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Assessment of the southern Gulf of St. Lawrence Atlantic Cod (*Gadus morhua*) stock of NAFO Div. 4T and 4Vn (November to April), March 2019

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The stock of Atlantic Cod (*Gadus morhua*) in the southern Gulf of St. Lawrence (sGSL) (NAFO Division 4T and Subdivision 4Vn (November to April)) supported landings averaging 30,000 tonnes (t) annually between 1917 and 1940 and 56,000 t annually between 1941 and 1992. The stock collapsed in the early 1990s due to high mortality. Moratoria on directed fishing for southern Gulf cod were put in place in 1994-1997, 2003 and since 2009. Reported by-catch in fisheries for other groundfish have averaged 110 t annually since 2009, with catches near 60 t in 2017 and 2018. Estimated fishing mortality since 2009 has averaged 0.2% annually for cod aged 5-8 years and 0.7% for cod 9 years and older. Spawning stock biomass (SSB) and abundance are at the lowest levels observed in the 69-year record and are declining. Estimated SSB at the start of 2018 was 13,947 t, 12% of the already low value in 2000 and 4% of the 1985 value (380,000 t). SSB is estimated to be 17% of the limit reference point (LRP = 80,000 t) with no chance of recovering to the LRP over the next five years, even with no fishing mortality. The probability that SSB will decline between 2018 and 2023 is 90% with annual catches of 0 or 100 t and 99% with catches of 300 t. SSB is projected to decline to 9,400 t at the start of 2023 with no fishery catch and to 9,100 t with annual catches of 300 t. If current conditions were to persist, the population would be expected to decline to extinction by mid-century (SSB < 1,000 t was used as a proxy for local extinction). The ongoing decline of this population is due to the high natural mortality of adult cod (i.e., ages 5 years and older). Natural mortality (M) of about 18% annually (an instantaneous rate of M=0.2) is considered normal for adult cod. In this population, natural mortality of adults has increased over the past 35 years and is now estimated to be about 55% annually (M=0.81-0.85). Predation by grey seals appears to currently be the main cause of this mortality. Based on population models, this predation can account for all of the adult M above the normal level (0.2) since about the year 2000. This cod population appears to be experiencing a predation-driven Allee effect. An Allee effect occurs when the per capita rate of population growth decreases as abundance decreases. This is opposite to the expected increase in population productivity at low abundance due to reduced intraspecific competition. In addition, southern Gulf cod are experiencing a strong Allee effect with a production deficit since 2001. If they persist, strong Allee effects will drive a population to extinction. This Allee effect is caused by the severely depleted abundance of southern Gulf cod and the high and increasing abundance of their grey seal predators. At the current high abundance of grey seals, this cod population is expected to continue to decline toward extinction.

1 INTRODUCTION

The southern Gulf of St. Lawrence (sGSL) stock of Atlantic Cod (*Gadus morhua*) overwinters in dense aggregations in relatively warm water along the southern slope of the Laurentian Channel in the sGSL and the neighbouring Cabot Strait area. In April and early May the stock migrates into the sGSL to spawn and feed, returning to the overwintering grounds in November. Consequently, the management unit for this stock consists of the Northwest Atlantic Fisheries Organization (NAFO) Division 4T as well as subdivision 4Vn from November to April (Fig. 1). This stock has been fished since the sixteenth century or earlier. Landings averaged over 47,000 tonnes (t) in the period from 1917 to 1993, but the stock collapsed in the late 1980s and early 1990s. Following the stock collapse, the fishery was closed from September 1993 to May 1998. The fishery was reopened in 1998 as an index fishery with a total allowable catch (TAC) of 3,000 t. The TAC increased to 6,000 t from 1999 to 2002. The directed fishery was closed again in 2003 but was re-opened with a TAC of 3,000 t in 2004. The TAC was increased to 4,000 t in 2005 and reduced to 2,000 t in 2007. The directed fishery was closed in 2009 and has remained closed since then (with a TAC of 300 t to cover by-catch in other groundfish fisheries, catch in a limited recreational fishery, catch for scientific purposes, and Indigenous food, social and ceremonial fisheries).

A limit reference point (LRP) has been established for this stock, based on the lowest spawning stock biomass (SSB) from which the stock has recovered, as well as the SSB below which the probability of poor recruitment is high. The LRP, established in 2003, is estimated to be 80,000 t of spawning stock biomass (Chouinard et al. 2003).

In its 2003 assessment of Atlantic Cod, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Maritimes Designatable Unit (DU) Special Concern. The sGSL stock was part of this DU. In April 2010, COSEWIC re-assessed Atlantic Cod and split the previous Maritimes DU into two populations, the Laurentian South DU and the Southern DU. The Laurentian South DU, which includes the sGSL cod stock, was designated Endangered, a higher risk category than Special Concern, due to a 90% decline in abundance over three generations. In response to the COSEWIC assessment, a recovery potential assessment (RPA) of the Laurentian South DU was conducted in 2011 based on data to the end of 2009 (DFO 2011; Swain et al. 2012). This RPA concluded that the sGSL cod stock was expected to continue to decline, even with no fishing, if productivity of the stock remained at its current low level. The main cause of low productivity was unusually high natural mortality of cod aged 5 years and older. Fishing mortality at the level it was in 2009 (following the closure of the cod-directed fishery; 1.4% annually for fully-recruited fish) was estimated to have a negligible impact on the probability of population survival, but fishing mortality at the level in 2007-2008 (10% annually for fully-recruited fish) decreased the probability of population survival under the prevailing low productivity conditions. The RPA concluded that the only additional action that could be taken to improve the chances for recovery of southern Gulf cod appeared to be action to reduce the rate of natural mortality on adult (5+) cod. Predation by grey seals was considered to account for a high proportion of this mortality.

The last full assessment of this stock was conducted in 2015, using data up to the end of 2014 (Swain et al. 2015b). The assessment estimated that SSB in 2014 was at the lowest level in the 65-year record (28,700 t, based on the Statistical Catch at Age, SCA population model) and was expected to decline further by 2019. SSB was estimated to be 40% of the LRP with no chance of recovering to the LRP by 2019, even with no fishing mortality. The lack of recovery was attributed to high and increasing natural mortality of adult cod (ages 5 years and older), estimated to be

50-60% annually. The population was expected to continue to decline at this level of natural mortality, even in the absence of fishing. Predation by grey seals was considered to be a major cause of this mortality.

This report describes the fisheries for the sGSL cod stock for 2015 to 2018 and provides an assessment of stock status to Jan. 1, 2019 based on research, sentinel and fishery data available to the end of 2018. A population model is fit to these data to provide estimates of population size and rates of fishing and natural mortality. Projections of population biomass over the 2019 to 2023 period are also provided, along with estimates of the uncertainty in these projections. An ecosystem approach is taken to identify causes of the changes in productivity of this stock and to evaluate options for reversing its ongoing decline.

2 THE FISHERY

2.1 LANDINGS

Annual landings of sGSL cod averaged 30,000 t between 1917 and 1940 (Fig. 2). Landings increased following the introduction of otter-trawling in the 1940s, reaching a peak of 104,000 t in 1956 and averaging 56,000 t annually between 1941 and 1992. The first TAC was established at 63,000 t in 1974, declining to 15,000 t in 1977 (when 27,000 t were landed; Table 1). The TAC then increased to a peak of 67,000 t in 1984 and 1985. Landings also increased, averaging 61,000 t in the 1980s with a peak of 69,000 t in 1986. Landings began to decline in the early 1990s and the fishery was closed in September 1993 due to low cod abundance. During the first moratorium on directed cod fishing, reported landings of cod by-catch averaged 1,300 t annually. Following an “index” fishery in 1998 (3,000 t TAC), the directed cod fishery re-opened in 1999 with a TAC of 6,000 t. Annual landings averaged 5,800 t in 1999-2002. The cod fishery was closed a second time in 2003. Reported by-catch in 2003 was 289 t, considerably lower than by-catch during the first moratorium. The directed fishery re-opened again in 2004 but was closed in 2009. The TAC varied between 4,000 and 2,000 t during the re-opening. Reported landings averaged 2,264 t and were consistently below the TAC (averaging about 75% of the TAC). The directed cod fishery has remained closed since 2009. Annual reported by-catch of cod landed in other groundfish fisheries (including the mobile and fixed sentinel fishery surveys) averaged 110 t over the 2009-2018 period (Table 1).

Prior to the collapse of the stock and the closure of the directed fishery in 1993, catches by mobile gear (otter trawls and seines) dominated the landings reported since 1965 (Table 2). Catches by fixed gears have been a more important component of the landings since 1994, and have dominated the landings since the closure of the directed fishery in 2009 (Table 2).

The proportion of cod catches is summarized by month, gear type and target species in Figure 3 for the 1991 to 2017 period. The most important sources of by-catch were American Plaice directed trips in the 1997 to 2004 period, Witch Flounder directed trips in the 2006-2017 period, and trips directing for Atlantic Halibut since 2009. By-catch rates were highest on trips directing for Atlantic Halibut, Witch Flounder and Greenland Halibut (Figs. 3 to 7). The recent return of redfish in the Gulf of St. Lawrence (Senay et al. 2019) and the fact that it will support a sizable fishery in the near future will likely be an additional source of by-catch as cod have historically been caught in the redfish fishery.

During the moratorium since 2009, catches of cod by mobile gears have occurred primarily in May and June in the Cape Breton trough, along the slope of the Laurentian Channel and east of the Magdalen Islands (Fig. 4). Most of these catches were from the Atlantic Halibut fishery, with the Witch Flounder and redfish fisheries also contributing to the by-catch. Catches were sparser in July to October, and mostly occurred along the southern slope of the Laurentian Channel and in the Cape Breton Tough in the Witch Flounder and redfish fisheries (Figs. 3 to 7). Catches by fixed gears occurred from April to October, primarily in the Atlantic halibut fishery (though 20-30% of the trips landing cod were identified as cod-directed trips) (Fig. 3, also see Swain et al. 2015b). Catches by fixed gears were highest in the Cape Breton Trough in April and June and near American Bank off the Gaspe coast in July and August. Catches also occurred off Miscou, along the north coast of PEI and around the Magdalen Islands in July to October. The sentinel programs contributed 15-25% of the landings during the moratorium, with 80-90% of the sentinel landings made by the longline program (Appendix A; Tables A.1 to A.5). Additional details related to the distribution of landings between months and gears are available in Appendix A for the recent period.

A recreational fishery also occurred during the moratorium, with openings of five weeks or less. This fishery had a daily bag limit of five Atlantic Cod and/or White Hake. Landings are not reported but DFO Fisheries and Aquaculture Management Gulf Region indicated these to be about 5 t in Gulf Nova Scotia in 2008, and are likely to be lower now. A similar estimate has been provided for the north shore of the Gaspe Peninsula in 2013. Charter boats fishing with rod and reel were also permitted to operate in LFA 24 and LFA 26a (groundfish management zones 4T2b and 4T8, Fig. 8) between July 1 and September 15 under a licence to fish for educational purposes. This fishery had a limit of 20 Atlantic Cod per trip to a maximum of 60 cod per calendar day. 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 Atlantic Cod catch by charter boats in 2017 was 10.2 t, with 7.0 t landed and 3.2 t released.

2.2 FISHERY CATCH-AT-AGE

2.2.1 Age Determination

Consistency of age determinations was verified by regular blind tests against a reference otolith collection. Tests were performed prior to the beginning of ageing and after every 500 – 1,000 fish had been aged. Each test consisted of readings of approximately 120 otoliths. The level of agreement with the reference collection varied between 85-93% with no bias detected. The minimum acceptable level of agreement is 75%. Based on these results, the consistency of age readings was considered to be adequate.

2.2.2 Catch-at-age

In most years there were four age-length keys: commercial mobile gears (usually April or May to October or November), commercial fixed gears (usually April to October or November), sentinel longline (July to November) and mobile sentinel (August). In some years, there were two keys for commercial mobile or sentinel longline, each covering shorter time periods. The catch-at-age for the unsampled catch (0.01 - 3.6 t depending on year) was calculated by prorating the catch-at-age by the ratio of total to sampled commercial landings. In 2018 a single key was used for both commercial and sentinel longline. Details for 2015 to 2018 are given in Appendix B.

Mean weights-at-age in the commercial catch were calculated for each year based on the length distribution in the samples of the catch in that year and the parameters of the length-weight relationship in that year (estimated using data from the September research vessel survey).

Details are given in Tables B.1 to B.7 of Appendix B for 2015 to 2018.

The most common age in the fishery catch was either 5, 6 or 7 years old in most years prior to the stock collapse and 7 years old in most years since the collapse at the beginning of the 1990s (Table 3). Weight-at-age in the catch declined between the late 1970s and the mid to late 1980s (Table 4). Catch weight-at-age has increased since the mid-1990s, possibly reflecting changes in the gear composition and thus the size-selectivity of the fishery.

3 ABUNDANCE INDICATORS

3.1 DFO BOTTOM-TRAWL SURVEY

3.1.1 Background

A research vessel (RV) survey of the sGSL has been conducted each September since 1971. This survey follows a stratified-random design, with stratification based on depth and geographic area (Fig. 9). Fishing was by the *E.E. Prince* using a Yankee 36 trawl from 1971 to 1985, by the *Lady Hammond* using a Western IIA trawl from 1985 to 1991, by the *CCGS Alfred Needler* using a Western IIA trawl from 1992 to 2005 (except 2003), and by the *CCGS Teleost* using a Western IIA trawl since 2004. When gear and/or vessels were changed, comparative fishing experiments were conducted and conversion factors have been applied where necessary (Benoît and Swain 2003; Benoît 2006) to maintain the consistency of the time series.

In 2003, the regular survey vessel, the *CCGS Alfred Needler*, was disabled by a fire and the survey was conducted by the *CCGS Wilfred Templeman*. However, the start of the survey was delayed, and only 83 fishing stations were surveyed. Three strata (402, 425 and 436; see Fig. 9) were sampled with only one fishing set and two strata (438 and 439) were missed altogether. Estimates for the missed strata were obtained using a general linear model (Chouinard et al. 2005a). Despite the correction for missed strata, numbers per tow for 2003 were the lowest in the time-series (prior to the 2010 to 2012 surveys; Table 5). Because of the difficulties with the survey, the index for 2003 is considered anomalous and is not used to fit population models.

In 2004 and 2005, the survey was conducted by two vessels, the *CCGS Teleost* and *CCGS Alfred Needler*, both using the Western IIA trawl. During both surveys, comparative fishing experiments were conducted, with the two vessels trawling side-by-side. These experiments showed no significant difference in the catchability of cod between the two vessels (Benoît 2006). Stratified abundance estimates for cod for 2004 and 2005 were calculated by averaging catches of the two vessels that occurred at the same location.

3.1.2 Taxonomic Issue

It is difficult to distinguish between Atlantic Cod (*Gadus morhua*) and Greenland Cod (*G. ogac*) at lengths less than 15 cm (< 15 cm). Gadoids of this size were collected during the 2013 and 2014 surveys in the Northumberland Strait and the southern Gulf of St. Lawrence, and identified to species based on genetic analysis. Most of the individuals collected from the central and eastern Northumberland Strait (strata 402, 403, 432 and 433) were *G. ogac* (Fig. 10). This consisted in most of the individuals collected. In other strata, the majority of individuals were *G. morhua*, though *G. ogac* were also widely distributed in these other strata. Some of the regions that are now dominated by small *G. ogac* (e.g., stratum 433) likely contained a higher proportion of small *G. morhua* in earlier years (the 1970s to 1990s). Because it does not appear to be possible to distinguish between these species at this small size based on morphology or distribution, we have omitted gadoids less than 15 cm in length from our analyses in all years in this assessment. This has no effect on the population modelling because cod of this size are all age 1 or less (mostly young of the year) whereas the population models start at age 2.

3.1.3 Abundance and biomass indices

The survey catch rates indicate that the stock was at a low level in the early to mid-1970s, increasing rapidly in the late 1970s to relatively high levels of abundance and biomass in the early to mid-1980s (Fig. 11). Abundance and biomass decreased rapidly in the late 1980s and early 1990s, and the stock has been at a low level since then. The RV abundance and biomass indices for 2017 and 2018 are the lowest in the 48-year time series.

Catch rates of cod at pre-commercial sizes ($<$ 42 cm; corresponding roughly to juvenile cod) generally declined slowly from 1992 to 2018 (Fig. 12a, 12b). This declining trend was interrupted by relatively high catch rates of small cod in 2002, 2004, 2009 and 2013-2014. However, uncertainty in the indices in these years was high, and these relatively high catch rates of small fish were not reflected in increased catch rates of large fish in subsequent years.

Catch rates of cod at commercial sizes ($\geq$ 42 cm; corresponding roughly to adult cod) recovered slightly in the early 1990s but declined substantially between 2002 and 2018 (Fig. 12c, 12d). Mean catch rates at these sizes in 2017 and 2018 were 5 and 8% of the average level in the 1995-2002 surveys, respectively. In conclusion, catch rates in the RV survey indicate that commercial-sized cod are at record-low levels of abundance and biomass, and have declined severely from the already low levels observed in the late 1990s and early 2000s.

3.1.4 Geographic distribution

Striking shifts in the geographic distribution of cod in the sGSL in September are evident over the long term (Figs. 13 and 14). In the early 1970s, cod densities were highest in western regions of the sGSL, including the area between PEI and Miramichi Bay. As cod abundance increased to a high level in the 1980s, distribution expanded, with relatively high densities throughout the Magdalen Shallows. As abundance declined to a low level in the 1990s, distribution contracted out of the central Magdalen Shallows, with densities highest in a band extending from Miscou, and along the northern coast of PEI, into the Cape Breton Trough and along the southern slope of the Laurentian Channel between Cape Breton and the Magdalen Islands. Since the early 2000s, cod distribution has progressively shifted out of inshore areas into deeper water along the southern slope of the Laurentian Channel. Cod are now rare throughout most areas of the sGSL, including inshore areas where cod densities were once highest (e.g., Chaleur Bay, Miscou and the Shediac Valley, along the northern coast of PEI). Cod distribution is now largely restricted to deeper waters along the south slope of the Laurentian Channel. The progressive shift in cod distribution out of shallow inshore areas throughout the 2000s appears to be related to increased risk of predation by grey seals in these areas (Swain et al. 2015a).

3.1.5 Length distribution

In addition to a large decline in abundance, length distributions of cod caught in the RV surveys indicate a disproportionate loss of large individuals in recent years (Fig. 15). Throughout the 1980s, 1990s and early 2000s, cod above the minimum commercial length (43 cm) made up a high proportion of the survey catch. This proportion has declined substantially in recent years. In the 2006-2008 surveys, the proportion of commercial-sized cod averaged 51% of the survey catch. This proportion declined to 23% in the 2012 survey and 13.5% in the 2013 and 2014 surveys. The decline between 2012 and 2013 reflects the relatively high catches of small cod in 2013 and 2014. However, in 2017 and 2018, this proportion was only 14% and 17% respectively, even though catches of small cod remained low.

3.1.6 Age composition

Catch rates in the RV survey indicate the abundance of older cod had declined to very low levels in the 2010s, especially in 2010-2012, 2017 and 2018 (Table 5; Fig. 16). Declines in the catch rates of younger cod were not as severe, with catch rates of 3-year-old cod in 2013 and 2014 the highest seen since 1990.

3.1.7 Size-at-age and condition

The predicted weight in September of an Atlantic Cod 45 or 55 cm in length was used as an index of condition. This index was based on the annual length-weight relationships estimated from the survey data. Estimated condition was relatively high in the early to mid-1970s, declining to relatively low values in the early to mid-1980s (Fig. 17). Condition recovered to average levels throughout the 1990s and early 2000s but declined to lower levels in recent years. Condition is now at the lowest level in the 48-year record. The high condition in the mid-1970s and the subsequant decline to low values in the early to mid-1980s may reflect density-dependent changes in intra-specific competition for food resources, with competition low when cod abundance was low in the mid-1970s and high at the high abundance in the 1980s. Condition would be expected to be high in the recent period given the low cod abundance (i.e., low intraspecific competition) and relatively warm conditions. The current low condition may reflect the high risk of predation by grey seals (see section 6 below).

Declines in mean length and weight-at-age of sGSL cod occurred between the late 1970s and mid- to late 1980s (Tables 6 and 7; Fig. 18). This was caused by a decline in growth rate and a change in the direction of size-selective fishing mortality (Sinclair et al. 2002a, 2002b). Size-at-age in the RV survey catches has remained stable at a low level since then. In contrast, size-at-age has shown some increase in commercial catches since then, particularly for age-5 cod. Changes in gear, in particular increased importance of longlines in the fishery (i.e., the longline sentinel fishery and the commercial halibut fishery) may contribute to this increase.

3.2 MOBILE SENTINEL SURVEY

The mobile sentinel (MS) survey, conducted each August since 2003, is a stratified-random bottom-trawl survey using the same stratification scheme as the RV survey. Each year the survey is conducted by four commercial fishing vessels, each using the same standardized otter trawl (the 300 Star Balloon) and standardized fishing protocols (see Savoie (2012) for details). Each year, the four vessels fish in overlapping areas, with each vessel assigned random fishing locations in most survey strata.

There have been nine vessel changes between 2003 and 2018. In order to account for these vessel changes, the relative fishing efficiency (E) of each vessel for cod was estimated each year. In previous assessments, E was estimated using a generalized linear model assuming a quasi-Poisson error distribution with overdispersion. When significant vessel effects were identified, further hypothesis tests were performed to determine which vessels could be grouped together under the same relative fishing coefficient. The model was then re-run to estimate coefficients for the vessel groups. See Swain et al. (2015b) for further details.

An alternate method was developed for this assessment. This new approach was based on a Generalized Additive Model with a negative binomial error distribution. Like the original model, the full model included parametric terms for year, stratum and vessel. In addition, a time-invariant spatial smooth over UTM (NAD83) coordinates (i.e., geographic position) and a smooth over log-transformed (log_e) water depth were included in the full model. The full model was compared to models incorporating subsets of the above model terms based on their respective Akaike Information Criteria (AIC). Unlike in the previous method, there was no attempt to combine vessels into groups with similar fishing efficiency. Instead, a correction factor was estimated for each vessel to standardize for variation in fishing efficiency. Catches were standardized for variation in distance towed by including tow distance as an offset. The same reference vessel was used in both approaches, the Miss Lamèque (vessel 151347), as it is the vessel with the longest history in the program (from 2003 to 2013).

Results from the two approaches were compared for this assessment. All three main effects were highly significant in the original method (Table 9). Substantial variation in E was identifed among the 12 vessels (Table 10). Based on pairwise comparisons between the vessels, E of two vessels (5688, 11873) did not differ from E of the reference vessel (151347). The remaining vessels were combined into three groups whose E relative to the reference vessel were estimated to be 0.6084, 1.4894 and 3.1810 (Table 10).

In the new approach, the full model was the best model based on AIC (Table 11). Differences in relative fishing efficiency were highly significant for 6 of the 12 vessels (Table 12).

Catch rates over the 16-year time series were adjusted using the correction factors in Table 12. Catches are compared between the two standardization methods and with the unstandardized catches in Figure 19. Trends were similar between all three time series over 2003-2013 and 2014-2018 for both abundance and weight (Fig. 19a, b). There was a shift in scale between 2013 and 2014, reflecting the introduction of two new vessels with high fishing efficiency (11502, 151573) in 2014. Standardizing catches for differences in fishing efficiency corrected for this break in the time series for the most part, especially using the new method. While there are minor differences in the time series from 2010 to 2013, the overall trend is very similar between the two methods and leads to the same conclusions about stock status (Fig. 19c). We chose to use the new method as the basis for advice because it performed better at maintaining the consistency within the time series and was more objective, eliminating the need to combine vessels into groups.

The abundance and biomass indices showed a declining trend over the 16-year history of this survey. The 2003 and 2004 indices were the highest in the time series whereas the 2017 and 2018 indices were the lowest, at about 10% of the 2003-2004 level.

The geographic distributions of catches in the sentinel survey in August (Fig. 21) are generally similar to those in the RV survey in September (Fig. 14). Catches in the sentinel survey show the same shift in distribution out of shallow inshore areas and into deep water along the southern slope of the Laurentian Channel as is observed in the RV survey.

The proportion of cod above the minimum commercial size of 43 cm has not varied as widely in the MS survey as observed in the RV survey (Fig. 20 vs. 15). This partly reflects the short history of the mobile survey, as well as the lower catchability of small cod to the sentinel bottom trawl. The main feature of the length distribution of mobile sentinel catches is an extreme decline in overall abundance rather than a contraction of length distribution.

Cod aged 3-5 years account for about 60% of the mobile sentinel catch (Table 13). Unlike in the RV survey, catches of 2 and 3 year old cod were not unusually high in the 2013 and 2014 sentinel surveys. No trends in size-at-age were apparent over this relatively short time series, except for an apparent increase in the weight-at-age of older ages in recent years (e.g. 9+ cod; Table 14).

3.3 LONGLINE SENTINEL PROGRAM

Sentinel longlines (LL) have been fished with consistent protocols since 1996. Each participating vessel is required to fish at two traditional fishing areas that were originally recommended by the participating fishermen (or their association). The fishing locations are 2.5 miles in radius and at least 5 miles apart. Once the locations were determined, they remained constant throughout the years. However, new sites have been incorporated since 1996 and several have been discontinued. Each vessel fished its gear a maximum of 18 times during the fishing season, with a maximum frequency of twice per week. The fishing days could be consecutive within each 7-day period. A maximum of 1,250 hooks (size 12 circle, 1 fathom apart) were set at each site. Soak time was a minimum of 4-6 hours and a maximum of 24 hours. On each fishing trip, detailed information was collected by fisheries observers on the catch composition and length frequency. Observers also collected material for age determination.

In 2014, there were 36 fishing sites in the sentinel longline program, distributed throughout inshore areas of the sGSL. Four sites were discontinued in 2016 and two in 2017. The locations of the sites for the 2017 season are shown in Figure 22. In order to comply with the North Atlantic Right Whales (NARW) regulations, two additional sites (205, 214) were cancelled and two (511 and 512) could not be fished in 2018. In 2018, the fishing protocol was also changed, with the maximum soak time reduced from 24 to 8 hours. The 2018 value has therefore been excluded from the longline index pending evaluation of the impact of this change in protocol.

Catch rates were standardized using a multiplicative analysis (Robson 1966; Gavaris 1980) with the SAS GLM procedure (SAS Institute Inc. 1989). The approach is similar to that used by Chouinard et al. (2000). Observations of catch and effort for each individual site were aggregated on a monthly basis. Data cells (eg. monthly aggregates) where effort was less than one complete fishing day were eliminated from the analysis. Analyses were restricted to the July-October period, except for the Cape Breton Trough sites which were not fished in July. Sites that have been fished in at least four years were included in the analysis. Catch rate data were log-transformed ($\log_e$) after adding a constant (1) to each catch rate to deal with zero catch rates.

The model was as follows:

$$\log A_{ijk} = \beta_0 + \beta_1 I + \beta_2 J + \beta_3 K + \epsilon \quad (1)$$

where A_{ijk} is the catch rate (+1) for year i during month j at site k, I is a matrix of 0 and 1 indicating year, J is a matrix of 0 and 1 indicating month, and K is a matrix of 0 and 1 indicating site.

Results of the catch rate standardization are shown in Tables 16, 17 and 18. The model accounted for 65% of the variation in catch rates aggregated by site, month and year. Effects of site, month and year were all highly significant (P<0.0001, except P=0.0012 for month based on the Type III analysis).

Standardized catch rates declined steadily between 2004 and 2011 (Fig. 23). The catch rate in 2011 was 12% of the 1995-2004 average. Catch rates remained at a low level in 2012-2017, averaging 18% of the 1995-2004 level. Declines in the sentinel longline catch rates are greater for older ages (Table 19).

4 POPULATION ANALYSES

4.1 SURVEY-BASED ANALYSES

4.1.1 Relative year-class strength

Catch rates at ages 2 and 3 years in the RV and mobile sentinel surveys were analyzed with a multiplicative model to obtain estimates of relative year-class abundance. Ages 2 and 3 were used in the analysis to minimize effects of fishery exploitation on year-class abundance. The model was:

$$\log A_{ijs} = \beta_0 + \beta_i + \beta_j + \beta_s + \beta_{is} + \epsilon \tag{2}$$

where A_{ijs} is the survey index at age i and year-class j in survey s, β_i is a parameter for the effect of age, β_j is a vector of parameters for the effect of year-class, β_s is a parameter for the survey effect, and β_{is} is a parameter for the interaction between survey and age. The interaction term was included to account for differences in recruitment at age to the two surveys. All log transformations use log_e.

The model accounted for 87% of the variation in log catch rates. Effects were highly significant for age, survey and year-class ($P \leq 0.0001$) but not for the interaction term ($P = 0.32$). Estimated year-class strength was relatively low in the late 1960s and early 1970s but increased to a high level for year classes produced from the mid-1970s through the mid-1980s (Fig. 24). Year-class strength declined in the late 1980s and then fluctuated throughout the 1990s and 2000s at a low level comparable to that in the late 1960s and early 1970s. Year-class strength declined further in recent years, with the 2014 year-class the lowest on record.

4.1.2 Mortality estimates

Trends in fishing mortality can be described using a relative index obtained from the ratio of fishery catch-at-age divided by the RV population estimates at age (Sinclair 1998). Provided that the survey index occurs close to the middle of the fishing year, these relative fishing mortality (F_r) estimates are insensitive to changes in natural mortality.

Relative fishing mortalities were high in the early 1970s, followed by a decline in the late 1970s (Fig. 25) as stock abundance increased (Fig. 12). F_r was stable throughout most of the 1980s, but increased beginning in about 1989 to a peak in 1992. With the closure of the cod fishery in September 1993, F_r dropped to the lowest level previously seen, and with the continued fishery closure, F_r declined further in 1994 and remained low until a limited commercial fishery was opened in 1999. This fishery, with a TAC of 6,000 t, resulted in an increase in F_r well above the very low levels during the moratorium. With the closure of the cod-directed fishery in 2003, F_r returned to levels near zero. The cod-directed fishery again re-opened in 2004 with a TAC of 3,000 t, increasing to 4,000 t in 2005 and 2006. This fishery resulted in levels of F_r above the levels observed in 1993 when the fishery was first closed. The TAC was reduced in 2007, resulting in a reduction in F_r. The directed fishery was again closed in 2009, and has remained closed since then. F_r has been near zero during the current moratorium.

Estimates of the instantaneous rate of total mortality (Z) were derived from the catch rates at age in the September RV and the August sentinel surveys. Estimates were obtained using analysis of covariance as described in Sinclair (2001). Analyses were conducted in 5-yr blocks, with log catch rate as the dependent variable, age as the covariate and year-class included as a factor (to control for variation in year-class strength). Ages 7-11 were used as these ages appear to be fully recruited to these surveys. Time series of relative fishing mortality for ages 7-11 averaged over the same 5-yr blocks, are compared to the time series of Z estimates. Z is an instantaneous rate whereas F_r is an annual rate.

Based on the RV survey catch rates at age, Z increased sharply in the late 1980s, peaking at values greater than 1.0 and then dropped sharply with the closure of the fishery in 1993 (Fig. 26). These changes in Z reflected changes in fishing mortality. However, Z remained high following the closure of the fishery. Based on the RV data, estimated Z was about 0.55 during the mid to late 1990s, increasing to values between 0.63 and 1.16 (mean 0.85) in the 2000s. The August sentinel trawl data also indicated high Z in the 2000s, with estimated values between 0.61 and 0.99 (mean 0.79).

The estimates of Z during the fishing moratorium in 1994 to 1997 indicate that the instantaneous rate of natural mortality (M) was 0.5 or higher during this period. Estimated Z in 1994 to 1997 was 0.56 (95% credible interval (CI) 0.49 - 0.63). Relative fishing mortality (ages 7-11 years) during this period averaged 0.025. Thus, even assuming that catchability to the survey is 100%, the contribution of estimated fishing mortality to Z during this period is negligible. It might be hypothesized that high Z during this period reflects high levels of unreported catch rather than high M. However, even if fishery removals were three to four times the reported landings during the moratorium (which is very unlikely), M would need to be 0.4 or higher to account for the estimated Z. The very high Z estimates throughout the 2000s indicate that natural mortality has increased to even higher levels, though the uncertainty in the recent estimates is high due to possible year effects in the survey data.

Earlier studies obtained estimates for M of southern Gulf cod using data from the 1970s and earlier (Dickie 1963; Beverton 1965; Myers and Doyle 1983). The estimates from these studies vary between 0.07 and 0.1-0.2. Our estimates of Z and F_r indicate that there have been large increases in M between the 1970s and the 1990s.

4.1.3 Age at maturity

Earlier assessments of sGSL cod have assumed that age at maturity has not varied over time (e.g., Swain et al. 2009). In these assessments, it was assumed that the percent mature was 12.1% for 3-year-olds, 36.8% for 4-year-olds, 72.1% for 5-year-olds, 90.5% for 6-year-olds, 97.4% for 7-year-olds, and 100% for older fish. However, recent research has indicated that age and size at maturation of sGSL cod decreased sharply over time in cohorts produced in the 1950s and 1960s, but has changed little since then (Swain et al. 2011; see Fig. 27 and Table 8). When mortality is high, fitness tends to be greater for individuals that mature early. The decline in age and size at maturity between the late 1950s and the early 1970s is thought to reflect an evolutionary response to high fishing mortality in the 1950s and 1960s. The continued early maturation following the sharp reduction in fishing mortality in the early 1990s is thought to reflect the current high natural mortality.

In this and recent assessments (e.g., Swain et al. 2015b), changes in age at maturity have been taken into account when calculating SSB. The maturity ogives used in this calculation are given in Table 8. Because changes in maturation have now been taken into account, SSB no longer represents a consistent measure of the biomass of large individuals (e.g., commercial-sized cod) in the population. For example, the biomass of commercial sized cod was relatively high in the 1950s (see section 4.3.2 below). However, many of these cod were not mature and are not included in SSB. Thus 5+ biomass is presented in addition to SSB in the analyses below in order to provide a consistent measure of variation in population biomass at commercial sizes.

4.2 POPULATION MODELS

4.2.1 Methods

An age-structured population model, implemented in AD Model Builder (Fournier et al. 2011), was fit to the sGSL cod data. Virtual Population Analysis (VPA) has historically been used in assessments of sGSL cod. Both VPA and Statistical Catch at Age (SCA) were used in the last assessment of this stock (Swain et al. 2015b). Results were very similar between the two models and led to the same conclusions about stock status. SCA has some statistical advantages over VPA, and was used to model the stock in this assessment.

The model extended from 1950 to 2018 and from age 2 to ages 12+ (i.e., 12 years and older). Data inputs were total annual fishery catch (tonnes), age-aggregated (ages 2-11) trawlable biomass in the RV and MS surveys, age-aggregated standardized catch rates (kg per 1,000 hooks) for ages 5-11 in the sentinel longline program and proportions at age in the fishery (ages 2-12+), RV and MS catches (ages 2-11) and in the longline program (ages 5-11).

