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Newfoundland and Labrador Region
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Science Advisory Report 2020/018

# STOCK ASSESSMENT OF NAFO SUBDIVISION 3PS COD

*Image:* Atlantic Cod *Gadus morhua.*

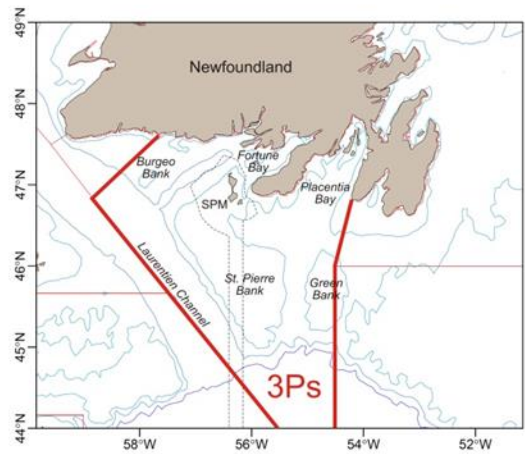


*Figure 1: Subdivision 3Ps management area and economic zone around the French islands of St. Pierre et Miquelon (SPM) (dashed line).*

## Context:

*In the Northwest Atlantic, cod are distributed from Greenland to Cape Hatteras and are managed as 12 stocks. The Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps stock off southern Newfoundland extends from Cape St. Mary's to just west of Burgeo Bank, and over St. Pierre Bank and most of Green Bank (Fig. 1).*

*The distribution of 3Ps cod does not conform well to management boundaries and the stock is considered a complex mixture of inshore and offshore sub-components. These may include fish that move seasonally between adjacent areas as well as fish that migrate seasonally between inshore and offshore. The extent to which the different components contribute to the fisheries is not fully understood.*

*Female cod from this stock have generally matured at younger ages since the mid-1990s. About 50% of the females are mature by age 5 (~47 cm) in these more recent cohorts, compared to only about 10% at age 5 (~55 cm) among cohorts present in the 1970s-1980s.*

*Catches from this stock have supported an inshore fixed gear fishery for centuries and are of vital importance to the area. Fish are caught offshore by mobile and fixed gear, and inshore by fixed gear only. Spanish and other non-Canadian fleets heavily exploited the stock in the 1960s and early 1970s. French catches increased in the offshore throughout the 1980s. A moratorium on fishing initiated in August, 1993 ended in 1997 with a quota set at 10,000 t. Beginning in 2000, the management year was changed to begin on 1 April. The Total Allowable Catch (TAC) for the 2018-19 management year was set at 5,980 t. Under the terms of a 1994 Canada-France agreement, Canada holds 84.4% of the TAC, while the remainder (15.6%) is held by France (St. Pierre et Miquelon).*

*The present assessment is the result of a request for science advice from the Fisheries and Aquaculture Management Branch (Newfoundland and Labrador [NL] Region). The main objectives were to determine a new limit reference point for the stock, evaluate the status of the stock and to provide scientific advice concerning conservation outcomes related to various fishery management options.*

*This Science Advisory Report is from the November 19-22, 2019 Assessment of NAFO Subdivision 3Ps Atlantic Cod. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.*

# SUMMARY


- A new integrated state space model resulting from the 2019 3Ps Cod Framework was used to assess the status of the stock and estimate fishing mortality. This model incorporates catch (1959-2019), time varying natural mortality informed by trends in cod condition, and includes abundance indices from bottom trawl surveys conducted by Canada (1983-2005, 2007-2019), France (1978-1991), industry (GEAC, 1998-2005), and standardized catch rate indices from the Sentinel gillnet and line-trawl surveys (1995-2018).
- A new biomass limit reference point (LRP) was determined for the stock based on the relationship between spawning stock biomass (SSB) and recruitment estimated from the model. The LRP is 66,000 t of SSB.
- Spawning Stock Biomass (SSB) at January 1, 2020 is estimated to be 16 kt (12 kt - 21 kt). The stock is in the Critical Zone (24% of $B_{lim}$ (18-32%)) as defined by the DFO Precautionary Approach (PA) Framework. The probability of being below $B_{lim}$ is >99.9%.
- The new model and the revision of the basis for defining the LRP has led to a change in the perception of status of this stock. The stock is now estimated to have been below $B_{lim}$ since the early 2000s
- The estimated fishing mortality rate (ages 5-8) has ranged between 0.12 and 0.21 since 2010 and in 2019 was 0.21 (0.15–0.30), with an assumed catch of 4453 t.
- Natural mortality was estimated to be 0.49 (0.41–0.58) (ages 5-8) in 2019. Values during the last four years are the highest in the time series.
- Recruitment (age 2) estimates have been below the long term average since the mid-1990s.
- Projection of the stock to 2022 was conducted assuming fishery removals to be within +/- 30% of current levels, assuming a catch of 4453 t for 2019, and with no catch. Under these scenarios, there is a probability >99% that the stock will remain below $B_{lim}$ between 2020 and the beginning of 2022.
- The probability of stock growth to 2022 is 1% or less across catch scenarios (+/- 30% of current levels), and is 16% when there are no removals.
- Natural mortality plays an important role in projections for this stock. If natural mortality rates are appreciably different from those used, projected outcomes will differ from values reported above.
- Bottom temperatures in 3Ps remain above normal, and the spring bloom continues to be reduced in magnitude. Zooplankton biomass in 3Ps was near normal in 2017 and 2018 after four years of low production, with an increased proportion of smaller species. Data were unavailable from 2019. Ongoing warming trends, together with an increased dominance of warm water fishes, indicate that this ecosystem continues to experience structural changes. Reduced growth and condition indicate that cod productivity in 3Ps is reduced.
- 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

## Oceanography and Ecosystem Overview

Oceanographic conditions in Subdivision 3Ps are influenced by several factors, including local atmospheric climate conditions, advection by the Labrador Current from the east and the warmer and saltier Gulf Stream waters from the south as well as the complex bottom topography in the region. Near bottom temperatures, while showing significant variability from one year to the next, have experienced a general warming trend in some areas since 1990.

Satellite remote sensing data indicate that the spring bloom in 3Ps was lower in magnitude during 2015-19, but the timing of onset and duration were near normal in 2019. The biomass of zooplankton in 3Ps was near normal during 2017 and 2018 after four years of low production. Abundance of small copepods (*Pseudocalanus* and *Oithona*) has been near normal in 3Ps since 2016, but the abundance of large, energy-rich C*alanus finmarchicus* copepods has remained below normal since 2015. Reductions in standing stocks of phytoplankton and zooplankton observed in recent years indicate changes in the structure of the ecosystem and lower productivity conditions that may influence higher trophic levels.

The overall biomass of the fish community in 3Ps has been relatively stable since the mid-1990s, whereas the overall abundance has increased due mainly to an increase in small planktivorous (plankton-eating) fishes (e.g. sandlance *Ammodytes sp.*). There has been an increased dominance of warm water species such as silver hake (*Merluccius bilinearis*) since 2010, linked to an ongoing warming trend. Cod in 3Ps have a variable diet. However, during some years recently, stomach contents have been dominated by invertebrates (e. g. snow crab) indicating a poorer quality diet than one dominated by fish. These changes in species composition and cod diet are evidence that the structure of the 3Ps ecosystem may be changing. Although the full impacts of these changes on cod are unknown, they imply that at least some aspects of the 3Ps ecosystem likely remains in a reduced productivity state.

## History of the Fishery

The stock was heavily exploited in the 1960s and early-1970s by non-Canadian fleets, mainly from Spain, with catches peaking at 87,000 t in 1961 (Fig. 2).

After the extension of jurisdiction in 1977, landings increased to peak at almost 59,000 t in 1987 due to increased landings by France. Landings then decreased sharply to about 40,000 t during 1988-91 before decreasing further to 36,000 t in 1992.

A moratorium was imposed in August 1993 and at that time 15,000 t of the 20,000 TAC had been landed. Although offshore landings fluctuated, the inshore fixed gear fishery reported landings around 20,000 t each year from 1959 to the moratorium.

