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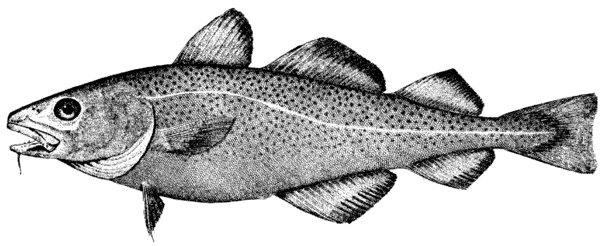
Gulf Region

Canadian Science Advisory Secretariat
Science Advisory Report 2019/021

ASSESSMENT OF ATLANTIC COD (*GADUS MORHUA*) IN THE SOUTHERN GULF OF ST. LAWRENCE (NAFO DIV. 4T-4VN (NOV. – APRIL)) TO 2018



Atlantic Cod (Gadus morhua)

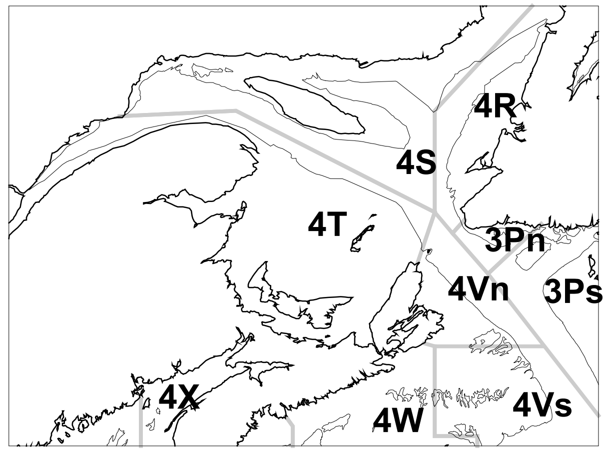


Figure 1. Map of the Gulf of St. Lawrence showing NAFO divisions.

Context:

The stock of Atlantic Cod in the southern Gulf of St. Lawrence (sGSL) has been exploited commercially since at least the 16th century. Landings varied between 20,000 and 40,000 t annually between 1917 and 1940 and then began to increase, peaking at over 100,000 t in 1958. Landings remained relatively high in the 1960s and early 1970s at close to 60,000 t. TACs were first imposed in 1974 and became more restrictive as the stock declined in the mid-1970s. The fishery was closed in September 1993 due to low abundance. A 3,000 t index fishery was allowed in 1998, and a TAC of 6,000 t was in effect from 1999 to 2002. The directed fishery was closed again in 2003 due to a lack of recovery but reopened at a TAC of 3,000 t in 2004, 4,000 t in 2005 and 2006 and 2,000 t in 2007 and 2008. The directed fishery has been under moratorium since 2009 and a 300 t bycatch TAC has been set.

Since 1999, the management year for the fishery runs from May 15 of the current year to May 14 of the following year. The management unit for this stock includes all of 4T and catches in 4Vn from November to April. In some years, catches in 4Vs in January to April are also attributed to this stock.

This assessment was conducted in support of DFO Fisheries and Aquaculture Management multi-year management approach and request for advice for a TAC decision for May 2019 to May 2023 for the sGSL stock of Atlantic Cod. A regional peer review meeting was held February 20-21, 2019 to address the request for science advice. Participants included DFO Science and DFO Fisheries Management personnel from Gulf, Quebec, and the Newfoundland and Labrador regions, the fishing industry, the province of Nova Scotia and an Indigenous community.

SUMMARY

- The cod-directed fishery has been closed since 2009, with a 300 t TAC in place to cover bycatch in other groundfish fisheries, Indigenous food, social and ceremonial fisheries, a limited recreational fishery, and scientific purposes. Preliminary landings for 2017 and 2018 are about 60 t.
- Since 2009, the exploitation rate has averaged 0.2% for ages 5-8 and 0.7% for ages 9 plus. These low levels have a negligible impact on the population trajectory.
- The biomass index for commercial-sized cod (≥ 42 cm) from the annual DFO research vessel survey was at the lowest level observed in the 48-year record in 2017 and 2018. The 2017 and 2018 indices averaged 8% of the already low values in 1995-2002, and 2.5% of the average biomass in the 1980s. Similar trends were observed for both sentinel survey indices.
- Estimated spawning stock biomass (SSB) declined steadily between 1997 and 2018.SSB at the beginning of 2018 was estimated at 13,900 t, the lowest level in the 69-year record, at 4% of the high biomass levels in the 1980s.
- The SSB in 2018 is estimated to be 17% of the Limit Reference Point (LRP), with no chance that the stock is at or above the LRP.
- Recruit abundance has been declining since the mid-1980s due to declining SSB, despite above average recruitment rates for most recent year-classes.
- Under current productivity conditions, there is a 90% (0-100 t annual catch) or 99% (300 t) probability that SSB will decline further between 2018 and 2023, with an expected decline of 32% from the 2018 SSB.
- Extremely high natural mortality of cod 5 years and older is the reason for the lack of recovery of this stock. Natural mortality of adults has increased over the past 40 years and is now estimated to be 55 - 57% annually (M = 0.81 – 0.85), much higher than what was estimated in the 1970s (18%, M = 0.2). At this high level of natural mortality, this stock is expected to continue to decline with high probability, even with no fishing.
- This stock is experiencing an “Allee effect”, in which the per capita rate of population growth decreases as population size decreases. This is opposite to the usual behaviour of populations at low abundance. Additionally, since 2000, this stock has been experiencing a production deficit, averaging negative 7,000 t per year, indicative of a “strong Allee effect”. If a strong Allee effect persists, it will drive a population to extinction.
- Predation by grey seals is concluded to be the main cause of the elevated natural mortality of this cod stock over the past 20 years, and thus of the Allee effect.
- Over the past 20 years, cod have progressively moved out of traditional foraging areas in inshore waters and into deeper offshore waters during their feeding season in the southern Gulf of St. Lawrence. This appears to result from the high and increasing risk of predation by grey seals in inshore waters in summer. This change in distribution is expected to incur costs (e.g., reduced foraging success) and has been coincident with declines in the condition of cod.
- At the current abundance of grey seals in this ecosystem, recovery of this cod population does not appear to be possible, and its extinction (SSB < 1,000 t) is highly probable.

BACKGROUND

Species Biology

Atlantic Cod (*Gadus morhua*) is a demersal species that occurs on both sides of the North Atlantic. Southern Gulf of St. Lawrence (sGSL) cod are normally relatively long-lived and may reach ages of 20 years or more when mortality is low. Cod from the sGSL are slow-growing compared to neighboring cod populations. Individual fish growth declined between the late 1970s and mid-1980s and has remained low since then. They begin to reach commercial size (43 cm) at about age 5 and are fully available to the commercial fishery by age 8. Historically, southern Gulf cod began to mature at 5-6 years of age and most were mature by age 9. However, age-at-maturation declined in the 1950s and 1960s, and since the early 1970s most fish in the population have been mature by age 6. It is estimated that the natural mortality of sGSL cod started to increase in the 1980s and has been high in the 1990s and 2000s.

Southern Gulf cod are highly migratory. Spawning occurs in the Shediac Valley and around the Magdalen Islands from late April to early July. During the summer, the cod are widely distributed while they feed heavily on krill, shrimp, and small fish, primarily herring, American Plaice, and Capelin. The fall migration begins in late October, and cod become concentrated off western Cape Breton in November as they move into the overwintering grounds. The stock overwinters along the edge of the Laurentian Channel in eastern 4T and in 4Vn, in some years extending into 4Vs. The return migration usually begins in mid-April, although this can be delayed if breakup of winter ice is late.

Fishery

The directed fishery for southern Gulf Atlantic Cod has been under moratorium since 2009. A TAC of 300 t has been in place since then for bycatch in fisheries directed at other species, mainly flatfish, for Indigenous food, social and ceremonial (FSC) fisheries, for scientific sampling, and for a limited recreational fishery.

Table 1. Reported landings (in tonnes) of Atlantic Cod by fishing component, 2013 to 2018. NA means not yet available, NR means not reported. Landings for 2017 and 2018 are preliminary.