Fu and Quinn (2000) and Jiao et al. (2012) demonstrated that it is possible to estimate time-varying M using length- or age-structured population models. Our model estimated independent time series of M for three age groups: ages 2-4 ($j = 1$), 5-8 ($j = 2$) and 9+ ($j = 3$). These time series were estimated on the log scale as random walks:

$$\log\left(M_{j,t}\right) = \begin{cases} \log M_j^{init} & \text{if } 1950 \leq t \leq 1971 \\ \log\left(M_{j,t-1}\right) + Mdev_{j,t} & \text{if } t > 1971 \end{cases} \tag{3}$$

$$Mdev_{j,t} \sim \text{Normal}\left(0, \sigma_j^M\right) \tag{4}$$

where $\log M_j^{init}$ is $\log(M)$ for age group j in 1950 to 1971. $\log M_j^{init}$ and $Mdev_{j,t}$ are parameters estimated by the model. The $Mdev_{j,t}$ were assumed to be normally distributed with a mean of 0 and σ_j^M fixed at 0.075 for all j. The random walk started in 1972, the second year in the time series with abundance index data. Priors were supplied for M_j^{init}. These priors were normally distributed with means of 0.65, 0.15 and 0.15 for cod aged 2-4, 5-8 and 9+ years, respectively. For ages 5+, prior means were based on empirical estimates of M of sGSL cod in the 1950s and 1960s (see above). The prior mean for ages 2-4 was selected based on empirical relationships between M and length and growth characteristics of marine fishes (Gislason et al. 2010). Standard deviations for the M priors were set at 0.05 for all age groups (i.e $M_1^{init} \sim N(0.65, 0.05)$, $M_2^{init} \sim N(0.15, 0.05)$ and $M_3^{init} \sim N(0.15, 0.05)$). While the sGSL cod data are informative regarding the level and trend in M of 5+ cod, they provide little information on the level of M at ages 2-4 years (Swain 2012; Supplementary Information in Swain and Benoît 2015). Thus, the estimates of M at ages 2-4 years are strongly influenced by the prior for M. However, the estimates for age 2-4 M have no impact on the estimates of mortality and abundance at older ages (Swain 2012; Supplementary Information in Swain and Benoît 2015).

Selectivity $s_{g,a,t}$ was indexed by sources of catch g, age a and year t. Fishery selectivity ($g = 1$) and selectivity in the surveys (RV, $g = 2$; MS, $g = 3$) and the LL program ($g = 4$) were assumed to be logistic functions of age. For the commercial fishery, separate functions were fit for four time periods: 1) 1950 to 1959 ($p = 1$), 2) 1960 to 1975 ($p = 2$), 3) 1976 to 1993 ($p = 3$) and 4) 1994 to 2018 ($p = 4$) (i.e. $S_{1,p} = f\left(s_{1,a,t}\right)$ and $t \in 1950, 1951, \dots 1959$ for $p = 1$, etc.). These time periods were chosen based on an examination of partial recruitment curves produced by VPA in the previous assessment.

Population abundance at all ages in year 1 ($N_{a,1}$ for $a \in 2, 3, \dots 12+$) and at age 2 in year 2 ($N_{2,2}$) was estimated based on estimates of R (recruitment to age 2) for each of these cohorts (see Table 2, equations T2.6 to T2.9 in Neuenhoff et al. 2019). For older ages a ($a \in 3, 4, \dots 12+$) in year 1, abundance in year 1 was estimated by projecting these cohorts forward from age 2 to their age in year 1. This involved estimating the following parameters: average $\log R$ ($\overline{\log R}$), 12 deviations around average $\log R$ ($Rdev_t$), and F_{init} (F in years prior to 1950).

In other years, abundance of age-2 recruits was estimated as recruitment rate in year t (RR_t) multiplied by SSB in year $t - 2$. Recruitment rate (RR) was modeled based on average log RR ($\overline{\log RR}$) plus annual deviations around the average log RR:

$$\log RR_t = \overline{\log RR} + RRdev_t \tag{5}$$

The recruitment rate deviations were assumed to be auto-correlated. The log deviations around $\overline{\log R}$ and $\overline{\log RR}$ were assumed to be normally distributed with a mean of 0 and standard deviation of 0.5 ($Rdev_t \sim N(0, 0.5)$ and $RRdev_t \sim N(0, 0.5)$).

After recruitment to age 2, cohorts were projected forward in the usual manner:

$$N_{a,t} = N_{a-1,t-1} * exp\left(-Z_{a-1,t-1}\right) \tag{6}$$

where $Z_{a,t} = s_{1,a,t}F_t + M_{a,t}$ and a and t index age and year, N denotes abundance, Z is total mortality, M denotes natural mortality, F is fully-recruited fishing mortality and $s_{1,a,t}$ is selectivity at age a in year t in the fishery.

The objective function for the model included the following components:

- Discrepancies between observed and predicted values of the age-aggregated biomass indices for the RV and MS surveys and the LL program. Indices were assumed to be lognormally distributed with standard deviations τ_I (parameters to be estimated; see Table 2 and equations T2.6 to T2.9in Neuenhoff et al. 2019 for details).
- Discrepancies between observed and predicted proportions at age (PAA) in the fishery, RV, MS and LL catches. The proportions at age were assumed to follow a multivariate logistic distribution, which estimates data variances. Alternative statistical models, such as the multinomial distribution, require pre-specified effective sample sizes, which can have a large impact on model results. See Table 4 and equations T4.6 to T4.9 in Neuenhoff et al. (2019) for details.
- a normal prior for the log M deviations,
- a normal prior for the initial values of log M, and
- a normal prior for the log recruitment/log recruitment rate deviations.

Approximate 95% credible intervals were obtained for quantities estimated by the model based on 1,010,000 Markov chain Monte Carlo (MCMC) samples, with the first 10,000 samples discarded as a burn-in and every 200th of the subsequent samples saved. All population estimates are posterior medians based on the MCMC sampling except those in Tables 21, 22, and 23, which are the maximum likelihood estimates.

4.3 RESULTS

4.3.1 Model fit

The model provided good fits to the age-aggregated biomass indices (Fig. 28). Some "blocking" of residuals is evident between observed and predicted proportions at age in the indices (Fig. 29). In the RV survey, there was a block of mostly small to moderate positive residuals (observed $>$ predicted) for ages 5-11 in 1994 to 2001 and negative year effects at adult ages in 2013, 2014, 2017 and 2018. There was also a small block of negative residuals at older ages in the mid to late 2000s for the MS index. Blocking of residuals in the LL index was negligible. Residual patterns in PAA in the indices were similar to those in recent assessments and are considered acceptable (unlike those observed in models without time-varying M, e.g. see Fig. A1c in Swain et al. 2009).

Residuals between observed and predicted PAA in the fishery catch were not severe, but tended to be negative at older ages in the 1960s and 1970s and positive at older ages in the 1980s and early 1990s (Fig. 30). Residuals tended to cluster along ages in the 1950s. This reflected limited catch sampling in this period (Swain et al. 2015a). These years were nonetheless included in the model to provide a historical perspective. Including these early years had a negligible effect on recent estimates of biomass, abundance or mortality (see Appendix C in Swain et al. 2015a).

The model also provided good fits to the observed trends in abundance by age group (Fig. 31), except for occasional outliers in the 2-4 age group.

Retrospective patterns refer to systematic changes (e.g., regular decreases) in model estimates as years of data are added to the analysis. The occurrence of these patterns suggests that the model fails to take into account non-stationarities in population dynamics (e.g., time-varying M) or the observation process (e.g., time-varying catchability). There were no retrospective patterns in model estimates of biomass and F (Fig. 32). Fluctuations in estimates of M occurred as recent years were sequentially removed from the analysis, but these changes did not occur in a consistent direction, as would be expected if there were non-stationarities unaccounted for by the model. When non-stationarities are accounted for using random-walks in process error (like M in our model), some fluctuation in estimates of the process-error deviations are expected as additional information (data) is added to models.

4.3.2 Model estimates

Cod were estimated to be fully recruited to the RV and MS surveys at about age 5-6 but not until age 11 or older for the sentinel longline program (Fig. 33). With the indices at the scale of trawlable abundance, fully-recruited catchability was estimated to be 0.72 for the RV survey and 0.46 for the MS survey. Considering that the calculation of trawlable abundance does not take herding by the trawl doors into account, these estimates are considered plausible. Selectivity by the fishery was estimated to be lower at younger ages since 1994 compared to earlier years. This is consistent with the increased importance of fixed gears, in particular longlines, in the catch since 1993.

Estimated 5+ biomass (approximately equal to adult or commercial biomass) peaked at about 460,000 t in the mid-1950s, declining to 110,000 t in the mid-1970s (Fig. 34; Table 21). Biomass rapidly recovered in the late 1970s, reaching a peak of 376,000 t in 1981. Biomass then collapsed equally rapidly between about 1987 and 1993, when the directed fishery was closed at a 5+ biomass of 104,000 t. Estimated biomass increased slightly to 125,000 t during the 1994 to 1997 moratorium on directed fishing for cod. The directed fishery then re-opened at a low level and the stock decline resumed, declining to 36,000 t by 2009, when a moratorium was again imposed on directed cod fishing. The stock decline slowed following the imposition of this moratorium, with biomass estimated to be 26,000 t at the start of 2016. However, estimated 5+ biomass dropped rapidly over the past two years, with biomass estimated to be 14,200 t at the start of 2018 (95% CI: 10,900 to 18,800 t). Biomass at the start of 2019 is estimated to be 9,750 t (95% CI: 7,300 to 14,000 t). Estimated biomasses at the beginning of 2017, 2018 and 2019 each set a new record for the lowest biomass observed. Biomass at the start of 2019 is estimated to be 8% of the biomass at the end of the moratorium in 1997, 9% of the previous low value in 1975, 3% of the average level in the 1980s and 2% of the estimated average 5+ biomass in the 1950s.

Estimated trends in SSB were similar to those described above for 5+ biomass (Fig. 34; Table 21). Estimated SSB at the start of 2018 is 13,947 t (95% CI: 10,700 to 18,500 t), an 88% decline since 2000 and a 96% decline since 1985. The model results indicate that there is no chance that SSB at the start of 2018 was above the Limit Reference Point (LRP) of 80,000 t. SSB is estimated to be 17% of the LRP at the start of 2018.

Estimates of F for cod aged 2-4 years were negligible in all years (Fig. 35; Table 22), though these abundance-weighted annual averages are dominated by the more abundant age-2 fish. Average F for these ages was 0.0023 in the 1950s, increasing to 0.0172 in the 1960s and early 1970s and then declining to an average value of 0.000071 during the current moratorium. Estimated F for cod aged 5-8 years increased from 0.08 in the early 1950s to 0.27 in 1969. It then fluctuated, increasing to an average of 0.48 (38% annually) in the early 1970s. F then declined sharply, averaging 0.18 (16% annually) in 1977 to 1985. F of ages 5-8 then increased steadily to 0.38 in 1991 (32% annually) before declining sharply to an average value of 0.0070 during the first moratorium, 0.025 during the small directed fisheries between 1999 and 2008, and 0.0022 since the closure of directed fishing in 2009. Temporal variation in F was similar but at a higher level for cod aged 9 years and older. F increased from 0.09 in 1951 to 0.55 (42% annually) in 1959, from 0.17 in 1962 to 0.53 in 1976, and from an average of 0.17 in 1980 to 1986 to 0.51 in 1991. F of these older cod then declined sharply to an average of 0.018 during the first moratorium, 0.075 when small directed fisheries were re-opened, and 0.007 since the directed fishery was re-closed in 2009.

Estimated M of juvenile cod (ages 2-4) fluctuated without trend near or slightly below its initial value of 0.41 (Fig. 35). The initial M of adult cod aged 5-8 years was estimated to be 0.18, consistent with the estimated values for commercial-sized cod in the 1960s (see above). Estimated M of this age group progressively increased from its initial value in 1971 to 0.43 (33% annually) in 2000, and then to 0.81 (55% annually) in 2018. The initial M of older adults (ages 9+) was estimated to be 0.33 (28% annually). M of this age group began to increase in the late 1970s, reaching about 0.61 (46%) in the 1991-2000 period. Estimated M then increased further to a peak of 0.93 (61% annually) in 2010. Since then it has fluctuated between 0.77 and 0.92, with the 2018 estimated at 0.85 (57% annually).

The estimated abundance of age-2 recruits averaged 250 million in the 1950s and 134 million from 1960 to 1974 (Fig. 36). Recruit abundance then rose to the highest level on record in 1975 to 1982, when it averaged 421 million with a peak at 569 million in 1982. Recruit abundance then declined to average levels of 277 million in 1983 to 1990, 113 million in 1991 to 2003 and 54 million in 2004 to 2013. Recruit abundance was at the lowest level in the 69-year record in 2014 to 2018, when it averaged 27 million. The lowest recruitment on record is 15 million in 2016.

Recruitment rate (age-2 abundance divided by SSB two years earlier) is a measure of spawning success and survival at early life history stages. The estimated mean recruitment rate is about 1,000 fish per tonne of SSB (Fig. 36). Recruitment rates were unusually high for the 1973 to 1977 year-classes, averaging 3,200 recruits per tonne with a peak at 4,540. These unusually high recruitment rates fueled the rapid recovery of the stock in the late 1970s and early 1980s. 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, averaging 1,278 recruits per tonne for the 2008 to 2016 year-classes with a peak in 2011 (1,591). Thus, low SSB, not low recruitment rate, is the cause of the very low recruit abundance in recent years. However, the relatively low recruitment rates for the 2013 and 2014 year-classes (878 and 596 recruits per tonne) contribute to the record low recruit abundances in 2015 and 2016.

Population abundance (ages 2+) was estimated to be high in the 1950s, averaging 765 million (Fig. 37; Table 23). Abundance declined during the 1960s due to overfishing, averaging 400 million in 1971 to 1974. The population then recovered rapidly due to exceptional recruitment rates, reaching an abundance of 1.2 billion in 1977. Abundance increased further to a peak of 1.5 billion in 1982. Abundance then declined steadily to 456 million in 1993, when the directed fishery was closed. This rapid decline ceased with the closure of the fishery. However, since then, abundance has continued to decline at a slower rate despite very low fishing mortality, especially since the moratoria in 1994 to 1997, 2003 and since 2009. Population abundance is now estimated to be at a record low level, averaging 86 million fish. It is now estimated to be 19% of the abundance in 1993 when the first moratorium was imposed and 7% of the average abundance from 1977 to 1987.

The time trend in adult abundance (approximatly ages 5+) resembled the total abundance trend with a 3-year lag to allow for recruitment of cohorts to age 5 (Fig. 37). Adult abundance averaged 219 million in the 1950s but declined to 71 million in 1974 to 1977. But abundance then increased rapidly to 335 million in 1980 and 448 million in 1985. Abundance then declined rapidly to 138 million in 1993 and more gradually to 20 million in 2018, the lowest level in the 69-year time series. The 2018 estimate is 14% of the 1993 level and 4% of the 1985 level. With the recruitment of the record-low 2014 year-class to the 5+ age-group in 2020, a further decline can be expected.

4.3.3 Projections

The population was projected forward five years based on the MCMC samples, which propagated uncertainty in model estimates into the projections. These projections assumed that the current productivity conditions would persist over the projection period. For each age group, M was set equal to the average of the last 5 years (2014 to 2018). For each projection year, the weight-at-age vector was randomly selected from those observed over the last 20 years (1999 to 2018). Fishery catches were set at a constant level for each projection, either at 0, at the by-catch quota of 300 t, or at 100 t. Fishery selectivity-at-age was assumed to remain the same as estimated for 1994 to 2018. In the assessment model, recruitment rate is assumed to follow an auto-correlated random walk. This approach was extended into the projection period using the average recruitment rate and the auto-correlation coefficient estimated by the model. For each year and iteration of the projection, the log residual in recruitment rate was based on the log residual in the previous year and a log residual that was randomly selected from those observed in the past 67 years. Projections were based on 1,010,000 MCMC iterations, with the first 10,000 discarded as a burn-in and every 200th subsequent iteration saved to generate posterior results.

At all catch levels (0, 100 and 300 t annually), SSB slowly declines during the five-year projection (Fig. 38). Projected differences between the three catch levels are negligible. With no fishery catch, estimated SSB declines from 13,900 t (95% CI: 10,700 to 18,500 t) in 2018 to 9,400 t (95% CI: 5,100 to 19,200 t) in 2023. With annual catches of 100 t or 300 t, SSB in 2023 is projected to be 9,300 t (95% CI: 5,000 to 19,100 t) or 9,100 t (95% CI: 4,800 to 18,800 t), respectively. 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 removals of 0, 100 or 300 t.

In conclusion, assuming that current productivity conditions persist to 2023, SSB is expected to decline by about 4,700 t given annual catches of 0 to 300 t. This is a small value, but not a negligible fraction of the 2018 estimate of SSB (about 34%). Swain and Chouinard (2008) projected that, even with no fishery catch, cod in the sGSL would be expected to be locally extinct within 40 years (2048) if the current productivity were to persist. To examine this, we extended the projection over 50 years (Fig. 39). Swain and Chouinard (2008) used an SSB less 1,000 t as a proxy for local extinction. Given the assumptions of the projection, the probability that SSB would be less than 1,000 t was 50% by 2040, 83% by 2050, and 95% by 2060. The probability that SSB would be less than 100 t was 77% at the end of the projection in 2068. Thus, if current productivity conditions were to persist, there remains a high probability of local extinction of Atlantic Cod by mid-century.

4.3.4 Population productivity and Allee effects

P_t, stock production in year t, was calculated as:

$$P_t = C_t + B_{t+1}^{2+} - B_t^{2+} \tag{7}$$

where B_t^{2+} is 2+ biomass at the start of year t and C_t is the fishery catch in year t. Production averaged 59,000 t between 1950 and 1985, with a minimum of 20,000 t (excluding 1963 and 1983) and a maximum of 150,000 t (Fig. 40). However, production has been very low since 1986. Since the beginning of the first moratorium in 1994 annual production has averaged -4,000 t (i.e. a production deficit). 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 -7,000 t.

The per capita rate of population growth (e.g., production per unit of biomass, P_t/B_t) is expected to increase as population size decreases due to decreases in intraspecific competition at low population size (Nicholson 1933). However, in some instances, per capita population growth decreases as population size decreases below some threshold. This is termed an Allee effect (Courchamp et al. 1999). Allee effects increase the risk of extinction at low population sizes.

The relationship between the rate of population production (P_t/B_t) and population biomass (B_t) has changed over time for sGSL cod (Fig. 41). From 1950 to 1990, the population exhibited negative density dependence, the expected relationship. However, the population has exhibited positive density dependence (an Allee effect) since population biomass declined below 200,000 t in the early 1990s.

Allee effects are often attributed to low reproductive success at small population size (Keith and Hutchings 2012). Predation can also cause Allee effects, with the prey exploitation rate per predator increasing as prey abundance declines (Gascoigne and Lipcius 2004). The current production deficit of sGSL cod appears to be due to predation-driven Allee effects, a demographic effect caused by the decline in cod abundance to very low levels due to overfishing and an emergent effect due to increasing predator abundance (Neuenhoff et al. 2019).

5 THE LIMIT REFERENCE POINT

The limit reference point for this stock was established in 2003 based on the model-based stock-recruit relationship as well as the minimum biomass from which the stock had previously recovered (Chouinard et al. 2003). As noted in the last assessment, there have been many model changes since 2003 and the LRP should be revised. Based on the current information, the LRP should be greater than 80,000 t of SSB. For example, $B_{recover}$, the smallest SSB from which the stock has shown a sustained recovery, is now estimated to be 107,000 t. Furthermore, the stock now appears to be experiencing a strong Allee effect. The LRP should be set well above the Allee threshold. Cod in the sGSL appeared to cross the Allee threshold in 1993 (Fig. 41), when SSB was estimated to be 112,000 t. Thus, the LRP should be set well above 112,000 t. Because the stock is experiencing a predation-driven Allee effect, the Allee threshold will depend on predator abundance, and the LRP should thus be set at higher levels as seal abundance increases.

SSB is currently estimated to be 13,900 t, well below 80,000 t with no chance that it is at or above that level. Projections indicate that it will remain below that level with high probability (100%) at current productivity and levels of fishery removals. Thus there is no urgency to revise the LRP to a higher level.

6 AN ECOSYSTEM APPROACH TO SCIENCE ADVICE AND FISHERIES MANAGEMENT

Fishing is only one of many processes affecting commercially-targetted species. The biomass and productivity of target species is also affected by interactions with their prey, competitors and predators and by effects of physical environmental conditions. Furthermore, the impacts of fishing can also be indirect, via impacts on the prey, competitors and predators of target species. This underlines the need for ecosystem-based fisheries management (EBFM; Link 2010).

Ecosystem effects have had a large impact on the dynamics of Atlantic Cod in the sGSL over the past 50 years. Many, though not all, of these have been driven by anthropogenic influences. For example, the dominant pelagic fishes in the sGSL, Atlantic Herring and Atlantic Mackerel, collapsed in the mid-1970s due to overfishing. Cod had also declined to low abundance at this time because of overfishing in the 1950s and 1960s. However, cod rapidly recovered due to unprecedented recruitment success, attributed to reduced predation on cod eggs and larvae by the collapsed pelagic fishes (Swain and Sinclair 2000). This resulted in a series of extremely strong cohorts of cod, leading to a period of intense intraspecific competition and density-dependent changes in geographic distribution (e.g., Swain and Wade. 1993), reductions in growth rates (Sinclair et al. 2002b) and body condition (Fig. 17), and changes in size-selective fishing mortality (Sinclair et al. 2002a).

However, by far the greatest ecosystem impact on this population has been an extreme increase in the natural mortality of adult cod over the past 40 years. These high levels of M are the cause of the failed recovery of this stock, its current lack of viability, and its continuing decline. Much research has been conducted to understand the cause(s) of this elevated M. Swain et al. (2011)

examined a suite of hypotheses for the causes of elevated M. The weight of evidence indicated that increases in adult M in the 1980s and early 1990s may have been due to poor fish condition, resulting from density-dependent effects in the early 1980s and unusually cold ocean waters in the late 1980s and early 1990s (Swain and Benoît 2015). Increases in unreported catch as the fishery intensified during the stock collapse in the late 1980s and early 1990s may have also contributed to the increasing mortality, with unknown fishery removals mistaken for natural mortality. However, since then cod density has declined further, fishing effort has been reduced to very low levels, waters have warmed and cod condition temporarily improved. This leads to the conclusion that competition for density-dependent resources, harsh environmental conditions (i.e., cold waters) and unreported fishery catch have not been important causes of high M since the late 1990s (Swain and Benoît 2015). The only hypothesis with empirical support since then is that predation, in particular by grey seals, has been an important cause of elevated M.

Grey seal abundance has increased dramatically in the southern Gulf ecosystem (Swain and Benoît 2015) and this increase coincides with the increases in natural mortality of cod (Chouinard et al. 2005b). Cod are known to be an important prey of grey seals, but their contribution to the average seal diet has been uncertain due to wide seasonal, spatial and individual variation in diet. Nonetheless, accumulating evidence indicates that adult cod are a much more important component of grey seal diets than previously thought. The foraging areas of adult male seals are seasonally associated with aggregations of large cod (Harvey et al. 2012). Grey seals feeding heavily in the vicinity of overwintering aggregations of cod contain a high proportion of cod in their diet, 57-80% of the male diet based on stomach contents and 31-64% of the diet determined from intestines (Hammill et al. 2014b). The majority of the cod consumed (66.5 to 86.9%) were aged 5 years or greater (i.e., the cod with elevated M; Neuenhoff et al. (2019), supplementary material). Furthermore, dramatic changes in the spatial distribution of cod in relation to increased risk of predation by grey seals are consistent with strong predation by grey seals on cod in the southern Gulf (Swain et al. 2015a).

Neuenhoff et al. (2019) directly examined the impact of predation by grey seals on the dynamics of sGSL cod by incorporating predation by grey seals in the population model for cod via a functional response. Their model indicated that since about the year 2000 predation by grey seals could account for all of the 5+ cod M above the normal level (0.2). Projections at the 2014 level of grey seal abundance (Hammill et al. 2014a)[1] suggested that cod would continue to decline rapidly to local extinction by mid-century if current conditions were to persist.

The future impact of grey seal predation on cod abundance depends on the functional response of grey seals preying on cod. Two types of functional response are commonly used, type II and type III. In a type III response, predators switch to alternate prey when focal prey abundance declines to very low abundance. In this case, the focal prey becomes trapped in a “predator pit”. It can persist at very low abundance when predators have switched to alternate prey, but it cannot recover. If it were to increase in abundance out of its low-abundance refuge, predation mortality would increase and the prey would fall back into the low-abundance refuge. However, predation by grey seals on cod appears to be mediated by a type II functional response (Neuenhoff et al. 2019). In this case, prey switching does not occur and the focal prey experiences a predation-driven Allee effect, which can drive it to local extinction. A type II functional response appears to be maintained by the aggregative behaviour of cod. At certain times of year sGSL cod assemble in dense aggregations (during overwintering, seasonal migrations and spawning).

[1]The population model for grey seals has been revised since Hammill et al. (2014a) but the updated estimates of abundance are not yet available.

Densities remain locally high in these aggregations and provide attractive feeding opportunities even when population abundance is low.

In addition to consumption, predators affect their prey through the “risk” effects of intimidation (Preisser et al. 2000). These risk effects involve changes in prey traits (e.g. behaviour) that reduce predation mortality at some cost (e.g. reduced foraging success). During their feeding season in the sGSL, cod have shifted out of their traditional foraging grounds into deeper waters where predation risk is low (Swain et al. 2015a). Historically, body condition of cod occurring in these deep waters was lower than that of cod occurring elsewhere in the sGSL (Chouinard and Swain 2002). Thus, while the changing space use by cod may reduce predation mortality, this would appear to be at the cost of reduced feeding success. High predation risk may also reduce foraging success by increasing the proportion of time spent spent hiding and evading predators instead of foraging. The condition of cod during their feeding season in September has declined to the lowest levels observed in the 48-year record in recent years (Fig. 17). This is consistent with the great increase in risk of predation by grey seals that has developed during this period. Thus, the contribution of risk effects to the declining productivity of cod in the sGSL may also be of growing importance.

The sGSL ecosystem has been severely perturbed by centuries of overexploitation. Top predators with negative impacts on seals have been extirpated (e.g., walrus) or driven to low abundance (e.g., large sharks). Marine fishes have been severely depleted by overfishing and are now a very small fraction of there former abundance (Rosenberg et al. 2005). Grey seals were once very abundant but were hunted to very low abundance by the mid to late 1880s (Lavigueur and Hammill 1993). Grey seals have now returned to very high abundance while their top predators and marine fish prey remain depleted. Under these conditions, it is unlikely that the ecosystem will return to its former condition without intervention (Peterson et al. 1999; Lessard et al. 2005).

Atlantic Cod in the sGSL now appears to be at high risk of local extinction. SSB at the start of 2018 is estimated to be 4% of the 1985 level, 12% of the 2000 level and 55% of the 2016 level. Employing an ecosystem approach to fisheries management, it is now necessary to confront a trade-off: increase grey seal removals to allow Atlantic Cod and other endangered demersal fishes to recover, or accept the high extinction risk of these fishes and allow grey seal abundance to remain high or increase further. If the choice is to reduce seal abundance, projections indicate that the seal reduction required would now be very large (Neuenhoff et al. 2019). Finally, it would also be necessary to examine the likelihood of negative indirect effects on cod and other ecosystem components, e.g. increases in the abundance of other predators that are also prey of grey seals (Yodzis 2001; Lessard et al. 2005), and to take this into account in evaluating the trade-off.

7 STOCK STATUS INDICATORS

The sGSL cod stock is currently assessed and managed on a four-year cycle. Indicators are needed to characterize stock status in the years between assessments. Suggested indicators are the biomass indices for commercial sizes of cod in the RV and mobile sentinel surveys and the longline sentinel program. Because observation error in the indices can be substantial, changes in stock status should not be inferred from annual observations. Instead, inferences should be based on moving averages. A minimum of a three-year moving average is recommended. Interpretation of changes in sentinel indices can be difficult due to changes in vessels between years in the case of the mobile index and changes in cod distribution in the case of the fixed index. Thus, consideration is given to use of the RV index as the primary indicator. Normally, a large change in the moving average from its value in the last assessment year would trigger an early re-assessment. Given the current status of the stock, an increase in the moving average to a level above the LRP should trigger a re-assessment.

In order to implement this approach it is necessary to re-scale the LRP from the scale of the population to the scale of the RV index. One way to do this is to model the RV biomass index as a function of the estimated SSB:

$$I_t = \beta S_t + \epsilon_t \tag{8}$$

where I_t is the RV biomass index in year t for cod 42 cm and longer, S_t is SSB in year t and ϵ_t is a randomly distributed normal deviate. The model intercept was assumed to be 0 (since I should be 0 when S is 0). This assumption was supported by models that included an intercept (which was not significantly different from 0). The model fit the observed index well and accounted for 94% of the variation in I (Fig. 42). Based on this model, the 80,000 t LRP was estimated to be 47,900 t on the scale of the biomass index (in units of trawlable biomass).

8 CONCLUSIONS

The outlook for this stock remains grim. SSB at the beginning of 2018 is estimated to be 13,950 t, the lowest level observed in the 69-year record. Estimated SSB has declined by 88% from the already low level in 2000 and 96% from the level in 1985. Fishing mortality has declined to negligible levels. For ages 5-8 and 9+, F was estimated to be 0.007 and 0.02 respectively at the start of the first moratorium in 1994, declining to average values of 0.0022 and 0.0071 during the current moratorium. The ongoing decline of this population is due to the high natural mortality of adult cod (i.e., ages 5 years and older). Natural mortality of about 18% annually is considered normal for adult cod. Over the past 35 years M has increased to extreme levels in this population, with adult M estimated to be about 55% annually in 2018. At current productivity, SSB is projected to decline further to 9,400 or 9,100 t in 2023 with fishery catches of 0 or 300 t, respectively. Over the longer term, the population is expected to be extinct (i.e., SSB < 1,000 t) by mid-century, even with no catch.

This population appears to have been experiencing an Allee effect since 1993 (when the directed fishery was first closed). Due to reduced intraspecific competition at small population sizes, per capita population growth is normally expected to increase as abundance decreases. An Allee effect occurs when the reverse happens, i.e. per capita production decreases as abundance decreases. If they persist, Allee effects will drive populations to extinction.

Over the past decade, evidence has accumulated in support of the hypothesis that the elevated natural mortality of sGSL cod is due to predation by grey seals. Population modelling that directly incorporated predation by grey seals via a functional response indicated that since the year 2000 this predation can account for all of adult natural mortality above the normal level for cod (Neuenhoff et al. 2019). Predation-driven allee effects appear to be preventing the recovery of this population. Further declines are expected at the current level of grey seal abundance in this ecosystem.

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10 TABLES

Table 1. Landings (t) of southern Gulf of St. Lawrence Atlantic Cod, 1965 to 2018, by area and time period. The column "stock" indicates the landings used in the analytical assessment, and is the total for 4T, 4Vn (Jan.-Apr.), 4Vn (Nov.-Dec.), and catches of 4T origin in 4Vs. The TAC applies to the traditional management unit, 4TVn (Jan.-Apr.) until 1994. The asterisk indicates that results for 2017 and 2018 are preliminary

Year	4T	4Vn (J-A)	4Vn (N-D)	4Vs	Stock	4TVn (J-A)	TAC
1965	46471	16556	2077	-	65104	63027	-
1966	38282	16603	2196	-	57081	54885	-
1967	34245	7071	2096	-	43412	41316	-
1968	37910	8641	2440	-	48991	46551	-
1969	40905	6914	2442	-	50261	47819	-
1970	43410	21055	1523	-	65988	64465	-
1971	40669	15706	1556	-	57931	56375	-
1972	42096	25704	1517	-	69317	67800	-
1973	25756	24879	1308	-	51943	50635	-
1974	28580	20167	1832	-	50579	48747	63000
1975	28853	13618	795	-	43266	42471	50000
1976	17600	15815	3928	-	37343	33415	30000
1977	19536	2683	4665	-	26884	22219	15000
1978	25453	12439	1128	-	39020	37892	38000
1979	46695	9301	1700	-	57696	55996	46000
1980	36157	18477	2592	-	57226	54634	54000
1981	48132	17045	1970	-	67147	65177	53000
1982	43418	14775	3476	-	61669	58193	60000
1983	48222	13073	2695	-	63990	61295	62000
1984	40652	14712	2200	-	57564	55364	67000
1985	47819	14319	1835	-	63973	62138	67000
1986	48066	15709	1444	3463	68682	63775	60000
1987	43571	7555	1437	2029	54592	51126	45200
1988	44616	7442	1165	2496	55719	52058	54000
1989	43617	9191	1887	2574	57269	52808	54000
1990	41552	9688	2031	4606	57877	51240	53000
1991	31938	6781	1830	8911	49460	38719	48000
1992	27899	6782	2282	4164	41127	34681	43000
1993	4121	1161	55	-	5337	5282	13000
1994	1198	139	1	-	1338	1337	Moratorium
1995	1032	-	4	-	1036	1032	Moratorium
1996	1140	-	2	-	1142	1140	Moratorium
1997	1725	< 1	1	-	1726	1725	Moratorium
1998	2671	7	15	-	2693	2678	3000
1999	6154	6	3	-	6163	6160	6000
2000	6038	4	9	-	6051	6042	6000
2001	6305	2	16	-	6323	6307	6000
2002	5060	8	59	-	5127	5068	6000
2003	288	-	1	-	289	288	Moratorium
2004	2259	7	46	-	2312	2266	3000

Year	4T	4Vn (J-A)	4Vn (N-D)	4Vs	Stock	4TVn (J-A)	TAC
2005	2825	20	6	-	2851	2845	4000
2006	3019	3	2	-	3024	3022	4000
2007	1343	144	3	-	1490	1487	2000
2008	1526	121	1	-	1648	1647	2000
2009	149	< 1	-	-	149	149	Moratorium
2010	103	< 1	-	-	103	103	Moratorium
2011	108	5	< 1	-	114	113	Moratorium
2012	150	22	< 1	-	172	172	Moratorium
2013	109	2	< 1	-	111	111	Moratorium
2014	111	3	< 1	-	114	114	Moratorium
2015	101	< 1	3	-	104	101	Moratorium
2016	100	11	4	-	116	111	Moratorium
2017*	55	3	< 1	-	59	58	Moratorium
2018*	58	< 1	< 1	-	59	58	Moratorium

Table 2. *Landings (t) by gear type of the southern Gulf of St. Lawrence Atlantic Cod stock, 1965 to 2018. These landings are for NAFO Div. 4T only and do not include landings from NAFO Div. 4Vn and 4Vs.*

Year	Otter trawls	Seines	Gillnets	Longlines	Handlines	Misc.	Total
1965	48854	2735	3571	4713	< 1	5231	65104
1966	37023	2444	9414	3062	< 1	5138	57081
1967	24823	2293	9948	2536	2469	1343	43412
1968	29553	1064	12933	1344	2942	1155	48991
1969	28131	1234	9581	5014	5066	1235	50261
1970	43652	1798	9786	6258	3205	1289	65988
1971	36338	2267	9676	3600	4011	2039	57931
1972	50615	2121	7896	1792	2103	4790	69317
1973	36467	2137	8223	925	2135	2056	51943
1974	37923	1765	6141	1352	1292	2106	50579
1975	29080	1983	6330	245	3530	2098	43266
1976	28928	1384	4459	163	1191	1218	37343
1977	14695	3269	5931	692	1299	998	26884
1978	22669	4504	8929	1015	1449	454	39020
1979	31727	8845	12022	1622	1957	1523	57696
1980	32698	10095	4260	2827	1562	5784	57226
1981	34509	12563	4053	7017	1061	7944	67147
1982	32242	11360	4205	5481	916	7465	61669
1983	32880	13857	3010	4754	1286	8203	63990
1984	32316	10732	6891	5058	1903	664	57564
1985	40177	11935	5287	4261	2078	235	63973
1986	41653	15380	4328	5314	1975	32	68682
1987	31961	9759	4792	5926	2106	48	54592
1988	34055	12017	3936	4074	1602	35	55719
1989	34260	15492	2796	3396	1190	135	57269
1990	37354	14094	1962	3289	1048	130	57877
1991	35216	9282	1679	2502	778	3	49460
1992	28408	8660	1263	1890	875	31	41127
1993	2143	328	1313	842	705	6	5337
1994	213	412	302	103	153	155	1338
1995	110	379	101	78	101	267	1036
1996	269	398	134	127	214	0	1142
1997	337	599	280	247	195	68	1726
1998	709	828	506	408	238	4	2693
1999	1642	1195	1665	882	777	1	6163
2000	1264	1275	1747	953	812	0	6051
2001	1717	1560	1409	882	743	12	6323
2002	1125	1652	1226	482	337	305	5127
2003	24	79	3	183	< 1	< 1	289
2004	650	569	454	444	194	1	2312
2005	1072	531	542	531	174	1	2851
2006	1224	876	279	471	172	2	3024
2007	562	482	100	281	62	3	1490
2008	709	409	139	282	109	< 1	1648
2009	39	26	5	72	7	< 1	149

Year	Otter trawls	Seines	Gillnets	Longlines	Handlines	Misc.	Total
2010	11	14	4	65	9	0	103
2011	4	14	5	74	13	< 1	109
2012	7	13	7	104	20	< 1	150
2013	3	7	8	89	2	< 1	109
2014	9	19	3	80	0	0	111
2015	12	10	1	77	0	0	101
2016	6	6	2	86	0	0	100
2017	2	5	2	46	1	0	55
2018	2	0	13	36	0	0	51

Table 3. Landings at age (numbers, 1,000s) of southern Gulf of St. Lawrence Atlantic Cod, 1971 to 2018. The table includes landings in 4T, 4Vn (Nov.-Apr.), and 4Vs (Jan.-Apr.). Data for 2017 and 2018 are preliminary.