The fishery reopened in May 1997 with a TAC of 10,000 t, increasing to 30,000 t by 1999. In 2000 the management year was changed to begin on 1 April. Total Allowable Catches and landings over the past decade are shown in Table 1 and are described in detail below. The TAC was set at 5,980 t for the 2018-19 and 2019-20 management periods.

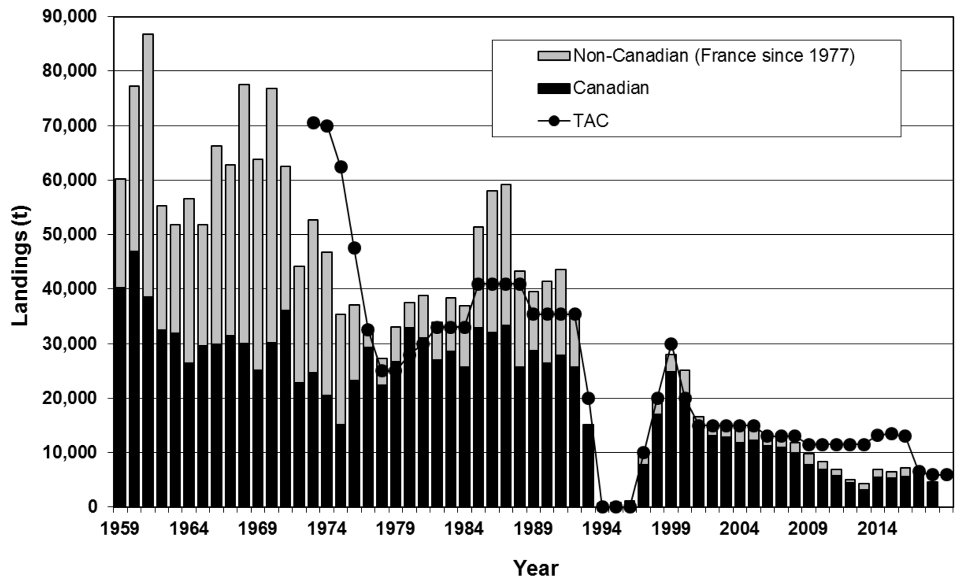


*Figure 2: Reported annual landings and TACs (t) from 1959-2019. Values are based on calendar year from 1959-2000 and on management year (1 April-31 March) since then. Landings for 2019 (2019-20 season) are incomplete and not displayed.*

## Landings

*Table 1: TAC and landings by management year (thousand metric tons).*

| Management Year | 10-11 | 11-12 | 12-13 | 13-14 | 14-15 | 15-16 | 16-17 | 17-18 | 18-19 | 19-20[1,2] |
|---|---|---|---|---|---|---|---|---|---|---|
| TAC[3] | 11.5 | 11.5 | 11.5 | 11.5 | 13.225 | 13.49 | 13.043 | 6.5 | 5.98 | 5.98 |
| Canada | 6.6 | 5.2 | 4.0 | 4.6 | 5.8 | 5.9 | 5.2 | 4.9 | 4.5 | 2.4 |
| France | 1.3 | 1.1 | 0.8 | 1.4 | 1.6 | 0.9 | 1.1 | 0.2 | 0.2 | |
| Totals | 7.8 | 6.3 | 4.8 | 6.0 | 7.3 | 6.8 | 6.3 | 5.0 | 4.7 | 2.4 |

[1] Provisional.
[2] Approximate landings to 30 October, 2019.
[3] TAC is shared between Canada (84.4%) and France (St. Pierre et Miquelon; 15.6%).

Reported combined landings by Canada and France were substantially below the TAC from the 2009-10 season to 2016-17, but during the 2017-18 and 2018-19 seasons, approximately three quarters (77% and 79%, respectively) of the 5,980 t TAC was landed. Prior to 2009-10, the TAC had been almost fully subscribed with the exception of the initial four years of TAC regulation. Industry participants have indicated multiple reasons contributing to the recent reduction in landings, including reduced cod availability and economic factors. Of the 4,742 t landed during the 2018-19 season, 4,452 t was taken by Canada (including 15 t from sentinel surveys), and 181 t was landed by France.

Provisional data indicate that landings during the ongoing 2019-20 management year were 2,370 t as of October 30, 2019. Although incomplete, these landings to date are slightly lower than those reported during the same period in 2018-19 when the TAC, also at 5,980 t, was not taken.

During the 2018-19 season, more than eighty percent of the total landings were taken by fixed gears (dominated by gillnet) with the remainder taken by the otter trawl fleet.

To estimate landings for the ongoing 2019-2020 fishing season, reported landings for the 2019-2020 season up to October 30, 2019 were combined with reported landings from the previous (2018-2019) November to March period.

## Species Biology

**Stock structure** and **migration patterns** of 3Ps cod are complex. Cod in 3Ps mix with adjacent stocks at the margins of the stock boundary. Some offshore components of the stock migrate seasonally to inshore areas, and there are inshore components that are shoreward of the spring DFO Research Vessel (RV) trawl survey area. These features add uncertainty to the assessment of stock status. However, since 1994, additional information has been obtained from various sources, including tagging, acoustic telemetry, and the sentinel fishery. This information has provided a basis for several measures to investigate the potential impact of these factors (i.e., stock structure and migration patterns) on the assessment. Survey timing was shifted to April (beginning in 1993) and winter fishery closures in some areas have been imposed to reduce the potential for migrant non-3Ps cod being sampled by surveys and included in commercial catches. The spring DFO RV trawl survey covers most of the stock area so survey trends are thought to broadly reflect stock trends.

**Spawning** is spatially widespread in 3Ps, occurring close to shore as well as on Burgeo Bank, St. Pierre Bank, and in the Halibut Channel. Timing of spawning is variable and extremely protracted, with spawning fish present from March until August in Placentia Bay. Detailed examination of fish collected from Halibut Channel (southern portion of 3Ps) in March and April of 2015 and 2016 suggested that spawning in this area began in April. Also, it was noted that for these fish, all females initially categorized as spent were in fact likely skipping spawning; therefore, previous estimates of spawning time may be biased and estimated to be earlier than actual spawning times.

**Maturation** in female cod was estimated by cohort. The proportion of female cod maturing at ages 4-6 is higher for all cohorts subsequent to the 1985 cohort. The reasons for the change toward earlier age at maturity are not fully understood but may have a genetic component that is partly a response to high levels of mortality including fishing. Males generally mature about one year younger than females but show a similar trend over time.

**Growth**, calculated from length-at-age in research trawl survey samples, has varied over time. For cod older than age 3 there was a general decline in length-at-age from the early 1980s to the mid-1990s. For most ages, there was an increase in length-at-age from the mid-1990s through the mid-2000s, followed by a period of lower length-at-age in recent years. Length-at-age has been lower than average in 9 of the last 13 years, being well below average in most of the last 7 years.

**Condition** (or condition factor) is a measure of fish weight relative to length and is considered a proxy for energy reserves. Comparison of post-1992 condition with that observed during 1985-92 is difficult because survey timing has changed. Condition varies seasonally and tends to decline during winter and early spring. There were signs of improved fish condition during 2008-13, but condition has been below average in 8 of the last 13 years, with 2017 being the lowest and 2019 the second lowest in the time series.

Estimates of condition (GSI, HSI, Fulton) from sentinel sampling during 2018 changed little from 2017 and the direction of change was inconsistent among condition factors. Data from 2019 were unavailable as the Sentinel survey was ongoing at the time of the assessment meeting.

# ASSESSMENT

## Resource Status

### Sources of Information

A new state-space stock assessment model was used for the first time to assess stock status. This model uses indices of abundance from research trawl surveys conducted by Canada (1983-2005, 2007-2019), France (1978-1991) and an industry organization GEAC (1997-2005), plus the Sentinel survey (1995-2018). Fisheries data used in the model includes landings and catch-at-age data from 1959 to 2019. The fisheries landings and catch-at-age data used were provisional for the year 2019, since this year's fishery was still continuing at the time of the assessment. In the model fitting exercise, the magnitude of the catch total weights (i.e. landings) and the age-composition information in the catch-at-age data were fitted separately. The age-composition information in the catch-at-age is fitted using continuation ratio logits. Our confidence in the magnitude of fisheries landings data has varied over the time-periods in the history of the fishery and the model uses censored likelihood on landings bounds. The model uses information on landings bounds developed based on literature review and fisher interviews (Fig. 3). Also included is a covariate that is added to a constant mortality value (M=0.3) that is time varying and based on proportion of cod in poor condition. Although additional sources of information are presented (see "Other Data Sources" below), only the indices listed above were selected as the input data for the model during a framework review process that concluded in October 2019.