Fishing component	2013	2014	2015	2016	2017	2018
Bycatch in groundfish fisheries	90	95	93	97	46	47
Sentinel fisheries	21	19	11	18	13	12
Charter boat catch [1]	14	13	6	6	10	NA
Recreational [2]	NR	NR	NR	NR	NR	NR
Aboriginal FSC fisheries [3]	NR	NR	NR	NR	NR	NR

[1] Includes harvested and released cod
[2] Estimates for Gulf Nova Scotia and the north shore of the Gaspe Peninsula are in the range of 5 t annually in each area
[3] No reports of fishing having taken place

In 1999, the fishery management year changed from the calendar year to the period from May 15 of the current year to May 14 of the following year. This stock assessment is based on calendar year, consistent with past practice. Landings since the closure of the cod-directed fishery in 2009 have been very small, averaging 5% of the landings by the small directed fisheries in 2004-2008 and 0.2% of the landings in the five years prior to the first closure of the cod fishery in 1993 (Fig. 2). Total reported landings in the 2013 to 2018 calendar years in commercial and sentinel fisheries ranged from 60 t to 115 t (Table 1; landings in 2017 and 2018 are preliminary). Sentinel programs, conducted in collaboration with the fishing industry to obtain additional indices of stock abundance, accounted for 11-25% of the reported landings, 6-22% by the sentinel longline program and 1-4% by the sentinel trawl survey. The research vessel survey caught an additional 0.9 to 3.7 t annually between 2009 and 2018.

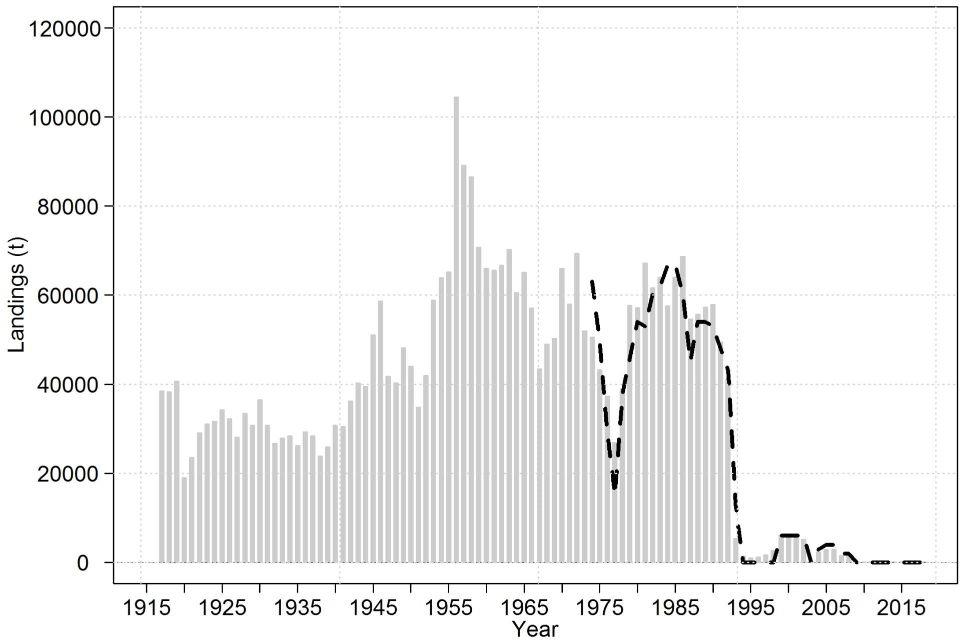


Figure 2. Reported landings (grey bars) and Total Allowable Catch (TAC; in tonnes, t; dashed line) for the southern Gulf of St. Lawrence cod stock, 1917 to 2018. Landings are for the calendar year; the TAC is for the management year which changed to the period from May 15 of the current year to May 14 of the following year starting in 1999.

The general recreational fishery for groundfish is open for five weeks or less with a daily bag limit of five cod and/or White Hake. Landings are not reported but DFO Fisheries and Aquaculture Management Gulf Region indicated these to be about 5 t annually in Gulf Nova Scotia. A similar estimate has been provided for the north shore of the Gaspe Peninsula in 2013. In addition, charter boats recreational fishing with rod and reel operate in management zones 4T2b and 4T8. Reported catches (kept and released fish) by charter boats were 6 – 12 t annually in 2009 to 2017, with 30% of the catch (by weight) released at sea. The total cod catch by charter boats in 2017 was 10.2 t, with 7.0 t landed and 3.2 t released.

Ages 6 to 9 were dominant in the 2009 to 2018 landings. Average weight-at-age declined in the early to mid-1980s in both the fishery and research vessel catches. Weight-at-age returned to a higher level in the fishery in recent years but has remained low in the research vessel catches (Fig. 3). This could reflect changes in the gear composition and thus size-selectivity of the fishery.

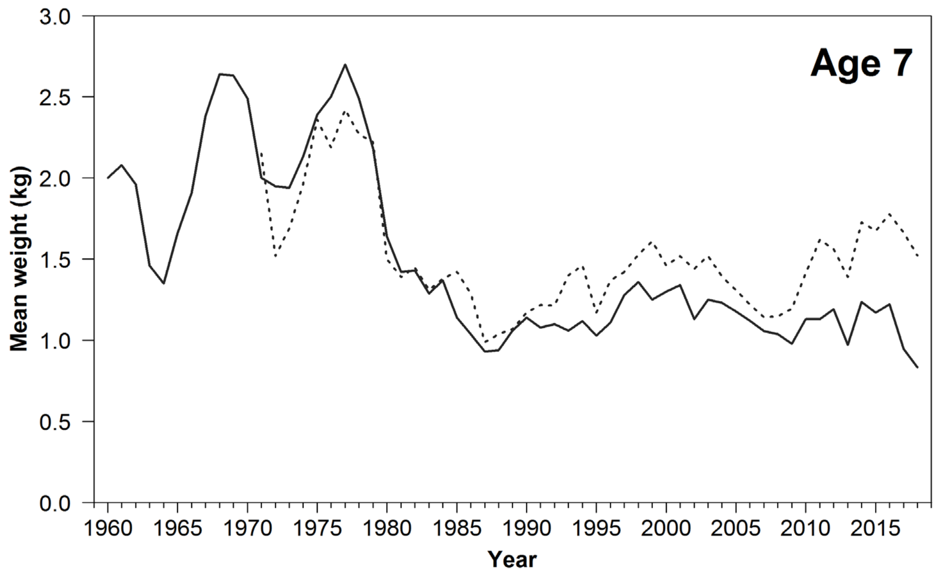


Figure 3. Mean weight (kg) of a 7-year-old southern Gulf Atlantic Cod in fishery catches (dashed line) and from the annual September research vessel survey (solid line).

ASSESSMENT

The information used in this assessment includes the annual research vessel survey (1971-2002 and 2004-2018), landings data from 1950 to 2018, commercial catch-at-age data from 1950 to 2018, and sentinel longline data from 1995 to 2017 and mobile sentinel data from 2003 to 2018.

Stock Trends

An annual research vessel (RV) survey has been conducted each year in September since 1971 and covers most of the stock area. The research vessel used to conduct the survey changed in 1985, 1992 and 2004. In each case, comparative fishing experiments were conducted to calibrate the fishing efficiency of the new vessel relative to the old vessel. In 2003, the survey was conducted by an uncalibrated vessel, the survey started late, and coverage was incomplete. For these reasons, the results in 2003 were not used here as an indicator of stock status. Gadoids <15 cm were excluded from the indices because Atlantic Cod cannot be easily distinguished from Greenland Cod at those small sizes.

The RV survey index indicated that the biomass of pre-commercial and commercial sizes of cod (corresponding roughly to juveniles and adults) was low in the early to mid-1970s, and then increased to the early 1980s (Fig. 4). Abundance was high until the late 1980s, but declined rapidly to low levels by 1992. With the closure of the fishery in 1993, the decline was arrested for commercial sizes of cod, but these cod declined further after 2002. The index for commercial-sized cod was at the lowest level observed in 2017 and 2018, when the biomass index averaged 8% of the already low values in 1995-2002, and 2.5% of the average biomass index in the 1980s.

