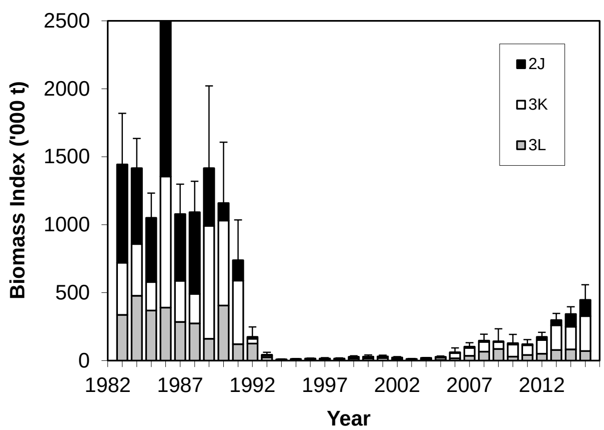


Figure 4. Offshore biomass index (+2 SE's) from autumn RV surveys in NAFO Divs. 2J3KL.

The three-year averages (2013-15) for the abundance and biomass indices are 28% and 24%, respectively, of the average during the 1980s.

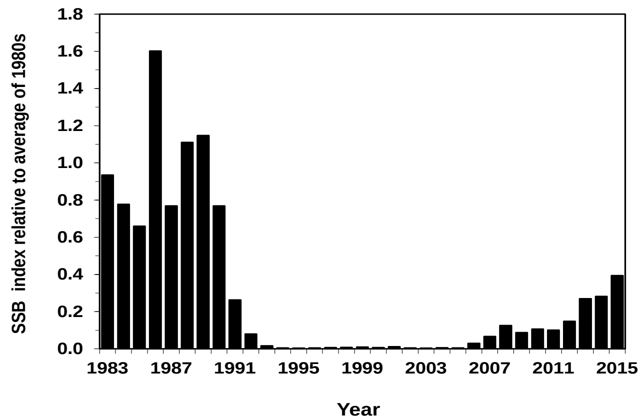


Figure 5. Spawning stock biomass (SSB) index from autumn DFO RV surveys in 2J3KL. Annual index values are scaled relative to the average survey index during the 1980s.

The SSB index from the autumn DFO RV survey declined rapidly in the late 1980s and early 1990s and remained very low for over a decade after the 1992 moratorium. After 2005 the SSB index shows an upward trend (Fig. 5). The three-year average SSB index increased from 23% to 32% of the average observed in the 1980s (from 2012-14 to 2013-15).

Model Results

The following results were obtained from the state-space Northern Cod Assessment Model (NCAM) M shift formulation.

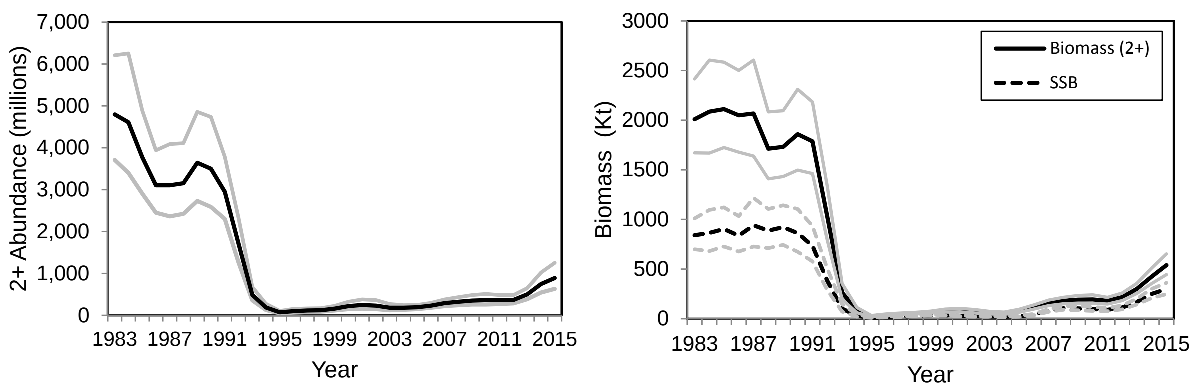


Figure 6. Trends in northern cod stock size. Black lines are the model estimates, and grey lines are 95% Confidence Intervals (CIs).