Year	3	4	5	6	7	8	9	10	11	12+	Total
1971	6	2099	7272	9262	5916	2331	1251	520	130	771	29558
1972	3179	22247	12018	6666	7561	3551	952	547	372	270	57361
1973	1374	6999	14498	5325	3720	2800	1861	557	338	252	37723
1974	2993	5400	5033	9690	3102	1854	1772	1054	260	333	31490
1975	1567	8910	6933	2540	3297	1319	1119	801	680	354	27519
1976	508	4093	9996	6975	1708	1257	478	285	148	231	25679
1977	659	4960	5899	3320	1773	400	284	182	114	122	17712
1978	548	10037	10897	4596	2681	1108	244	248	110	140	30610
1979	148	5138	15913	11251	3509	1724	865	295	253	140	39235
1980	295	1920	14674	14142	9789	1522	808	404	143	96	43793
1981	98	3829	7380	19144	13116	6200	913	463	203	180	51526
1982	518	1621	10671	8700	12539	7663	2533	444	142	86	44917
1983	42	1147	6311	12124	11936	7646	5379	2668	139	89	47481
1984	30	1319	4210	7410	9085	6949	5173	2937	942	224	38278
1985	175	1561	10307	17163	8342	6094	3975	2277	971	399	51265
1986	136	3546	8295	23645	9739	4069	3041	2372	1197	986	57027
1987	80	1029	7400	10851	18933	7011	2250	1684	700	688	50627
1988	111	1725	5241	11259	9072	12151	6813	1818	970	771	49931
1989	71	1658	6065	12398	10714	7316	7628	5171	990	719	52730
1990	540	2973	7508	10613	10207	6983	4467	4644	2066	604	50603
1991	286	5178	10371	9586	8416	4735	3173	1754	955	728	45184
1992	487	3437	12511	9912	5290	3453	2059	910	510	513	39081
1993	53	262	904	1174	946	499	223	135	74	85	4353
1994	26	54	98	211	281	156	71	28	19	14	957
1995	69	133	145	130	223	134	60	24	13	8	939
1996	39	84	134	142	124	174	89	34	11	11	842
1997	27	53	120	182	174	180	208	109	38	16	1106
1998	70	82	211	329	336	252	206	186	73	32	1776
1999	42	199	361	535	776	609	448	252	231	120	3571
2000	35	107	344	682	530	822	411	387	186	182	3685
2001	25	113	365	945	921	530	480	239	189	154	3962
2002	25	64	348	553	890	717	260	243	93	90	3283
2003	4	5	13	19	23	29	26	8	10	11	150
2004	8	18	65	181	297	359	247	155	32	41	1404
2005	7	42	160	330	357	360	307	180	103	28	1875
2006	3	110	392	552	462	204	243	185	82	59	2291
2007	6	13	42	255	325	247	102	71	38	39	1139
2008	3	34	122	171	438	301	121	52	29	28	1299
2009	4	6	6	16	16	26	11	10	3	5	102
2010	1	3	10	9	16	9	11	6	2	1	69
2011	1	3	8	11	12	14	10	5	2	1	68
2012	1	6	9	23	29	12	11	7	3	2	103
2013	1	2	5	6	9	14	10	8	2	4	61
2014	2	4	10	10	9	9	8	2	4	4	62

Year	3	4	5	6	7	8	9	10	11	12+	Total
2015	1	7	12	14	13	5	5	6	1	2	67
2016	1	4	9	17	15	13	4	3	3	2	70
2017	0	2	4	6	7	5	4	1	1	1	31
2018	0	0	2	6	10	8	5	2	0	1	34

Table 4. Average weight at age (kg) of 3 to 16+ of removals or the southern Gulf of St. Lawrence Atlantic Cod stock, 1971 to 2018. "Total" represents the abundance-weighted average weight of 3+ fish.

Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1971	0.76	0.82	1.11	1.40	2.15	3.67	3.83	5.25	6.00	4.78	6.85	7.42	7.96	17.72	1.96
1972	0.36	0.56	0.91	1.33	1.52	2.55	4.82	5.97	7.13	8.08	8.85	10.25	5.65	11.23	1.16
1973	0.46	0.67	0.92	1.28	1.69	2.31	3.59	5.51	6.03	7.95	6.16	6.72	8.86	6.12	1.37
1974	0.60	0.78	1.09	1.49	1.96	2.68	2.89	4.11	5.97	7.07	8.3	6.87	9.84	12.65	1.61
1975	0.48	0.74	1.15	1.76	2.36	2.75	3.22	3.70	4.46	6.95	9.2	6.30	8.39	6.19	1.57
1976	0.46	0.78	1.11	1.54	2.19	2.84	3.23	3.79	4.62	5.09	6.19	9.87	10.45	15.05	1.45
1977	0.52	0.81	1.27	1.79	2.42	3.51	4.27	4.31	5.10	5.57	6.45	8.61	12.56	9.88	1.52
1978	0.40	0.68	1.03	1.66	2.27	2.81	4.33	4.63	6.37	6.46	6.23	5.09	11.56	10.17	1.27
1979	0.51	0.71	1.01	1.42	2.22	3.31	4.07	7.14	6.96	6.69	4.7	8.79	15.52	17.34	1.47
1980	0.58	0.69	0.92	1.22	1.50	2.78	3.08	4.00	7.83	6.01	9.98	5.81	9.13	9.35	1.30
1981	0.50	0.68	0.85	1.13	1.39	1.84	3.19	4.17	4.47	5.60	6.11	7.08	3.49	8.35	1.30
1982	0.75	0.76	0.97	1.16	1.45	1.72	2.27	3.27	4.01	4.14	6.46	6.92	4.18	11.1	1.37
1983	0.33	0.61	0.89	1.14	1.31	1.58	1.73	2.01	4.84	7.63	8.55	10.51	12.09	14.76	1.35
1984	0.45	0.65	0.79	1.09	1.38	1.61	2.07	2.27	3.05	4.93	5.66	8.61	11.74	13.23	1.50
1985	0.44	0.57	0.76	0.99	1.42	1.67	1.83	2.14	2.41	2.89	8.33	5.71	11.41	12.97	1.24
1986	0.43	0.60	0.81	1.01	1.29	1.75	1.98	1.89	2.64	2.23	3.07	4.83	15.36	13.55	1.20
1987	0.27	0.49	0.70	0.86	0.99	1.25	1.85	2.16	2.24	3.15	3.57	4.03	12.41	14.21	1.08
1988	0.40	0.60	0.77	0.92	1.04	1.13	1.29	1.90	2.23	2.72	3.52	5.67	5.92	14.32	1.12
1989	0.53	0.63	0.77	0.90	1.07	1.19	1.22	1.40	1.94	2.16	2.55	3.49	3.41	2.76	1.09
1990	0.56	0.72	0.85	1.03	1.17	1.28	1.36	1.41	1.50	1.84	2.59	3.36	2.81	7.98	1.14
1991	0.53	0.65	0.85	1.01	1.22	1.41	1.51	1.60	1.63	1.73	2.2	2.50	3.08	3.8	1.09
1992	0.55	0.65	0.81	1.00	1.22	1.45	1.61	1.85	1.88	1.91	2.27	5.52	6.58	9.88	1.05
1993	0.41	0.56	0.70	1.00	1.40	1.81	1.93	2.21	2.29	2.09	2.04	3.00	5.84	13.18	1.23
1994	0.34	0.56	0.79	1.04	1.46	1.87	2.26	2.18	2.52	2.41	2.03	2.29	2.38	13.52	1.40
1995	0.25	0.49	0.67	0.90	1.17	1.49	2.11	2.52	2.98	3.39	4.87	4.93	4.19	10.16	1.08
1996	0.36	0.47	0.81	0.99	1.37	1.68	2.07	2.64	3.29	2.88	3.59	4.82	6.03	5.4	1.32
1997	0.24	0.56	0.80	1.15	1.42	1.85	2.03	2.28	2.56	2.89	2.77	3.36	2.21	4.67	1.57
1998	0.30	0.52	0.96	1.19	1.53	1.74	1.96	2.11	2.46	3.01	2.84	3.74	5.44	3.99	1.48
1999	0.32	0.69	0.92	1.28	1.61	1.95	2.10	2.58	2.58	2.94	3.62	3.82	4.63	5.52	1.73
2000	0.30	0.56	0.88	1.18	1.46	1.81	2.10	2.15	2.32	2.53	2.94	3.63	3.83	4.68	1.64
2001	0.29	0.65	0.88	1.22	1.52	1.87	2.12	2.26	2.35	2.44	2.32	2.71	3.36	2.89	1.60

Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
2002	0.28	0.69	0.90	1.13	1.44	1.83	2.00	2.27	2.47	2.56	2.68	2.53	4.93	4.78	1.56
2003	0.28	0.49	0.87	1.21	1.52	1.96	2.55	2.80	2.78	3.77	2.84	3.82	3.86	3.36	1.93
2004	0.33	0.56	0.84	1.08	1.40	1.72	1.91	2.26	2.65	2.49	2.62	2.93	2.8	2.75	1.65
2005	0.42	0.68	0.85	1.06	1.31	1.50	1.86	2.21	2.52	3.30	3.17	3.79	4.39	4.7	1.52
2006	0.35	0.68	0.81	0.99	1.22	1.50	1.73	2.16	2.64	3.00	3.11	3.32	2.97	4.23	1.32
2007	0.32	0.46	0.71	0.93	1.14	1.37	1.61	1.95	2.34	2.22	2.57	2.80	2.37	4.95	1.29
2008	0.25	0.60	0.76	0.95	1.15	1.37	1.77	2.08	2.32	2.27	2.67	2.88	2.13	4.2	1.27
2009	0.25	0.42	0.76	1.05	1.19	1.60	1.96	2.28	2.46	2.59	2.84	2.95	2.55	3.14	1.45
2010	0.29	0.59	0.82	1.20	1.41	1.69	1.92	2.16	2.05	3.43	2.92	3.13	3.67	2.15	1.50
2011	0.20	0.70	1.07	1.25	1.62	1.97	2.23	2.46	2.62	3.02	2.38	1.78	2.49	7.5	1.69
2012	0.27	0.65	1.13	1.53	1.56	1.96	2.09	2.46	2.80	2.27	2.51	2.01	2.67	3.19	1.66
2013	0.23	0.65	0.82	1.11	1.39	1.82	2.09	2.50	2.67	3.17	2.89	3.57	2.95	-	1.82
2014	0.26	0.46	1.04	1.30	1.73	2.11	2.16	2.78	3.26	2.84	4.09	3.13	6.06	-	1.82
2015	0.27	0.73	1.01	1.20	1.68	2.16	2.22	2.70	2.48	2.79	3.21	3.47	2.55	7.33	1.56
2016	0.38	0.67	0.95	1.25	1.78	1.96	2.53	2.40	2.75	2.84	3.40	2.76	3.53	4.02	1.64
2017	0.41	0.83	1.21	1.37	1.66	2.30	2.94	3.02	3.31	5.13	4.72	4.59	5.63	4.79	1.92
2018	0.18	0.63	1.07	1.35	1.52	2.00	2.21	2.22	3.80	2.89	-	5.33	-	2.38	1.71

Table 5. Mean numbers per tow at age of southern Gulf of St. Lawrence cod in the annual research vessel surveys, 1971 to 2018. Set 127 in 1995 is excluded. About 6,600 cod aged 1-3 years were caught in this tow. It is considered to be anomalous and has not been included in the index (see Sinclair et al. 1997). In 2002, two large sets (47 and 48) are included. The 2003 survey is incomplete and estimates for strata that were not sampled or sampled with only one set were obtained as described in the text. Data for ages 0 and 1 may include Greenland Cod, which are not distinguishable from Atlantic Cod at lengths under 15 cm.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	0+	3+	5+
1971	0.00	0.10	0.73	8.72	8.84	7.90	6.09	3.99	1.24	0.32	0.35	0.25	0.11	0.02	0.11	0.13	0.28	39.16	38.34	20.78
1972	0.00	0.53	3.60	7.85	18.02	6.84	5.77	3.97	2.40	0.49	0.40	0.44	0.14	0.06	0.05	0.05	0.08	50.70	46.56	20.70
1973	0.03	0.12	6.20	12.24	5.79	9.25	4.32	3.07	2.25	1.43	0.38	0.11	0.27	0.04	0.07	0.02	0.19	45.77	39.42	21.40
1974	0.00	0.14	3.55	14.51	11.03	4.73	5.67	2.12	1.44	1.46	0.49	0.19	0.10	0.24	0.00	0.04	0.13	45.83	42.13	16.59
1975	0.00	0.54	8.19	6.27	9.24	7.24	2.46	1.73	1.14	0.51	0.35	0.43	0.11	0.05	0.01	0.01	0.00	38.27	29.54	14.03
1976	0.00	4.30	9.85	38.38	9.91	7.45	3.36	0.92	0.64	0.34	0.31	0.27	0.09	0.05	0.02	0.03	0.03	75.95	61.80	13.51
1977	0.01	1.05	30.26	26.55	19.01	7.08	3.69	1.91	0.91	0.64	0.41	0.34	0.33	0.32	0.00	0.06	0.10	92.66	61.33	15.77
1978	0.00	1.23	9.29	54.73	40.86	19.72	5.55	3.21	1.01	0.43	0.54	0.64	0.11	0.00	0.15	0.05	0.00	137.50	126.99	31.40
1979	0.19	0.18	32.52	31.85	65.04	39.17	15.98	4.14	1.71	0.82	0.26	0.26	0.21	0.07	0.06	0.04	0.02	192.51	159.63	62.74
1980	0.32	1.41	6.73	41.14	30.51	53.54	26.39	9.50	1.65	0.80	0.34	0.11	0.04	0.03	0.05	0.02	0.02	172.60	164.14	92.48
1981	0.28	5.34	21.91	21.92	67.15	56.53	55.54	23.42	12.72	1.77	0.74	0.36	0.14	0.06	0.06	0.10	0.14	268.18	240.66	151.59
1982	0.34	4.74	38.42	23.22	27.50	31.90	50.82	26.51	12.83	4.05	0.47	0.20	0.13	0.07	0.02	0.00	0.03	221.25	177.75	127.03
1983	0.01	7.62	24.76	53.29	48.05	26.14	18.58	16.02	10.65	5.03	3.28	0.82	0.16	0.43	0.05	0.07	0.00	214.95	182.56	81.22
1984	0.00	1.91	11.39	16.73	37.11	49.22	17.56	9.89	10.34	4.70	2.09	0.79	0.07	0.04	0.07	0.02	0.02	161.96	148.66	94.82
1985	4.31	9.73	15.60	38.91	41.96	67.95	70.28	15.59	6.49	4.46	2.06	1.52	0.39	0.17	0.00	0.00	0.07	279.48	249.84	168.97
1986	2.06	7.11	24.72	35.35	36.85	37.13	44.32	32.04	9.52	2.01	2.76	1.09	0.77	0.21	0.13	0.00	0.05	236.10	202.22	130.03
1987	0.43	0.84	12.75	25.03	23.10	31.71	23.94	31.04	11.11	2.49	1.76	0.66	0.53	0.23	0.11	0.03	0.02	165.76	151.74	103.61
1988	1.70	3.89	19.05	70.02	64.56	51.26	35.85	19.35	20.93	12.17	2.38	0.54	0.32	0.27	0.10	0.11	0.00	302.51	277.87	143.29
1989	0.28	12.78	27.01	34.63	32.49	29.46	30.93	16.98	10.84	10.62	6.99	1.33	0.43	0.23	0.18	0.05	0.12	215.35	175.27	108.16
1990	0.20	2.07	6.62	35.40	26.35	19.31	13.64	9.41	5.31	3.13	3.61	1.69	0.34	0.06	0.09	0.02	0.01	127.26	118.38	56.63
1991	1.47	2.74	7.70	15.89	33.24	26.37	10.18	5.85	3.97	1.66	1.05	1.08	0.63	0.08	0.02	0.01	0.01	111.95	100.05	50.91
1992	0.61	1.92	4.69	9.81	13.78	12.24	6.58	2.55	1.20	0.75	0.32	0.20	0.10	0.06	0.01	0.00	0.01	54.83	47.61	24.02
1993	0.66	0.60	6.51	9.17	14.01	16.45	10.80	4.94	1.61	0.65	0.37	0.11	0.05	0.12	0.02	0.02	0.01	66.09	58.31	35.14
1994	1.25	0.66	1.79	7.61	9.07	9.73	12.03	7.76	2.79	1.12	0.41	0.30	0.08	0.04	0.02	0.00	0.01	54.67	50.97	34.29
1995	8.25	1.12	4.17	5.86	10.23	10.11	8.01	10.39	4.82	1.82	0.57	0.30	0.12	0.03	0.03	0.02	0.00	65.84	52.29	36.21
1996	0.78	2.73	2.20	7.20	12.49	11.03	9.70	7.42	8.06	3.81	1.11	0.38	0.11	0.10	0.01	0.01	0.03	67.15	61.44	41.75
1997	2.46	2.41	4.70	5.54	6.17	10.37	7.03	5.04	3.38	3.84	1.42	0.39	0.06	0.02	0.01	0.00	0.01	52.85	43.29	31.57
1998	0.42	3.12	5.23	7.93	7.38	5.85	7.59	4.88	3.29	2.80	2.46	0.77	0.17	0.10	0.06	0.01	0.00	52.07	43.30	27.99
1999	4.63	2.12	6.39	8.70	12.88	12.25	5.47	6.61	3.65	3.37	1.31	1.70	0.53	0.14	0.03	0.02	0.00	69.79	56.65	35.07
2000	0.36	1.05	2.45	6.86	9.33	9.93	8.23	3.34	4.01	1.50	1.13	0.84	0.40	0.23	0.01	0.01	0.00	49.67	45.80	29.62
2001	8.93	71.05	2.00	4.38	7.77	8.75	7.60	4.98	2.43	1.49	0.93	0.48	0.25	0.08	0.05	0.00	0.02	121.17	39.19	27.05
2002	0.58	6.80	2.83	4.81	15.42	21.10	14.52	9.17	5.61	1.34	1.12	0.55	0.23	0.19	0.06	0.00	0.00	84.33	74.12	53.89
2003	0.41	3.28	2.36	2.98	2.57	2.56	2.70	3.10	2.47	1.10	0.35	0.25	0.07	0.06	0.04	0.01	0.00	24.29	18.24	12.70
2004	1.90	0.70	11.37	12.92	11.74	9.42	5.52	5.67	4.40	2.42	1.45	0.21	0.31	0.03	0.03	0.00	0.04	68.12	54.16	29.50
2005	1.18	2.01	0.97	6.27	9.88	6.82	3.14	1.21	0.97	0.75	0.41	0.30	0.07	0.04	0.00	0.00	0.04	34.05	29.89	13.75
2006	1.42	0.32	2.74	2.75	6.10	12.25	7.10	2.97	0.79	0.77	0.36	0.17	0.16	0.01	0.00	0.00	0.00	37.90	33.42	24.58
2007	0.61	2.62	1.60	4.11	5.75	4.81	7.36	4.08	1.53	0.54	0.37	0.11	0.09	0.01	0.00	0.01	0.02	33.61	28.79	18.93
2008	1.73	1.22	1.87	3.73	2.51	5.71	3.17	7.16	4.39	1.77	0.45	0.31	0.01	0.01	0.00	0.00	0.00	34.03	29.21	22.98

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	0+	3+	5+
2009	0.30	0.50	1.69	10.39	15.24	5.18	5.43	1.99	3.29	1.20	0.52	0.04	0.05	0.02	0.00	0.01	0.00	45.85	43.35	17.73
2010	1.00	1.44	3.04	3.29	3.17	5.06	1.17	1.66	0.87	1.30	0.60	0.16	0.04	0.07	0.00	0.00	0.01	22.88	17.40	10.94
2011	1.92	0.32	1.09	3.89	2.61	2.00	2.15	0.35	0.58	0.18	0.32	0.08	0.05	0.00	0.00	0.00	0.00	15.54	12.21	5.71
2012	3.15	0.69	1.75	2.67	5.61	1.11	1.08	1.06	0.13	0.22	0.10	0.08	0.05	0.01	0.00	0.00	0.00	17.72	12.13	3.85
2013	0.08	1.33	12.96	20.78	11.81	10.23	3.98	2.43	1.93	0.37	0.27	0.09	0.10	0.03	0.02	0.00	0.00	66.40	52.04	19.46
2014	0.00	0.29	3.84	16.04	9.36	4.17	2.83	0.47	0.60	0.39	0.13	0.07	0.03	0.03	0.01	0.00	0.00	38.23	34.11	8.71
2015	0.00	0.54	1.91	4.21	8.33	5.18	3.11	2.76	0.55	0.37	0.28	0.06	0.04	0.02	0.00	0.01	0.00	27.36	24.91	12.37
2016	0.00	0.10	0.70	2.46	3.30	2.68	2.18	1.22	1.07	0.29	0.27	0.11	0.03	0.02	0.01	0.00	0.00	14.41	13.61	7.86
2017	0.00	1.00	1.11	1.37	2.64	2.07	0.70	0.37	0.23	0.13	0.02	0.00	0.01	0.01	0.00	0.00	0.00	9.66	7.54	3.54
2018	28.00	0.05	0.91	3.94	2.32	1.73	1.30	0.74	0.36	0.17	0.26	0.02	0.01	0.01	0.01	0.00	0.00	39.81	10.85	4.59

Table 6. Mean length (cm) at age of southern Gulf Atlantic Cod from research vessel surveys, 1971 to 2018. Dashes indicate that no Atlantic Cod were sampled at that age. Data for age 1 may include Greenland cod (see Table 5).

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1971	14.5	22.9	35.2	43.0	49.5	53.1	59.5	67.8	77.8	82.6	86.0	74.4	73.0	75.7	87.6
1972	17.0	24.8	34.4	42.2	50.0	53.9	57.7	64.1	71.8	75.9	82.0	82.3	77.7	101.0	85.0
1973	14.3	26.4	33.3	43.1	49.8	54.4	58.3	62.0	65.2	77.9	79.5	94.0	70.7	66.4	79.0
1974	16.9	28.2	36.2	42.5	49.6	55.4	59.7	61.2	62.0	70.0	73.4	81.0	102.2	-	76.0
1975	15.8	19.7	30.5	41.6	48.9	56.1	61.5	65.4	67.8	73.4	77.4	82.4	100.3	104.7	112.0
1976	17.2	25.2	30.3	42.3	51.4	57.4	62.9	66.7	66.5	73.5	79.6	74.7	85.0	79.0	70.0
1977	17.1	24.0	32.7	41.0	52.1	58.6	65.2	75.9	73.1	81.1	78.9	83.0	92.1	-	114.7
1978	15.9	26.6	33.5	42.9	50.2	59.2	62.2	70.1	80.1	84.6	93.3	92.8	-	87.7	98.8
1979	15.2	24.8	31.9	41.1	47.8	54.1	60.4	65.2	70.8	86.1	87.3	83.4	101.7	74.0	105.1
1980	14.5	22.9	33.5	40.4	46.6	51.0	55.6	67.9	73.0	77.8	81.6	88.0	99.5	102.4	94.0
1981	15.2	19.7	31.7	41.4	45.6	50.5	53.6	57.5	68.8	74.3	77.1	93.6	108.0	100.8	108.8
1982	18.1	26.1	31.0	39.8	46.4	49.2	53.2	55.8	60.7	73.8	84.5	101.6	92.3	112.0	-
1983	16.8	25.5	31.9	37.0	44.3	51.3	52.5	55.9	59.4	59.4	71.9	82.9	105.1	76.0	100.0
1984	20.6	25.1	31.8	36.8	41.1	48.2	53.1	53.9	58.9	60.8	69.2	104.4	91.0	104.4	91.0
1985	15.6	24.5	33.2	38.2	42.3	45.1	49.6	56.1	56.2	58.4	63.2	83.6	107.8	-	-
1986	17.2	24.7	30.4	37.9	40.9	44.0	47.5	51.0	59.8	56.1	63.1	68.7	83.1	102.7	-
1987	19.3	24.9	31.1	36.8	42.2	44.9	47.3	49.9	53.6	56.9	59.8	59.1	70.7	79.8	115.1
1988	17.9	26.0	32.0	37.1	41.6	45.2	46.7	48.5	51.1	59.9	63.1	65.7	69.5	110.8	114.8
1989	18.0	24.2	31.2	37.6	42.2	45.7	48.3	49.0	49.9	51.6	57.6	65.5	76.1	81.8	82.8
1990	16.9	26.9	32.9	38.5	43.2	46.6	49.1	50.5	51.1	51.9	52.9	59.6	83.3	88.5	79.2
1991	17.3	25.1	30.6	37.4	42.1	46.4	48.6	50.7	52.5	52.0	52.3	55.2	68.8	91.4	124.2
1992	16.5	26.6	32.0	35.8	42.6	46.5	49.0	50.9	53.7	56.1	58.1	53.1	53.6	56.0	-
1993	16.8	24.9	32.0	36.9	41.3	46.3	48.6	51.4	52.5	59.5	54.1	61.4	55.0	77.6	94.0
1994	15.8	24.5	32.5	36.6	41.4	44.6	49.1	52.0	53.6	54.4	60.9	66.0	59.5	58.1	-
1995	18.6	24.9	29.9	38.0	41.9	44.9	47.9	51.0	54.5	60.7	62.1	68.1	70.6	85.8	95.8
1996	15.4	27.8	33.4	36.5	43.5	46.3	48.7	50.9	54.2	60.1	62.7	72.8	67.9	57.0	75.0
1997	14.5	24.5	29.1	39.4	43.7	48.8	51.1	53.7	54.6	57.6	59.7	60.7	67.4	67.5	-
1998	15.9	24.2	31.8	36.4	44.1	48.0	52.3	53.6	56.0	56.8	61.6	62.1	66.7	67.8	72.0
1999	16.7	25.5	31.4	37.6	43.1	47.5	51.0	54.3	55.1	56.8	56.3	58.5	62.8	69.6	62.0
2000	18.3	25.2	32.7	37.3	44.2	48.2	51.9	54.1	57.2	55.6	56.3	59.6	65.5	70.0	70.0
2001	14.3	20.8	32.6	38.7	43.8	48.0	51.9	54.2	57.5	58.9	60.0	61.8	68.7	67.4	-

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2002	13.6	22.9	30.8	37.4	41.5	45.7	49.3	52.8	54.4	57.7	59.8	67.0	60.5	67.5	-
2003	15.2	24.0	30.6	35.7	43.8	48.5	51.0	53.8	56.8	58.3	58.8	62.0	61.0	66.4	75.0
2004	19.2	23.9	28.2	34.2	41.4	46.6	50.4	53.8	55.6	59.2	61.9	62.0	73.4	75.1	-
2005	15.4	24.9	31.9	34.1	40.1	45.3	49.8	52.8	55.0	58.0	58.5	65.6	59.2	-	-
2006	16.6	26.4	29.9	39.0	41.6	45.9	49.6	53.3	55.2	58.9	58.6	61.8	59.0	-	-
2007	15.0	20.6	33.4	37.2	43.0	46.0	48.7	51.5	54.4	56.0	61.8	64.9	58.0	-	73.0
2008	12.6	21.9	28.9	36.8	41.0	45.7	48.3	51.7	53.4	55.6	56.8	70.5	59.0	-	-
2009	9.1	25.6	30.2	35.0	39.3	44.7	47.4	51.2	54.0	56.6	64.8	61.9	55.0	-	65.0
2010	12.6	18.5	30.5	35.6	40.7	46.3	49.8	52.9	55.4	56.1	58.2	54.8	54.3	-	-
2011	14.3	22.6	27.2	33.0	41.3	46.0	50.1	52.3	55.6	60.6	56.9	58.6	-	-	-
2012	8.8	20.6	29.6	34.2	42.8	46.9	51.0	53.3	57.2	58.4	60.8	66.5	89.0	-	-
2013	16.5	22.8	27.7	32.8	39.0	43.0	47.4	53.2	58.8	62.9	56.8	68.3	67.9	58.0	-
2014	17.4	24.1	28.5	34.0	40.3	45.3	51.2	54.7	59.4	63.2	67.4	73.7	74.4	63.0	-
2015	16.7	21.0	29.1	34.8	40.7	46.4	50.4	55.5	58.8	64.2	66.0	72.2	70.6	-	78.0
2016	18.6	22.5	30.2	36.6	42.0	46.6	51.7	55.0	58.5	67.3	66.2	64.6	75.8	76.0	-
2017	18.7	23.6	29.6	35.3	38.6	43.2	46.9	53.5	58.4	65.4	-	99.0	74.0	-	-
2018	13.2	23.5	27.9	33.1	38.6	41.8	45.9	47.1	61.1	64.8	52.5	93.0	79.0	66.0	-

Table 7. Mean weight (kg) at age of southern Gulf Atlantic Cod from research vessel surveys, 1960 to 2018. Data from 1960 to 1970 are from non-stratified-random surveys. A dash indicates that no Atlantic Cod of that age was sampled. Data for age 1 may include Greenland Cod (see Table 5).

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1960	-	-	0.35	0.67	1.12	1.72	2.00	2.77	3.57	3.25	3.71	3.31	4.29	12.85	5.98
1961	-	-	0.31	0.55	0.90	1.36	2.08	2.75	3.41	4.83	6.51	6.87	7.56	9.01	14.86
1962	-	-	0.36	0.65	0.93	1.33	1.96	2.86	5.64	7.22	7.90	11.03	-	14.86	-
1963	-	-	0.38	0.61	0.92	1.09	1.46	2.00	2.79	4.91	2.99	8.15	9.04	5.98	-
1964	-	-	0.40	0.58	0.91	1.20	1.35	1.95	2.55	4.28	6.71	8.99	-	4.53	-
1965	-	-	0.40	0.69	1.18	1.24	1.66	2.01	2.52	2.88	4.93	-	8.31	-	9.38
1966	-	-	0.39	0.79	1.29	1.58	1.91	2.26	2.43	3.36	4.75	6.53	7.82	9.95	-
1967	-	-	0.45	0.70	1.45	1.88	2.38	2.46	2.86	4.14	4.62	6.17	8.00	10.19	11.18
1968	-	-	0.41	0.79	1.34	1.88	2.64	3.85	2.58	3.08	3.90	5.61	6.41	10.22	10.60
1969	-	-	0.44	0.85	1.40	1.96	2.63	3.51	4.23	2.84	7.19	6.73	6.82	7.04	10.77
1970	-	-	0.42	0.75	1.22	1.73	2.49	3.30	4.44	4.77	3.70	4.25	5.29	4.96	8.62
1971	0.03	0.12	0.41	0.75	1.15	1.42	2.00	3.03	4.59	5.49	6.31	4.43	3.56	4.26	6.61
1972	0.05	0.15	0.39	0.73	1.22	1.55	1.95	2.72	3.92	4.61	6.00	6.30	5.08	10.77	6.13
1973	0.03	0.17	0.34	0.75	1.18	1.56	1.94	2.39	2.84	4.97	5.29	8.78	3.58	2.98	4.89
1974	0.04	0.21	0.46	0.74	1.20	1.67	2.13	2.31	2.42	3.51	4.39	5.66	11.03	-	4.31
1975	0.04	0.09	0.30	0.74	1.20	1.80	2.39	2.87	3.22	4.29	4.81	5.99	10.04	11.35	13.88
1976	0.05	0.15	0.26	0.73	1.32	1.87	2.50	3.04	3.06	4.07	5.31	4.41	6.97	4.90	3.37
1977	0.05	0.13	0.34	0.66	1.35	1.95	2.70	4.33	3.88	5.38	4.92	5.87	8.75	-	14.96
1978	0.03	0.16	0.33	0.74	1.22	2.06	2.49	3.63	5.40	6.57	9.46	9.03	-	7.37	10.47
1979	0.02	0.11	0.26	0.59	0.97	1.48	2.18	2.81	3.65	6.94	7.37	6.41	11.97	4.84	13.29
1980	0.03	0.12	0.35	0.61	0.94	1.24	1.64	3.05	3.79	4.61	5.16	6.45	9.35	10.22	7.77
1981	0.03	0.08	0.30	0.65	0.87	1.18	1.42	1.78	3.09	3.89	4.58	7.67	11.49	9.52	11.67
1982	0.06	0.17	0.28	0.60	0.94	1.13	1.43	1.67	2.18	4.03	5.77	9.91	7.61	13.10	-
1983	0.04	0.13	0.26	0.43	0.74	1.17	1.29	1.54	1.97	1.97	4.60	5.94	12.38	3.94	9.41
1984	0.07	0.13	0.27	0.42	0.60	1.00	1.37	1.45	1.92	2.21	3.45	11.59	7.44	11.59	7.44
1985	0.03	0.13	0.32	0.50	0.69	0.83	1.14	1.72	1.70	1.92	2.65	5.90	12.66	-	-
1986	0.05	0.14	0.27	0.51	0.65	0.81	1.04	1.32	2.29	1.79	2.73	3.56	6.65	11.55	-
1987	0.06	0.12	0.25	0.42	0.65	0.79	0.93	1.13	1.49	1.79	2.36	2.18	4.45	6.77	15.66
1988	0.05	0.16	0.30	0.47	0.66	0.85	0.94	1.06	1.27	2.40	2.48	3.62	3.97	13.91	15.32
1989	0.05	0.13	0.28	0.49	0.70	0.89	1.06	1.11	1.17	1.29	2.03	3.59	5.16	6.94	7.66

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1990	0.05	0.18	0.33	0.54	0.76	0.96	1.14	1.24	1.27	1.35	1.44	2.34	6.47	8.74	5.66
1991	0.05	0.15	0.27	0.48	0.69	0.93	1.08	1.24	1.40	1.36	1.37	1.68	3.88	7.91	18.61
1992	0.04	0.17	0.30	0.43	0.72	0.93	1.10	1.25	1.49	1.89	1.98	1.41	1.43	1.62	-
1993	0.05	0.14	0.30	0.45	0.64	0.91	1.06	1.26	1.41	2.21	1.49	2.47	1.53	5.23	8.81
1994	0.04	0.14	0.31	0.46	0.66	0.83	1.12	1.34	1.49	1.58	2.42	2.83	1.96	1.83	-
1995	0.06	0.14	0.25	0.50	0.67	0.84	1.03	1.25	1.60	2.33	2.54	3.36	3.60	6.62	8.59
1996	0.03	0.19	0.34	0.45	0.77	0.93	1.11	1.29	1.58	2.36	2.59	4.33	3.54	1.76	4.19
1997	0.03	0.13	0.22	0.56	0.77	1.09	1.28	1.55	1.63	1.97	2.25	2.34	3.02	2.97	-
1998	0.04	0.13	0.30	0.45	0.79	1.05	1.36	1.49	1.76	1.83	2.32	2.39	3.09	3.47	3.55
1999	0.04	0.15	0.28	0.49	0.74	0.99	1.25	1.53	1.61	1.77	1.69	1.90	2.57	3.54	2.21
2000	0.06	0.15	0.32	0.47	0.79	1.03	1.30	1.48	1.78	1.61	1.74	2.05	2.84	3.17	3.17
2001	0.03	0.10	0.32	0.54	0.78	1.05	1.34	1.56	1.89	2.05	2.13	2.31	3.30	3.21	-
2002	0.02	0.11	0.27	0.48	0.67	0.89	1.13	1.43	1.55	1.91	2.12	3.07	2.24	3.09	-
2003	0.03	0.12	0.26	0.41	0.78	1.07	1.25	1.49	1.79	1.97	1.98	2.46	2.22	3.05	4.13
2004	0.06	0.12	0.21	0.37	0.67	0.96	1.23	1.52	1.69	2.09	2.37	2.36	3.90	4.19	-
2005	0.03	0.14	0.30	0.37	0.60	0.88	1.18	1.42	1.63	1.93	2.03	2.97	2.01	-	-
2006	0.04	0.16	0.24	0.53	0.65	0.88	1.12	1.41	1.58	1.94	1.91	2.29	1.90	-	-
2007	0.03	0.08	0.33	0.47	0.71	0.89	1.06	1.27	1.51	1.65	2.27	2.81	1.78	-	3.62
2008	0.02	0.09	0.21	0.43	0.61	0.86	1.04	1.31	1.46	1.71	1.74	3.38	1.91	-	-
2009	0.01	0.16	0.26	0.40	0.56	0.82	0.98	1.24	1.44	1.68	2.55	2.20	1.49	-	2.44
2010	0.02	0.06	0.26	0.41	0.60	0.91	1.13	1.38	1.57	1.63	1.79	1.48	1.47	-	-
2011	0.03	0.10	0.17	0.33	0.62	0.86	1.13	1.30	1.54	2.05	1.64	1.82	-	-	-
2012	0.01	0.08	0.23	0.35	0.69	0.91	1.19	1.37	1.72	1.78	2.01	2.69	6.37	-	-
2013	0.04	0.11	0.19	0.32	0.54	0.72	0.97	1.40	1.93	2.37	1.70	3.06	2.91	1.77	-
2014	0.05	0.13	0.21	0.36	0.60	0.85	1.24	1.52	1.96	2.42	2.84	4.10	3.91	2.26	-
2015	0.04	0.08	0.21	0.36	0.59	0.91	1.17	1.59	1.98	2.52	2.66	3.52	3.22	-	4.32
2016	0.05	0.09	0.22	0.41	0.62	0.87	1.22	1.52	1.82	2.97	2.60	2.48	3.92	3.86	-
2017	0.05	0.11	0.21	0.37	0.49	0.72	0.95	1.44	1.86	2.75	2.75	9.59	3.80	-	-
2018	0.02	0.10	0.17	0.30	0.47	0.62	0.83	0.95	2.30	2.55	1.26	7.63	4.55	2.57	-

Table 8. Maturity ogives (proportion mature at age) used in the calculation of spawning stock biomass of southern Gulf of St. Lawrence Atlantic Cod. Ogives are shown only for years in which the ogive changes.