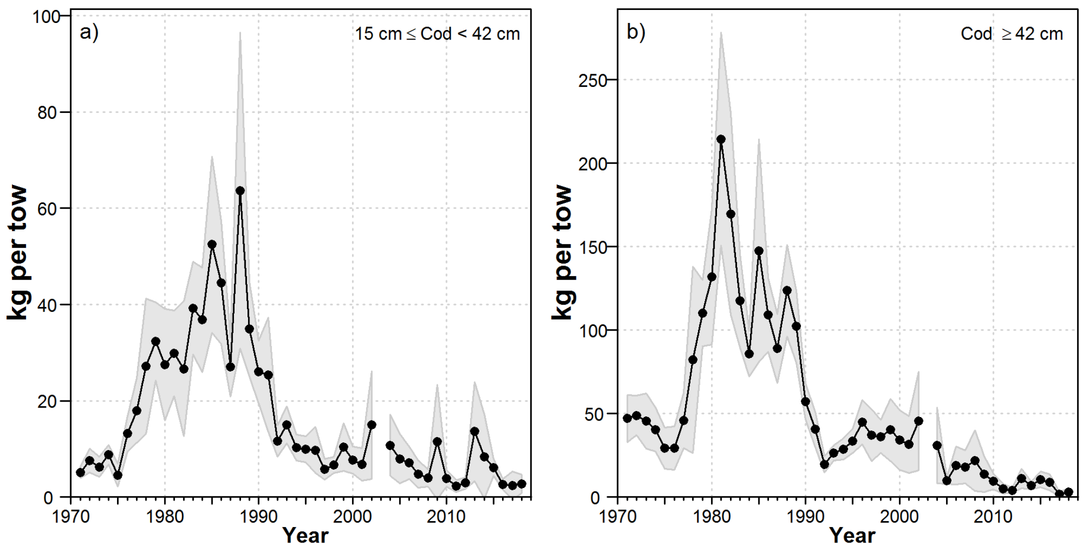


Figure 4. September research survey biomass indices (kg per tow; mean and approximate 95% confidence intervals) for Atlantic Cod 15-42 cm length (left panel, a) and of commercial length (≥ 42 cm; right panel b) from the southern Gulf of St. Lawrence.

The index for pre-commercial sizes continued to decline at a slow rate after 1992. The decline was interrupted by high but uncertain values in 2002, 2004, 2009 and 2013. The high catch rates at small sizes in these years did not result in subsequent increases in abundance at larger sizes (Fig. 4).

The geographic distribution of cod in September has changed dramatically over the past 20 years (Fig. 5). Over this period there has been a progressive shift in distribution out of inshore areas and into deeper water along the slope of the Laurentian Channel. This appears to represent a response to increased risk of predation by grey seals, with cod shifting out of areas where predation risk is now high and into low risk areas.

The August sentinel trawl survey started in 2003 and covers most of the stock area. The biomass index from this survey was at the lowest levels observed in 2015 to 2018, averaging 9% of the level at the start of this time series in 2003 (Fig. 6). The geographic distribution of catches in the sentinel trawl survey indicated an offshore shift in cod distribution in August similar to that observed in the September survey (Fig. 7). This change is also consistent with a shift in cod distribution out of areas where risk of predation by grey seals is now high and into lower risk areas.

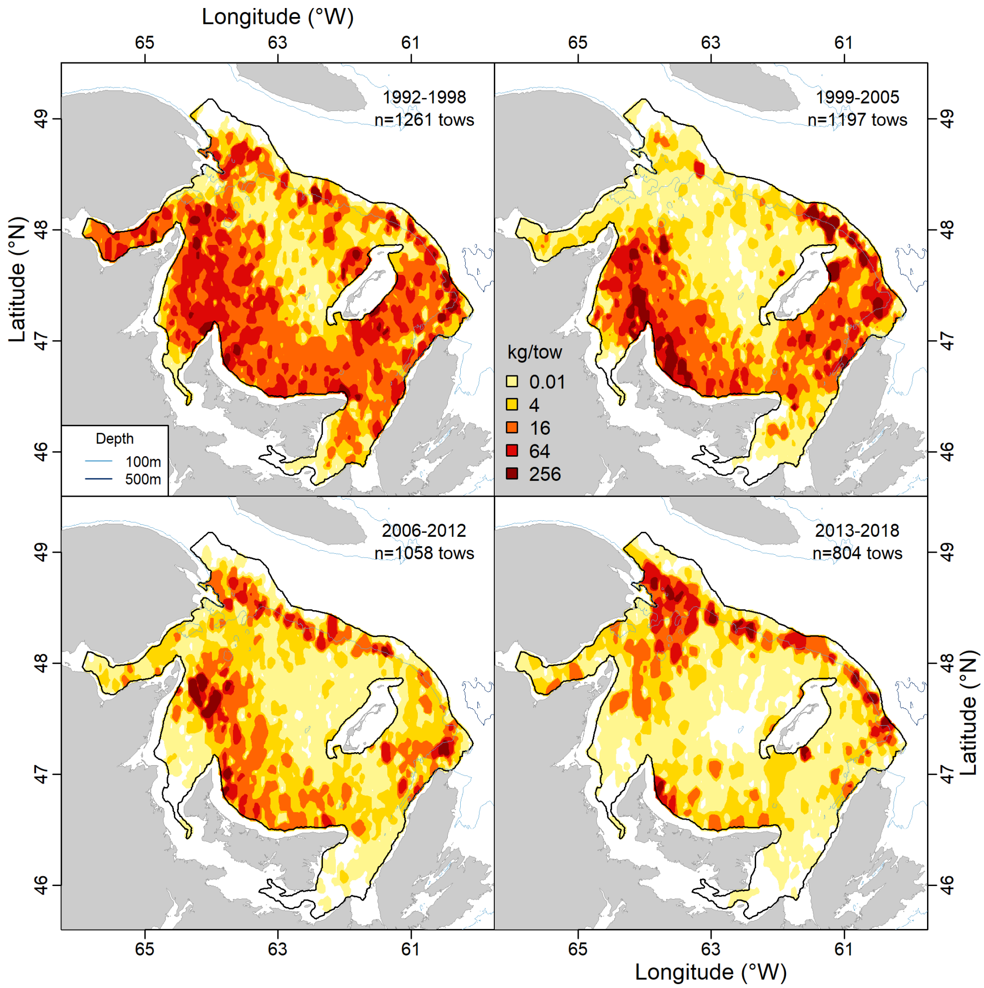


Figure 5. Changes in the spatial distribution of southern Gulf of St. Lawrence Atlantic Cod in September as indicated by the RV survey biomass indices (kg per tow) by seven year groups, 1992 to 2018.

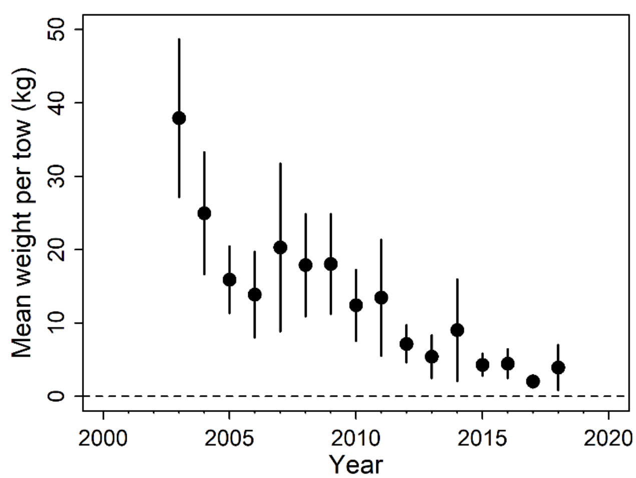


Figure 6. Biomass index (all sizes, kg per tow; mean and approximate 95% confidence intervals) of Atlantic Cod from the August sentinel trawl survey of the southern Gulf of St. Lawrence, 2003 to 2018. Indices are standardized for differences in fishing efficiency between vessels.