The abundance of northern cod has remained low after the collapse and moratorium in 1992, but has increased in the past decade from 194 million in 2005 to 894 million (95% CI, 636-1256 million) in 2015 (Fig. 6, left panel). Biomass of fish aged 2+ shows a similar trend to abundance and has increased from 78 kt in 2005 to 539 kt (95% CI, 444-654 kt) in 2015 (Fig. 6, right panel). Spawning stock biomass increased from 25 kt in 2005 to 300 kt (95% CI, 246-362 kt) in 2015. An independent spring 2015 acoustic survey for cod along the outer shelf at depths from 200 m to 550 m [by the Centre for Fisheries Ecosystem Research at Memorial University] produced an estimate of 320 kt which is broadly consistent with the NCAM result.

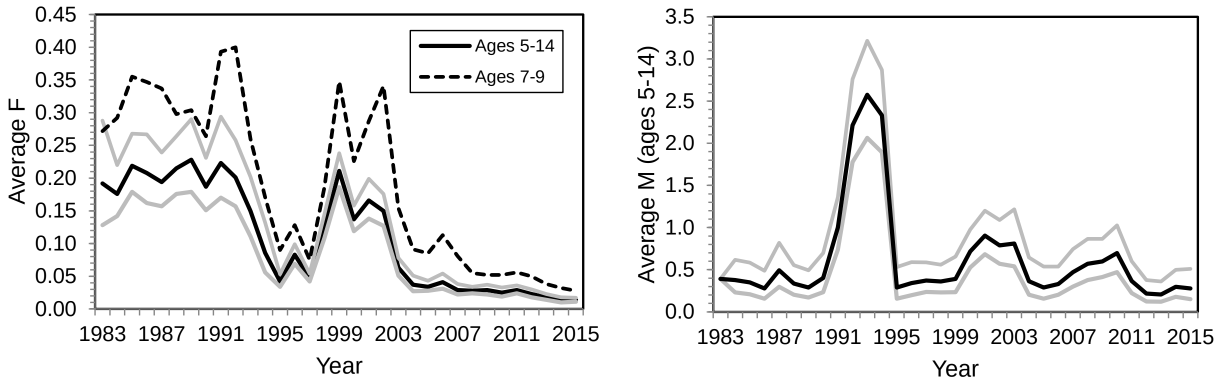


Figure 7. Trends in population-weighted fishing mortality rates (F, left panel) and natural mortality rates (M, right panel). Dark lines are the age-aggregated model estimates (solid lines for ages 5-14, dashed lines in left panel for ages 7-9) and grey lines are 95% CI's.

Fishing mortality (*F*) has been highly variable during 1983-2015 (Fig. 7, 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. Values for *F* on older ages (ages 7-9) were higher, particularly just before the moratorium (*F*=0.4), but showed a similar trend to the estimates for ages 5-14. 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 and declined further, from 0.04 in 2006 to 0.01 in 2015 in spite of increased inshore catches during the ongoing directed inshore commercial and recreational fisheries (see Fig. 2).

The rate of natural mortality (*M*) has been variable during 1983-2015 (Fig. 7, right panel), ranging from 0.3 to 0.5 in the early to mid-1980s, increasing rapidly to a peak of 2.5 during 1992-94, then declining to approximately 0.35 during 1995-99. Additional periods of high *M* are evident in 2000-03 (*M* = 0.7 to 0.9) and 2009-10 (*M* = 0.6 to 0.7). Recent values of *M* have been declining, from 0.70 (equivalent to an annual reduction of 50%) in 2010 to 0.28 (equivalent to an annual reduction of 24%) in 2015.