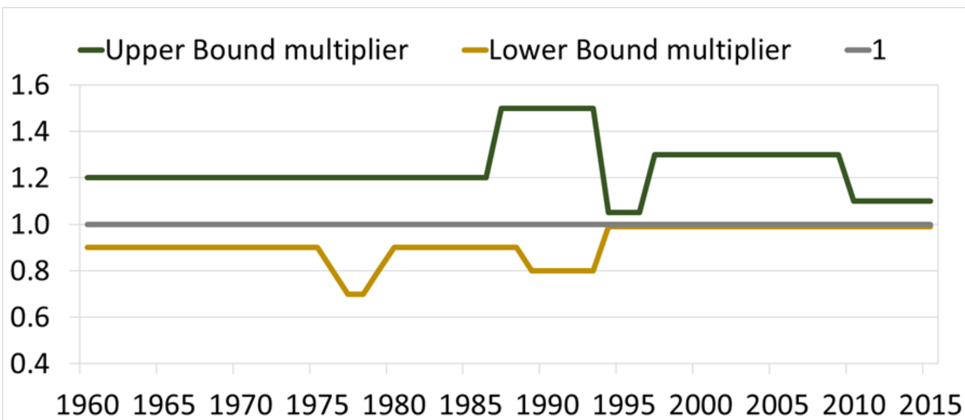


*Figure 3: Landings bounds by year decided at the Framework meeting for 3Ps cod in October 2019.*

The new model estimates stock trends from 1959 to 2019. In comparison, the previous assessment used only one of the above data series (the Canadian research trawl survey data from 1983 onwards) and hence produced stock trends starting from 1983. Stock weights describe the average fish weight-at-age in a given year, and this key input changed from the previous years' assessment. Stock weights were previously estimated based on data from sampling of commercial catch. Due to concerns related to influence of gear selectivity on fish weights-at-age averages generated from commercial catch, the stock weights in this assessment are based on fish weights-at-age sampled by the RV trawl surveys. As a result, estimates of biomass and SSB are reduced for most ages relative to the previous assessment, especially for ages five to eight which comprise the bulk of the fishery removals (see Fig. 4 for comparison).


*Figure 4: Comparison of stock weights (kg) calculated from commercial sampling (red), versus those estimated from analysis of fish sampled by the research trawl survey (teal). Numbers at top of plots indicate fish age-class.*

## Surveys

### *Canadian Research Vessel Survey*

Canadian DFO RV bottom **trawl surveys** have been conducted in 3Ps since 1972, however, surveys from 1972-82 had poor coverage. The surveyed area was increased 18% by the addition of strata closer to shore in 1994 and 1997. The survey was not completed in 2006.

Survey indices based on strata <550 m (<300 ftm) are presented for the expanded DFO survey area since 1997 (inshore plus offshore; denoted “All index strata”) as well as for the offshore only strata (“Offshore index strata”) in Figures 5 and 6. Any near-shore aggregations in April would not be measured by the DFO RV survey. The majority of the area shoreward of the DFO RV survey lies within inner and western Placentia Bay. There is no recent evidence that a large fraction of the stock is shoreward of the DFO RV survey in April.

The **biomass index** from the offshore strata is variable but exhibits a downward trend from the mid-1980s to the early 1990s (Fig. 5). Values for most of the post-moratorium period from 1997 to 2004 were higher than those of the early 1990s, but not as high as those of the 1980s. Biomass estimates in recent years have generally been low, with nine of the last twelve years being below the 1997-2019 average. Survey catches in 2019 were generally low, with higher catches only in strata in the Halibut Channel, near Burgeo Bank and in Fortune Bay. Survey biomass from the expanded index (“All index strata”) shows similar trends to the offshore-only index.

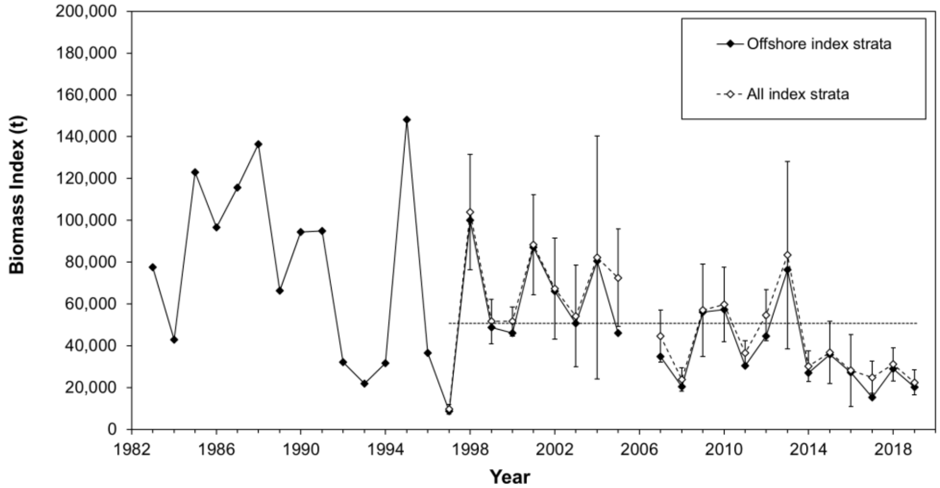


*Figure 5: Research vessel survey biomass indices (t). Error bars are ± one standard deviation for all index survey; dashed line is the time series average of the all index survey.*

The offshore DFO RV abundance index is variable, but values during the 1990s were generally lower than those from the 1980s (Fig. 6). Abundance was low during the 2000s but somewhat higher over 2010-15 with four of the six years being at or above average. In particular, the 2013 estimate was very high with a high measure of uncertainty. In 2019, abundance levels were below the 1997-2019 average, similar to those observed in 2018 and during the 2000s.

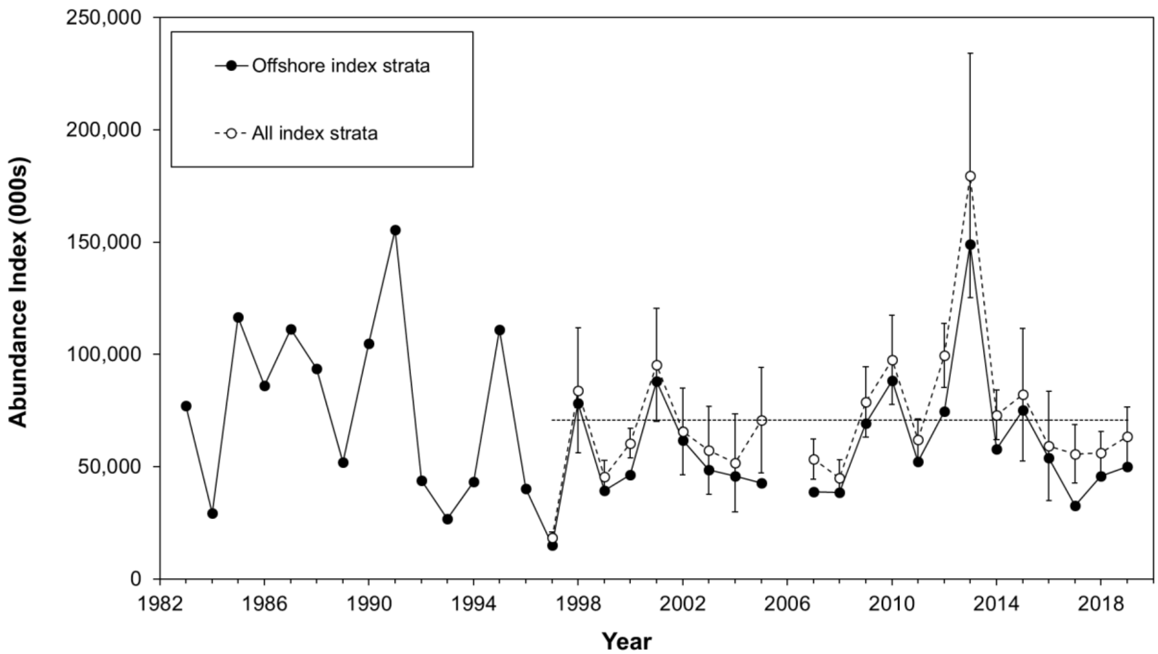


*Figure 6: Research vessel survey abundance indices. Error bars are ± one standard deviation for combined survey; dashed line is average of combined survey index.*

*Age Composition*

Catches during the 2019 RV survey consisted mainly of cod aged 2-4 (71% of abundance index). No strong year classes have been observed in the survey data since the 2011 cohort. The abundance of cod older than age 7 is relatively low.