Year	2	3	4	5	6	7	8	9	10	11	12+
1950	0.006	0.019	0.054	0.148	0.344	0.613	0.828	0.936	0.978	0.993	0.998
1963	0.021	0.049	0.112	0.238	0.440	0.673	0.847	0.937	0.976	0.991	0.996
1964	0.035	0.080	0.171	0.328	0.536	0.732	0.866	0.939	0.973	0.989	0.995
1968	0.006	0.039	0.206	0.624	0.914	0.986	0.998	1.000	1.000	1.000	1.000
1974	0.015	0.104	0.473	0.875	0.982	0.998	1.000	1.000	1.000	1.000	1.000
1977	0.032	0.144	0.465	0.818	0.959	0.992	0.998	1.000	1.000	1.000	1.000
1985	0.020	0.109	0.441	0.842	0.971	0.995	0.999	1.000	1.000	1.000	1.000
1988	0.009	0.073	0.417	0.867	0.983	0.998	1.000	1.000	1.000	1.000	1.000
1994	0.018	0.097	0.382	0.781	0.954	0.992	0.999	1.000	1.000	1.000	1.000
1997	0.013	0.074	0.334	0.765	0.955	0.993	0.999	1.000	1.000	1.000	1.000
1998	0.007	0.052	0.287	0.748	0.956	0.994	0.999	1.000	1.000	1.000	1.000

Table 9. Analysis of deviance results of the generalized linear model analysis of Atlantic Cod catches (kg/tow) by the vessels used in the August sentinel trawl survey. Only parameter estimates for vessel differences are presented.

Source	Deviance	Numerator DF	Denominator DF	F Value	Pr>F	Chi-square	Pr>Chi-square
Statistics for Type I analysis							
Intercept	273515	-	-	-	-	-	-
Year	260345	15	3002	15.17	< 0.0001	227.61	< 0.0001
Strat	185895	25	3002	51.47	< 0.0001	1286.69	< 0.0001
cfvn	173701	11	3002	19.16	< 0.0001	210.73	< 0.0001
Statistics for Type III analysis							
Year	-	15	3002	12.63	< 0.0001	189.47	< 0.0001
Strat	-	25	3002	49.46	< 0.0001	1236.6	< 0.0001
cfvn	-	11	3002	19.16	< 0.0001	210.73	< 0.0001

Table 10. Parameter estimates from the generalized linear model analysis of Atlantic Cod catches (kg/tow) by the vessels used in the August sentinel trawl survey. Only parameter estimates for vessel differences are presented. Wald 95% CL are the Wald 95% Confidence Limits

				Wald 95% CL			
CFVN	DF	Estimate	Standard Error	lower	upper	Chi-square	Pr > Chi-square
5688 (1)	1	-0.0245	0.1527	-0.3238	0.2749	0.03	0.8727
8106 (4)	1	-0.1270	0.3586	-0.8300	0.5759	0.13	0.7232
11502 (2)	1	1.7394	0.2095	1.3288	2.1499	68.96	< 0.0001
11870 (3)	1	0.5535	0.1150	0.3281	0.7789	23.16	< 0.0001
11873 (1)	1	-0.0188	0.1896	-0.3905	0.3529	0.01	0.921
17354 (3)	1	0.6607	0.1318	0.4023	0.9190	25.12	< 0.0001
17790 (3)	1	0.1329	0.0925	-0.0484	0.3141	2.06	0.1508
64796 (4)	1	-0.2135	0.1887	-0.5833	0.1564	1.28	0.2579
100278 (4)	1	-0.8147	0.2782	-1.3600	-0.2694	8.57	0.0034
151573 (2)	1	1.0624	0.2547	0.5632	1.5616	17.4	< 0.0001
176573 (3)	1	0.6916	0.7153	-0.7104	2.0937	0.93	0.3336
151347	0	0.0000	0.0000	0.0000	0.0000	-	-

Vessel specific correction factors: (1) 0, (2) 3.1810, (3) 1.4894, (4) 0.6084

Table 11. Akaike Information Criterion (AIC) of the generalized additive model analysis of Atlantic Cod catches (kg/tow) by the vessels used in the August sentinel trawl survey. Catches were adjusted for distance towed.

Model parameters	AIC
vessel + s(log.depth)	18300
year + vessel + s(log.depth)	18126
stratum + vessel + s(log.depth)	17515
year + stratum + vessel + s(log.depth)	17332
vessel + s(x, y)	17787
vessel + s(x, y) + s(log.depth)	17256
year + vessel + s(x, y) + s(log.depth)	17086
stratum + vessel + s(x, y) + s(log.depth)	17178
year + stratum + vessel + s(x, y) + s(log.depth)	16979 (*)

(*) model selected for the analysis

Table 12. Parameter coefficients from the generalized additive model analysis of Atlantic Cod catches (kg/tow) by the vessels used in the August sentinel trawl survey.

Vessel	Estimate	Standard error	Z value	Pr(>|z|)	Correction factor
5688	0.1634	0.1616	1.012	0.3118	1.1775
8106	0.2030	0.2760	0.736	0.4619	1.2251
11502	2.1095	0.2122	9.942	< 2.0E-16	8.2442
11870	0.7446	0.1302	5.719	1.10E-08	2.1055
11873	-0.0942	0.2749	-0.343	0.7319	0.9101
17354	0.9895	0.1698	5.828	5.60E-09	2.6898
17790	0.5345	0.1036	5.159	2.50E-07	1.7066
64796	-0.1498	0.1892	-0.792	0.4285	0.8609
100278	-1.0697	0.1874	-5.707	1.20E-08	0.3431
151573	1.6233	0.2590	6.268	3.70E-10	5.0697
176573	0.2442	0.4668	0.523	0.6009	1.2766

Table 13. Mean number per tow by age for Atlantic Cod in the August sentinel trawl surveys from the southern Gulf of St. Lawrence, 2003 to 2018. Abundance estimates are adjusted for vessel differences. Data for ages 0 and 1 may include Greenland cod (see Table 5).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total
2003	0.00	2.25	8.66	8.52	8.11	6.52	5.16	4.82	3.39	1.62	0.42	0.50	0.12	0.13	0.09	0.02	50.34
2004	0.02	0.20	5.96	9.10	9.78	7.33	2.92	2.73	1.94	1.08	0.67	0.15	0.11	0.02	0.04	0.00	42.05
2005	0.00	0.49	0.47	4.13	7.89	6.28	3.14	1.35	0.95	0.47	0.34	0.23	0.05	0.02	0.01	0.01	25.80
2006	0.00	0.16	2.03	1.81	3.45	6.11	3.88	1.89	0.50	0.27	0.15	0.09	0.06	0.00	0.01	0.01	20.41
2007	0.00	0.21	1.17	9.11	10.00	5.27	5.01	1.98	0.96	0.41	0.28	0.08	< 0.01	0.01	0.00	0.00	34.48
2008	0.02	0.42	3.44	6.40	4.85	7.32	2.66	3.72	1.37	0.59	0.14	0.11	0.08	0.00	0.00	0.00	31.13
2009	0.00	0.12	3.07	10.41	9.85	2.54	4.06	1.27	2.39	0.92	0.27	0.08	0.03	0.01	0.01	0.00	35.02
2010	0.00	0.28	1.33	4.39	4.14	4.95	1.33	1.61	0.54	0.62	0.39	0.20	0.00	0.01	0.03	0.00	19.80
2011	0.00	0.15	1.11	5.53	3.53	4.98	5.38	0.80	0.89	0.39	0.53	0.09	0.04	0.00	0.00	0.01	23.44
2012	0.01	0.03	0.74	1.88	3.78	0.87	1.15	1.10	0.20	0.30	0.11	0.16	0.04	< 0.01	< 0.01	0.00	10.38
2013	0.01	0.35	1.24	1.51	2.17	3.51	0.94	0.58	0.23	0.15	0.06	0.03	0.05	0.00	0.00	0.00	10.82
2014	0.00	0.03	0.49	2.29	4.95	3.24	1.86	0.53	0.31	0.24	0.04	0.05	0.01	< 0.01	0.00	< 0.01	14.03
2015	0.00	0.00	0.10	0.61	1.58	1.45	0.90	0.71	0.10	0.08	0.06	0.01	0.02	< 0.01	0.00	0.00	5.62
2016	0.00	0.02	0.08	0.88	1.83	1.36	0.77	0.37	0.25	0.07	0.03	0.02	0.01	< 0.01	0.00	0.00	5.69
2017	0.00	0.13	0.12	0.19	0.55	0.66	0.52	0.24	0.18	0.08	0.02	0.01	0.01	< 0.01	0.00	0.00	2.71
2018	0.00	0.04	0.92	1.56	0.79	0.94	0.59	0.65	0.41	0.15	0.21	0.02	0.01	0.00	0.00	0.00	6.28

Table 14. Average weight (kg) by age for Atlantic Cod in the August sentinel trawl surveys from the southern Gulf of St. Lawrence, 2003 to 2018. A dash indicates that no Atlantic Cod of that age was sampled. Data for ages 0 and 1 may include Greenland Cod (see Table 5).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total
2003	-	0.05	0.11	0.27	0.42	0.73	0.99	1.18	1.44	1.82	1.89	1.95	2.28	2.31	2.78	4.09	0.65
2004	<0.01	0.05	0.10	0.22	0.36	0.59	0.90	1.10	1.44	1.66	1.79	1.73	1.77	2.07	1.85	-	0.53
2005	-	0.04	0.13	0.28	0.36	0.58	0.84	1.15	1.34	1.55	1.93	2.28	2.27	2.48	3.51	2.30	0.59
2006	-	0.08	0.13	0.23	0.49	0.60	0.79	1.03	1.32	1.44	1.88	1.88	2.20	-	3.16	2.28	0.62
2007	-	0.02	0.12	0.31	0.41	0.67	0.88	1.09	1.31	1.64	1.85	2.43	2.45	3.46	-	-	0.57
2008	<0.01	0.04	0.11	0.21	0.44	0.62	0.83	1.01	1.37	1.39	1.73	1.89	1.65	-	-	-	0.57
2009	-	0.03	0.13	0.24	0.33	0.53	0.81	1.02	1.28	1.56	1.64	1.80	1.42	2.06	2.16	-	0.49
2010	-	0.02	0.06	0.25	0.37	0.58	0.87	1.16	1.37	1.68	1.65	1.51	-	2.40	1.12	-	0.58
2011	-	0.02	0.09	0.17	0.39	0.55	0.78	1.17	1.39	1.47	1.73	1.75	1.88	-	-	2.10	0.56
2012	0.01	0.02	0.07	0.21	0.32	0.66	0.93	1.19	1.64	1.60	2.49	2.09	2.52	3.05	3.05	-	0.59
2013	<0.01	0.03	0.09	0.22	0.36	0.51	0.71	0.88	1.49	1.27	1.89	3.52	1.97	-	-	-	0.46
2014	-	0.03	0.15	0.26	0.40	0.64	0.81	1.13	1.36	1.86	2.03	2.22	2.59	4.42	-	4.75	0.56
2015	-	0.00	0.10	0.25	0.40	0.60	0.90	1.16	1.64	1.94	2.55	3.51	2.76	1.89	-	-	0.69
2016	-	0.05	0.14	0.30	0.44	0.59	0.85	1.12	1.26	1.85	2.43	3.25	3.53	4.16	-	-	0.62
2017	-	0.03	0.06	0.23	0.40	0.57	0.74	1.05	1.46	2.72	2.31	2.55	5.94	4.09	-	-	0.69
2018	-	0.05	0.11	0.18	0.39	0.57	0.71	0.94	1.63	2.02	2.11	1.39	1.96	-	-	-	0.59

Table 15. Average length (cm) by age for Atlantic Cod in the August sentinel trawl surveys from the southern Gulf of St. Lawrence, 2003 to 2018. A dash indicates that no Atlantic Cod of that age was sampled. Data for ages 0 and 1 may include Greenland cod (see Table 5).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Total
2003	-	18.3	23.2	31.1	35.8	43.0	47.3	50.0	53.2	57.0	57.8	58.8	60.8	61.7	64.7	74.7	38.0
2004	7.1	17.7	22.1	28.5	33.9	40.0	46.2	49.2	53.6	55.7	57.3	56.6	57.4	60.8	58.6	-	35.9
2005	-	16.5	24.1	31.4	33.9	39.6	44.6	49.3	51.8	54.3	58.0	60.6	61.2	63.6	71.0	62.0	38.1
2006	-	20.9	24.4	29.0	38.0	40.6	44.2	48.3	52.2	53.9	58.4	58.6	61.4	-	70.0	63.0	39.5
2007	-	13.5	23.7	32.5	35.7	41.9	45.6	48.9	51.8	55.4	57.3	63.4	64.0	71.5	-	-	38.4
2008	8.1	16.7	23.5	28.4	36.4	40.8	44.9	47.8	52.5	52.9	56.8	58.1	55.8	-	-	-	37.4
2009	-	14.8	24.3	29.9	33.2	38.6	44.7	48.1	51.7	55.0	56.1	57.7	53.0	60.9	62.0	-	35.7
2010	-	13.3	18.5	30.5	34.4	40.0	45.7	50.0	53.0	55.9	56.3	54.9	-	64.0	50.0	-	37.4
2011	-	14.3	21.9	26.8	35.2	39.7	44.5	50.6	53.5	54.7	57.7	58.2	59.7	-	-	62.0	37.7
2012	10.0	13.4	20.1	28.6	33.3	42.0	46.9	51.0	56.7	56.3	63.9	61.3	65.2	70.0	70.0	-	37.5
2013	6.0	15.1	21.4	28.9	34.1	38.4	42.5	45.6	54.0	51.4	58.9	70.7	59.7	-	-	-	35.0
2014	-	15.0	25.1	30.6	35.5	41.2	44.6	49.7	53.1	57.4	60.4	61.3	66.0	78.9	-	80.9	38.3
2015	-	-	22.7	30.2	35.7	40.7	46.3	50.1	55.3	59.1	64.4	72.9	67.1	60.0	-	-	40.9
2016	-	17.8	24.8	32.4	37.1	40.8	45.8	50.0	51.8	58.3	64.7	72.0	74.6	78.9	-	-	40.2
2017	-	16.1	19.5	30.0	35.6	39.8	43.1	48.3	53.0	64.5	61.1	65.0	82.9	76.0	-	-	39.5
2018	-	17.5	23.6	27.7	35.6	40.5	43.3	47.2	55.3	59.4	60.4	53.3	61.0	-	-	-	37.2

Table 16. Factors in the general linear model for the standardization of longline sentinel catch rates of Atlantic Cod from 1995 to 2017. There are a total of 2,262 observations in the analysis.

Factor	Number of levels	Values
Year	23	1995 to 2017
Month	4	July, August, September, October
Site	44	17, 19, 22, 23, 24, 25, 28, 29, 30, 31, 34, 35,
-	-	40, 45, 50, 51, 52, 53, 60, 61, 65, 68, 71, 72,
-	-	75, 76, 85, 89, 97, 98, 103, 104, 109, 110, 113, 114,
-	-	115, 116, 121, 122, 123, 124, 125, 126

Table 17. Analysis of variance results of the general linear model for the standardization of longline sentinel catch rates of Atlantic Cod from 1995 to 2017. There are a total of 2,262 observations in the analysis.

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	68	8853.85	130.20	61.14	< 0.0001
Error	2193	4670.53	2.13	-	-
Corrected Total	2261	13524.37	-	-	-
Statistics for Type I analysis					
year	22	1128.30	51.29	24.08	< 0.0001
month	3	333.14	111.05	52.14	< 0.0001
site	43	7392.41	171.92	80.72	< 0.0001
Statistics for Type III analysis					
year	22	1445.29	65.69	30.85	< 0.0001
month	3	33.90	11.30	5.31	0.0012
site	43	7392.41	171.92	80.72	< 0.0001

Note: R^2=0.65, Coeff. of variation=47.52, Root mean square Error=1.46, CPUE Mean=3.07

Table 18. Predicted annual catch rates (LS Mean, least-squares mean of log kg per 1,000 hooks of Atlantic Cod) from the general linear model for the standardization of longline sentinel catch and effort data, 1995 to 2017.

Year	LS Mean	Year	LS Mean
1995	3.416298	2007	2.520062
1996	4.008928	2008	2.362990
1997	4.153538	2009	2.092121
1998	3.217991	2010	1.912409
1999	3.749385	2011	1.631911
2000	3.952161	2012	2.251994
2001	3.675432	2013	1.988590
2002	3.483964	2014	1.776920
2003	3.634168	2015	1.630872
2004	3.749277	2016	2.144122
2005	3.275500	2017	2.247400
2006	3.024916	-	-

Table 19. Standardized longline sentinel survey abundance indices (number per 1,000 hooks) by age for southern Gulf of St. Lawrence Atlantic Cod, 1995-2017. Data for age 1 may include Greenland Cod (see Table 5).

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1995	< 0.01	0.05	0.21	1.46	3.52	5.17	12.94	9.25	5.21	1.96	1.12	0.40	0.13	0.07	0.00	0.00	41.49
1996	0.00	0.00	0.56	2.48	9.84	14.45	12.05	20.80	14.88	5.90	2.82	1.24	0.88	0.20	0.01	0.06	86.19
1997	0.00	0.00	0.23	2.68	8.06	13.23	18.18	17.98	23.45	12.51	4.01	1.23	0.24	0.24	0.20	0.02	102.25
1998	0.00	< 0.01	0.34	1.13	3.00	6.31	6.34	5.30	4.51	5.67	2.80	0.88	0.34	0.09	0.01	0.01	36.71
1999	0.00	< 0.01	0.33	2.95	7.68	7.56	15.44	10.88	9.75	6.62	3.63	0.79	0.41	0.23	0.08	0.05	66.40
2000	0.00	< 0.01	0.39	1.90	7.76	12.05	11.47	19.12	8.59	6.68	6.94	3.47	1.15	0.53	0.04	0.01	80.12
2001	0.00	0.00	0.31	1.52	5.13	7.72	14.89	10.13	7.11	4.24	3.06	2.14	1.28	0.13	0.02	0.02	57.69
2002	0.00	< 0.01	0.58	2.11	6.55	8.22	11.86	10.60	4.50	2.68	1.41	0.90	0.84	0.30	0.16	0.00	50.72
2003	0.00	< 0.01	0.13	1.52	6.60	9.82	11.21	12.31	9.10	3.56	3.46	1.31	1.03	0.48	0.38	0.13	61.04
2004	0.00	< 0.01	0.35	1.88	7.01	9.61	12.95	11.80	12.14	7.00	1.78	2.72	0.87	0.66	0.12	0.32	69.23
2005	0.00	0.00	0.09	0.47	2.56	5.45	7.63	7.97	7.20	4.24	2.90	0.67	0.67	0.18	0.10	0.09	40.23
2006	0.00	0.00	0.11	0.95	3.75	5.51	6.10	5.29	5.11	3.07	2.15	1.64	0.63	0.30	0.07	0.04	34.72
2007	0.00	0.00	0.04	0.53	1.32	4.18	4.90	4.02	1.74	1.99	1.17	0.81	0.62	0.14	0.11	0.02	21.61
2008	0.00	0.00	0.01	0.20	1.57	2.79	4.56	3.49	2.24	1.38	0.59	0.71	0.24	0.10	0.03	0.03	17.95
2009	0.00	< 0.01	0.03	0.41	0.75	3.72	1.80	3.63	1.72	1.43	0.44	0.42	0.21	0.12	0.05	0.00	14.73
2010	0.00	0.00	0.05	0.56	1.97	1.66	3.10	1.67	2.12	1.22	0.42	0.13	0.05	0.02	0.01	0.01	12.98
2011	0.00	0.01	0.14	1.48	2.41	2.59	1.14	1.20	0.80	0.59	0.14	0.07	0.02	0.02	0.00	0.00	10.61
2012	0.00	< 0.01	0.17	1.16	3.74	4.89	3.53	1.37	1.25	0.66	0.53	0.20	0.06	0.04	0.02	0.01	17.63
2013	0.00	0.00	0.01	0.33	1.43	1.98	2.80	2.88	0.97	1.19	0.45	0.45	0.18	0.06	0.01	0.00	12.74
2014	< 0.01	0.02	0.53	2.29	2.27	1.70	1.30	1.02	0.30	0.50	0.20	0.14	0.06	0.01	0.00	0.00	10.35
2015	0.00	0.00	0.04	0.37	1.64	2.33	2.34	1.03	0.83	0.71	0.22	0.20	0.07	0.09	0.03	0.01	9.90
2016	0.00	0.02	0.41	1.77	3.16	4.61	3.86	2.00	0.82	0.59	0.38	0.09	0.09	0.05	0.03	0.00	17.87
2017	0.00	0.00	0.34	1.47	3.27	4.35	2.94	2.06	1.60	0.24	0.24	0.09	0.01	0.02	0.02	0.00	16.64

Table 20. Average weight (kg) at age from the longline sentinel survey catches for southern Gulf of St. Lawrence Atlantic Cod, 1995-2017. A dash indicates that no Atlantic Cod of that age was sampled.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Average
1995	0.09	0.21	0.35	0.62	0.84	1.07	1.43	1.64	2.18	2.67	2.88	2.94	3.86	3.62	-	-	1.56
1996	-	-	0.49	0.67	1.01	1.26	1.62	1.84	2.06	2.53	3.13	2.79	3.29	4.04	2.32	5.36	1.74
1997	-	-	0.38	0.64	0.96	1.35	1.63	2.08	2.14	2.37	2.75	2.95	3.19	3.49	2.16	4.71	1.87
1998	-	0.33	0.53	0.75	1.09	1.42	1.80	1.95	2.14	2.23	2.61	2.97	3.45	3.26	6.15	5.10	1.87
1999	-	0.28	0.54	0.81	1.04	1.43	1.68	2.04	2.06	2.25	2.61	3.25	3.26	2.98	3.08	5.08	1.79
2000	-	0.14	0.53	0.75	1.01	1.33	1.65	1.84	2.20	2.39	2.10	2.56	3.04	2.73	3.99	5.16	1.78
2001	-	-	0.59	0.77	0.97	1.36	1.76	2.00	2.31	2.43	2.68	2.66	2.80	4.02	6.22	4.79	1.88
2002	-	0.23	0.53	0.72	1.06	1.36	1.70	2.07	2.25	2.70	2.75	2.82	2.56	3.24	2.24	-	1.76
2003	-	0.15	0.43	0.61	0.90	1.24	1.57	1.96	2.30	2.51	2.69	3.06	2.53	3.10	2.88	3.07	1.80
2004	-	0.38	0.49	0.67	0.88	1.13	1.51	1.78	1.91	2.36	2.70	2.44	2.89	2.91	3.34	3.00	1.68
2005	-	-	0.60	0.67	0.89	1.23	1.47	1.76	1.96	2.22	2.30	2.73	2.60	2.97	2.94	2.77	1.73
2006	-	-	0.45	0.62	0.86	1.16	1.43	1.74	1.89	2.11	2.49	2.46	2.58	2.79	2.59	2.75	1.63
2007	-	-	0.46	0.61	0.79	1.10	1.36	1.65	1.91	2.05	2.54	2.45	2.68	2.61	3.23	2.88	1.58
2008	-	-	0.31	0.68	0.82	1.14	1.44	1.84	2.04	2.26	2.24	2.50	3.13	2.76	2.39	2.80	1.65
2009	-	0.18	0.37	0.57	0.78	1.08	1.24	1.65	1.74	2.22	2.25	2.28	2.63	2.92	2.47	-	1.51
2010	-	-	0.37	0.67	0.87	1.17	1.41	1.59	1.79	1.94	1.92	2.37	2.11	2.76	3.61	2.15	1.43
2011	-	0.09	0.51	0.76	1.02	1.27	1.63	1.68	1.71	2.12	2.44	1.55	2.28	2.50	-	-	1.32
2012	-	0.24	0.51	0.71	1.07	1.38	1.60	1.89	2.04	2.44	2.30	2.12	2.61	1.95	2.70	3.19	1.47
2013	-	-	0.71	0.82	0.88	1.18	1.42	1.69	1.94	2.13	2.32	2.59	2.72	2.55	2.63	-	1.57
2014	-	0.31	0.43	0.81	1.13	1.25	1.63	1.75	2.08	2.32	2.45	2.64	3.25	2.97	4.93	-	1.56
2015	-	-	0.43	0.58	0.84	1.10	1.32	1.71	1.92	2.33	2.43	2.91	3.03	2.94	2.55	3.67	1.41
2016	-	0.24	0.64	0.85	1.01	1.23	1.42	1.65	2.05	2.21	2.69	3.14	2.56	2.71	2.79	4.02	1.35
2017	-	-	0.63	0.87	1.12	1.31	1.61	1.77	2.02	2.41	1.91	2.68	3.07	1.96	4.01	-	1.43

Table 21. Population model estimates of beginning of the year population biomass (t) by age for the southern Gulf of St. Lawrence Atlantic Cod stock (1971 to 2019). Biomass for ages 3+, 5+ and spawning stock biomass (SSB) are also shown. For 2019, a dash indicates that no estimate is yet available.

Year	2	3	4	5	6	7	8	9	10	11	12+	3+	5+	SSB
1971	6519	26435	33668	38797	43170	40653	19226	12854	11299	4938	6659	237700	177597	174004
1972	10813	13838	36829	35022	34738	31937	29761	14078	7625	6591	6612	217029	166363	164592
1973	14372	22691	21827	35907	27360	22350	20385	17455	7718	3504	6321	185518	141000	135999
1974	11507	28154	31290	21501	30063	18365	13813	11472	8911	3675	6069	173313	113869	128476
1975	26072	24374	35987	32379	17487	20504	11878	8484	6693	5057	4327	167170	106809	122322
1976	39179	39412	27846	34849	27876	12662	13775	7095	5263	4642	5021	178440	111183	124111
1977	46867	72610	69937	37072	33614	19556	8952	8005	4282	2866	5015	261908	119361	155508
1978	36561	83166	106309	98902	40967	26571	15510	7480	6496	4152	6192	395744	206270	248909
1979	21388	58843	121572	120664	97093	29552	17904	10114	5048	4772	6167	471729	291314	330775
1980	15213	49513	77834	136738	103324	65379	20609	12647	6014	2604	6381	481043	353696	367798
1981	27133	38044	82554	96525	131007	76273	43228	14777	8056	3652	5451	499567	378969	400038
1982	46483	59137	59564	93566	86992	96186	51970	29204	8882	5196	5636	496333	377632	393824
1983	29421	93019	97721	65676	82221	63246	64756	35996	16331	5771	9373	534109	343369	387162
1984	23882	44102	103664	99921	54201	56407	40479	42153	20377	10133	9877	481312	333547	367909
1985	33013	49591	60612	116866	91909	40110	40405	27395	22794	11427	16525	477634	367432	378882
1986	21261	45412	68654	63782	107594	72384	27319	30962	14137	12647	15738	458628	344563	366638
1987	22800	39628	55168	63565	52710	74532	49459	18357	14074	7417	14839	389749	294953	312073
1988	28436	36441	46755	54970	52688	36524	48645	31121	10916	6454	15145	339660	256464	270595
1989	25986	39371	45933	49124	48592	36300	22965	28857	14260	5442	11450	302294	216990	231825
1990	24718	41669	46007	45573	39936	30428	20465	12490	12468	5808	6972	261815	174139	189792
1991	14659	36487	51806	45126	33424	21234	15029	9789	4671	4558	4263	226388	138095	155890
1992	13993	23751	35980	47555	30746	16430	9616	6822	3819	1839	2622	179179	119449	129432
1993	10674	22857	27043	35088	33822	15725	7682	4390	2940	1272	1812	152632	102732	110505
1994	11332	19069	24377	25997	31310	26358	11702	5557	2524	1916	1744	150553	107108	111091
1995	7009	17763	24427	24396	23134	25844	19952	9196	4020	1807	2792	153333	111142	115661
1996	15611	14394	22055	25997	23009	19682	21089	15389	6505	2822	3269	154210	117762	120908
1997	9201	21224	19896	26731	25343	20818	17459	17235	10315	4129	3219	166369	125249	125987
1998	7274	19738	22371	20994	26772	22014	17075	14217	11058	6739	4102	165080	122971	123853
1999	8895	17152	27144	28257	18204	22016	16643	12154	8228	6097	5722	161617	117320	117994
2000	6262	17959	22846	30626	27983	14954	16326	11631	6575	4263	6473	159635	118830	117313
2001	7128	11958	23858	26407	29013	23877	11523	12103	6650	3727	6192	155311	119494	118931
2002	5656	11058	15411	24460	22833	21388	16745	7320	6415	3385	5586	134600	108131	105860
2003	7790	12991	16321	16994	20973	17168	14698	10974	3772	3008	4478	121376	92065	92159

Year	2	3	4	5	6	7	8	9	10	11	12+	3+	5+	SSB
2004	4434	16302	16584	17966	14210	16809	13166	10538	6577	2311	3784	118247	85361	85732
2005	6931	9854	19383	17163	15448	10207	11106	8516	5605	3274	3124	103681	74443	75492
2006	3302	9099	13661	22646	15466	11582	6978	7007	4069	2515	2618	95641	72881	70836
2007	4662	6851	10888	14089	20042	11413	7528	4193	3006	1905	2331	82247	64508	63519
2008	3454	6876	7783	11883	9705	13479	7265	4418	1788	1221	1848	66266	51607	50714
2009	2333	6880	10240	6831	8194	5794	7951	4164	1929	883	1164	54030	36910	38099
2010	1760	6158	9816	11745	4997	5621	3689	4922	1872	862	728	50409	34435	34366
2011	2629	5266	5773	9928	8927	3659	3628	2378	2464	776	626	43424	32385	31416
2012	3025	6185	8409	6144	7400	6232	2234	2210	1119	1152	761	41845	27251	28094
2013	1950	5373	7326	9774	4265	4313	3669	1348	1341	527	1079	39015	26317	26032
2014	3224	6894	7470	7614	7199	2679	2612	2201	825	796	979	39271	24907	25178
2015	1625	4746	7989	8172	6219	5158	1925	1805	1360	446	960	38779	26044	26229
2016	946	2264	5368	8803	6094	4253	3293	1115	1072	667	613	33543	25911	25062
2017	2557	1498	3262	5376	5779	3601	2475	1917	566	483	716	25672	20913	20314
2018	2401	3188	1799	3128	2920	2957	1656	1490	1036	196	711	19082	14096	13859
2019	-	4184	4319	1866	1955	1642	1547	857	745	500	530	18147	9643	-

Table 22. The instantaneous rate of fishing mortality at age for the southern Gulf of St. Lawrence Atlantic Cod stock based on model estimates for 1971 to 2018.