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 most 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 are continuing.

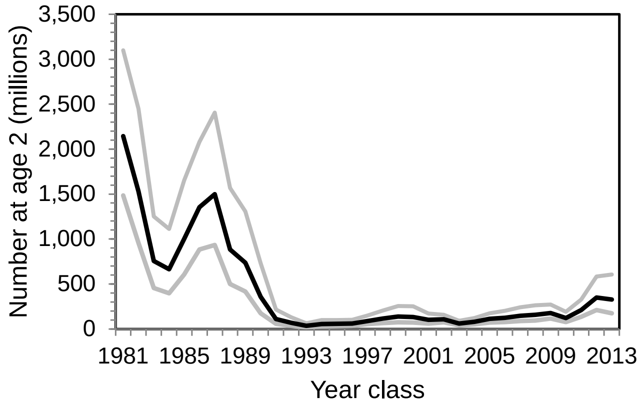


Figure 8. Trends in northern cod recruitment (number at age 2). Solid line is the model estimate, and grey lines are 95% CI's.

Recruitment (age 2) in the 1990s and 2000s has been poor compared to the 1980s (Fig. 8), but has improved slightly in the past decade, particularly in year classes produced during 2011-13. The numbers of age 2's during 2011-13 correspond to approximately 25% of the numbers of age 2's in the year classes of the 1980s.

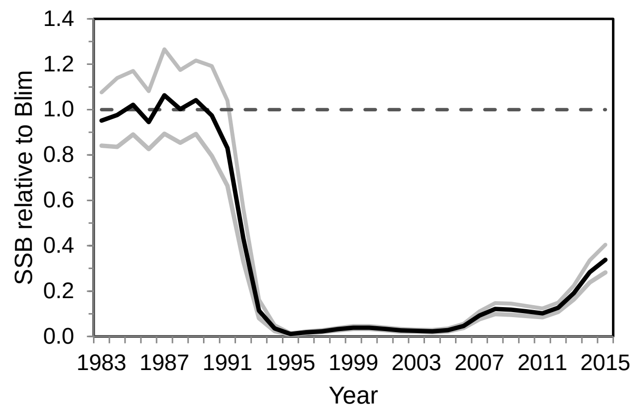


Figure 9. Trends in northern cod Spawning Stock Biomass (SSB) relative to the limit reference point Blim, where Blim (dashed line) is defined as the average SSB during the 1980s. Solid line is the model estimate and grey lines are 95% CI's.

Spawning stock biomass (SSB) declined rapidly in the late 1980s and early 1990s and has remained low and well into the critical zone, but shows an increasing trend during 2005-08 and during 2011-15 (Fig. 9). SSB has increased from 3% of B*lim* in 2005 to 34% of B*lim* in 2015 (95% CI, 28-40%).

Projections

Three-year projections (to 2018) were conducted to investigate the potential impact of a range of catch options from zero catch (no fishing) to a 5-fold increase in catch. Projections were based on the model estimate of catch for 2015 (6,900 t). The age-pattern in *F* values was assumed to be the same as in 2015. The natural mortality rate applied is a progressive transition from the recent values to the long-term average estimated in NCAM. Projected recruitment, stock weights, and proportions mature were assumed to be equal to the mean of their 2013-15 values. Assumed recruitment (age 2) has minimal impact on the projected SSB.

Table 1. Results of the three-year projections for catch multipliers from 0 (no catch) to 5 times the estimated catch in 2015.