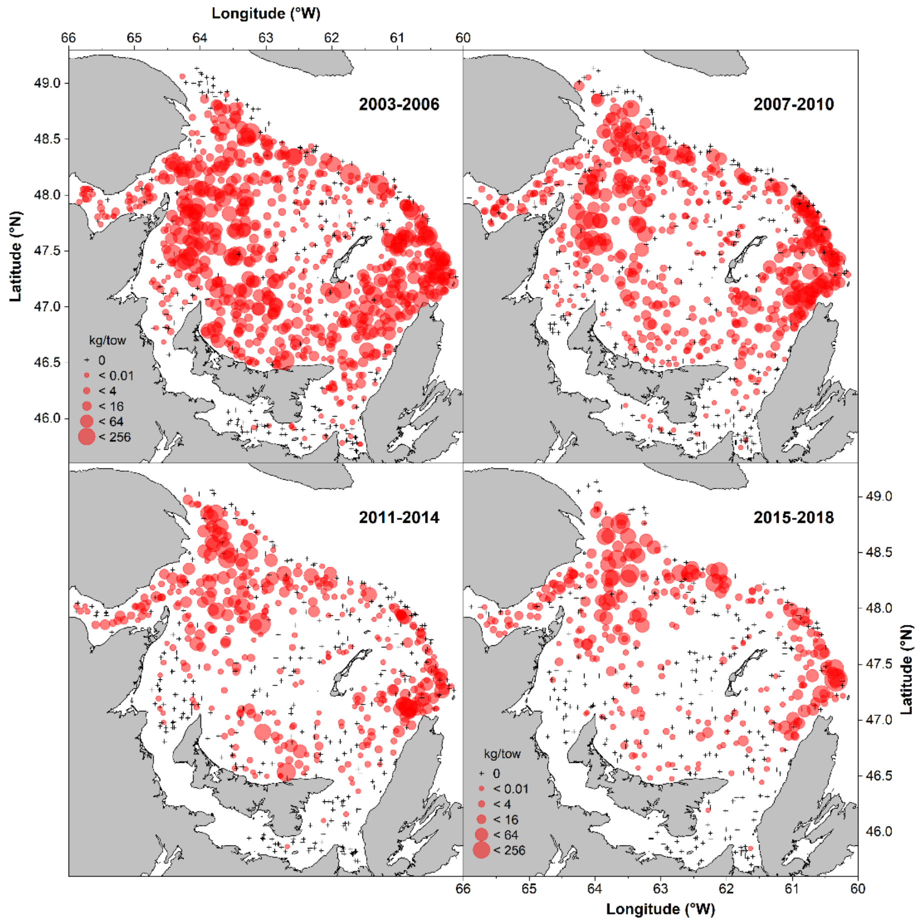


Figure 7. Changes in the distribution of southern Gulf of St. Lawrence Atlantic Cod in August as indicated by the sentinel trawl survey biomass indices (kg per tow) by four year groups, 2003 to 2018.

Each participant in the sentinel longline program fishes at two of the approximately 30-40 sites distributed throughout coastal areas of the sGSL. Each site is fished up to 9 times in July to November using standardized protocols (Savoie 2014). In 2014, 36 sites were fished, but this had declined to 26 sites in 2018. The maximum soak time was also reduced from 24 h to 8 h in 2018. Results for 1995 to 2017 indicate that standardized catch rates declined steadily between 2004 and 2011 (Fig. 8). The 2011 value was 12% of the 1995-2004 mean value. The index remained low in 2012-2017, averaging 18% of the 1995-2004 mean value.

In summary, indices from the September RV survey, the August sentinel trawl survey and the longline sentinel program all indicate that the stock is at or near a record-low level and is declining.

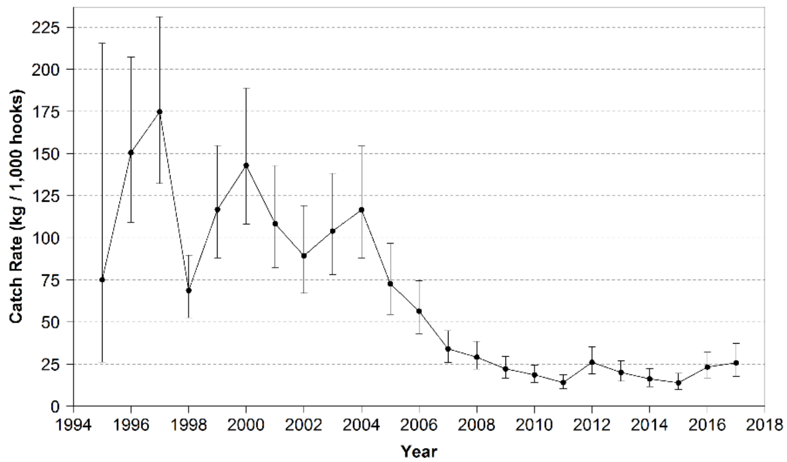


Figure 8. Longline sentinel catch rate index (kg per 1000 hooks; mean and approximate 95% confidence intervals) of southern Gulf of St. Lawrence Atlantic Cod, 1995 to 2017.

Current Status

Spawning stock biomass (SSB) and the biomass of cod 5 years and older declined from the 1950s to the mid-1970s (Fig. 9). The difference in trend between the two measures of biomass reflects the changing maturation schedule during this period. Biomass recovered rapidly in the late 1970s due to unusually high recruitment rates but rapidly collapsed in the late 1980s and early 1990s due to high adult mortality. The decline halted with the closure of the directed cod fishery in September 1993. Biomass recovered little following the fishery closure and resumed its decline in the late 1990s. Both SSB and 5+ biomass have steadily declined since 1997. Estimated SSB at the start of 2018 is 13,900 t, the lowest level in the 69-year record, at 11% of the 1997 level, and 4% of the average level in the 1980s.

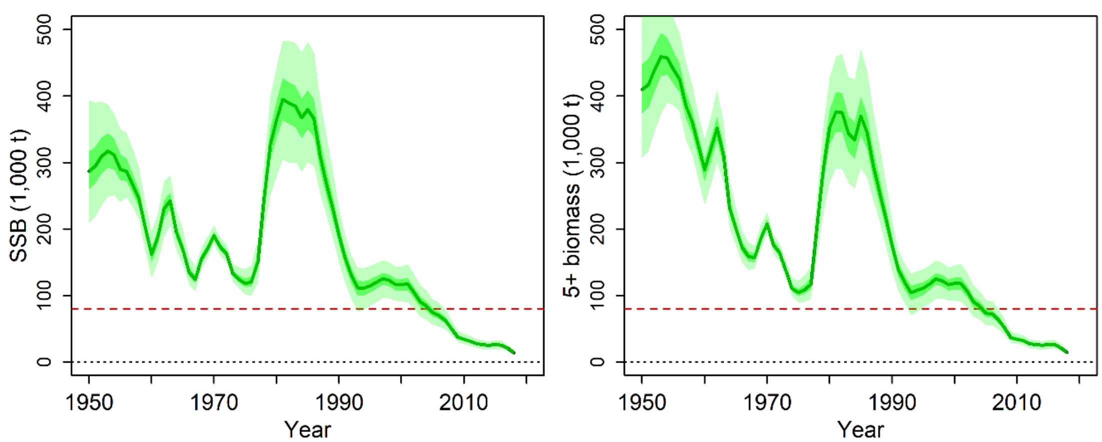


Figure 9. Estimated spawning stock biomass (SSB; left panel a)) and biomass of Atlantic Cod 5 years and older (right panel b)) in thousands of tonnes (1,000 t) in the southern Gulf of St. Lawrence, 1950 to 2018. Light and dark shading shows 95% and 50% confidence intervals respectively. The red dashed line is the Limit Reference Point, estimated to be 80,000 t of SSB.

The limit reference point (LRP) for this stock, the level below which the stock is considered to have suffered serious harm to its productivity, was estimated in 2003 to be 80,000 t of SSB.

Estimated SSB has been below this level since 2005. The SSB in 2018 is estimated to be 17% of the LRP, with no chance that the stock is at or above the LRP.

Recruitment rate (age-2 abundance divided by SSB two years earlier) is a measure of spawning success and survival at early life history stages. Recruitment rates were unusually high for the 1973 to 1977 year-classes. These unusually high recruitment rates fueled the rapid recovery of the stock in the late 1970s and early 1980s (Fig. 10b). Herring and mackerel are potential predators of cod eggs and larvae, and the collapse of these fishes in the sGSL during this period is thought to be the cause of these unusually high rates (Swain and Sinclair 2000). Recruitment rates were also above average in recent years.