Year	2	3	4	5	6	7	8	9	10	11	12+	5 to 8	9+
1971	0.00023	0.00433	0.06768	0.29330	0.35571	0.35974	0.35995	0.35996	0.35996	0.35996	0.35996	0.33161	0.35996
1972	0.00034	0.00632	0.09867	0.42758	0.51856	0.52443	0.52474	0.52476	0.52476	0.52476	0.52476	0.48542	0.52476
1973	0.00031	0.00587	0.09160	0.39695	0.48140	0.48686	0.48715	0.48716	0.48716	0.48716	0.48716	0.44253	0.48716
1974	0.00034	0.00636	0.09935	0.43053	0.52214	0.52805	0.52837	0.52838	0.52839	0.52839	0.52839	0.48959	0.52838
1975	0.00030	0.00557	0.08700	0.37700	0.45721	0.46239	0.46266	0.46268	0.46268	0.46268	0.46268	0.41362	0.46268
1976	0.00007	0.00140	0.02536	0.25771	0.49779	0.52345	0.52488	0.52495	0.52496	0.52496	0.52496	0.37217	0.52496
1977	0.00004	0.00077	0.01396	0.14189	0.27406	0.28820	0.28898	0.28902	0.28902	0.28902	0.28902	0.20567	0.28902
1978	0.00004	0.00081	0.01460	0.14843	0.28670	0.30148	0.30230	0.30234	0.30235	0.30235	0.30235	0.18790	0.30235
1979	0.00004	0.00076	0.01377	0.13993	0.27028	0.28422	0.28499	0.28503	0.28504	0.28504	0.28504	0.19266	0.28503
1980	0.00003	0.00061	0.01111	0.11287	0.21802	0.22926	0.22988	0.22992	0.22992	0.22992	0.22992	0.16073	0.22992
1981	0.00003	0.00065	0.01173	0.11925	0.23034	0.24222	0.24288	0.24291	0.24291	0.24291	0.24291	0.18991	0.24291
1982	0.00003	0.00056	0.01018	0.10345	0.19982	0.21012	0.21070	0.21073	0.21073	0.21073	0.21073	0.16688	0.21073
1983	0.00003	0.00066	0.01197	0.12161	0.23490	0.24701	0.24768	0.24772	0.24772	0.24772	0.24772	0.19833	0.24772
1984	0.00003	0.00056	0.01022	0.10389	0.20066	0.21101	0.21158	0.21161	0.21162	0.21162	0.21162	0.14591	0.21161
1985	0.00003	0.00057	0.01041	0.10576	0.20429	0.21482	0.21541	0.21544	0.21544	0.21544	0.21544	0.15372	0.21544
1986	0.00003	0.00060	0.01091	0.11093	0.21427	0.22532	0.22593	0.22596	0.22597	0.22597	0.22597	0.18503	0.22597
1987	0.00003	0.00063	0.01138	0.11568	0.22344	0.23497	0.23560	0.23564	0.23564	0.23564	0.23564	0.19064	0.23564
1988	0.00004	0.00075	0.01368	0.13908	0.26865	0.28250	0.28327	0.28331	0.28331	0.28331	0.28331	0.22301	0.28331
1989	0.00005	0.00101	0.01829	0.18590	0.35909	0.37760	0.37863	0.37868	0.37868	0.37868	0.37868	0.29365	0.37868
1990	0.00007	0.00126	0.02291	0.23289	0.44984	0.47304	0.47432	0.47439	0.47440	0.47440	0.47440	0.36165	0.47440
1991	0.00007	0.00139	0.02512	0.25526	0.49306	0.51848	0.51989	0.51996	0.51997	0.51997	0.51997	0.37923	0.51997
1992	0.00007	0.00133	0.02410	0.24489	0.47303	0.49742	0.49877	0.49884	0.49885	0.49885	0.49885	0.34862	0.49884
1993	0.00001	0.00016	0.00288	0.02923	0.05646	0.05938	0.05954	0.05955	0.05955	0.05955	0.05955	0.04303	0.05955
1994	0.00003	0.00013	0.00055	0.00218	0.00706	0.01452	0.01920	0.02074	0.02113	0.02122	0.02124	0.00770	0.02094
1995	0.00002	0.00009	0.00040	0.00159	0.00512	0.01054	0.01394	0.01505	0.01534	0.01540	0.01542	0.00632	0.01518
1996	0.00002	0.00009	0.00037	0.00148	0.00478	0.00984	0.01301	0.01405	0.01431	0.01438	0.01439	0.00583	0.01415
1997	0.00003	0.00013	0.00057	0.00227	0.00733	0.01508	0.01993	0.02153	0.02194	0.02203	0.02205	0.00815	0.02172
1998	0.00005	0.00021	0.00091	0.00365	0.01180	0.02428	0.03210	0.03467	0.03532	0.03548	0.03551	0.01419	0.03508
1999	0.00011	0.00048	0.00203	0.00811	0.02621	0.05393	0.07130	0.07701	0.07846	0.07880	0.07888	0.02782	0.07797
2000	0.00013	0.00054	0.00232	0.00926	0.02993	0.06159	0.08143	0.08795	0.08961	0.09000	0.09009	0.03009	0.08906
2001	0.00014	0.00058	0.00249	0.00995	0.03214	0.06613	0.08743	0.09443	0.09621	0.09663	0.09672	0.03382	0.09552
2002	0.00012	0.00051	0.00218	0.00873	0.02819	0.05801	0.07669	0.08284	0.08440	0.08476	0.08485	0.03193	0.08392
2003	0.00001	0.00003	0.00012	0.00047	0.00151	0.00311	0.00411	0.00444	0.00453	0.00455	0.00455	0.00184	0.00449
2004	0.00007	0.00029	0.00122	0.00487	0.01575	0.03241	0.04285	0.04628	0.04715	0.04736	0.04740	0.01752	0.04675

Year	2	3	4	5	6	7	8	9	10	11	12+	5 to 8	9+
2005	0.00010	0.00042	0.00179	0.00717	0.02317	0.04766	0.06301	0.06806	0.06934	0.06965	0.06972	0.02305	0.06882
2006	0.00012	0.00053	0.00225	0.00899	0.02905	0.05977	0.07902	0.08535	0.08695	0.08733	0.08742	0.02544	0.08627
2007	0.00007	0.00031	0.00133	0.00531	0.01717	0.03533	0.04671	0.05046	0.05140	0.05163	0.05168	0.01907	0.05107
2008	0.00009	0.00040	0.00168	0.00674	0.02176	0.04478	0.05920	0.06395	0.06515	0.06543	0.06550	0.02577	0.06456
2009	0.00001	0.00004	0.00017	0.00068	0.00221	0.00454	0.00601	0.00649	0.00661	0.00664	0.00664	0.00273	0.00655
2010	0.00001	0.00003	0.00014	0.00056	0.00179	0.00369	0.00488	0.00527	0.00537	0.00539	0.00540	0.00157	0.00531
2011	0.00001	0.00004	0.00016	0.00064	0.00206	0.00424	0.00561	0.00606	0.00618	0.00620	0.00621	0.00181	0.00613
2012	0.00001	0.00006	0.00026	0.00106	0.00341	0.00703	0.00929	0.01003	0.01022	0.01027	0.01028	0.00349	0.01014
2013	0.00001	0.00005	0.00021	0.00085	0.00275	0.00566	0.00748	0.00808	0.00824	0.00827	0.00828	0.00230	0.00819
2014	0.00001	0.00005	0.00020	0.00081	0.00262	0.00540	0.00714	0.00771	0.00785	0.00789	0.00789	0.00220	0.00778
2015	0.00001	0.00005	0.00020	0.00078	0.00252	0.00519	0.00687	0.00742	0.00756	0.00759	0.00760	0.00218	0.00750
2016	0.00001	0.00005	0.00023	0.00090	0.00292	0.00601	0.00794	0.00858	0.00874	0.00878	0.00879	0.00254	0.00869
2017	0.00001	0.00003	0.00011	0.00045	0.00146	0.00301	0.00398	0.00430	0.00438	0.00440	0.00441	0.00142	0.00433
2018	0.00001	0.00004	0.00016	0.00063	0.00204	0.00421	0.00556	0.00601	0.00612	0.00615	0.00615	0.00226	0.00606

Table 23. Model estimates of the beginning of the year population abundance (thousands) by age for the southern Gulf of St. Lawrence Atlantic Cod stock, 1971 to 2018.

Year	2	3	4	5	6	7	8	9	10	11	12+	3+	5+
1971	97306	103260	60015	41852	32779	21880	6996	3303	2289	900	1379	274654	111379
1972	159008	63475	67083	36596	26099	19205	12767	4082	1657	1148	1143	233255	102697
1973	165193	101299	40197	38734	19841	12919	9451	6281	1748	709	981	232160	90664
1974	157631	102008	62207	22656	21413	10080	6528	4774	2826	786	761	234039	69824
1975	420521	95962	61727	34300	11912	10272	4807	3112	2080	1231	674	226078	68389
1976	495939	261003	59247	35130	18609	5964	5117	2394	1455	973	891	390782	70533
1977	608663	319869	168118	37259	20917	8715	2722	2332	1055	641	821	562449	74462
1978	425124	405686	213043	110505	24531	12067	4957	1547	1288	582	807	775013	156284
1979	375225	288448	275049	142461	72242	13966	6769	2778	824	686	740	803964	240467
1980	298290	255220	196055	184532	94274	41963	8000	3875	1467	435	753	786574	335299
1981	577301	204538	174903	132955	124887	57434	25280	4817	2099	795	644	728350	348909
1982	628151	399574	141483	119650	88227	74160	33703	14824	2518	1097	752	875989	334932
1983	330570	442949	281615	98761	78380	52486	43665	19833	7886	1340	984	1027898	303334
1984	351204	234583	314134	197473	63024	44661	29546	24564	9768	3884	1144	922783	374066
1985	358837	246720	164706	218440	129632	37556	26340	17416	11884	4726	2433	859853	448427
1986	322133	245470	168682	111507	144422	77665	22265	15606	8097	5525	3328	802566	388414
1987	296105	213055	162258	110357	73515	85866	45668	13084	6957	3609	3947	718316	343003
1988	299328	191795	137919	103913	71009	42470	49038	26064	5767	3066	3330	634371	304657
1989	324822	189282	121196	86032	63519	38131	22492	25951	11141	2465	2734	562942	252464
1990	262955	205265	119499	75203	48761	30277	17842	10514	9926	4261	1989	523537	198773
1991	178767	167369	130494	74343	39886	20818	12630	7433	3555	3357	2113	461997	164134
1992	157221	114186	106765	81291	38385	16236	8261	5005	2343	1121	1724	375315	154364
1993	142324	101587	73687	67348	41962	15773	6511	3308	1620	758	921	313474	138200
1994	145277	92566	66061	47788	43127	26149	9800	4045	1694	829	860	292918	134292
1995	97341	97066	61841	44116	31178	28000	16851	6286	2157	903	900	289298	130391
1996	148680	66026	65835	41931	29052	20459	18275	10961	3350	1149	960	257996	126136
1997	148399	102530	45528	45384	27607	19064	13358	11894	5861	1791	1127	274145	126086
1998	129897	102803	71020	31523	29813	18044	12364	8622	6414	3159	1573	285335	111512
1999	120196	90274	71433	49314	20569	19296	11534	7842	4672	3474	2562	280968	119262
2000	79261	83143	62422	49317	32164	13175	12022	7062	4092	2434	3144	268975	123410
2001	96321	55362	58049	43505	31918	20391	8092	7239	3485	2016	2747	232804	119392

Year	2	3	4	5	6	7	8	9	10	11	12+	3+	5+
2002	106714	68257	39214	41039	27345	19622	12117	4707	3381	1625	2220	219528	112057
2003	146984	75970	48573	27859	24879	16258	11323	6863	2158	1548	1759	217191	92648
2004	76454	103174	53325	34092	16428	14655	9561	6653	3406	1071	1641	244005	87506
2005	73736	51865	69976	36133	20088	9575	8401	5424	3107	1589	1265	207424	85583
2006	45239	49183	34584	46596	21274	11640	5414	4678	2291	1311	1204	178173	94407
2007	77706	30179	32796	23022	26511	11864	6295	2872	1859	909	997	137303	74329
2008	66414	52892	20537	22295	12364	14070	6183	3243	1114	721	739	134157	60728
2009	44860	44970	35803	13884	11542	6305	7012	3037	1234	423	555	124764	43991
2010	80012	30037	30110	23969	7018	5825	3175	3526	1223	497	394	105774	45627
2011	62591	52664	19770	19816	12365	3616	2996	1631	1372	476	347	115052	42618
2012	67214	40960	34462	12935	9853	6140	1792	1482	675	568	341	109208	33786
2013	72216	44038	26835	22573	6024	4578	2842	828	666	303	408	109095	38222
2014	46061	46581	28404	17305	10633	2832	2146	1330	382	308	328	110250	35266
2015	27535	28939	29264	17842	8426	5168	1373	1038	612	176	293	93130	34928
2016	16887	17553	18447	18652	8560	4035	2468	655	442	260	199	71271	35271
2017	36013	11011	11445	12026	8678	3974	1868	1140	253	171	178	50745	28288
2018	33821	23438	7166	7448	5300	3820	1747	820	476	105	145	50466	19862

11 FIGURES

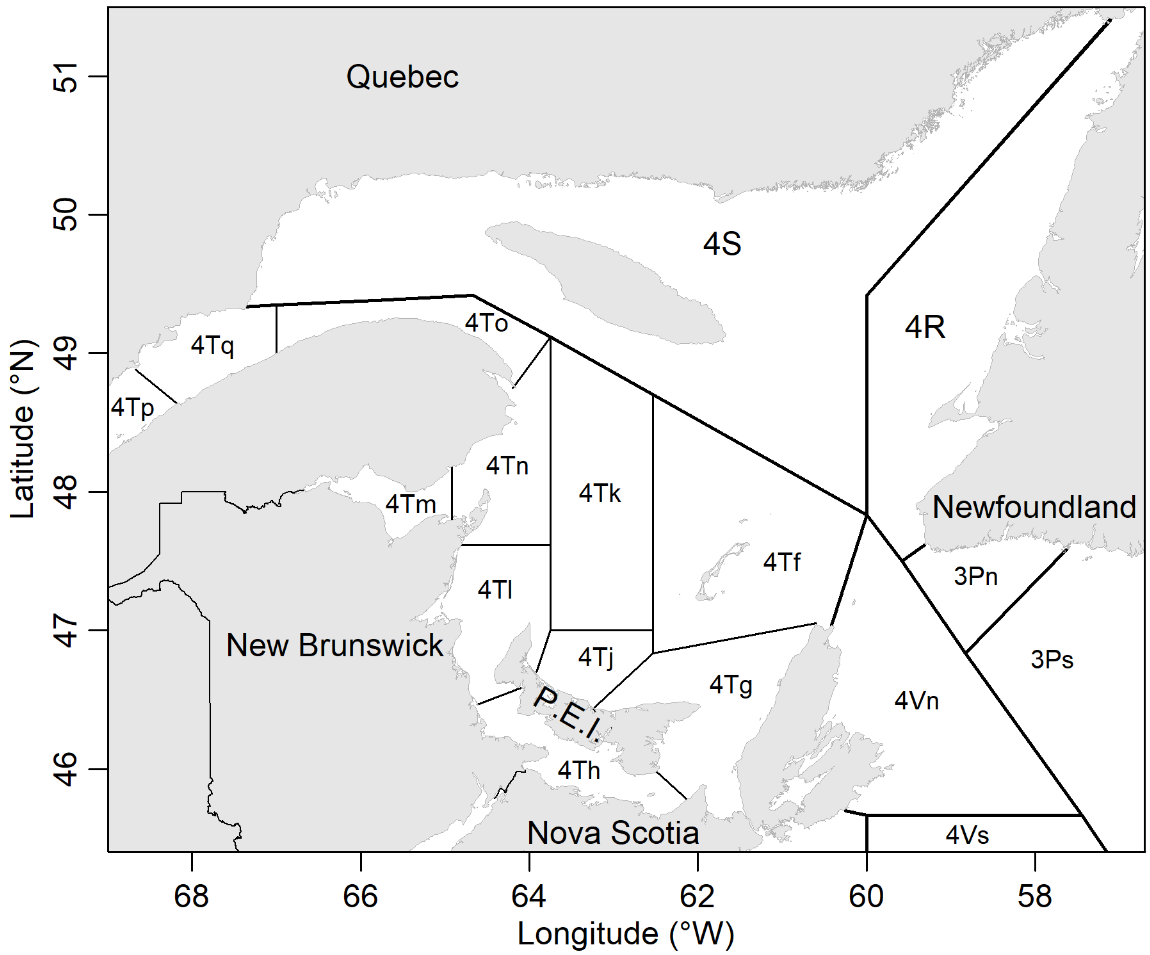

Figure 1. NAFO Divisions in the area of the Gulf of St. Lawrence. Unit areas are indicated for Division 4T.

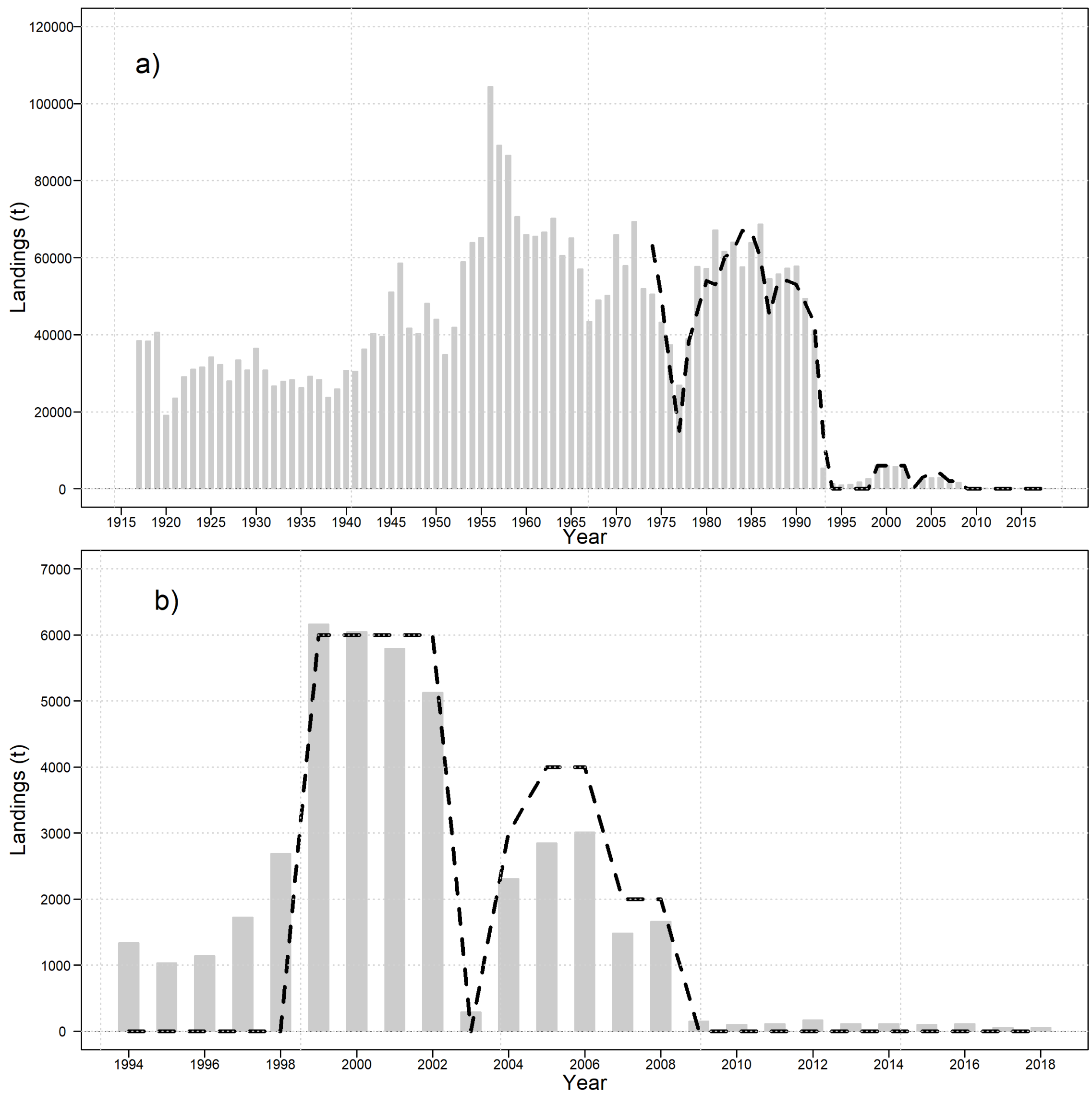

Figure 2. Landings (t, vertical gray bars) and Total Allowable Catch (t, dashed lines) of southern Gulf of St. Lawrence (4T-Vn (November-April)) Atlantic Cod, 1917 to 2018 (upper panel a)). The lower panel b) shows the values for 1994 to 2018.

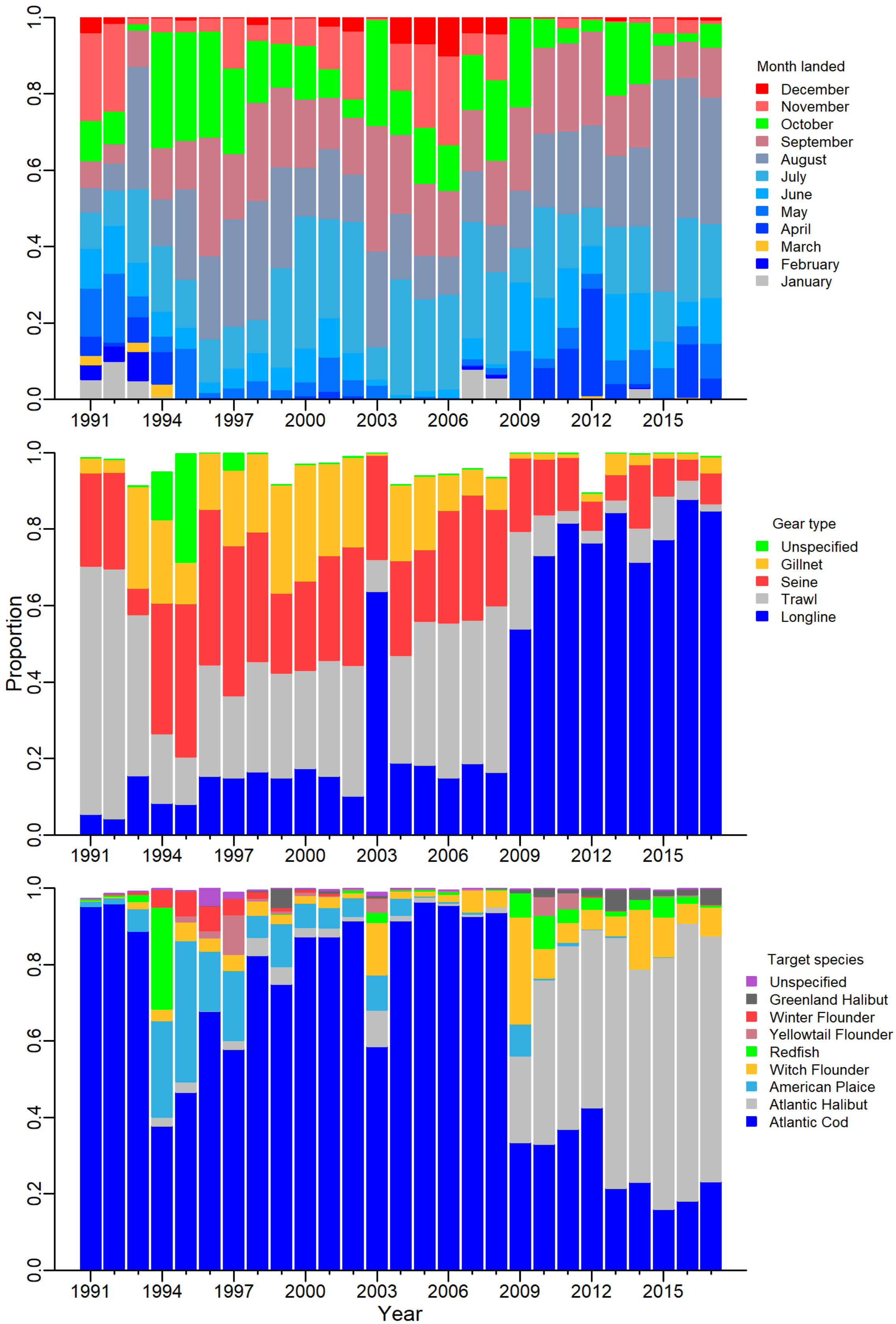

Figure 3. Proportion of annual Atlantic Cod landings in NAFO Divisions 4T and 4VN by month (top panel), by type of fishing gear (middle panel) and by target fishing species (lower panel), 1991 to 2017.

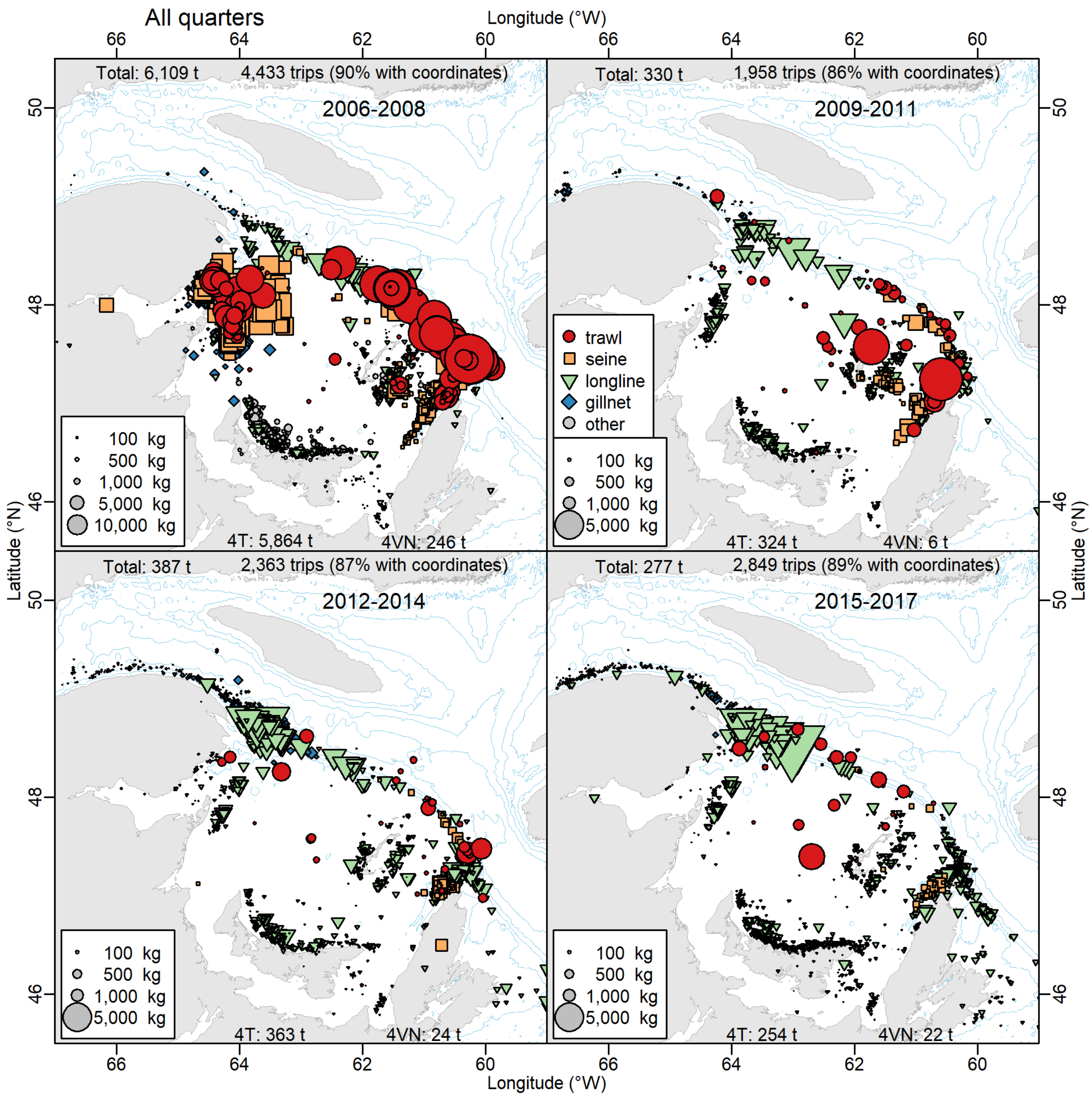

Figure 4. Geographic location of catches of Atlantic Cod by gear type in NAFO Divisions 4T and 4VN, 2006 to 2017, all months. Note that the scale of the symbols is different for the 2006 to 2008 period when there was still a commercial fishery operating in the area and the post-2009 period when a moratorium was in effect. For each time period, the number of fishing trips where Atlantic Cod was caught is presented, along with the percentage of trips for which geographic coordinates were available. Additionally, the total catch of Atlantic Cod for each time period appears in the top left corner of the map, and the catch for NAFO Divisions 4T and 4VN appear on the bottom of the map.

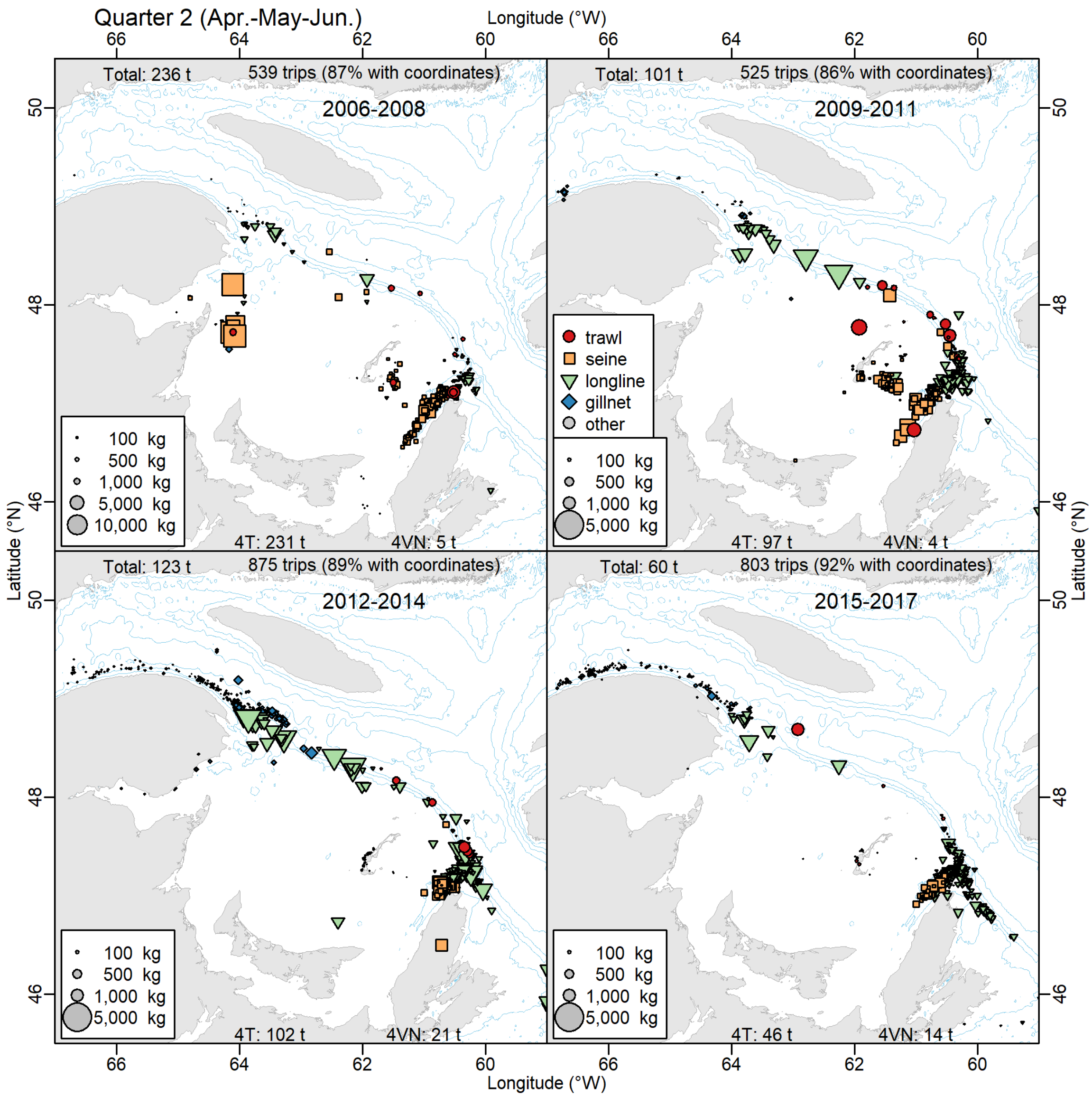

Figure 5. Geographic location of catches of Atlantic Cod by gear type in NAFO Divisions 4T and 4VN, 2006 to 2017, second quarter (Apr.-Jun.). Note that the scale of the symbols is different for the 2006 to 2008 period when there was still a commercial fishery operating in the area and the post-2009 period when a moratorium was in effect. For each time period, the number of fishing trips where Atlantic Cod was caught is presented, along with the percentage of trips for which geographic coordinates were available. Additionally, the total catch of Atlantic Cod for each time period appears in the top left corner of the map, and the catch for NAFO Divisions 4T and 4VN appear on the bottom of the map.

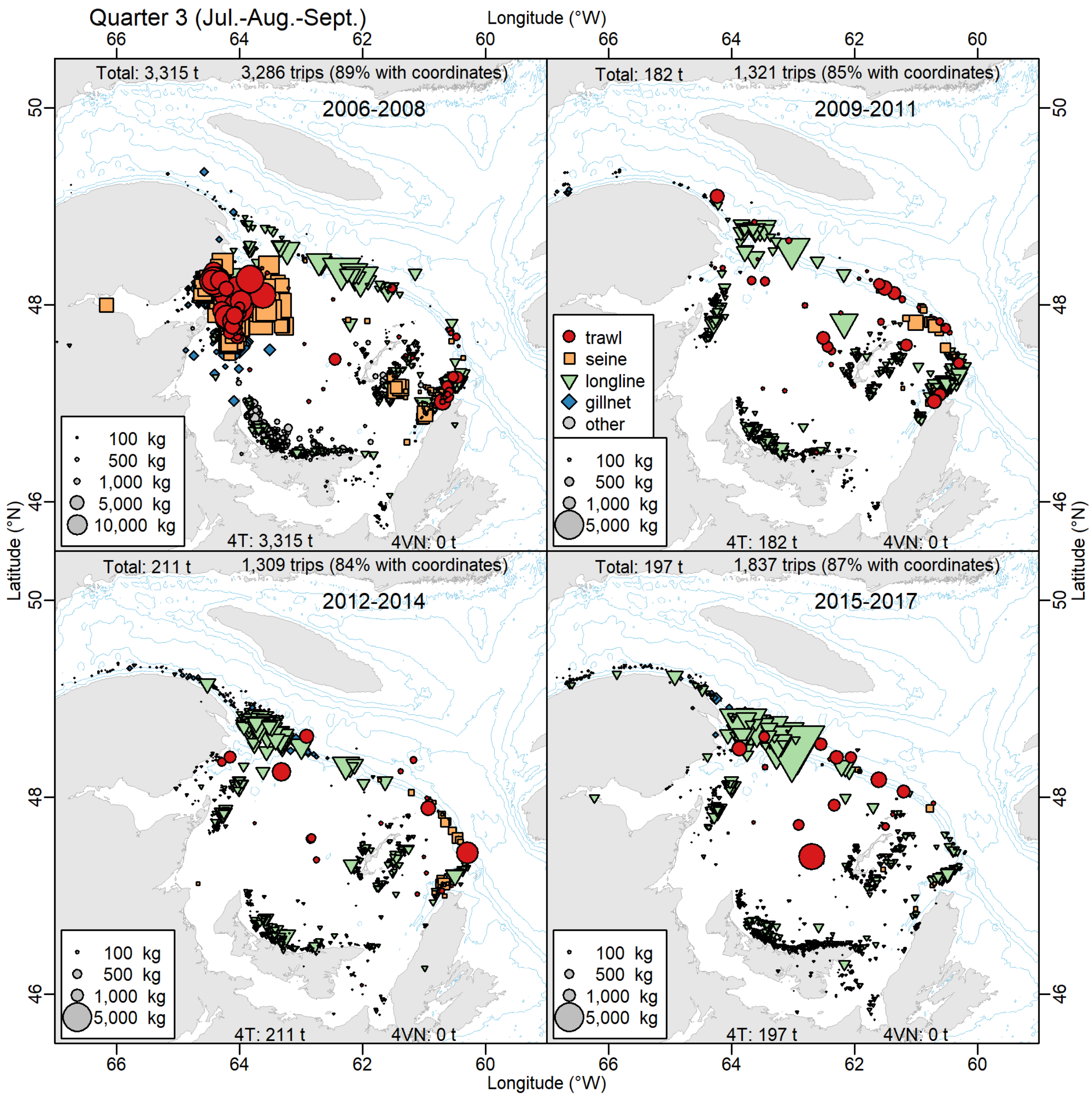

Figure 6. Geographic location of catches of Atlantic Cod by gear type in NAFO Divisions 4T and 4VN, 2006 to 2017, third quarter (Jul.-Sept.). Note that the scale of the symbols is different for the 2006 to 2008 period when there was still a commercial fishery operating in the area and the post-2009 period when a moratorium was in effect. For each time period, the number of fishing trips where Atlantic Cod was caught is presented, along with the percentage of trips for which geographic coordinates were available. Additionally, the total catch of Atlantic Cod for each time period appears in the top left corner of the map, and the catch for NAFO Divisions 4T and 4VN appear on the bottom of the map.