*France (ERHAPS) Research Vessel Survey*

France conducted a bottom trawl survey in 3Ps during February-March of 1978 to 1992 (Bishop *et al*. 1993 ). The vessel changed in 1992 and as data from the two vessels could not be converted, the 1992 data were excluded from the assessment model. The ERHAPS survey used the same stratification scheme as the Canadian survey. However, only the offshore strata were sampled. A Lofoten trawl was used during daylight hours to conduct 30 minute tows and data for unsampled strata were estimated from a multiplicative model based on the results of the Canadian survey for the same strata.

*GEAC Industry Survey*

An industry led, bottom trawl survey (see McClintock 2011 and references therein) was conducted from 1997 to 2005 and in 2007. This survey also used the stratification scheme of the Canadian and French surveys but, the 1997 and 2007 data were excluded from the model because of coverage and vessel issues.. An Engel trawl was used, although it did not have a cod-end liner. Tows were 30 minute duration.

*Sentinel Survey*

Fixed gear sentinel surveys have been conducted at sites along the south coast of Newfoundland from St. Bride’s to Burgeo from 1995 through 2018. Gillnet results come mostly from sites in Placentia Bay whereas line-trawl results come mostly from sites west of the Burin Peninsula. The sentinel survey for 2019 is still ongoing; hence, the data for 2019 are incomplete and were not included in the modeling reported below.

The sentinel survey data were standardized to remove site and seasonal effects to produce annual indices of the total and age-specific catch rates (Fig. 7).

The standardized total annual catch rate for gillnets was highest from 1995-97, but progressively lower in 1998 and 1999, and remained quite low from 2000 to 2018 (Fig. 7, upper panel). The line-trawl catch rates were high in 1995 with a steady decline to 1999, but were subsequently fairly constant through 2009 (Fig. 7, lower panel). More recent (2013-18) values are the lowest in the time-series.

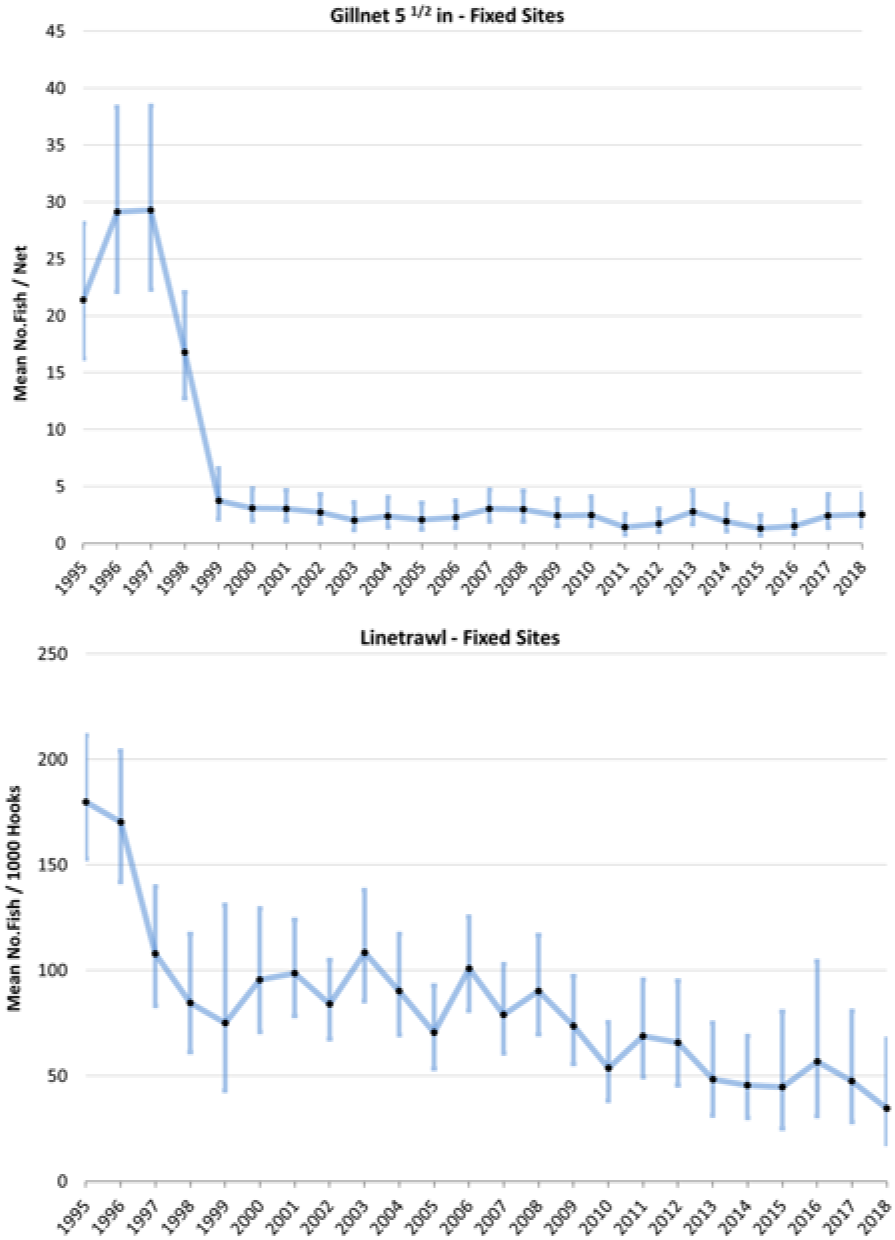


*Figure 7: Standardized catch rates from the Sentinel survey using gillnets (upper panel) and line-trawls (lower panel).*

The standardized age-specific catch rates for sentinel gillnets and line-trawls show similar trends with the relatively strong 1989 and 1990 year-classes being replaced subsequently by weaker year-classes resulting in an overall decline in catch rates. Although the magnitude of the sentinel catch rates has been generally constant for more than a decade, the 1997 and 1998 year-classes were consistently evident in both age disaggregated sentinel indices. In addition, the 2004 year-class appears to be well-represented only within line-trawl results. The relative strength of more recent year-classes in the sentinel results is less clear, but generally indicates that they are relatively weak. Comparison of sentinel catch rates and the RV index at times show inconsistent age compositions; these differences are not fully understood. As an example, the 2006 year-class ranks above average in the RV survey, but does not appear particularly strong in either sentinel index even though fish in this year-class are now available to these gears. The 2011 year class, which appears as the strongest in the RV survey, appears prominently in the 2017 sentinel survey. The 2012 year class also appeared strong in both the RV survey and the 2017 line-trawl data from the sentinel survey.

### Biological Limit Reference Point

A revised Limit Reference Point (LRP) was determined for the stock. It is based on stock productivity and considered to be an improvement over the previous LRP, which was based on the lowest point from which the stock showed sustained recovery ($B_{rec}$). A breakpoint analysis was performed whereby the regression of recruitment (pre-2011) and SSB (pre 2009) estimates from the model was sequentially segmented with up to six breaks and the Bayesian Information Criterion (BIC) compared. Using this breakpoint analysis, a break near 70 kt of SSB was selected for further investigation as a potential LRP. Visual inspection of a plot of recruitment and SSB (Fig. 8) showed a small gap in the time-series between 66 kt and 70 kt and it was clear that at higher values of SSB there was a positive relationship between recruitment and SSB. When SSB was less than 66 kt, the relationship was complex with a distinct plateau between approximately 25 kt and 66 kt of SSB. The revised LRP was determined to be 66 kt.