The estimated abundance of age-2 recruits rose to the highest levels on record in 1975 to 1982, reflecting the unusually high recruitment rates at this time. Recruit abundance has been declining since then due to declining SSB. Year-classes produced since 2002 have been the weakest on record, despite above average recruitment rates for most recent year-classes. Estimated recruit abundance in 2016 was 15 million, less than 5% of the level in the 1980s. Population abundance (ages 2+) dropped sharply in the early 1960s (Fig. 10a) following a steady rise in fishing mortality throughout the 1950s (Fig. 11). Abundance recovered rapidly in the late 1970s, reaching levels considerably higher than the level at the start of the time series in 1950. This recovery resulted from the unusually high recruitment rates occurring at this time. Population abundance decreased rapidly from 1982 to the fishery closure in 1993 and has declined at a slower rate since then. Population abundance is now estimated to be at a record low level, averaging 86 million fish, an 80% decline since 1993, and a 94% decline since 1982.

The time trend in the abundance of older cod (ages 5+) resembled the total abundance trend with a 3-year lag to allow for recruitment of cohorts to age 5 (Fig. 10). The abundance of 5+ cod in 2018 is estimated to be 20 million fish, the lowest level observed and representing an 85% decline from the 1993 abundance, and a 95% decline from the 1985 level.

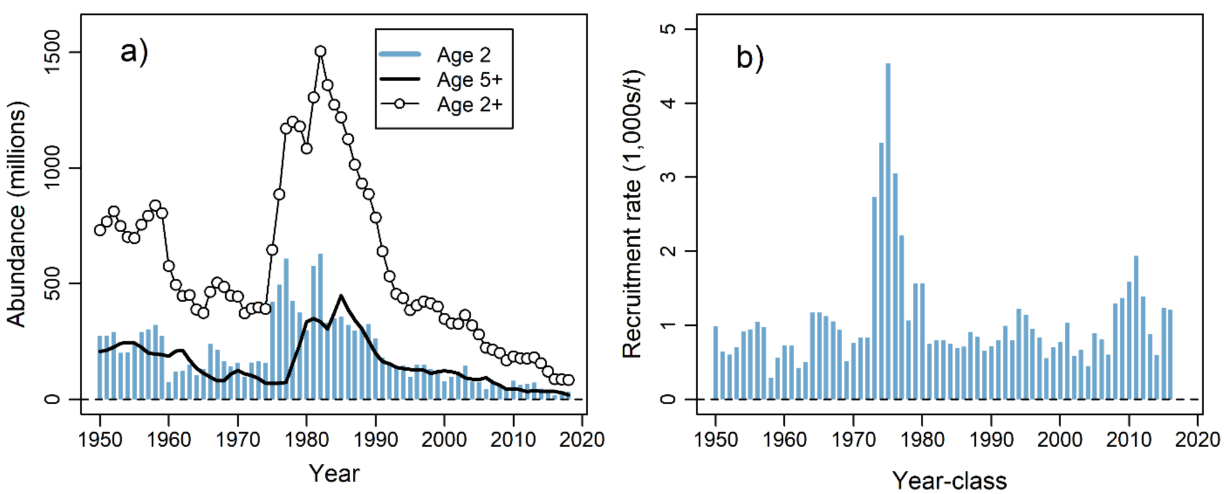


Figure 10. Estimates of abundance (number in millions; left panel a) by year of sampling (1950 to 2018) and recruitment rate at age 2 (thousands of age-2 recruits per tonne of spawning stock biomass; right panel b) by year class (1950 to 2016) of Atlantic Cod from the southern Gulf of St. Lawrence.

The instantaneous rate of fishing mortality (*F*) increased 5-fold from the early 1950s to the early 1970s (Fig. 11). *F* then declined to a lower level with the brief reduction in landings and the rapid increase in biomass in the late 1970s. However, *F* increased rapidly as stock biomass collapsed in the late 1980s and early 1990s, reaching a peak near 0.4 (33% annually; ages 5-8) or over 0.5 (39%; ages 9+). Estimated *F* was very low during the 1994-1997 moratorium (0.007 or 0.7% and 0.018 or 1.8% annually for ages 5-8 and 9+, respectively). During the fishery openings in 1999-2002 and 2004-2008, the annual exploitation rate on 9+ cod averaged 0.088 or 8.6% annually and 0.0645 or 6.4%, respectively, a small fraction of natural mortality but unsustainable given the low stock productivity. During the moratorium since 2009, annual exploitation rates on 5-8 year-old and 9+ cod have been negligible, averaging 0.2% and 0.7%, respectively.

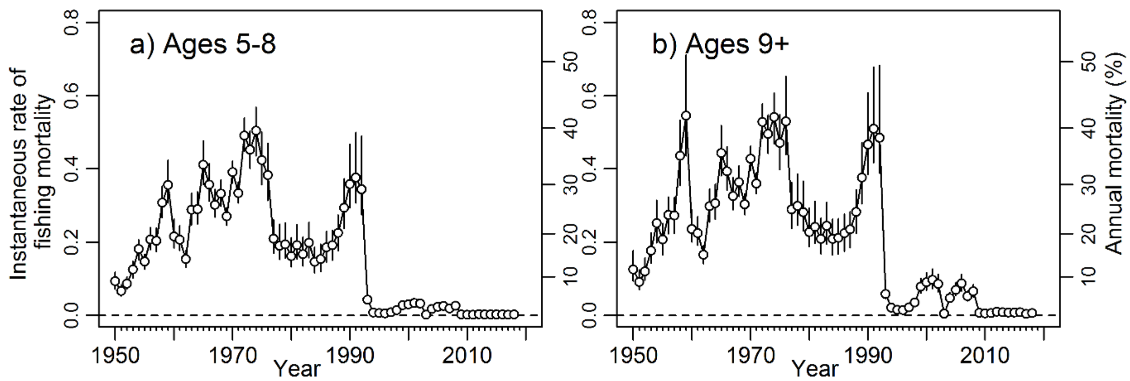


Figure 11. Estimated instantaneous rate of fishing mortality F for southern Gulf of St. Lawrence Atlantic Cod aged 5-8 (panel a, left) and 9+ years (panel b, right), 1950 to 2018.

The population model used in this assessment estimates time trends in natural mortality for three age groups, cod aged 2-4, 5-8 and 9+ years (Fig.12; Swain et al. 2019). Natural mortality of about 18% annually (*M* = 0.2) is considered normal for adult cod. For adult cod (ages 5+), *M* began to increase in the 1970s, reaching very high levels in recent years. For ages 5-8, the maximum value was estimated for 2018 (*M* = 0.81, 55% annually). For ages 9+, the maximum *M* was estimated at 0.93 (61% annually) in 2010 with the estimated value in 2018 of *M* = 0.85 (57% annually). Extremely high natural mortality of cod 5 years and older is the reason for the lack of recovery of this stock and its continued decline.

In contrast to adults, there is no indication of an increase in *M* for younger cod (ages 2-4 years).

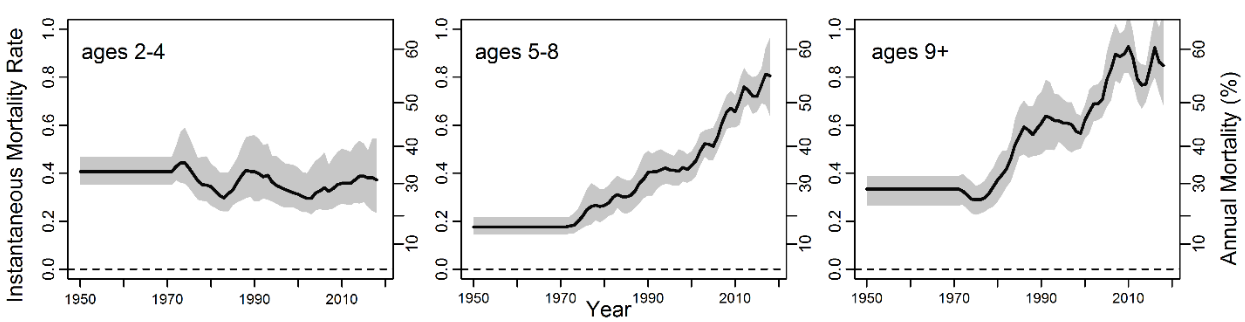


Figure 12. Estimated natural mortality rates of southern Gulf of St. Lawrence Atlantic Cod aged 2-4 (left panel), 5-8 (middle panel) and 9+ (right panel) years, 1950 to 2018. The solid black line are the median values and the shadings show the corresponding 95% confidence intervals.