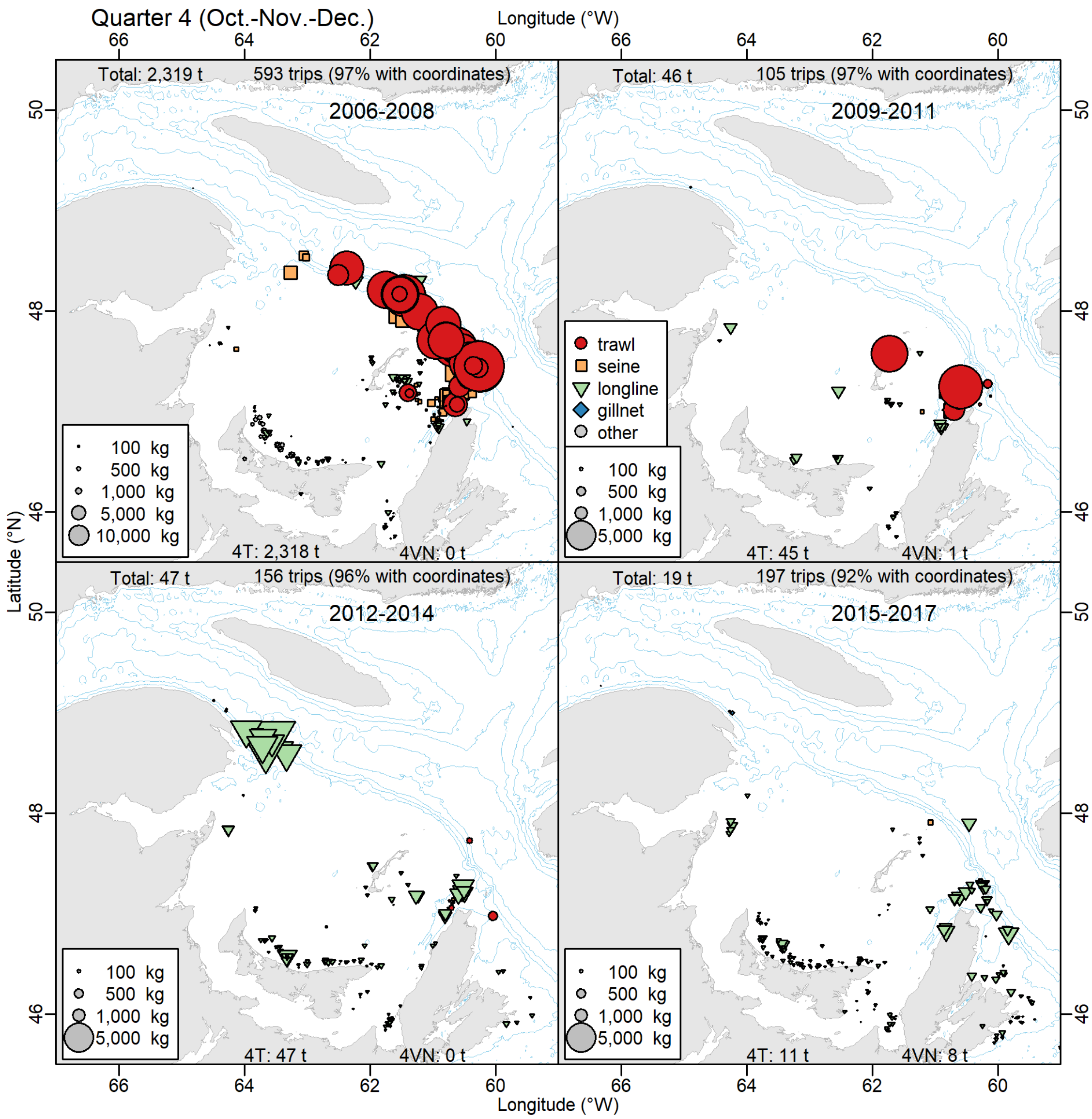

Figure 7. Geographic location of catches of Atlantic Cod by gear type in NAFO Divisions 4T and 4VN, 2006 to 2017, fourth quarter (Oct.-Dec.). Note that the scale of the symbols is different for the 2006 to 2008 period when there was still a commercial fishery operating in the area and the post-2009 period when a moratorium was in effect. For each time period, the number of fishing trips where Atlantic Cod was caught is presented, along with the percentage of trips for which geographic coordinates were available. Additionally, the total catch of Atlantic Cod for each time period appears in the top left corner of the map, and the catch for NAFO Divisions 4T and 4VN appear on the bottom of the map.

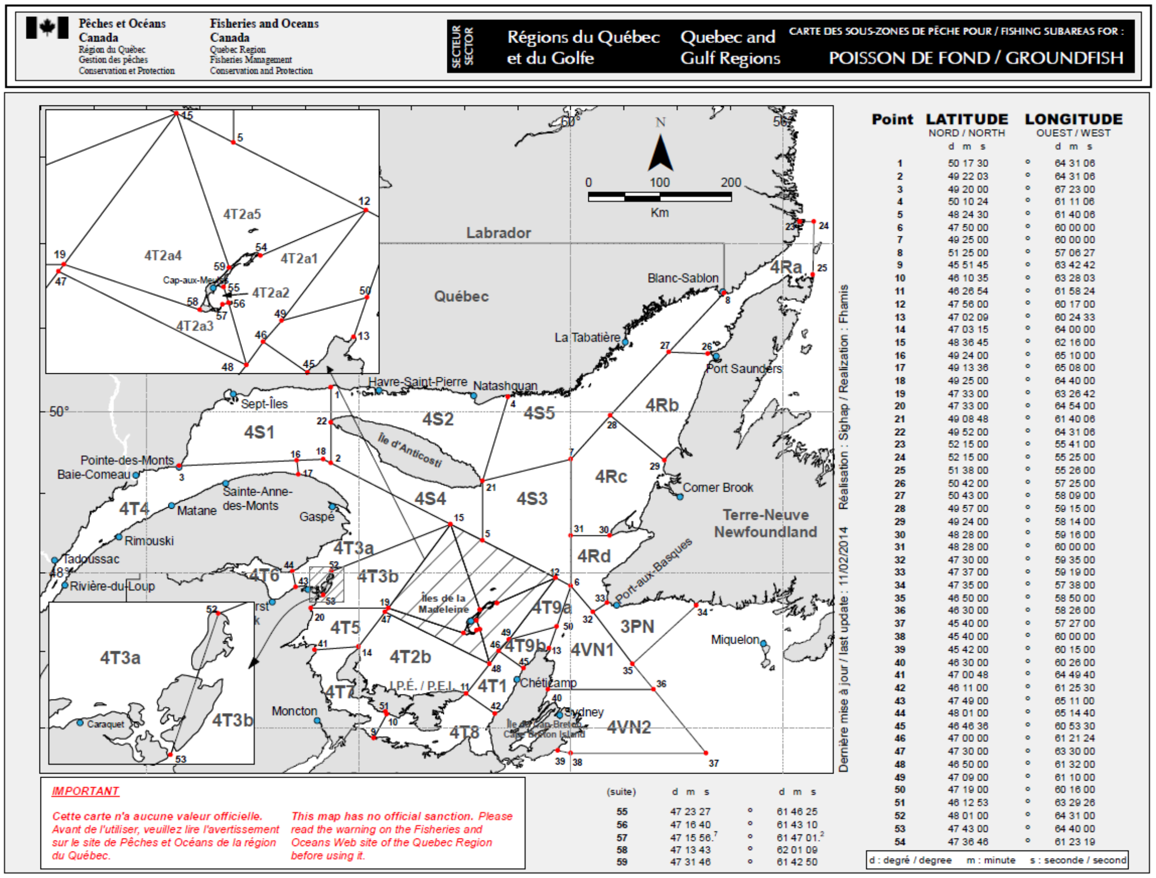

Figure 8. Groundfish fishing management zones in NAFO Division 4T. Source: http://www.qc.dfo-mpo.gc.ca/peches-fisheries/en/cartes/pdf/PoissonFond.pdf

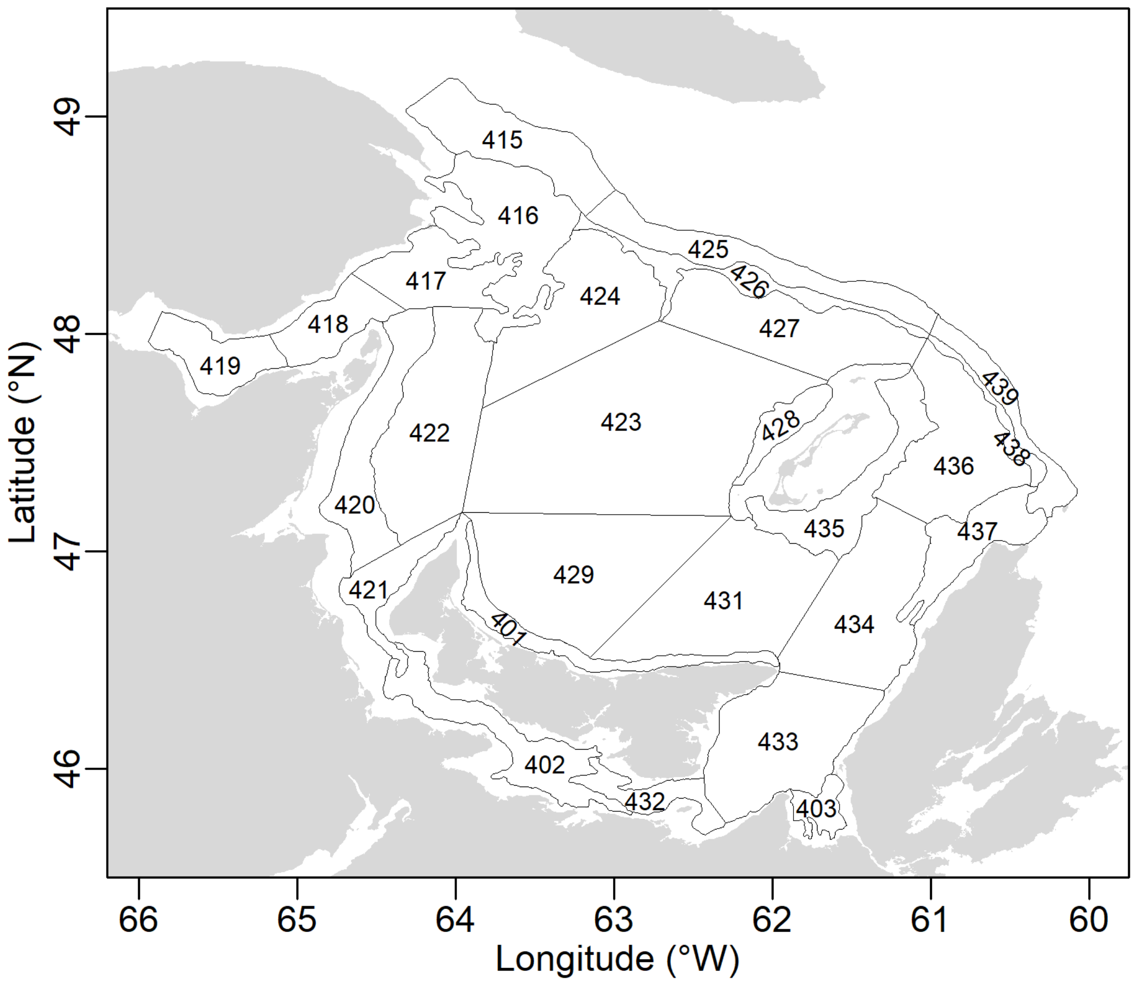

Figure 9. Stratification scheme for the southern Gulf of St. Lawrence September trawl survey. Strata depths are as follows: < 50 fathoms: 401 to 403, 417 to 424, 427 to 436; 51 to 100 fathoms: 416, 426, 437 and 438; >100 fathoms: 415, 425, 439.

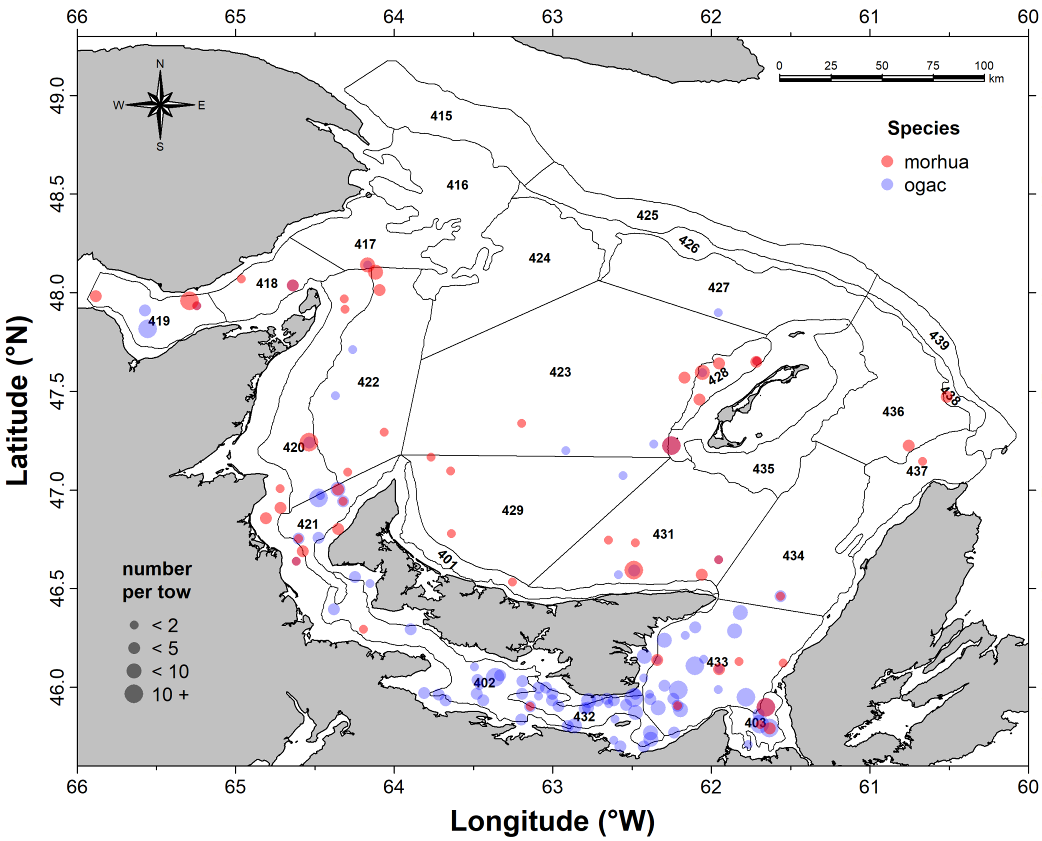

Figure 10. Distribution of Atlantic Cod (Gadus morhua) and Greenland Cod (G. ogac) individuals measuring less than 15 cm caught during the 2013 and 2014 Northumberland Strait and southern Gulf of St. Lawrence September bottom-trawl surveys. Species identification was based on genetic analysis.

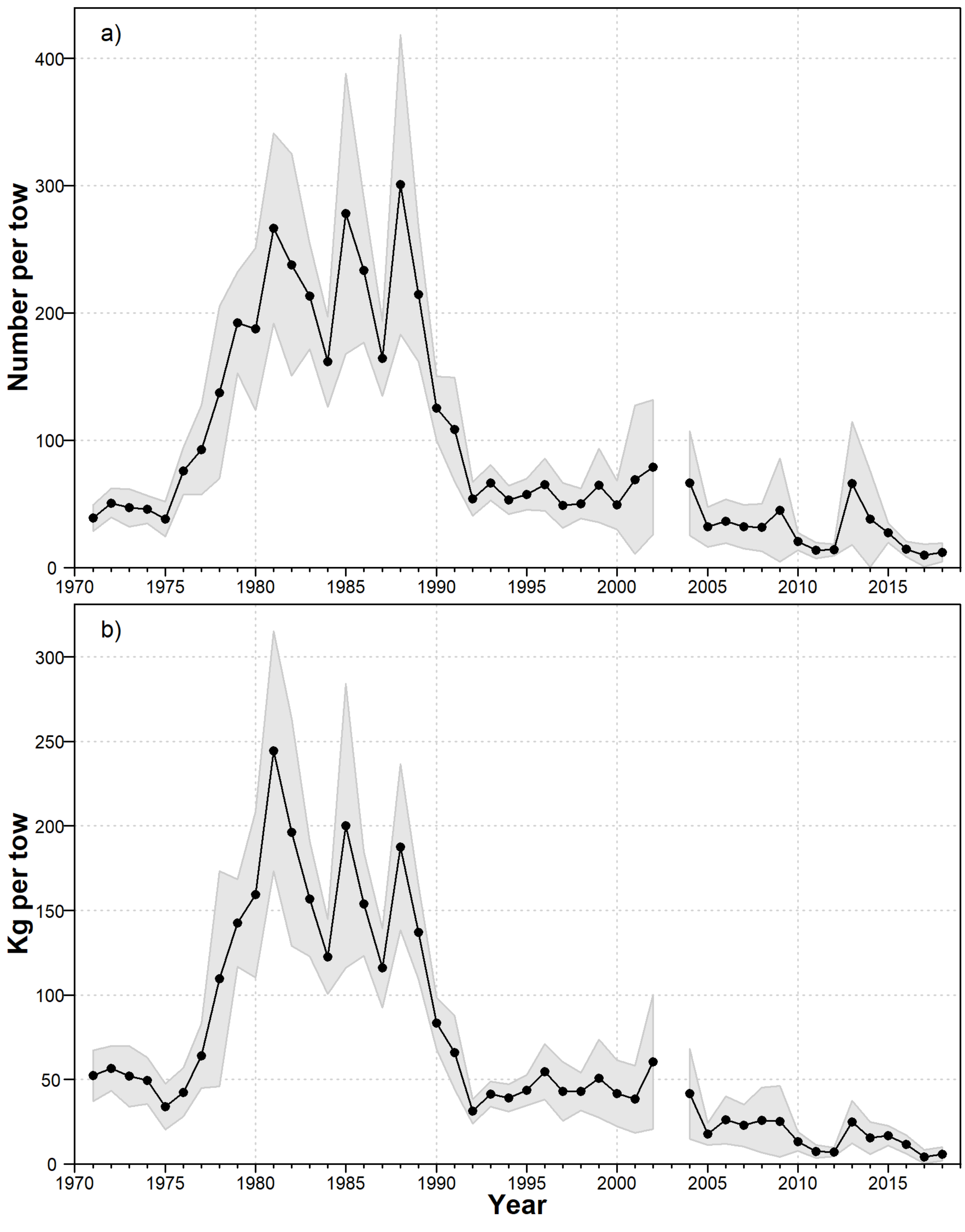

Figure 11. Annual mean catch indices (number per tow, top panel a); kg per tow, bottom panel b)) of Atlantic Cod in the southern Gulf of St. Lawrence September bottom-trawl surveys. The gray shading denotes approximate 95% confidence limits (± 2 standard errors).

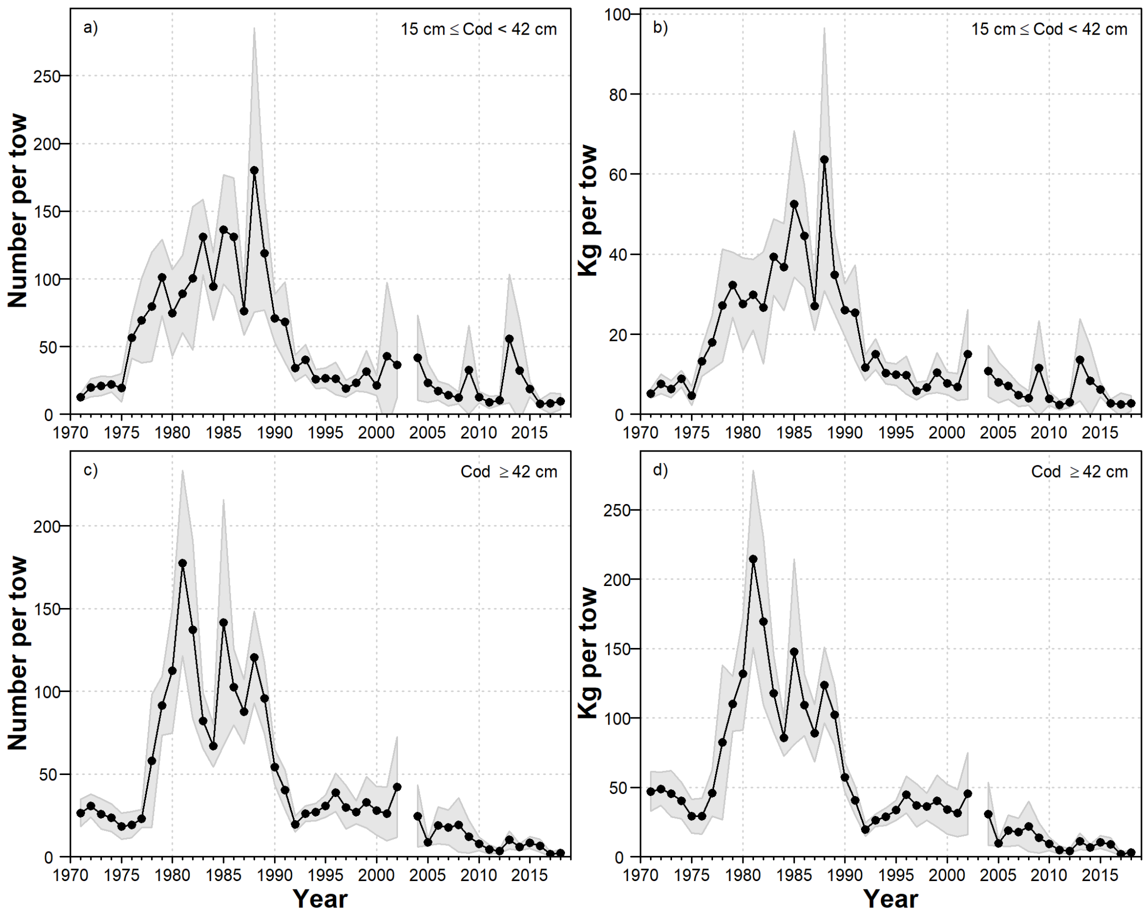

Figure 12. Mean annual catch indices (number per tow, panels a) and c); kg per tow, panels b) and d)) of Atlantic Cod 15 to 42 cm in length (a and b) and ≥42 cm (c and d) in the southern Gulf of St. Lawrence September bottom-trawl surveys. The gray shading denote approximate 95% confidence limits (± 2 standard errors).

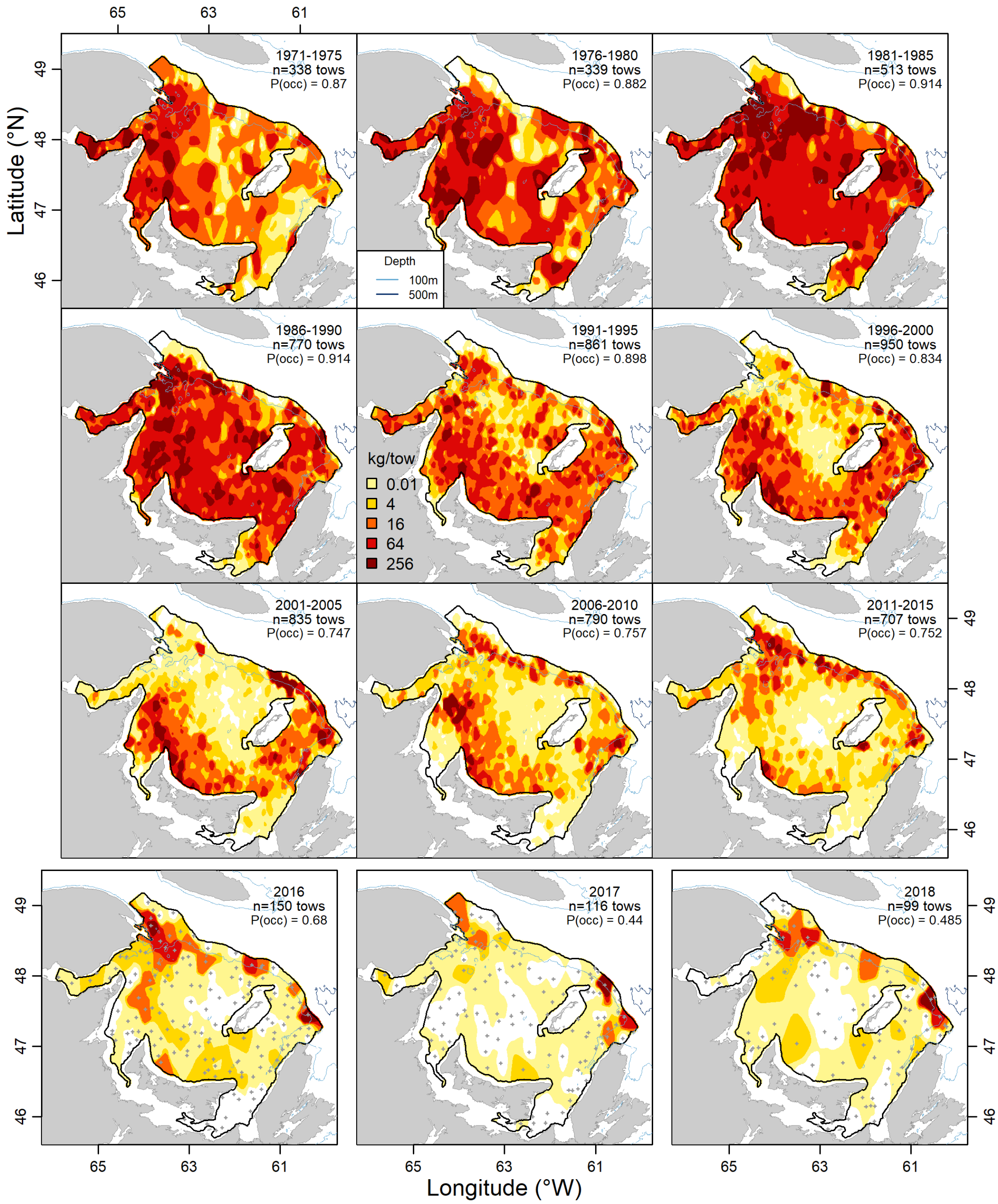

Figure 13. Spatial distribution of Atlantic Cod catches by blocks of years in the southern Gulf of St. Lawrence based on September bottom-trawl surveys, 1971 to 2018. P(occ) indicates probability of occurrence (the number of tows catching Atlantic Cod divided by the total number of tows).

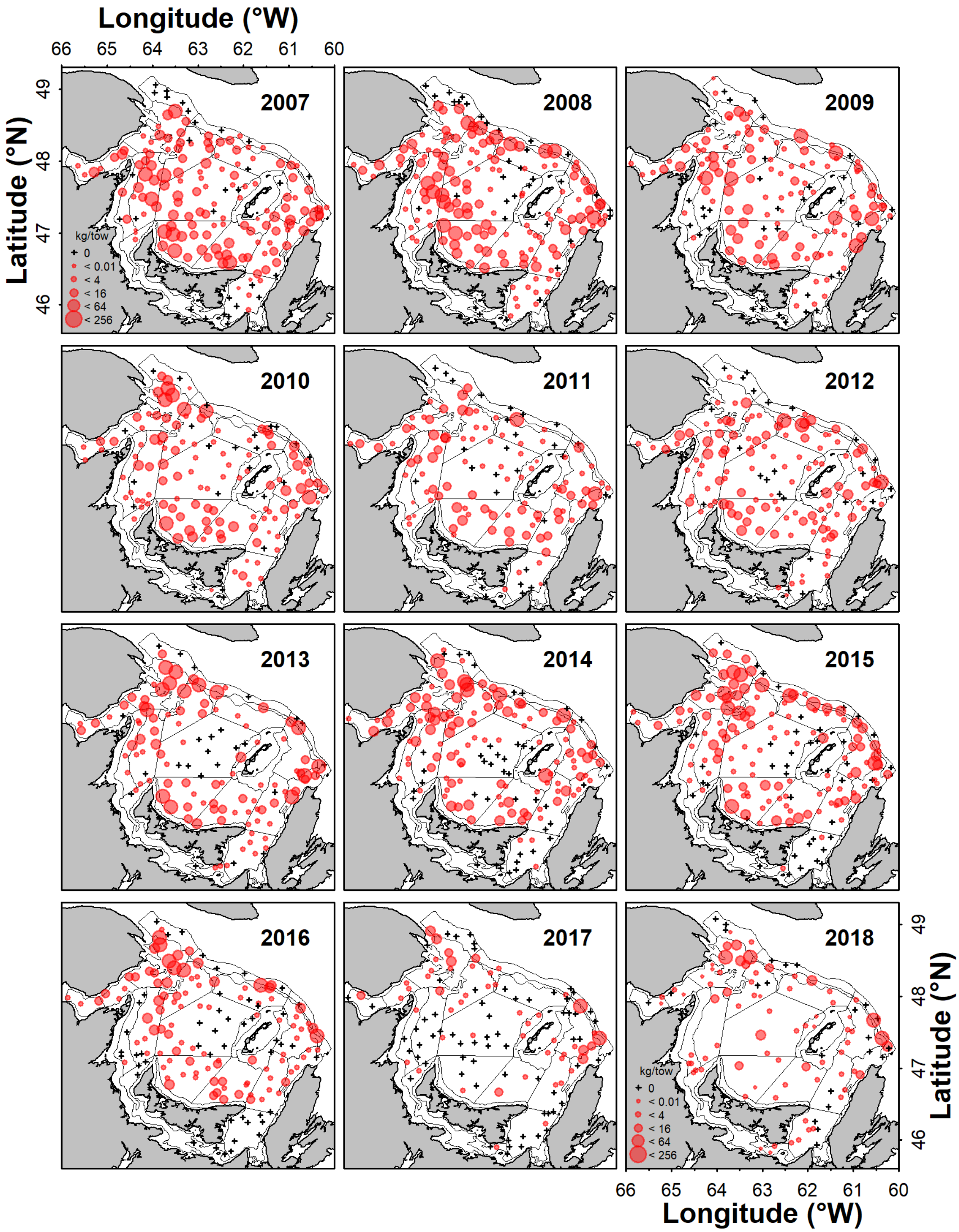

Figure 14. Catches (kg per tow) of Atlantic Cod in the southern Gulf of St. Lawrence September bottom-trawl surveys from 2007 to 2018. Circle area is proportional to kg caught.

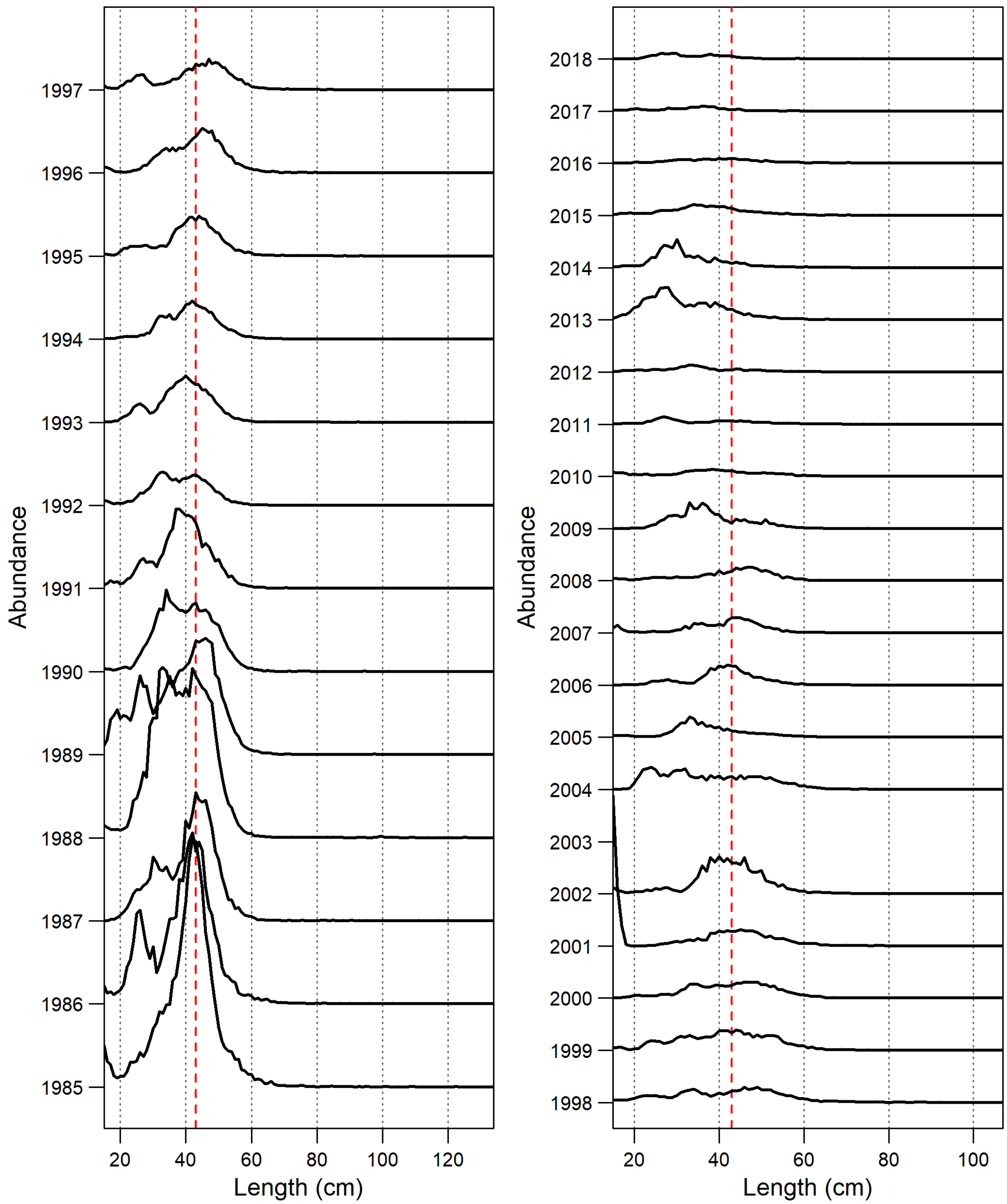

Figure 15. Stratified abundance (mean number per tow) at length for Atlantic Cod in in the southern Gulf of St. Lawrence from the September bottom-trawl surveys, 1985 to 2018. The red dashed vertical line indicates the regulated minimum size in the commercial fishery (43 cm). Atlantic Cod less than 15 cm are not included in the analysis.