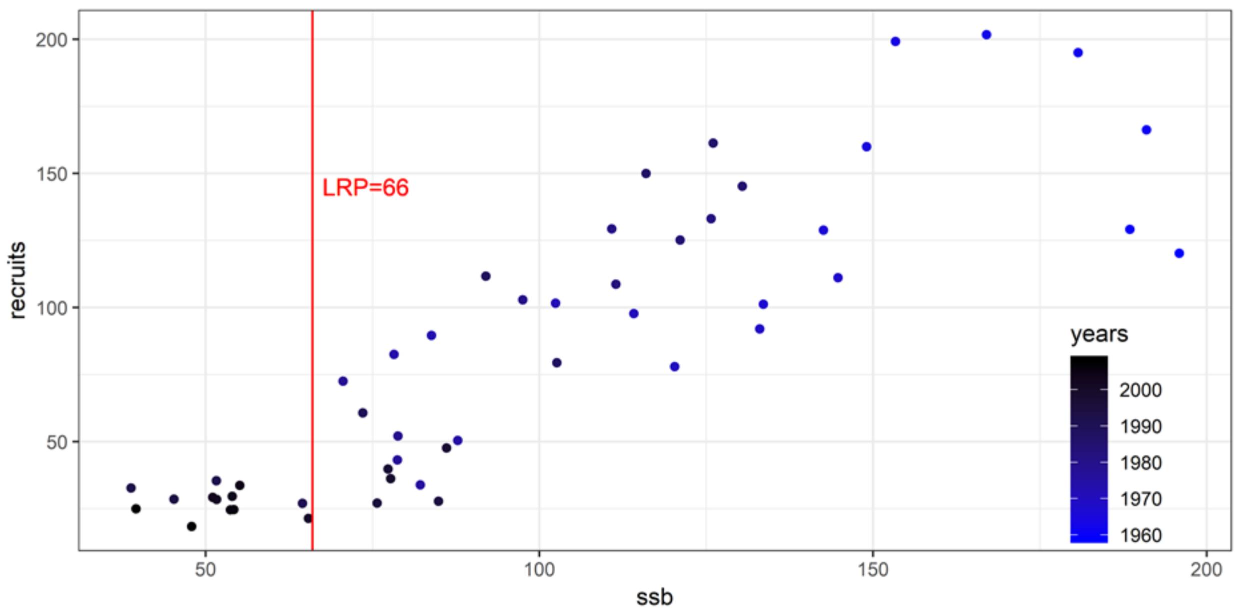


*Figure 8: Recruitment and spawning stock biomass estimated from the new population model for 3Ps cod with the revised LRP of 66 kt that was established at the 2019 assessment. Data are from 1959 to 2008 (SSB) or 2010 (recruitment).*

### Spawning Biomass

Cohort analyses indicated that SSB declined from the beginning of the time-series in 1959 (195 kt) to values near the LRP by the mid-1970s (Fig. 9). Subsequently, SSB increased and was estimated to be approximately 110 kt over 1980 to 1988, but this period was followed by a continuous decline to a low of 39 kt in 1993. The SSB was below the LRP from 1991 to 1994. (Fig. 9). During the first two years (1993 to 1995) of the moratorium, SSB increased; then, SSB was stable at about 80 kt over 1995 to 1999. During the early 2000s, SSB was also relatively stable, but at values that were just below the LRP. The SSB decreased further since the early 2000s and in 2019, SSB is 24% of the LRP.

The trajectory in SSB from the new and previous models are quite similar from 1983 to 2000, but there are differences apparent in more recent years. SSB estimates are comparatively lower during 2011 to 2013 in the new versus previous model. These relative differences in SSB estimates are due to a combination of factors including different (reduced) weight estimates for the stock, the addition of a time varying natural mortality covariate, an adjustment in catchability, and the inclusion of Sentinel indices which are lower and less variable than those from the Canadian research survey.

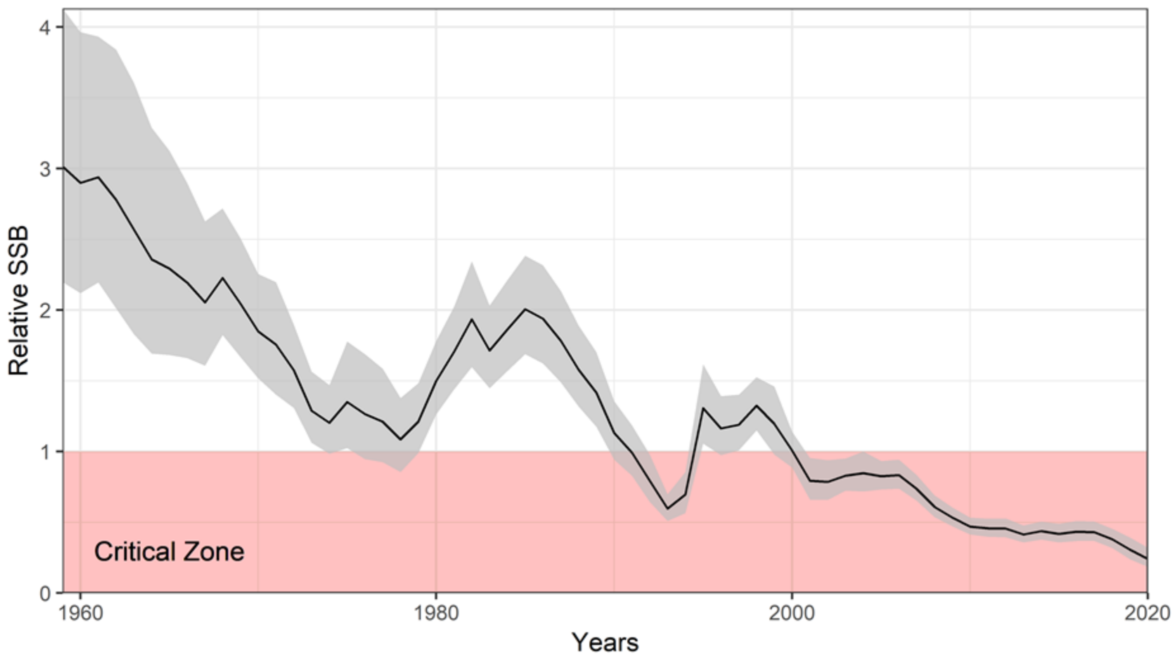


*Figure 9: Cohort analysis estimates of SSB for the period 1959 to 2020, relative to the $B_{lim}$ value (median estimate with 95% confidence interval). This reference point represents the boundary between the critical and cautious zones of DFO's precautionary approach framework.*

### Mortality Rates

The new assessment model provides estimates of both fishing (F) and natural mortality (M). The estimated fishing mortality rate for ages five to eight generally increased from 1959 (F=0.27) to the mid-1970s (peaked at 0.42 in 1975) leading up to the extension of jurisdiction in 1977, then declined rapidly to approximately 0.3 and remained at similar values until the mid-1980s. Then, fishing mortality estimates generally increased again until the moratorium in 1993. Average F was near zero (< 0.02) during the moratorium (1993-1997) when removals were only from bycatch. The estimated fishing mortality rate has ranged between 0.12 and 0.21 since 2010 and in 2019 was 0.21 (0.15-0.30), with an assumed catch of 4,453t (Fig. 10).