Projections

The population was projected forward to the start of 2023 assuming that the current productivity conditions would persist until then. SSB is expected to decline below the 2018 level (13,900 t) by about 4,700 t over this 5-year period (Figs. 13 and 14). This is a small value, but a large fraction of the current estimate of SSB (about 34%). Estimated SSB at the start of 2023 is 9,400 t with no fishery catch, 9,300 t with annual fishery removals of 100 t and 9,100 t with annual removals of 300 t. The probability that SSB equals or exceeds the LRP is 0 in all projection years at all the catch levels examined. The probability that SSB will decline between 2018 and 2023 is 0.891, 0.896, or 0.991 with bycatches of 0, 100 or 300 t.

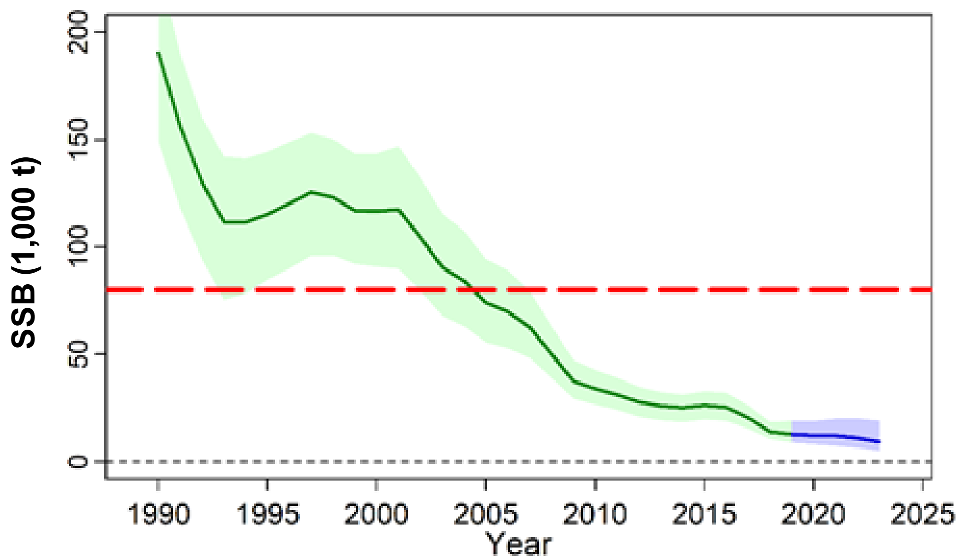


Figure 13. Projected SSB of southern Gulf of St. Lawrence Atlantic Cod assuming current productivity and no fishery catch. Lines show the median and shading the 95% confidence band. Green indicates historical values and blue the projected values (2019 to 2023). The horizontal red dashed line is the LRP value of 80,000 t of SSB.

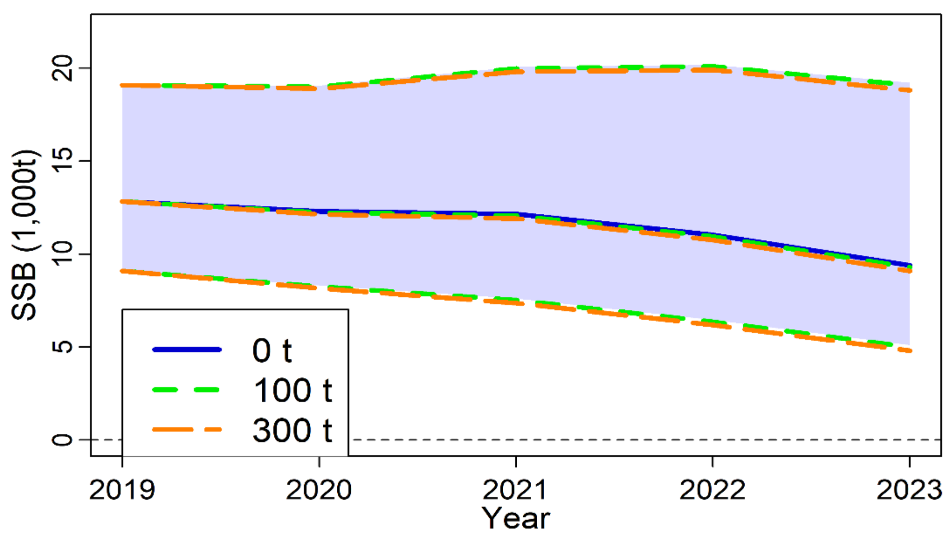


Figure 14. Projected SSB of southern Gulf of St. Lawrence Atlantic Cod (median and 95% confidence bands) for 2019 to 2023 assuming current productivity and fishery catches of 0 t (solid blue line and shading), 100 t (short dashed green lines), or 300 t (long dashed orange lines).

Biological Considerations

The ecosystem in the southern Gulf of St. Lawrence has changed dramatically in recent decades. Abundances of many large-bodied demersal fishes (e.g., Atlantic Cod, White Hake, American Plaice, skates) have declined to very low levels, and continue to decrease. These fish currently have elevated natural mortality at adult sizes. In contrast, many small fishes (e.g., shannies, sculpins) have increased dramatically in abundance. Most of the important prey of cod are at high levels of abundance. Grey seals (year-round residents) and harp seals (present in winter and early spring) are also at high levels of abundance.

Population Productivity

Stock production in year t (Pt) was calculated as:

$P_t = C_t + B_{t+1} – B_t$

where B_t is 2+ biomass at the start of year *t* and C_t is the fishery catch in year *t*.

Surplus production is the gain in biomass due to recruitment and growth minus the losses to natural mortality and is the production that can be used to grow the stock and/or support a fishery. Estimated surplus production was substantial in most years from 1950 to the mid-1980s, averaging 59,000 t annually (Fig. 15). Since then production has been very low in most years. Annual production has averaged negative 4,000 t (i.e. a production deficit) since the beginning of the first moratorium in 1994. There has been a production deficit in all years since 2001, except for a surplus of 1,600 t in 2013. The average production deficit since 2001 is estimated to be negative 7,000 t. In this situation, the stock will decline even with no fishery removals.

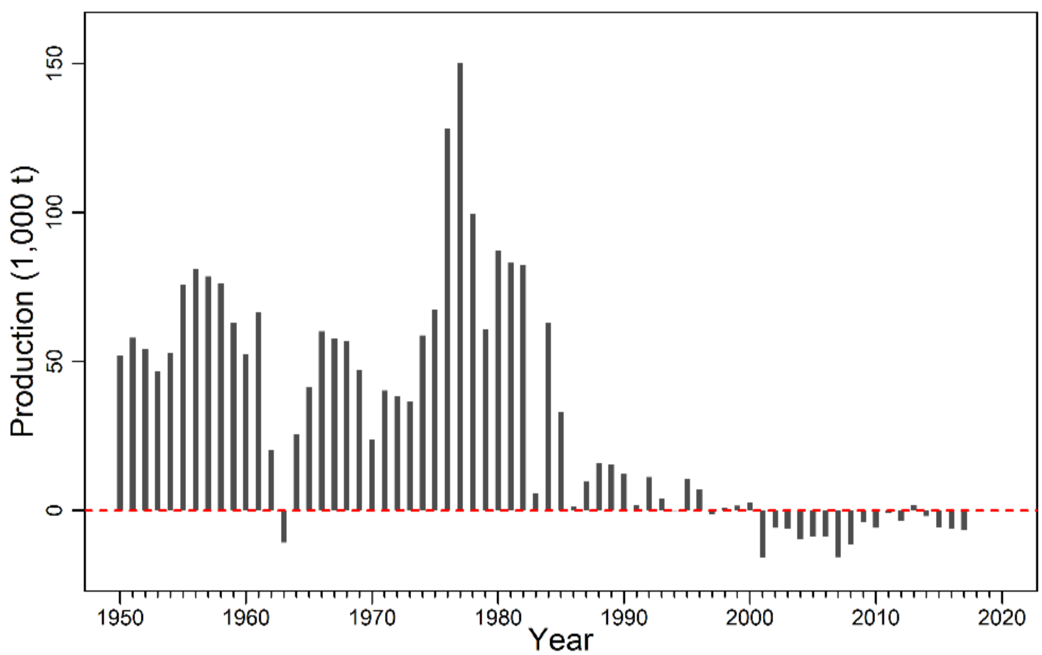


Figure 15. Estimated surplus production (ages 2+) of southern Gulf of St. Lawrence Atlantic Cod, 1950 to 2017.