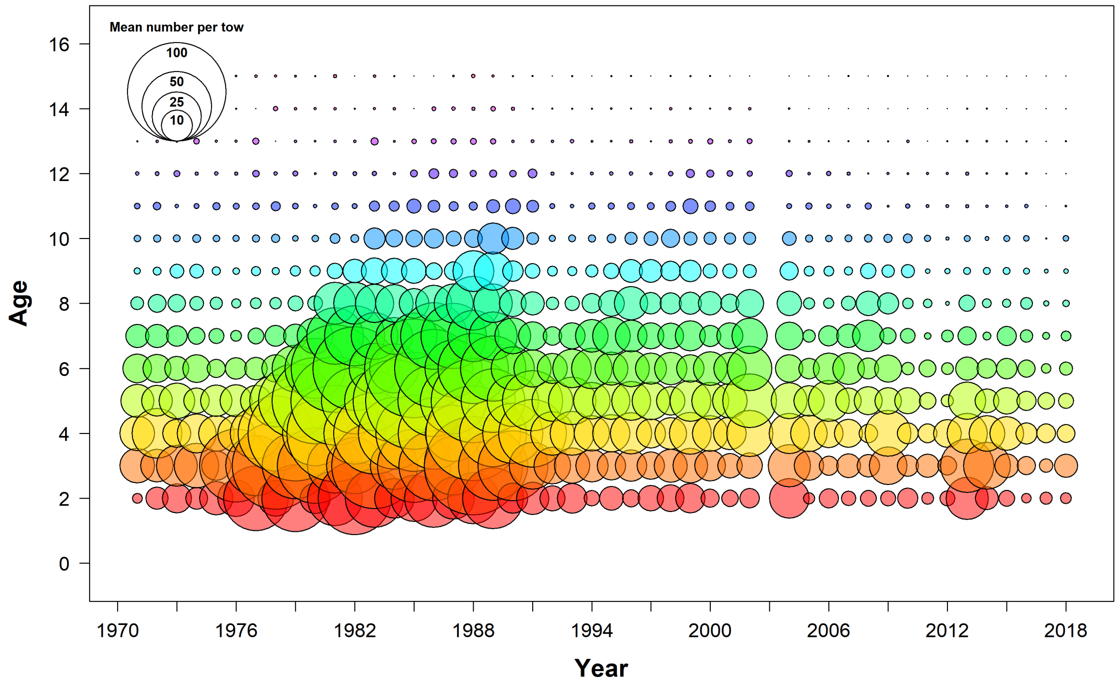

Figure 16. Indices of relative abundance (numbers per tow at age) for Atlantic Cod from the southern Gulf of St. Lawrence September trawl survey, 1971 to 2018. Circle area is proportional to catch rate at age. Results for ages 0 and 1 were excluded because they may include Greenland Cod (See Table 5 caption).

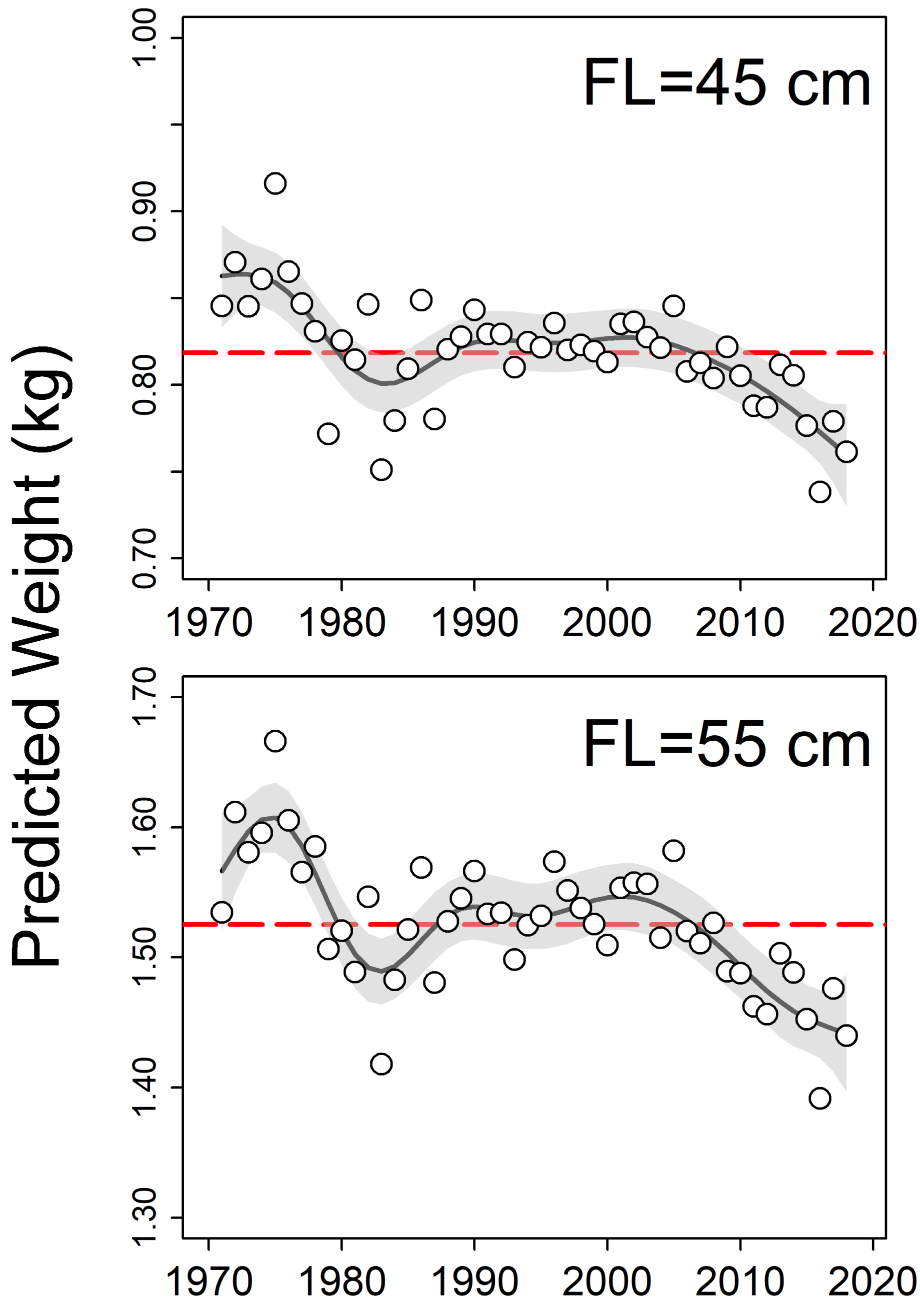

Figure 17. Condition indices, predicted weight (kg) for a 45 cm fork length (FL, upper panel) and a 55 cm (lower panel) Atlantic Cod, based on annual length-weight relationships derived from length and weight data collected during the September trawl surveys in the southern Gulf of St. Lawrence, 1971 to 2018. Circles are the observed values and the black line and shading show the expected values and 95% confidence band from a Generalized Additive Model fit to the observations.

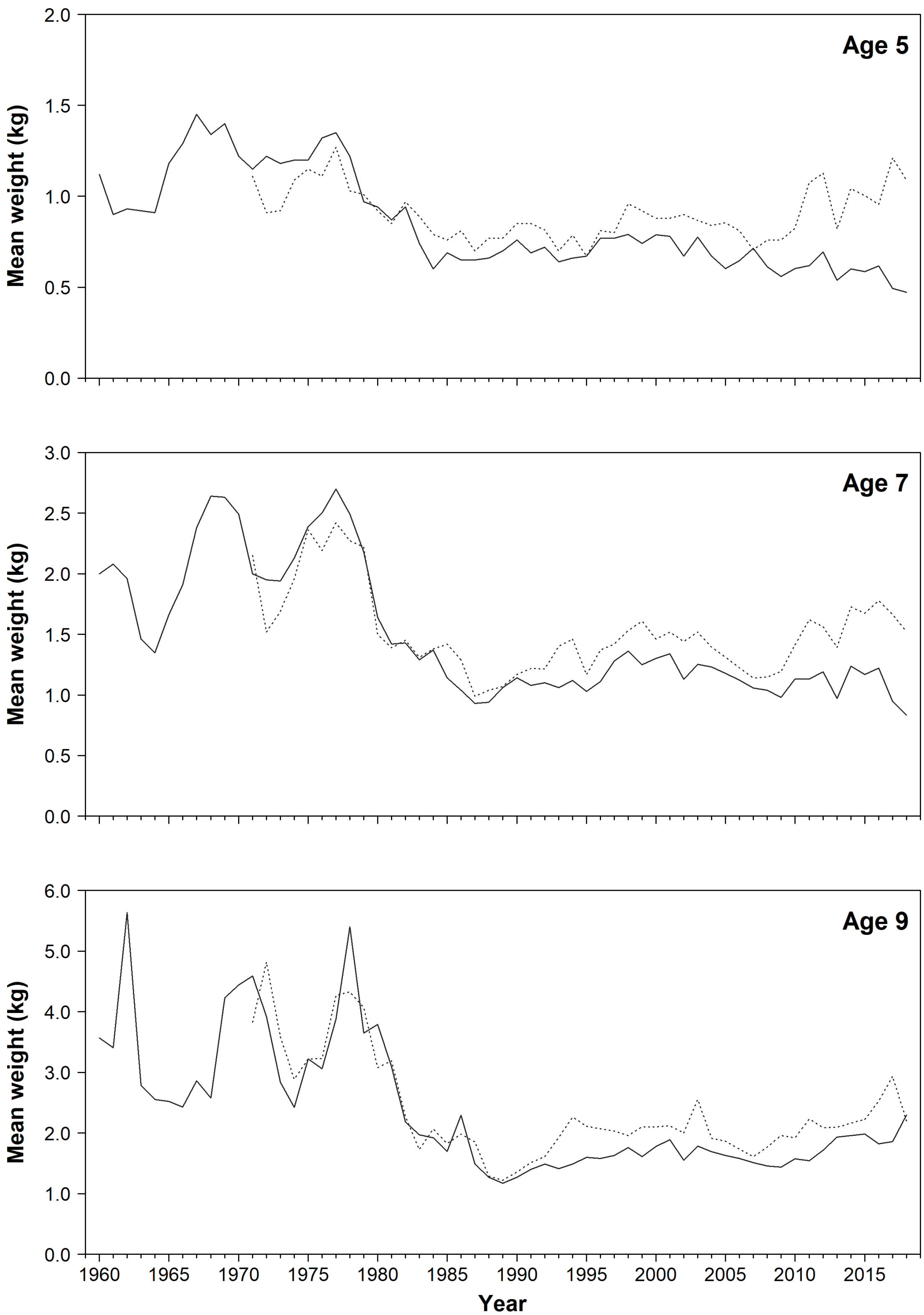

Figure 18. Trends in mean weights (kg) at ages 5 (upper panel), 7 (middle panel), and 9 (lower panel) years of southern Gulf of St. Lawrence Atlantic Cod from the research vessel survey (solid lines), 1960 to 2018, and the commercial fishery (dashed lines), 1971 to 2018. Data from 1960 to 1970 are from non-stratified-random surveys.

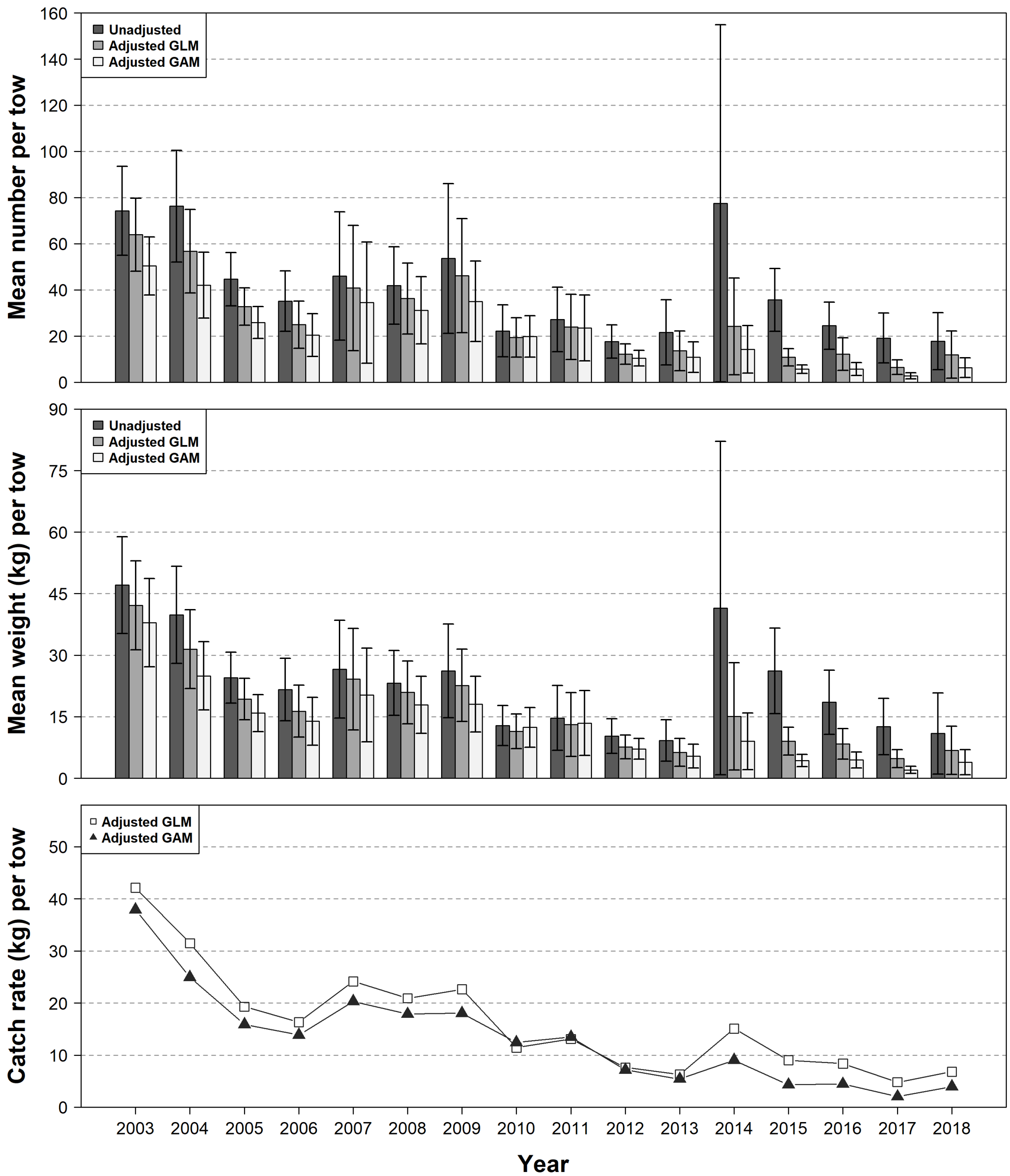

Figure 19. Stratified mean number and weight (kg) per tow of Atlantic Cod in the sentinel bottom trawl surveys of the southern Gulf of St. Lawrence, 2003 to 2018. In the top (numbers) and middle (weight) panels, catch rates that are adjusted for differences in fishing efficiency between vessels are compared with unadjusted values. Two adjustment methods are also compared in these panels: GLM, the method used in previous assessments; and GAM, the method used in this assessment. The two adjustment methods are compared in the bottom panel (kg per tow). Vertical lines denote approximate 95% confidence limits (± 2 standard errors) in the upper and middle panels. See the text for details of the adjustment methods.

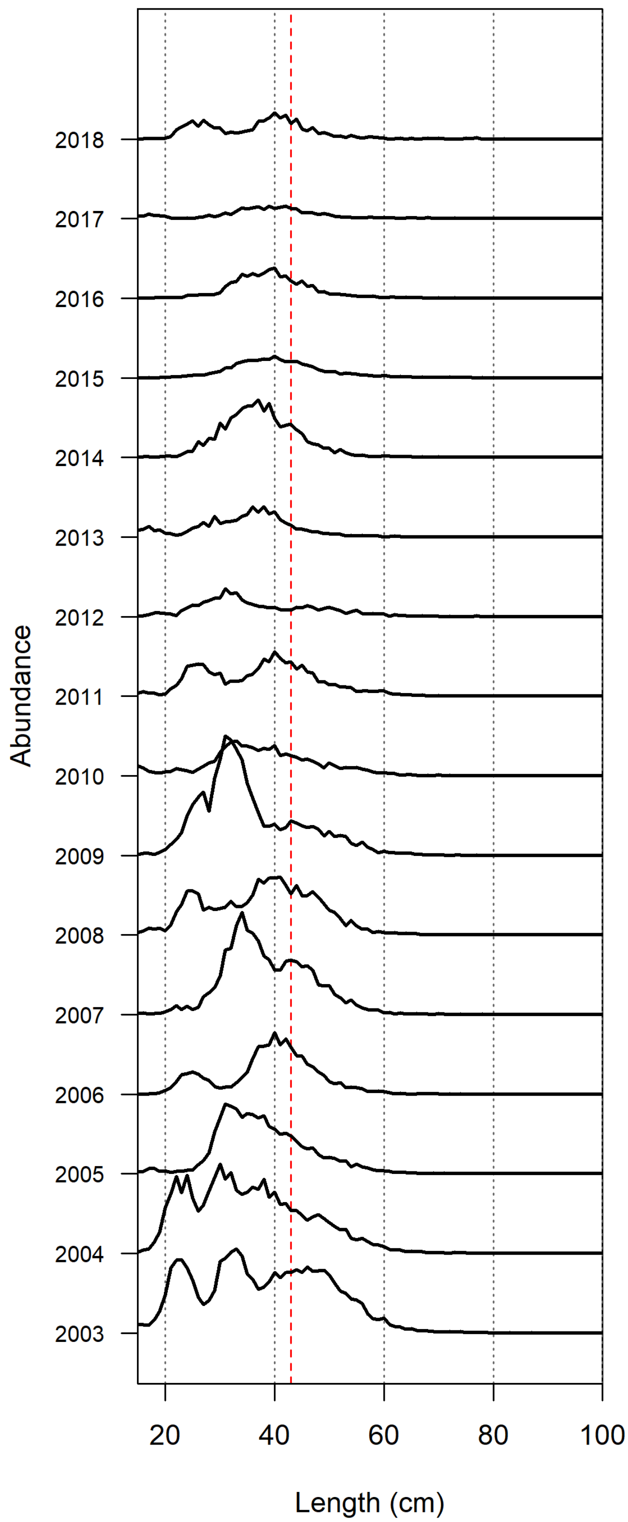

Figure 20. Stratified abundance (mean number per tow) at length for Atlantic Cod in in the southern Gulf of St. Lawrence from the August sentinel bottom-trawl surveys, 2003 to 2018. Strata 401 to 439 were used for the abundance index. The red dashed vertical line indicates the regulated minimum size in the commercial fishery (43 cm).

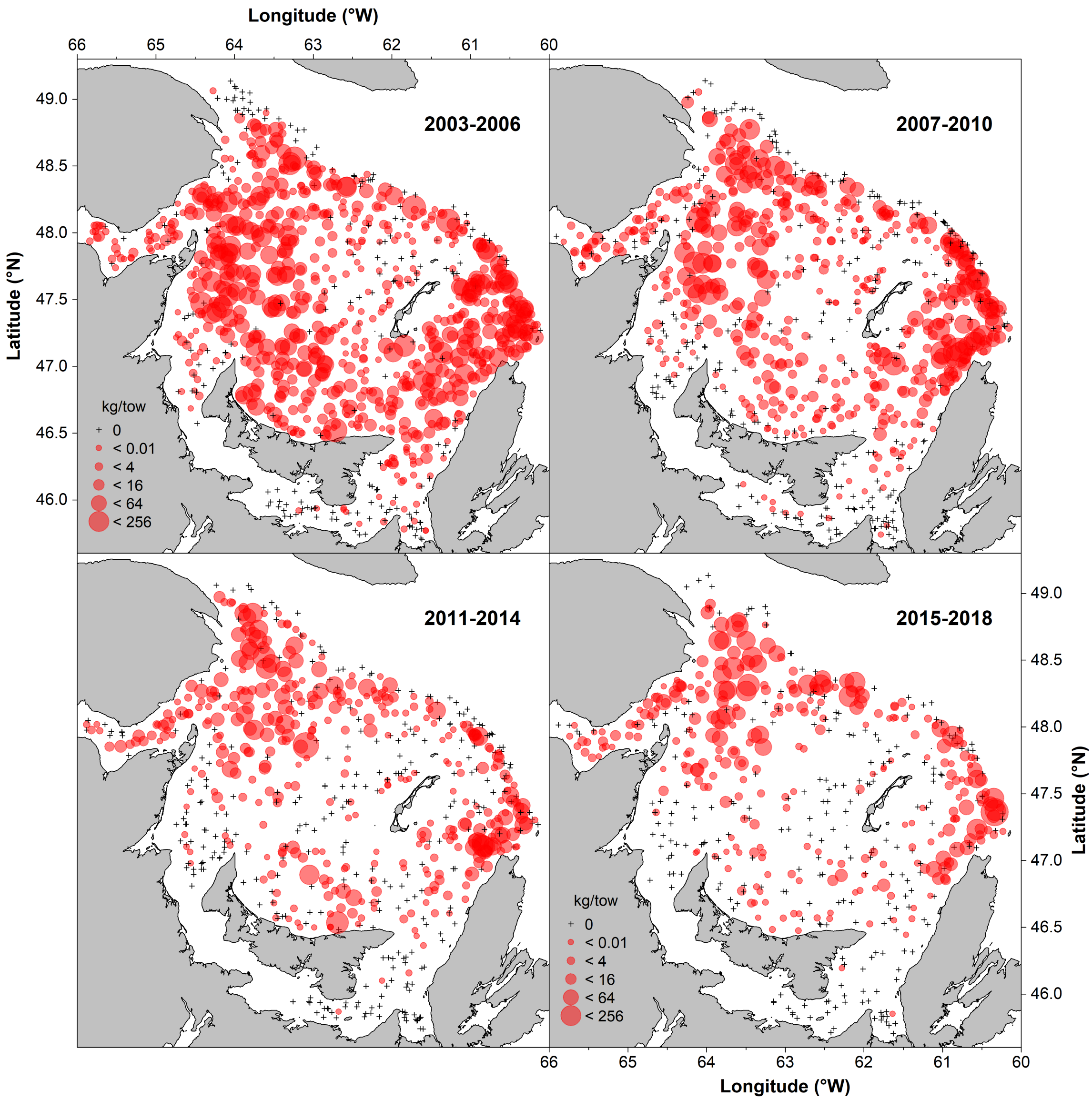

Figure 21. Annual spatial distribution of Atlantic Cod catches in the southern Gulf of St. Lawrence from the August sentinel bottom-trawl surveys, 2003 to 2018. Catches (kg per tow) have been adjusted for vessel differences.

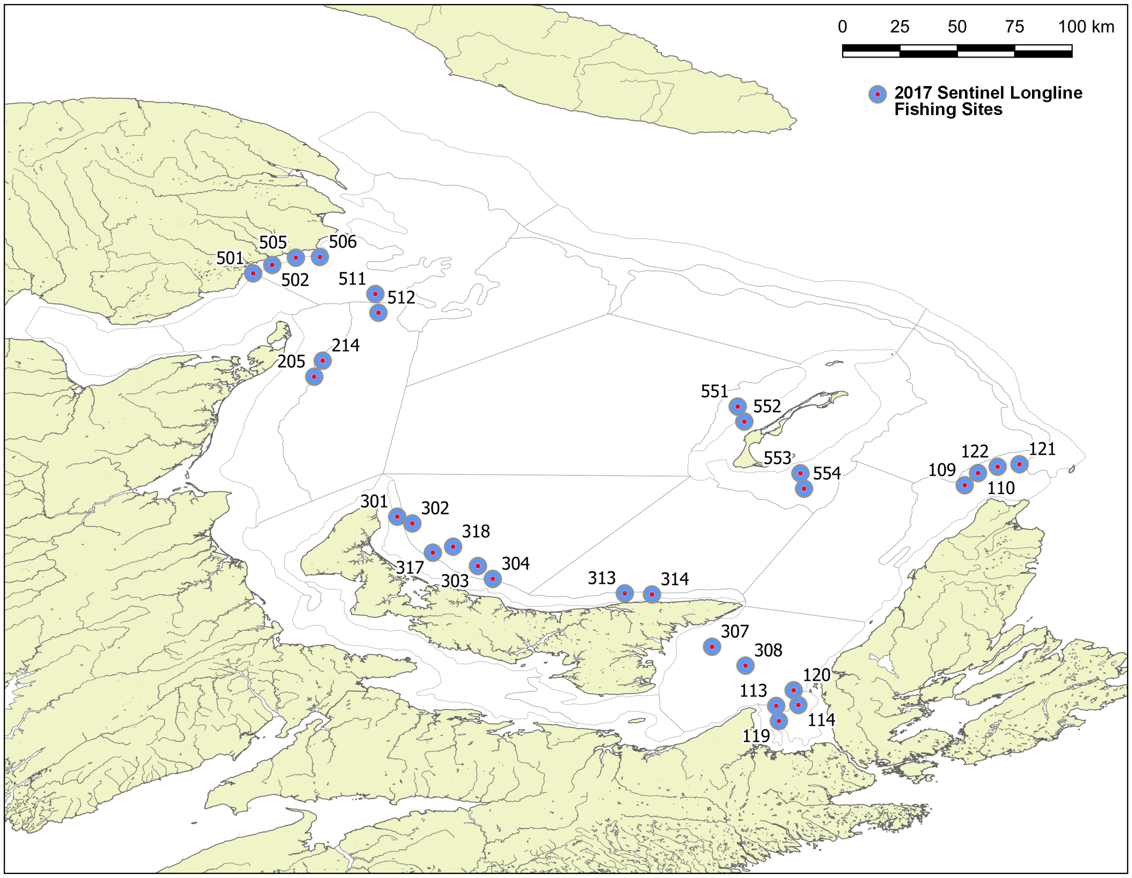

Figure 22. Location of sentinel longline fishing sites in 2017.

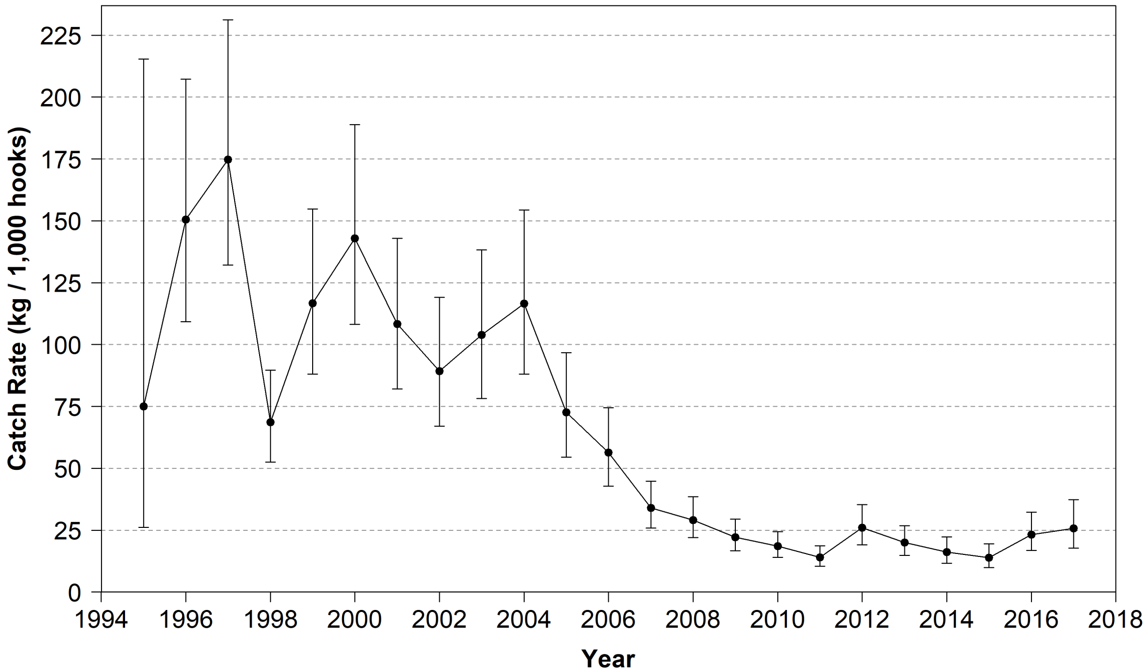

Figure 23. Standardized catch rates (kg per 1,000 hooks) of Atlantic Cod in the longline sentinel surveys in the southern Gulf of St. Lawrence, 1995 to 2017. Error bars indicate approximate 95% confidence intervals.

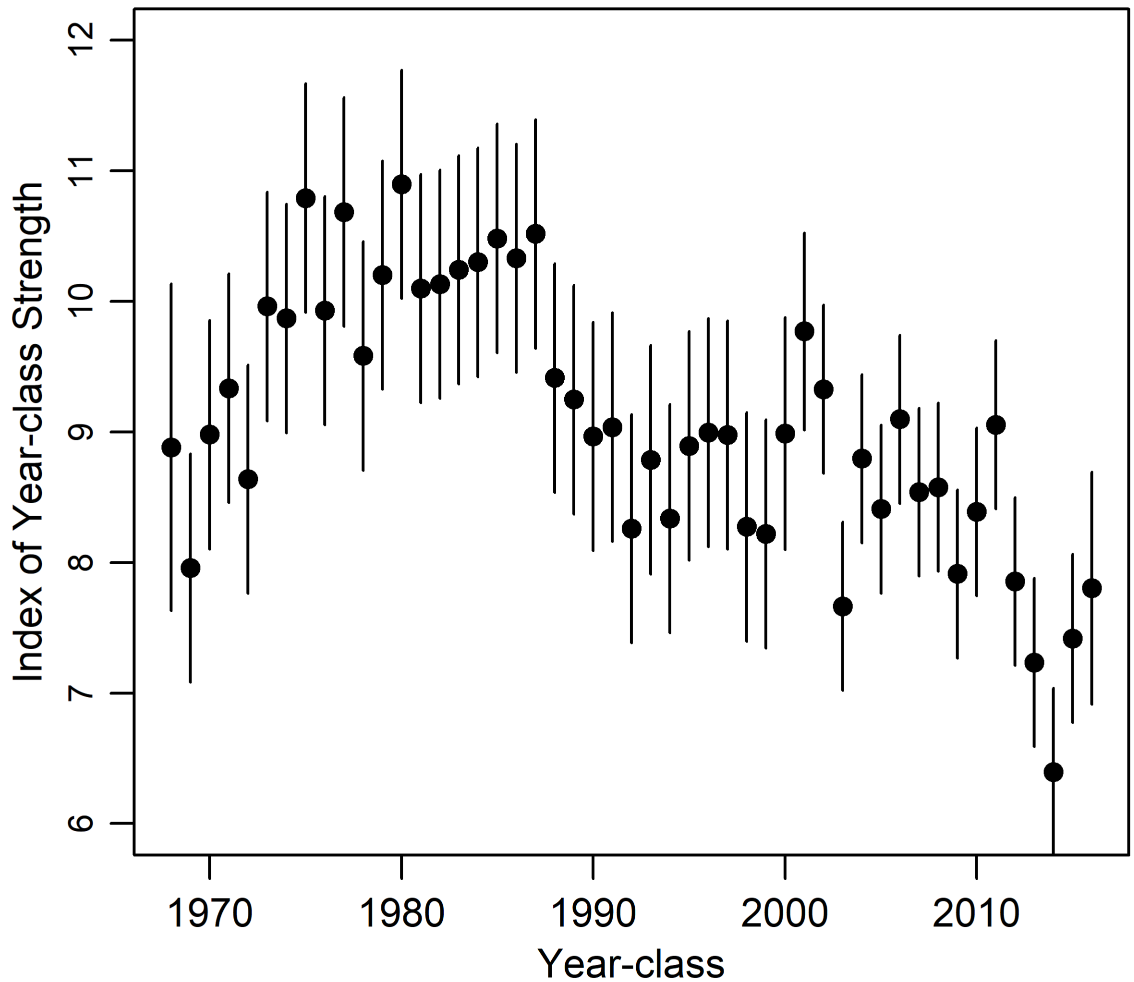

Figure 24. Index of year-class strength based on a multiplicative analysis of log catch rates at ages 2 and 3 years in the RV and mobile sentinel surveys. The index is the predicted log catch rate at age 2 in the RV survey in units of log trawlable abundance (1,000s). Vertical lines are ± 2 SE.

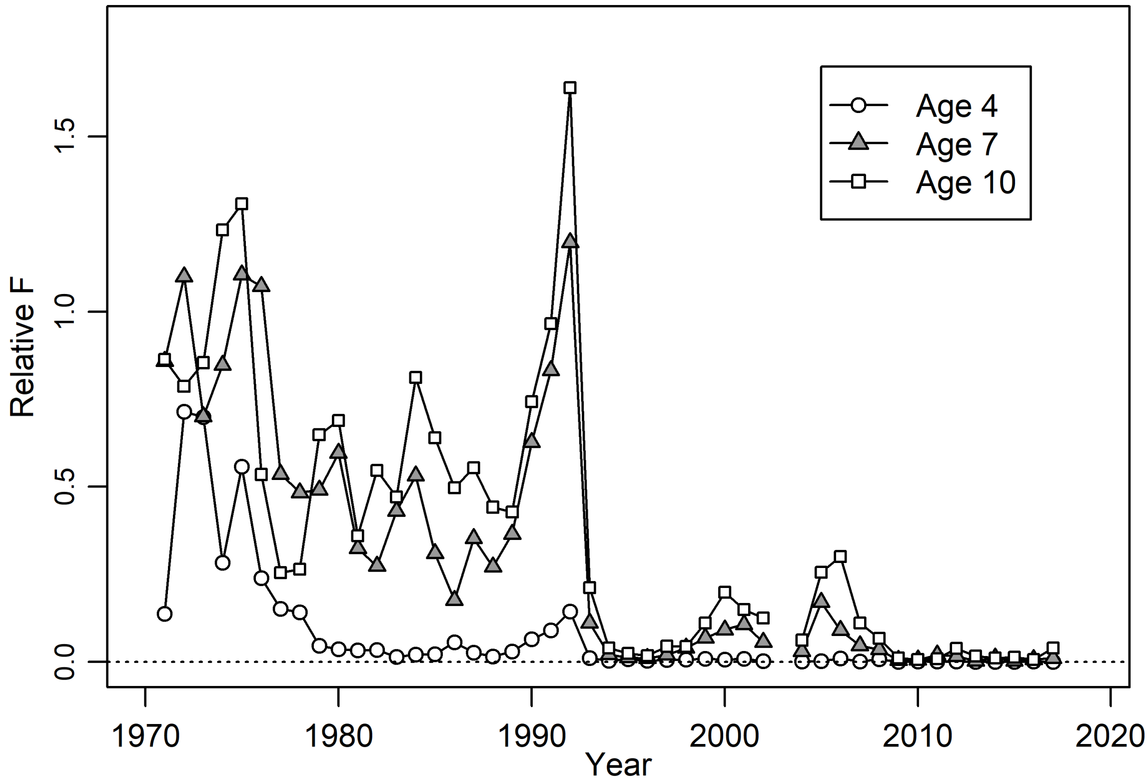

Figure 25. Relative fishing mortality of southern Gulf of St. Lawrence Atlantic Cod aged 4, 7, and 10 years old, 1971 to 2018. Relative F is fishery catch at age divided by RV survey population indices at age (at the scale of trawlable abundance).