Projections	Catch Multiplier 0	Catch Multiplier 1	Catch Multiplier 2	Catch Multiplier 3	Catch Multiplier 4	Catch Multiplier 5
Risk (in %) of SSB declining below 2015 value	1.0	1.3	1.7	2.1	2.6	3.3
Probability (in %) of exceeding B_{lim} in 2018	7.9	7.1	6.5	5.9	5.3	4.8
SSB in 2018 relative to B_{lim}	0.66	0.65	0.64	0.62	0.61	0.60

The projections indicate a low risk (< 4%) of SSB in 2018 declining below the 2015 value, but also a low probability (5-8%) of exceeding B*lim* in 2018. The stock is projected to be less than B*lim* (0.60-0.66) and remain in the critical zone in 2018 over the full range of catch options considered, including no fishing (Table 1).

Tagging

Information from recaptures of cod tagged during 1983-2015 was integrated in the assessment model, and these data are particularly important for estimating *F*. 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 2006-15.

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 2015 was 44%, the lowest in the time series.

During 2006-15 recreational fishers were responsible for a substantial percentage of the total number of tags returned (average 23%) after numbers were adjusted by respective tag reporting rates. The ratio of tags returned by recreational versus commercial fishers has averaged 0.3 (range 0.13 to 0.54) during the past 10 years (2006-15). This ratio is lower than reported previously because with the new estimates of reporting rates the proportion of tags from commercial harvesters increased. Nonetheless, overall the results suggest that recreational landings are substantial and that total removals are much higher than reported landings.

Indicators and procedure to trigger full assessment during interim years

This stock is currently on a three-year management cycle and stock status indicators will be provided from interim updates conducted during periods when there is no full assessment scheduled. Total Biomass (ages 2+) from the autumn DFO RV survey will be used as an interim year indicator of stock status. This index covers most of the stock area.

A full assessment before the scheduled three-year cycle will be triggered if the autumn DFO RV survey biomass is outside the 75% CI of the projected RV biomass value for 2016 or 2017. The 75% CI threshold was chosen over wider CIs to provide greater sensitivity to resource changes. The projected survey values will be taken directly from the catch multiplier projection. For example, if there was no change in catch in 2016, the DFO RV survey biomass in autumn 2016 is projected to be 22% higher than in 2015 with 75% CI of 0.9% and 49%. A survey biomass outside this range would trigger a full assessment. Projected values from the current assessment can only be used to evaluate the trigger if the harvest level does not change during the interim years as each projection scenario assumes a constant catch.

An interim indicator value would typically be available by early January, and this would allow sufficient time to prepare a full assessment and plan the peer review for the following March if the indicator signals that a full assessment is warranted.

Additional sources of information

Other information reviewed at the assessment but not included in this report included the following: trends in recruitment, 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 NCAM (i.e. 3¼ inch mesh gillnet and line-trawls) from three inshore regions; logbooks from vessels < 35 ft for post-moratorium fisheries to investigate area-specific inshore catch rate trends; an acoustic survey of spawning cod in the offshore of 2J3KL during 2015 conducted by the Centre for Fisheries Ecosystems Research at Memorial University was also presented and the estimate used in one formulation of NCAM; 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 posted on the DFO Science Advisory Research Document Series web site as they become 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, 2013-15) 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.

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 improving, the estimate of 2015 SSB is 34% 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.

The recent increase in stock size is due to marginally stronger year–classes contributing to the SSB, a decrease in natural mortality rates and low fishing mortality rates. Projections to 2018 indicate that over a wide range of catch multipliers the SSB has a low risk (< 4%) of declining below the 2015 value. However, the stock also has a low probability (5-8%) of reaching the LRP within the next three years. 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.

OTHER CONSIDERATIONS

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, 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.

Both shrimp and capelin are important prey for cod; capelin availability has improved since the very low levels of the 1990s, but is still well below pre-collapse values, whereas shrimp have declined. A combined low availability of two major forage species in the ecosystem could compromise the potential for recovery of cod. A decline in capelin biomass would signal the need for a more cautious approach with regard to harvesting decisions.