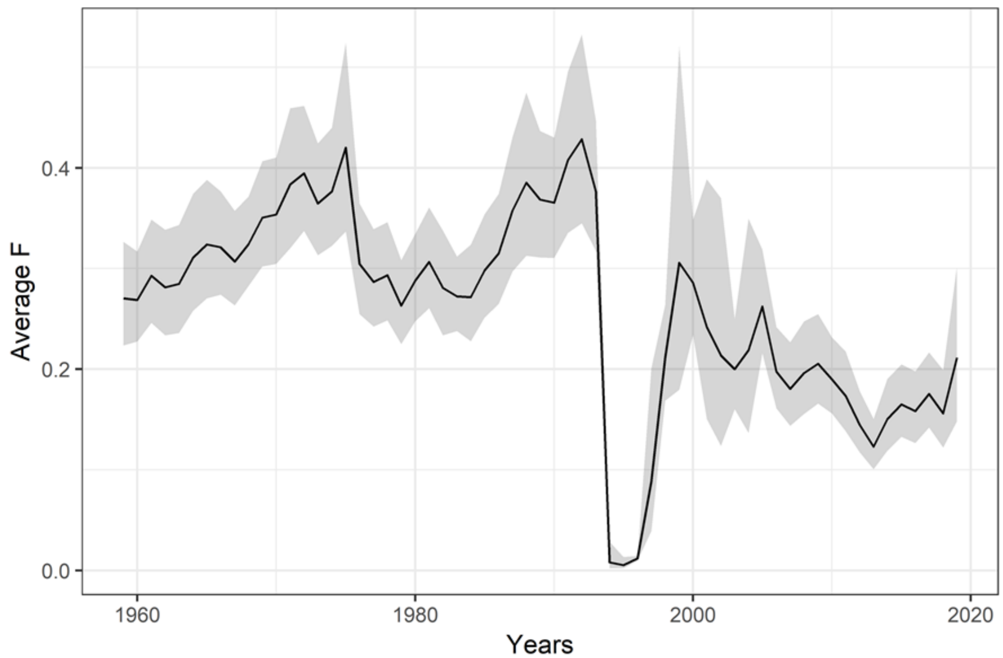


*Figure 10: Average F (ages 5 to 8) estimates from 2019 assessment.*

Generally, natural mortality (M) was between 0.27 and 0.33 during the 1980 to 2010 period, but values subsequently increased considerably and the highest values in the time-series were observed during the last four years (Fig. 11). M was estimated to be 0.49 (0.41-0.58) (ages 5-8) in 2019 which corresponds to approximately 35 percent of the stock being removed annually by sources other than reported landings.

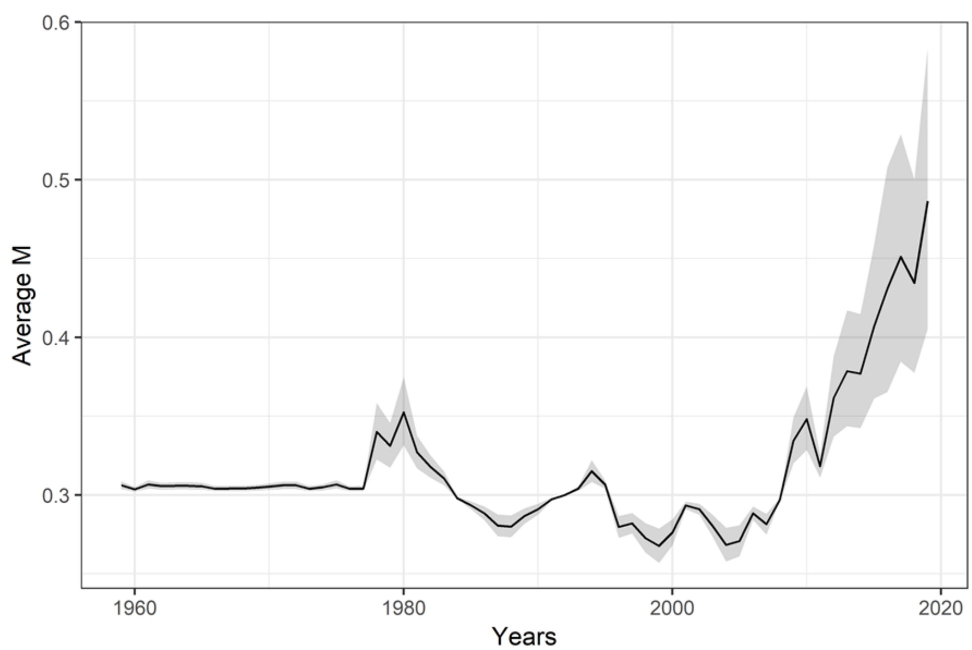


*Figure 11: Average M (ages 5 to 8) estimates from 2019 assessment.*

### Recruitment

Recruitment (Fig. 12) peaked in 1965-66 at approximately 200 million age 2 fish, then generally declined until the mid - to late 1970s when there were about 35 million age two cod in the population. During most of the 1980s, recruitment was variable between 70 and 150 million fish. From 1993 onward, recruitment was generally low at values around 25 to 40 million fish with particularly low values (6 to 7 million ) during 2016 to 2017.

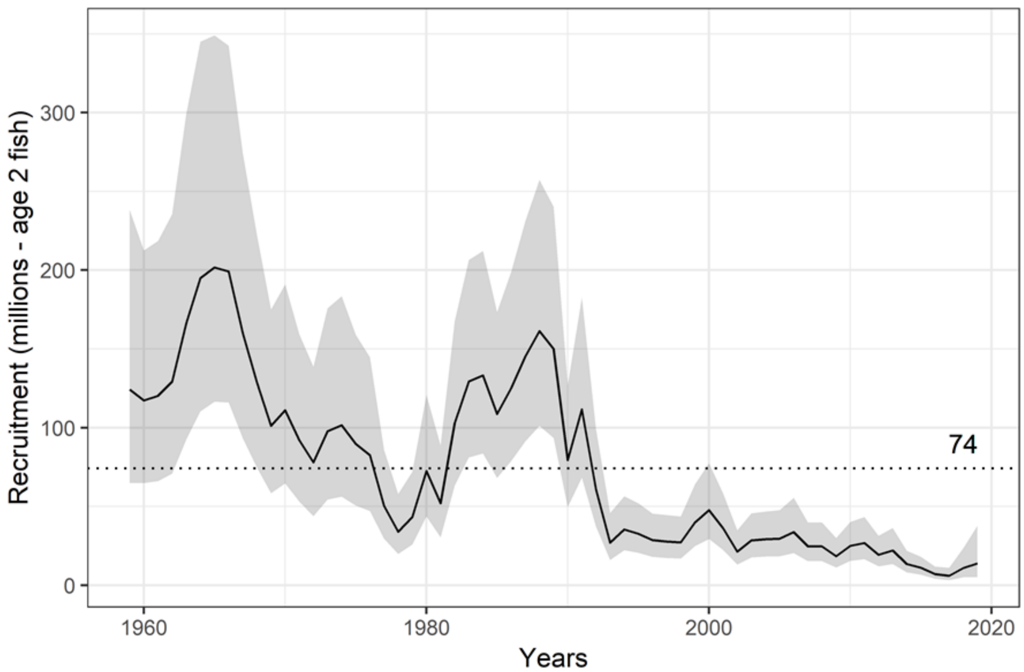


*Figure 12: Estimated relative year-class strength from cohort model (median estimate with 95% confidence intervals). The dashed horizontal line is the time-series median.*

### Projection

Projection of the stock to 2022 was conducted assuming fishery removals to be within ±30% of current values, assuming a catch of 4,453 t for 2019, and with no catch. Under these scenarios, there is a high probability (>99%) that the stock will remain below $B_{lim}$ between 2020 and the beginning of 2022 (Table 2). The probability of stock growth to 2022 is 1% or less across catch scenarios (+/- 30% of current levels), and is 16% when there are no removals.

*Table 2: Risk of projected SSB being below $B_{lim}$ under six scenarios of total mortality (catch at status quo, ±15% status quo and ±30% status quo and no catch) over 2020-22. Status quo catch was assumed to be 4,453 t. $B_y$ represents SSB in projection year.*

| Projected Catch | Probability of growing out of the critical zone $P(B_y>B_{lim})$ | | | Probability of growth from current levels<br>$P(B_y>B2019)$ | | |
|---|---|---|---|---|---|---|
| - | 2020 | 2021 | 2022 | 2020 | 2021 | 2022 |
| $0.001*Catch_{2019}$ | <0.1% | <0.1% | <0.1% | 5% | 7% | 16% |
| $0.7*Catch_{2019}$ | <0.1% | <0.1% | <0.1% | 5% | 1% | 1% |
| $0.85 *Catch_{2019}$ | <0.1% | <0.1% | <0.1% | 5% | 1% | 1% |

| Projected Catch | Probability of growing out of the critical zone $P(B_y>B_{lim})$ | | | Probability of growth from current levels $P(B_y>B2019)$ | | |
|---|---|---|---|---|---|---|
| 1.0*$Catch_{2019}$ | <0.1% | <0.1% | <0.1% | 5% | <1% | <1% |
| 1.15*$Catch_{2019}$ | <0.1% | <0.1% | <0.1% | 5% | <1% | <1% |
| 1.3*Catch | <0.1% | <0.1% | <0.1% | 5% | <1% | <1% |

### Other Data Sources

Other sources of information were considered in the assessment to provide perspectives on stock status in addition to the DFO survey indices. These sources of information include data from science logbooks for vessels less than 35 feet (1997-2018), logbooks from vessels greater than 35 feet (1998-2018), and observer sampling. Information from tagging experiments in Placentia Bay (and more recently Fortune Bay), were also available. Any differences in trends between these additional data sources and the DFO survey are difficult to reconcile but attributed to differences in survey/project design, seasonal changes in stock distribution, differing selectivity of various gear types, or the degree to which the various data sources track only certain subareas/ components versus the entire distribution of the stock.