Due to reductions in intraspecific competition, the per capita rate of population growth is expected to increase as population size decreases. This “compensatory” relationship between production rate and population size helps to maintain populations above very low levels. The sGSL cod stock is exhibiting the opposite behaviour, with the rate of production decreasing as abundance decreases (Fig. 16). This “depensatory” relationship, termed an Allee effect, hinders recovery from low abundance. The rate of production from 2001 to 2018 (with one exception) has been negative, indicative of a strong Allee effect. If this effect persists, it will drive this population to extinction.

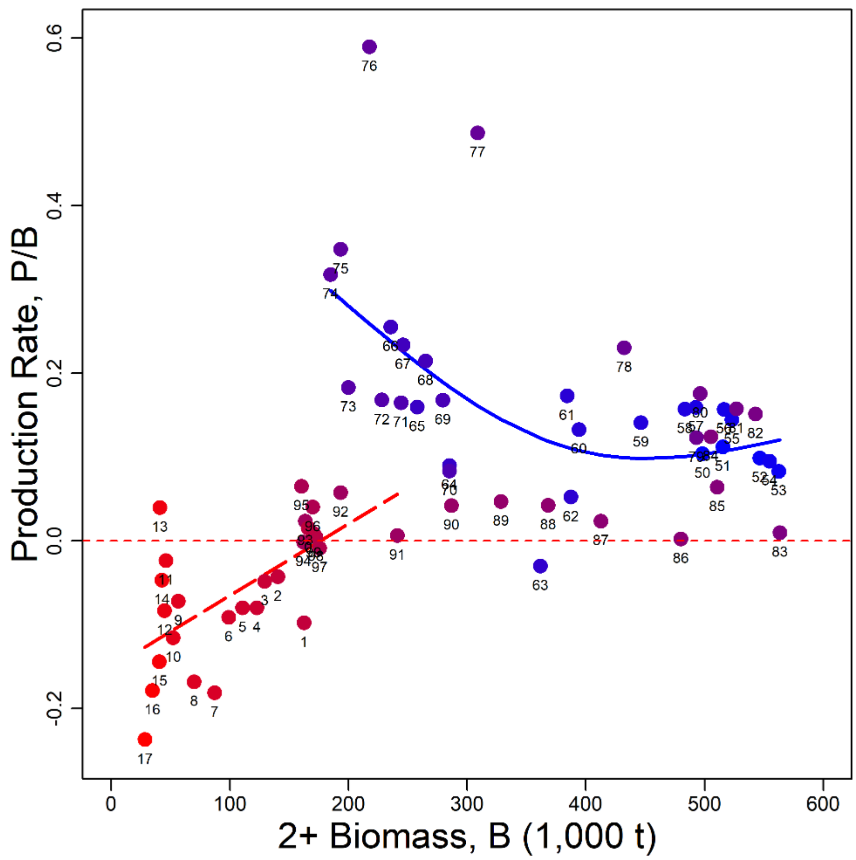


Figure 16. Annual rate of production (P/B; population production in biomass per unit of population biomass) of southern Gulf of St. Lawrence Atlantic Cod, 1950 to 2017. Circle annotations and colours indicate year (from the earliest time period in blue to the latest time period in red). The relationship between population biomass and the rate of population production is shown by the solid blue line for the 1950-1990 period and the dashed red line for the 1991-2017 period.

Predation can be a cause of Allee effects. Based on accumulating evidence, predation by grey seals now appears to be the main cause of the elevated natural mortality of this cod stock and thus of the Allee effect. This evidence includes:

- Increases in *M* coincided with large increases in grey seal abundance (Chouinard et al. 2005).
- Given the estimated spatio-temporal overlap between grey seals and cod, and the energetic requirements of grey seals, it is plausible that predation by grey seals can account for a high proportion of *M* even if the contribution to the seal diet is moderate (15%; Benoît et al. 2011).

- Winter foraging by male seals is concentrated in the vicinity of the overwintering aggregation of sGSL cod (Harvey et al. 2012).
- Grey seals consume much more large cod (ages 5+) than previously thought. Cod contribute 55-77% of the diet based on stomach contents and 33-53% of the diet based on intestines in grey seals feeding heavily in the vicinity of the overwintering aggregation of sGSL cod (Hammill et al. 2014).
- As seal abundance has increased, cod have abandoned their traditional summer foraging grounds and moved into deeper water where risk of predation is lower. Other grey seal prey with elevated natural mortality have exhibited similar changes in space use, but fishes that are not important prey of grey seals have not. This indicates that cod perceive grey seals as an important threat (Swain et al. 2015).
- Predation by grey seals has been incorporated in a population model for sGSL cod via a functional response. Other factors (e.g., poor condition of cod, unreported catch interpreted as natural mortality) appeared to contribute to increases in M in the 1980s and early 1990s. However, predation by grey seals accounted for all of natural mortality in excess of normal levels (M = 0.2,18% annually) since 2000 (Neuenhoff et al. 2019).
- The changes in the spatial distribution of cod in response to increased risk of predation are expected to incur costs to cod (e.g., reduced foraging success). An index of the condition of cod in September has concurrently declined to the lowest levels observed (Swain et al. 2019). Thus grey seals may also increase mortality of cod via non-consumptive risk effects.

Sources of Uncertainty

Directed recreational fishing for Atlantic Cod is still allowed in NAFO division 4T. Harvests from these fisheries are only documented from the charter boat recreational fishery component. Although the harvests in these fisheries are expected to represent a very small proportion of the total annual mortality of cod and insufficient to account for the sustained decline of cod in the southern Gulf, documentation of these catches should be required, particularly for a species at such low abundance and with a high probability of extinction.

As Atlantic Cod distribution has shifted to the offshore slope areas of the Laurentian Channel, they may become vulnerable to capture in fisheries occurring in this area. The recent increase in redfish abundance in the Gulf of St. Lawrence is expected to support a commercial fishery in the near future and will likely be an additional source of bycatch as cod have historically been caught in the redfish fishery in this area.

Increased Atlantic water inflow has resulted in substantial warming of the Laurentian Channel in recent years (DFO 2018), including on the cod overwintering grounds. Southern Gulf cod feed very little over winter, and their energy reserves are depleted over this period. This energy depletion will become more severe as their ambient temperature increases, resulting in possible increases in mortality due to poor cod condition. Even if predation mortality is reduced, recovery of this cod stock may not be possible if warming of these deep waters persists as result of climate change effects and leads to high mortality due to poor condition.

The condition of cod measured in September has declined in recent years to the lowest levels observed in the 48-year record. Historically, body condition of cod occurring in deep waters along the slope of the Laurentian Channel was lower than that of cod occurring elsewhere in the sGSL during the feeding season. This was attributed to reduced prey resources in these deep waters. If food is indeed a limiting factor in this deep water, then declines in condition will become more severe if cod densities increase due to further shifts in distribution into these areas or if temperatures in these deep waters continue to warm.

There is considerable uncertainty about the average annual seal diet in the southern Gulf due to wide spatial, seasonal and individual variation in diet. Furthermore, diet analyses used here rely on the presence of hard parts (such as otoliths) from prey species in seal digestive tracts. Estimated consumption of adult cod would be underestimated if seals tend not to eat the heads of larger cod, a behaviour consistent with foraging strategies observed in some other predators.