DFO has formed a joint working group with industry, provincial government, and NGO participation to address the rebuilding of northern cod and 5 year projections were requested by this group. However, projection results for a 5-year time frame were found to be highly uncertain and therefore not reliable for advice on development and evaluation of interim stock growth targets. Probabilities of achieving a proposed interim target of 50% SSB growth in five-years were converted to an equivalent three-year growth target of 28%. For three-year projections uncertainty was lower and results considered informative.

Table 2. Results of the three year projections (to 2018) of stock growth.

Projections	Catch Multiplier 0	Catch Multiplier 1	Catch Multiplier 2	Catch Multiplier 3	Catch Multiplier 4	Catch Multiplier 5
Probability (in %) of achieving growth target by 2018.	92.9	91.7	90.3	88.7	87.0	85.1

The projections indicate a high probability (> 85%) of achieving the re-scaled interim growth target by 2018 over the full range of catch options considered (Table 2).

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. In setting future harvests, fisheries managers should consider the proportion that is expected to be unreported.

SOURCES OF INFORMATION

This Science Advisory Report is from the March 21-24 and 30-31, 2016 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.

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APPENDICES

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

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]
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
Can. Mobile	9	84	-	-	-	-	-	-	-	-	-	-	-
Others	405	38	-	-	-	-	-	-	-	-	-	-	-
Totals	502	212	5	9	5	7	4	1	3	3	3	3-4	4-5

[1] There was no TAC in the last 10 years, but fishers were permitted an annual allowance per license holder of 1 360 kg in 2006-07, 1 135 kg in 2007-08, 1 475 kg in 2008-09, 1 700 kg in 2010-12, and 2,270 kg thereafter.

[2] Does not include Canadian recreational fisheries for 2007, 2009-10, and 2013-15 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	4797.08	2008.16	841.08	2144.36	0.391	0.192
1984	4609.75	2085.10	863.23	1529.95	0.377	0.176
1985	3772.10	2110.15	902.94	755.68	0.349	0.219
1986	3105.69	2048.58	836.00	663.83	0.277	0.208
1987	3106.33	2066.51	940.75	1000.20	0.494	0.194
1988	3155.82	1712.97	886.40	1355.34	0.335	0.215
1989	3641.70	1731.46	921.66	1498.12	0.289	0.228
1990	3501.70	1859.28	861.92	884.00	0.403	0.187
1991	2950.23	1786.08	734.51	737.25	1.002	0.223
1992	1721.29	1028.43	381.95	357.99	2.214	0.201
1993	491.18	263.34	101.05	110.94	2.575	0.150
1994	189.31	81.75	30.55	67.18	2.331	0.086
1995	73.57	25.92	9.68	35.19	0.288	0.042
1996	102.99	37.96	16.05	53.33	0.341	0.083
1997	117.44	47.32	20.57	57.37	0.372	0.047
1998	124.54	55.14	28.25	59.70	0.360	0.124
1999	161.51	65.27	34.59	89.03	0.392	0.211
2000	219.14	80.16	34.42	115.34	0.717	0.137
2001	248.21	84.21	29.50	136.93	0.905	0.166
2002	232.95	73.21	23.87	132.62	0.789	0.150
2003	182.57	58.98	22.07	101.23	0.810	0.063
2004	181.26	54.56	20.07	106.97	0.362	0.037
2005	194.24	78.39	25.18	60.02	0.288	0.034
2006	234.48	116.34	40.83	79.71	0.330	0.041
2007	291.86	156.69	81.10	111.70	0.472	0.029
2008	326.41	180.27	106.65	124.65	0.570	0.028
2009	354.01	191.52	104.56	145.33	0.599	0.029
2010	367.09	193.60	96.91	156.27	0.696	0.025
2011	362.44	179.07	90.56	176.89	0.366	0.029
2012	371.99	218.04	112.12	120.94	0.216	0.023
2013	499.81	301.34	169.17	210.85	0.207	0.018
2014	748.91	424.05	250.12	349.56	0.298	0.014
2015	893.81	538.72	298.65	325.73	0.278	0.014

* 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.

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