### Logbooks

There is considerable uncertainty in the interpretation of fishery catch rate data. These data may be more reflective of changes in fishery performance or the nature of the fishery than changes in population size.

#### *Logbooks for <35’ Vessels*

Standardized annual catch rates from science logbooks (<35’ sector) for Canadian vessels fishing gillnets show a declining trend over 1998-2000, but have subsequently been fairly constant (Fig. 13, upper panel) near the time series average. Line-trawl catch rates show a much different pattern with a greater degree of variation (Fig. 13, lower panel). After peaking in 2006, line-trawl catch rates generally declined to near the time-series average in 2009 and remained at similar levels up to 2015. Catch rates for line trawls during 2016 to 2018 were the lowest in the time series, but this result is based on very low reporting rates (<40 logbooks annually) with no logbooks returned from some areas. The commercial catch rate index is based on weight of fish caught whereas the sentinel index is based on numbers. As with the sentinel results, there is contrast between the two gear-types in current catch rates relative to the time-series average. For gillnets, current CPUE is slightly above the series average, whereas current line-trawl CPUE is 40% below average.

The percentage of the catch from the <35’ sector that is accounted for in the standardized logbook indices has declined over time and now represents less than 30% of the catch as compared to approximately 70% at the start of the time series in 1997. This likely affects the quality and comparability of this index over time, such that it is unclear if the CPUE trends reflect the fishery as a whole.

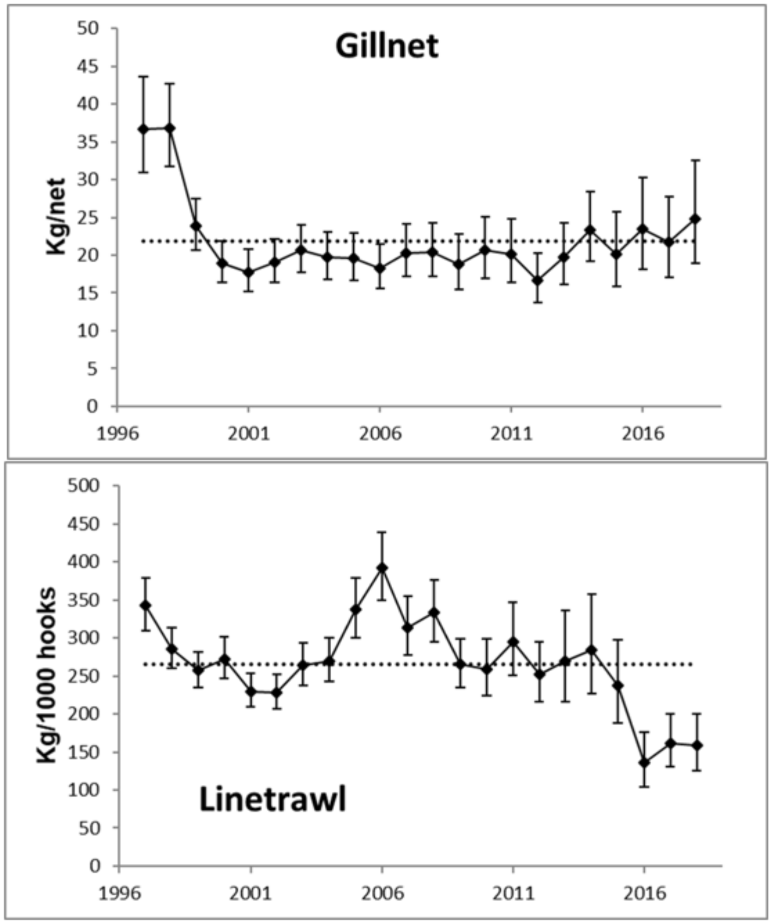


*Figure 13: Standardized catch rates for gillnets (upper panel) and line-trawls (lower panel) derived from logbook data for vessels less than 35 feet. Error bars are 95% confidence intervals; dashed lines represent the time-series average.*

*Logbooks for >35' Vessels*

Catch rates for gillnets from vessels >35' were standardized to account for spatial and seasonal effects. For these vessels, standardized annual catch rates (Fig. 14) were higher in magnitude than those from vessels less than 35 feet (Fig. 13), but the general pattern was similar up to 2017. Both time series showed an initial decline over 1998 to 2000 followed by fairly constant catch rates to 2017. In 2018, catch rates for gillnets from vessels > 35 ' were the third highest in the time-series and comparable to those during 2000. Over the last decade, approximately two thirds of the reported landings from vessels >35' were accounted for by the standardized gillnet index, which is slightly higher than earlier in the series when less than 50% coverage occurred frequently. Further analyses are required to develop a standardized catch rate index for line trawls fished by vessels >35'.

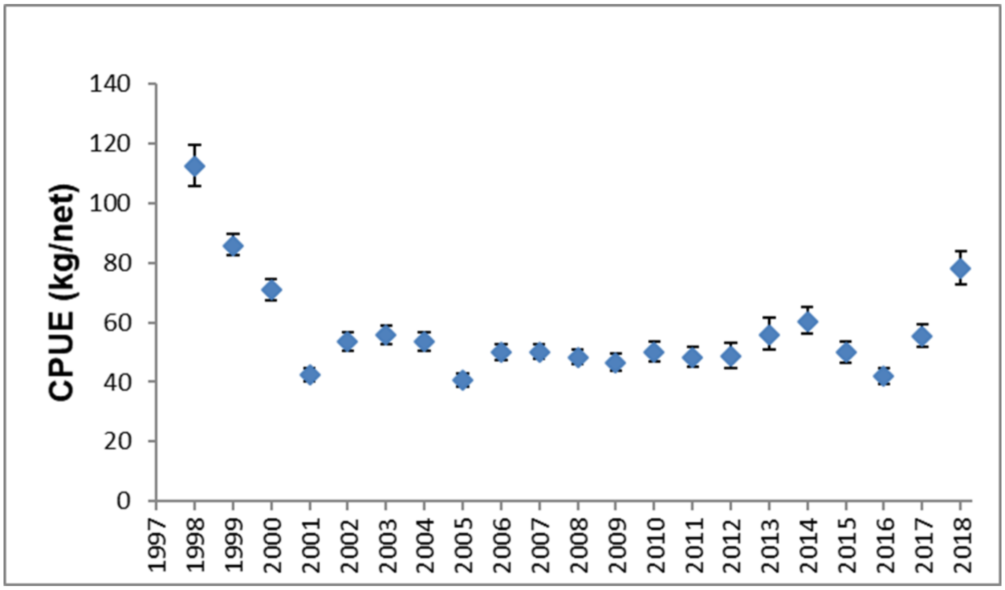


*Figure 14: Standardized catch rates for gillnets derived from logbook data for vessels greater than 35 feet. Error bars are 95% confidence intervals.*

### Observer sampling

Data collected at sea by observers on Canadian vessels fishing for cod (1997-2018) were analyzed to calculate a standardized catch rate index for gillnets. There were substantial variations in observer coverage over time and among unit areas, as well as by fleet sector. Although the proportion of the landings observed is low (<3%) for most years and areas, data from gillnets support that the catch rates during 2018 were generally among the lowest in the times series (1997 to 2018). Data on line trawl effort was not available in time for the assessment. There was insufficient data from otter trawl sampling to develop a standardized index.