It is uncertain whether predation by grey seals will restrict southern Gulf cod to very low levels of abundance or drive them to extinction. This depends on the functional response of grey seals preying on cod. If seals switch to alternate prey when cod abundance becomes very low, cod will be trapped at very low abundance. If switching does not occur, then cod will be driven to extinction via an Allee effect. Based on the population modelling, an Allee effect is consistent with the time trends in cod *M* and seal abundance. It is possible that prey switching will develop at even lower cod abundance. Alternately, an Allee effect may persist because of the aggregative behaviour of cod. Cod occur in dense aggregations during overwintering, spring and fall migrations, and spawning. Even though population size is very low, densities remain very high within these aggregations and they remain an attractive foraging opportunity.

The effect of reduced seal abundance on cod status is uncertain. An expectation would be increased cod abundance, but this could be prevented by indirect effects. Declines in seal abundance could result in increased abundance of other predators or competitors of cod. For example, Atlantic Herring are an important prey of grey seals and a potential predator of the early life stages of cod. Increases in the abundance herring as grey seal abundance declined could result in reduced recruitment success of cod. However, herring are also important prey of cod and the target of a fishery. Other factors may regulate the abundance of herring if grey seal abundance declined.

Limit Reference Point

The limit reference point (LRP) for this stock was established in 2003 based on criteria that depend on the population model used (Chouinard et al. 2003). There have been many model changes since 2003 and the LRP should be revised. For example, one criterion used to establish the LRP was $B_{recover}$, the lowest SSB from which the stock has shown a sustained recovery. The current model estimates $B_{recover}$ to be 107,000 t of SSB, rather than 80,000 t as previously defined. Furthermore, the stock now appears to be experiencing a strong Allee effect. The LRP should be set well above the Allee threshold. This threshold was crossed in 1993 (Fig. 16) when SSB was estimated to be 112,000 t. The LRP should be well above 112,000 t, though this now appears to be a moot point. There is no chance that SSB will exceed 80,000 t at current productivity. Thus, there is no chance that it will exceed a higher value.

CONCLUSION AND ADVICE

Estimated SSB at the start of 2018 is 13,900 t, 17% of the LRP and the lowest level on record. There is no chance that SSB was at or above the LRP at the start of 2018. Projected SSB at the start of 2023 is 9,400 t assuming that there are no fishery catches in 2019 to 2022. There is essentially zero chance that SSB will be at or above the LRP into 2023 even in the absence of fishing. Below the LRP, a stock is considered to have suffered serious harm because the probability of poor recruitment is high. Under the precautionary approach policy (DFO 2009), when a stock is below this level, fishery management actions should give priority to promoting stock growth, and removals by all human sources should be kept to the lowest possible level.

The cod-directed fishery has been closed since 2009, with a 300 t TAC in place to cover bycatch in other groundfish fisheries, Indigenous food, social and ceremonial fisheries, scientific purposes, and a limited recreational fishery. Annual landings since 2009 have varied between 103 and 172 t, but preliminary landings are about 60 t in 2017 and 2018. Since 2009, the exploitation rate has averaged 0.2% for ages 5-8 and 0.7% for ages 9+. Fishing mortality is now so low that it has a negligible impact on the declining population trajectory.

Projected SSB at the start of 2023 is 9,400 t with no fishery catch, 9,300 t with annual fishery removals of 100 t and 9,100 t with annual removals of 300 t. The probability that SSB will decline between 2018 and 2023 is 0.891, 0.896, or 0.991 with fishery removals of 0, 100 or 300 t. There is no longer an opportunity to promote stock growth by reducing fishery removals. Reductions in fishery removals would at best result in a negligible reduction in the rate of decline and time to extinction of this stock.

The sGSL ecosystem is now vastly different from the state that provided a rapid recovery of cod in the early 1980s. Grey seals have dramatically increased from low abundances and many demersal fish species remain severely depleted. High adult mortality due predation by grey seals is estimated to be the main factor causing the ongoing decline of the southern Gulf Atlantic Cod stock.

At the current abundance of grey seals in this ecosystem, recovery of this cod population does not appear to be possible, and its extinction is highly probable (SSB < 1,000 t was used as a proxy for extinction). Projections indicate that even arresting the decline in SSB of cod would require a very large reduction in grey seal abundance (Neuenhoff et al. 2019). Such large reductions in grey seal abundance may result in unexpected indirect effects on cod, such as increases in the abundance of competitors or other predators of cod that are also prey of grey seals. If steps to reduce the abundance of grey seals in this ecosystem were to be planned the possibility of such indirect effects should be examined.

OTHER CONSIDERATIONS

Procedure for Interim Year Updates

The three-year moving average of the RV survey biomass indices for adult (commercial-sized) cod will be used as the indicator of stock status in the interim years of the multi-year management cycle. Commercial-sized cod will be approximated by cod 42 cm and longer instead of the commercial size of 43 cm, because of the 3-cm grouping used in the RV survey prior to 1985. This index will be compared to the LRP value adjusted to the scale of the biomass index, which is not corrected for catchability. The re-scaled LRP is 47,900 t of trawlable biomass in the September RV survey.

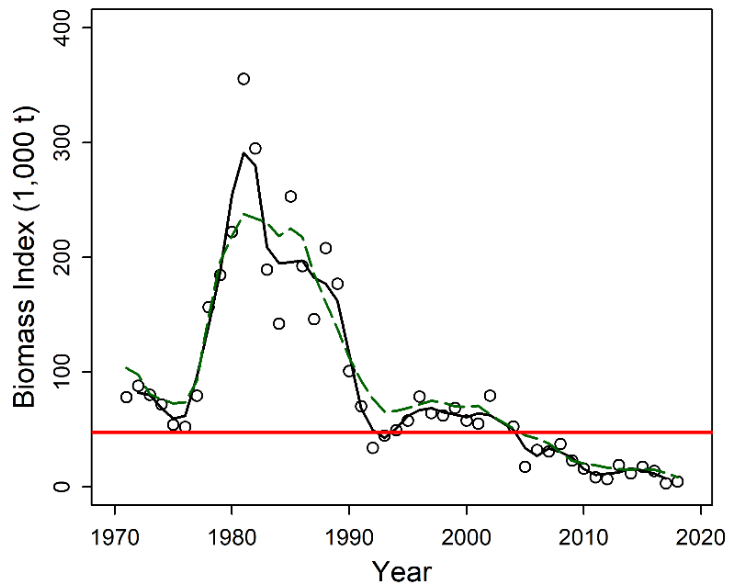


Figure 17. Time trend in the observed biomass index (circles), the index predicted from SSB (dashed green line), and the 3-year moving average of the observed index (solid black line) of Atlantic Cod from the September RV survey of the southern Gulf of St. Lawrence, 1971 to 2018. The horizontal red line is the value of the limit reference point (LRP) and the LRP and the indices are expressed as trawlable biomass (1,000 t).

An assessment before the scheduled four-year cycle would be recommended if the three-year moving average of the RV trawlable biomass index for cod 42 cm and longer exceeds the trawlable biomass re-scaled LRP of 47,900 t. In 2018, the three-year moving average of the RV biomass index (scaled to trawlable biomass) for cod 42 cm and longer was 17% of the re-scaled LRP (Fig. 17).

An interim year update will be provided mid-way in the four-year assessment cycle, i.e. in early December 2020, to allow sufficient time to complete a full assessment and plan the peer review if the indicators signal that a re-assessment is warranted in winter 2021.

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SOURCES OF INFORMATION

This Science Advisory Report is from the February 20-21, 2019 meeting on the Assessment of Atlantic Cod (*Gadus morhua*) of the southern Gulf of St. Lawrence (NAFO Div. 4T-4Vn (Nov. – April)) to 2018 with advice for fishing periods May 2019 to May 2023. 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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MPO. 2019. Évaluation de la morue franche (Gadus morhua) du sud du golfe du Saint-Laurent (Div. de l’OPANO 4T-4Vn (nov. – avril)) jusqu’en 2018. Secr. can. de consult. sci. du MPO, Avis sci. 2019/021.