### Tagging

The geographical coverage of tagging since 2007 has been largely limited to areas of Fortune Bay and Placentia Bay, which causes some uncertainty as to how results from these inshore areas relate to the stock as a whole. The number of cod tagged has varied annually and by area with tagging conducted annually in 3Psc (Placentia Bay) during 2007 to 2015 plus 2017, in 3Psb (Fortune Bay) during 2012 to 2018 (plus 2007) and in 3Psa only during 2007, 2013 and 2017. Although exploitation rates based on tagging of cod in these inshore areas may not be applicable to other areas, or to the stock as a whole, these inshore regions account for a significant portion (~50%) of the overall annual landings from the stock. Dedicated efforts were made in 2019 to expand the areas where fish were tagged, and tagging was conducted in all the three inshore subareas in 2019 (3Psa, 3Psb, 3Psc).

The general pattern of cod tag returns remains unchanged with most of the fish tagged in 3Ps being harvested in 3Ps. Recent tagging suggests exploitation of 3Ps cod in neighbouring stock areas (Divs. 3KL) is minimal and not a major issue for management. No new information was available to evaluate mixing in the western part of the stock (3Pn or 4R). The timing of tagging experiments with respect to the annual commercial fishery complicates analysis aimed at developing exploitation rates, although analytical work is underway to try and address these complications.

In 2018, part of an array of acoustic receivers was placed in upper Placentia Bay. In 2019 this array was expanded to all waters leading to the upper reaches of Placentia Bay. In July 2019, 38 cod were implanted with acoustic tags in upper Placentia Bay, this telemetry information will help to inform the timing and movements of cod using Placentia Bay and nearby areas.

A comparison of returns of tags from recreational fishers compared to commercial fishers indicate that removals due to the recreational harvest in 3Ps are a relatively small component of the total removals in 3Ps.

### Sources of Uncertainty

The accepted population model for the stock includes Sentinel data, but model fits to the young ages in the Canadian survey are reduced compared to model runs without the Sentinel data, especially for the post-2010 period. The model fits well to all other ages (6-14+) in the Canadian survey and all ages in other surveys plus the catch at age. This reduction in model fitting for young fish adds uncertainty to the model outputs and derivation of the revised LRP. This issue requires further research in the context of gaining a better understanding of how data from the various sources interact within the model. Although a concern, the decision was made to use the new model to provide advice and generate a revised LRP. Note that data from only the period prior to 2011 were used in estimation of the LRP due to concern about the model fits for young fish in recent years. Model performance is greatly reduced when the Sentinel data are excluded as evidenced by strong retrospective patterns over the past five years.

Although the RV survey of Subdivision 3Ps includes coverage of 45 index strata, the majority of the survey indices for cod are typically influenced by catches from only a small number of those strata. In some years the high estimates in some of these strata are a result of a single large survey tow. For example, a large survey tow on Burgeo Bank during 2016 had a major influence on survey indices (e.g. 60% of the biomass index resulted from a single survey tow in stratum 309). The presence of single large survey tows results in increased uncertainty in the survey data which is not accounted for in the model.

Survey indices are at times influenced by “year-effects”, an atypical survey result that can be caused by a number of factors (e.g., environmental conditions, movement, degree of aggregation, etc.) which may be unrelated to absolute stock size. There are strong indications that the 2013 survey may have been influenced by a year effect that resulted in a large spike in the survey indices for that year. The 2013 RV survey estimated that the abundance of multiple cohorts increased compared to observations of these same cohorts at one age younger in 2012. Since the number of fish in a cohort cannot increase after it is fully recruited to the survey gear (without immigration), such results are usually considered clear evidence for a year effect. Year effects in the survey data have the potential to mask trends in the data for several years and contribute to retrospective patterns.

Burgeo Bank is a known seasonal mixing area for cod from 3Ps and from the Northern Gulf of St. Lawrence. The DFO RV survey was moved to April in 1993 to minimize the impact of migratory Northern Gulf fish on the assessment of 3Ps cod. However, at least one published study suggests that a non-trivial portion of fish in the Burgeo Bank area in April is of Northern Gulf origin (Méthot *et al*. 2005). The potential presence of non-3Ps fish in this area at the time of the survey combined with the fact that a large portion of the survey indices have come from the Burgeo Bank area in recent years suggests the potential for overestimation of survey results.

## CONCLUSIONS AND ADVICE

A new integrated state space model resulting from the 2019 3Ps Cod Framework was used to assess the status of the stock and estimate fishing mortality. This model incorporates catch

(1959-2019), time varying natural mortality informed by trends in cod condition, and includes abundance indices from bottom trawl surveys conducted by Canada (1983-2005, 2007-2019), France (1978-1991), industry (GEAC, 1998-2005), and standardized catch rate indices from the Sentinel gillnet and line-trawl surveys (1995-2018). A new biomass limit reference point (LRP) was determined for the stock based on the relationship between spawning stock biomass (SSB) and recruitment estimated from the model. The LRP is 66,000 t of SSB. Spawning Stock Biomass (SSB) at January 1, 2020 is estimated to be 16 kt (12 kt - 21 kt). The stock is in the Critical Zone (24% of $B_{lim}$ (18-32%)) as defined by the DFO Precautionary Approach (PA) Framework. The probability of being below $B_{lim}$ is >99.9%. The new model and the revision of the basis for defining the LRP has led to a change in the perception of status of this stock. The stock is now estimated to have been below $B_{lim}$ since the early 2000s. The estimated fishing mortality rate (ages 5-8) has ranged between 0.12 and 0.21 since 2010 and in 2019 was 0.21 (0.15–0.30), with an assumed catch of 4,453 t. Natural mortality was estimated to be 0.49 (0.41–0.58) (ages 5-8) in 2019. Values during the last four years are the highest in the time series. Recruitment (age 2) estimates have been below the long term average since the mid-1990s. Projection of the stock to 2022 was conducted assuming fishery removals to be within +/- 30% of current levels, assuming a catch of 4,453 t for 2019, and with no catch. Under these scenarios, there is a probability >99% that the stock will remain below $B_{lim}$ between 2020 and the beginning of 2022. The probability of stock growth to 2022 is 1% or less across catch scenarios (+/- 30% of current levels), and is 16% when there are no removals. Natural mortality plays an important role in projections for this stock. If natural mortality rates are appreciably different from those used, projected outcomes will differ from values reported above. Bottom temperatures in 3Ps remain above normal, and the spring bloom continues to be reduced in magnitude. Zooplankton biomass in 3Ps was near normal in 2017 and 2018 after four years of low production, with an increased proportion of smaller species. Data were unavailable from 2019. Ongoing warming trends, together with an increased dominance of warm water fishes, indicate that this ecosystem continues to experience structural changes. Reduced growth and condition indicate that cod productivity in 3Ps is reduced. 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

A seasonal closure of the entire 3Ps stock area (typically March to mid-May) occurs annually and is intended to minimize fishing on spawning aggregations. Some harvesters have suggested that the time of spawning has been delayed in recent years and that the timing of the closure may no longer be appropriate.. In 2015 and 2016, samples collected from the Halibut Channel area (Southern 3Ps) by industry (March) and from the DFO multispecies survey (April) indicated that spawning in this area began in April. No spawning was observed in March but egg sizes suggested that at least some fish were nearing spawning at the time of capture. The original recommendation for the 3Ps spawning closure came with the suggestion that spawning in this stock occurs during April-June but with the acknowledgement that “spawning ground behavior typically begins in March” (FRCC 2001). Hence, the recommended (and subsequently adopted) closure time of March 1-June 30 was presumably intended to protect not only spawning but also pre-spawning aggregations. If the objective of the 3Ps spawning closure is still to protect spawning and pre-spawning aggregations, then the starting date of the closure is likely still appropriate. It should be noted, however, that the current closure end date of mid-May almost certainly does not protect the full spawning period for this stock.

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# SOURCES OF INFORMATION

This Science Advisory Report is from the November 19-22, 2019 Assessment of NAFO Subdivision 3Ps Atlantic Cod. An assessment of 3Ps American Plaice was also conducted during this meeting and a separate advisory report is available for that stock. 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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