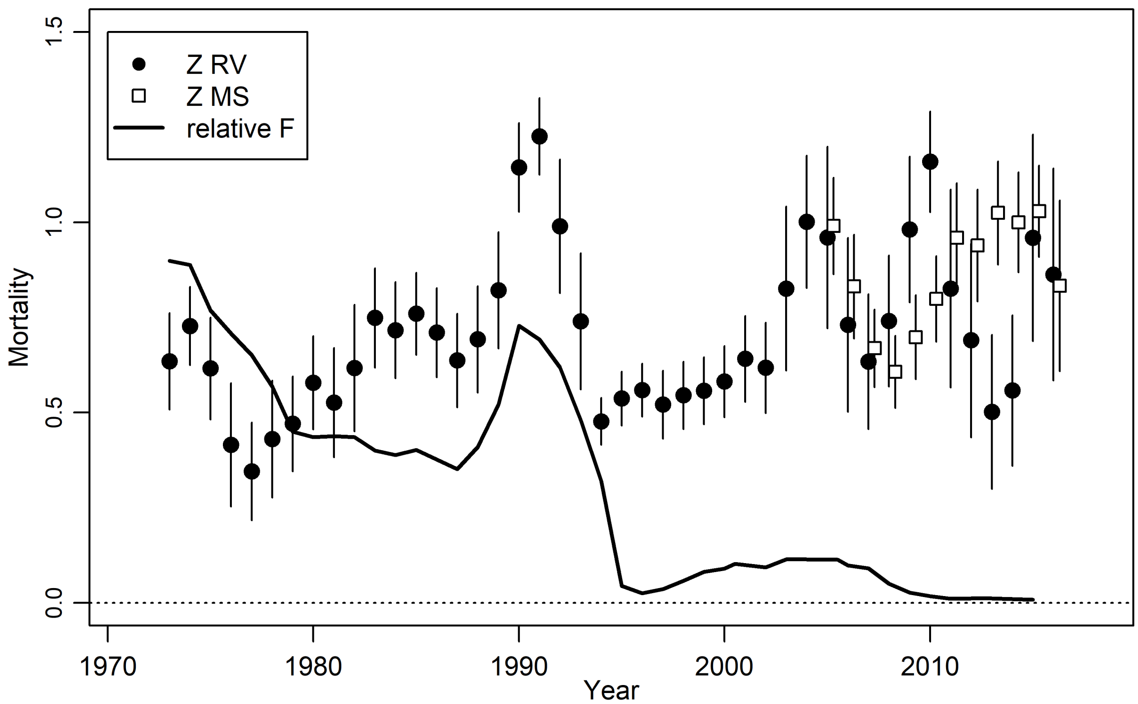

Figure 26. Estimates of the instantaneous rate of total mortality (Z) of Atlantic Cod from the southern Gulf of St. Lawrence derived from survey data. Estimates are from an analysis of covariance of the catch rates at age in the September RV survey (closed circles) and August mobile sentinel survey (MS, open squares). Estimates are for moving 5-yr blocks, plotted at the center of each block. Vertical lines are 95% confidence intervals. Lines are relative fishing mortality for ages 7-11 years, averaged over the same 5-yr blocks.

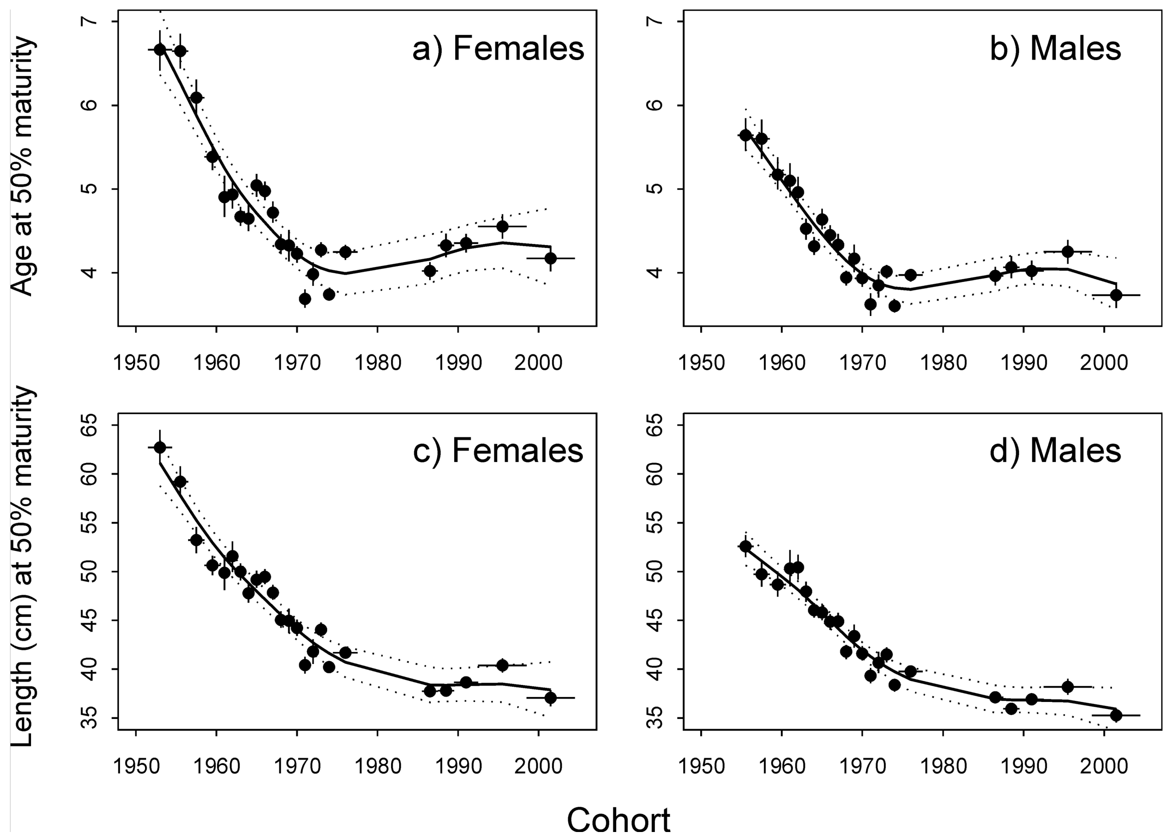

Figure 27. Age (upper row) and length (lower row) at 50% maturity for female (left column) and male (right column) Atlantic Cod in the southern Gulf of St. Lawrence (from Swain 2011). Vertical lines are 95% confidence intervals. Horizontal lines indicate the range of cohorts grouped together for the estimate. Time trends are summarized by a smoothing spline (heavy line) ± 2 SE (dotted lines). Lengths have been adjusted to September values.

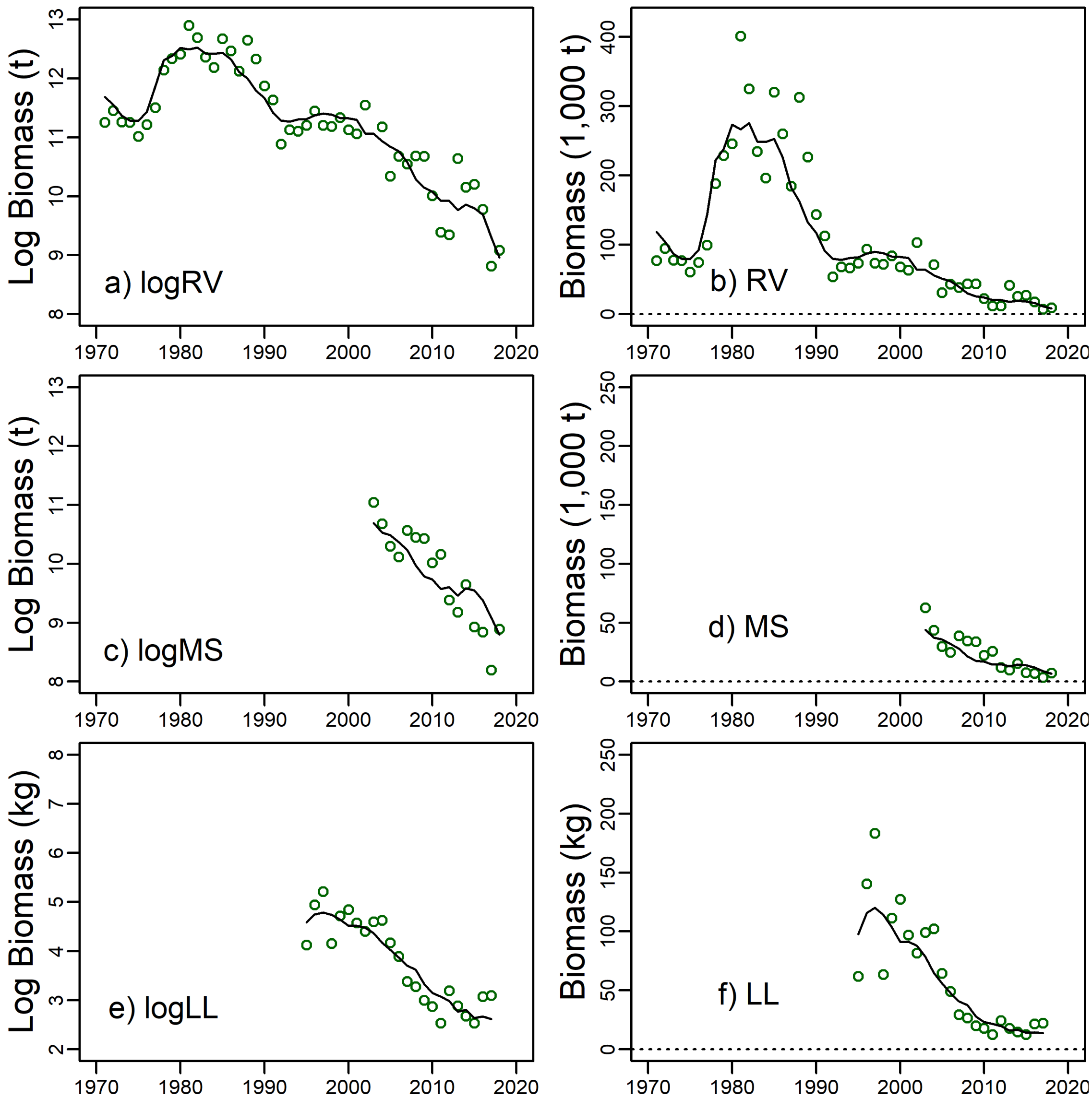

Figure 28. Observed age-aggregated log biomass indices (circles) for Atlantic Cod from a) the RV survey (logRV), c) the mobile sentinel survey (logMS), and e) the sentinel longline program (logLL) and the biomass indices predicted (lines) by the SCA. The right column shows the biomass indices predicted (lines) by the SCA and the same indices on a linear scale for b) the RV survey (RV), d) the mobile sentinel survey (lMS) and f) the sentinel longline program (LL).

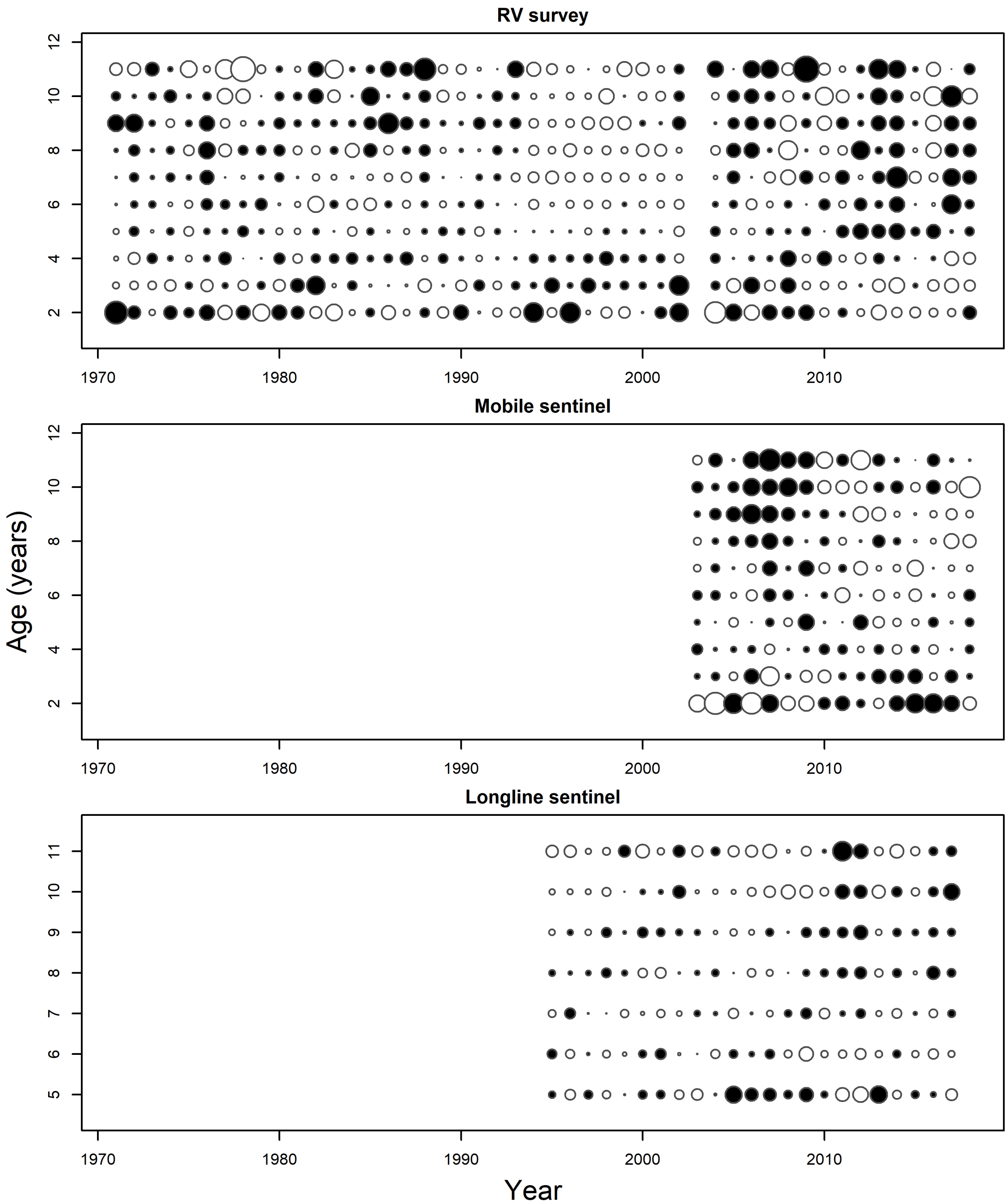

Figure 29. Residuals between the observed proportions at age (PAA) in the abundance indices and the proportions predicted by the SCA model for Atlantic Cod in the southern Gulf of St. Lawrence. Residuals are proportional to circle radii. Black circles denote negative residuals (i.e., observed < predicted).

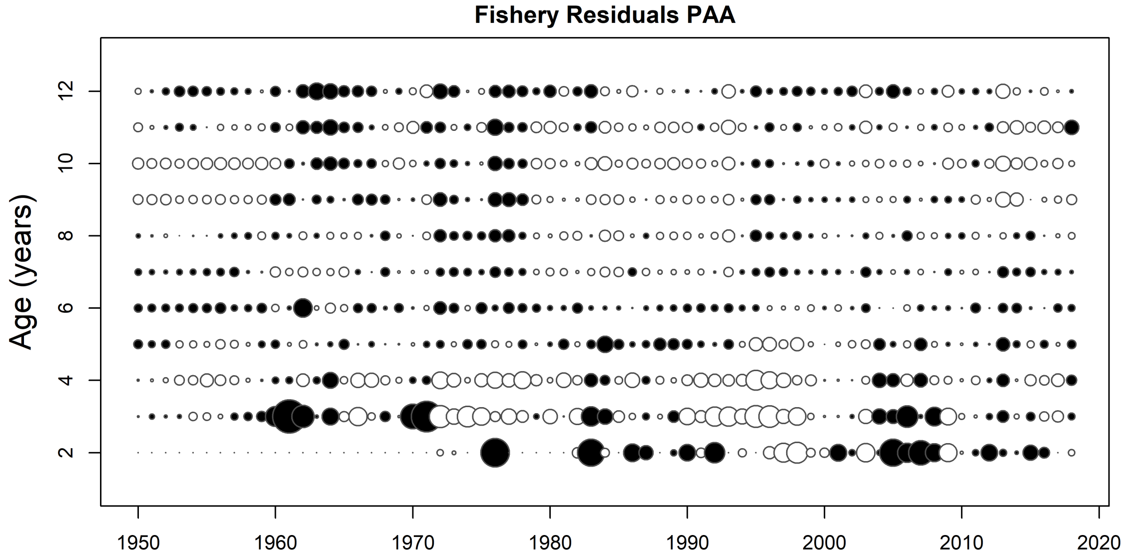

Figure 30. Residuals between the observed proportions at age (PAA) in the fishery catch and the proportions predicted by the SCA model for Atlantic Cod in the southern Gulf of St. Lawrence. Residuals are proportional to circle radii. Black circles denote negative residuals (i.e., observed < predicted).

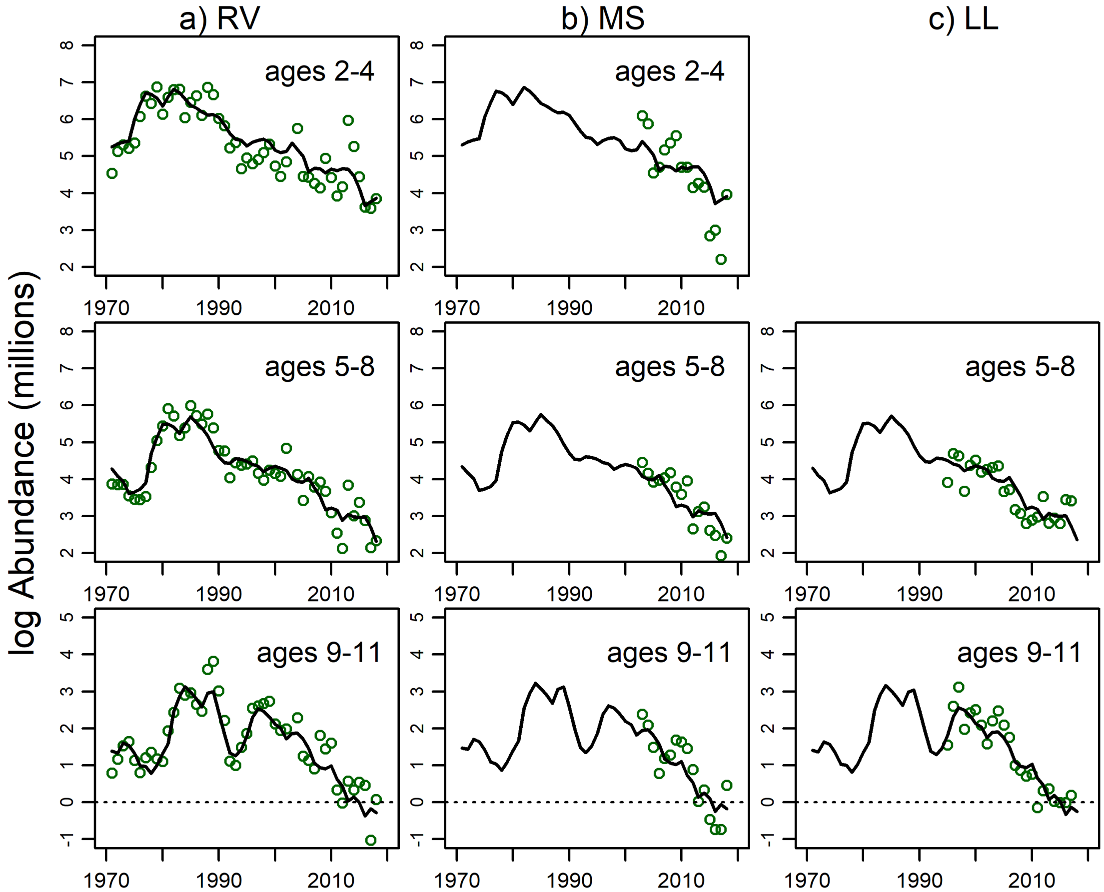

Figure 31. Comparison of catchability-corrected abundance indices (circles) by age group and SCA model predictions (lines) of abundance indices of Atlantic Cod for a) the RV survey indices, b) the mobile sentinel indices, and c) the sentinel longline indices. The indices are adjusted to the time of year when the index data were collected.

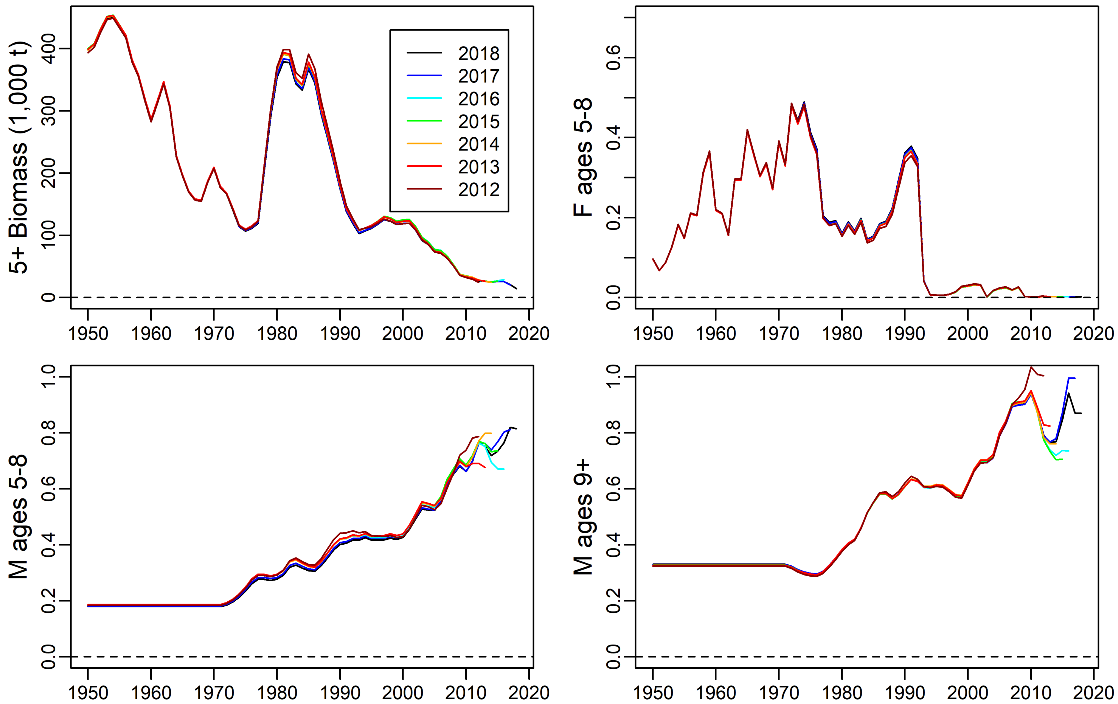

Figure 32. Retrospective analysis of estimates of southern Gulf of St. Lawrence Atlantic Cod 5+ biomass (upper left panel), F at ages 5-8 years (upper right panel), and M at ages 5-8 (lower left panel) and 9+ years (lower right panel) from the assessment model, 1950 to 2018.

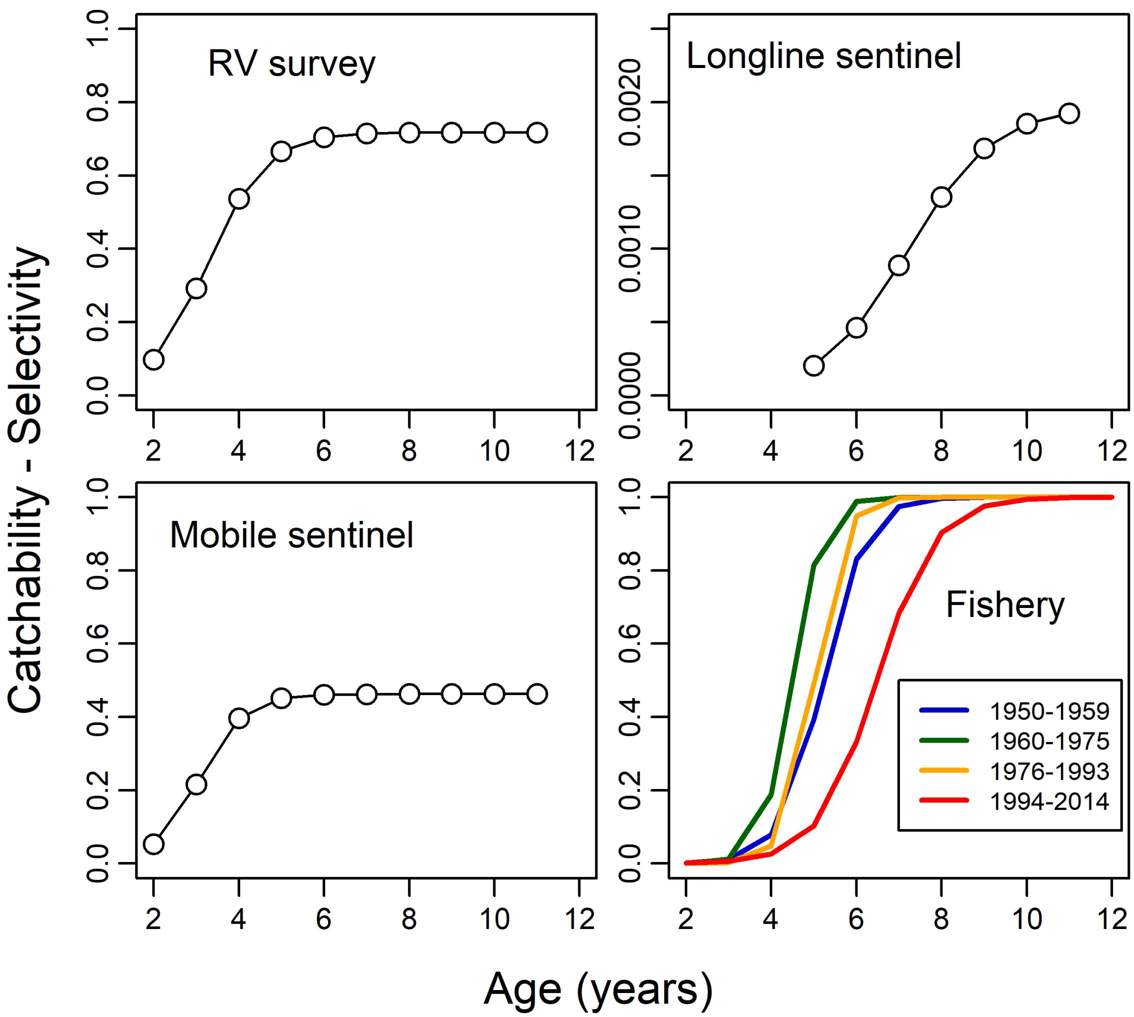

Figure 33. Estimates of catchabilities at age of southern Gulf of St. Lawrence Atlantic Cod to the RV survey (top row, left column), the mobile sentinel survey (bottom row, left column), and the longline sentinel program (top row, right column). The estimated selectivity at age to the fishery is shown in the lower right panel for four time periods.

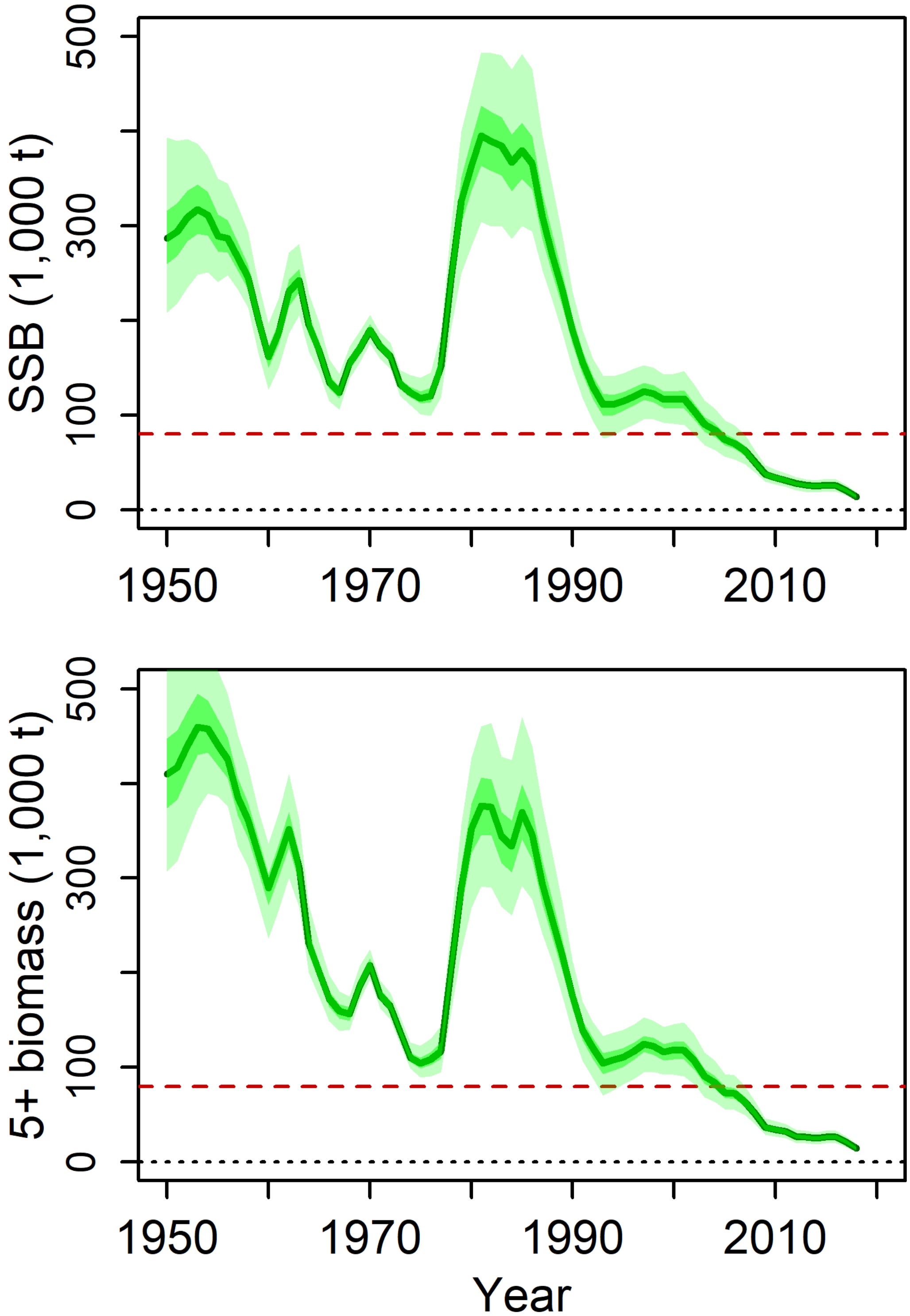

Figure 34. Estimates of spawning stock biomass (SSB; top row) and 5+ biomass (bottom row) in 1,000s of tonnes for southern Gulf of St. Lawrence Atlantic Cod. Lines show the median estimates and shading their approximate 95% credible intervals based on MCMC sampling. The dashed horizontal red line is the limit reference point value of 80,000 t of SSB.

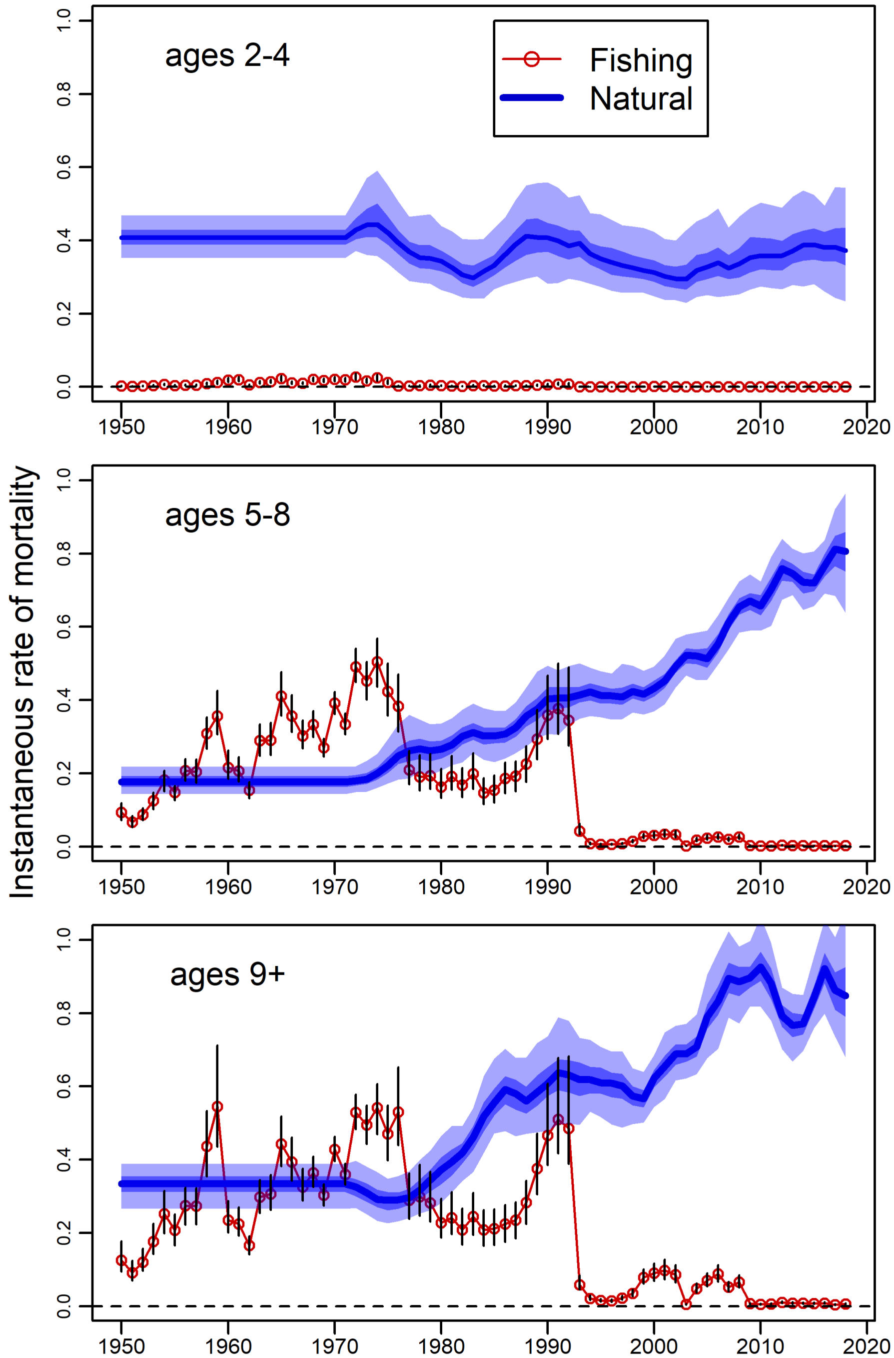

Figure 35. Estimates of the instantaneous rates of fishing (F; circle symbols) and natural (M; blue lines) mortality of southern Gulf of St. Lawrence Atlantic Cod for ages 2 to 4 (upper row), ages 5 to 8 (middle row), and ages 9+ (bottom row), 1950 to 2018. Circles and blue lines show the median estimates, and vertical lines and blue shading their approximate 95% credible intervals based on MCMC sampling. Dark blue shading shows the central 50% of estimates. F values are abundance-weighted averages of the values at each age within age groups.

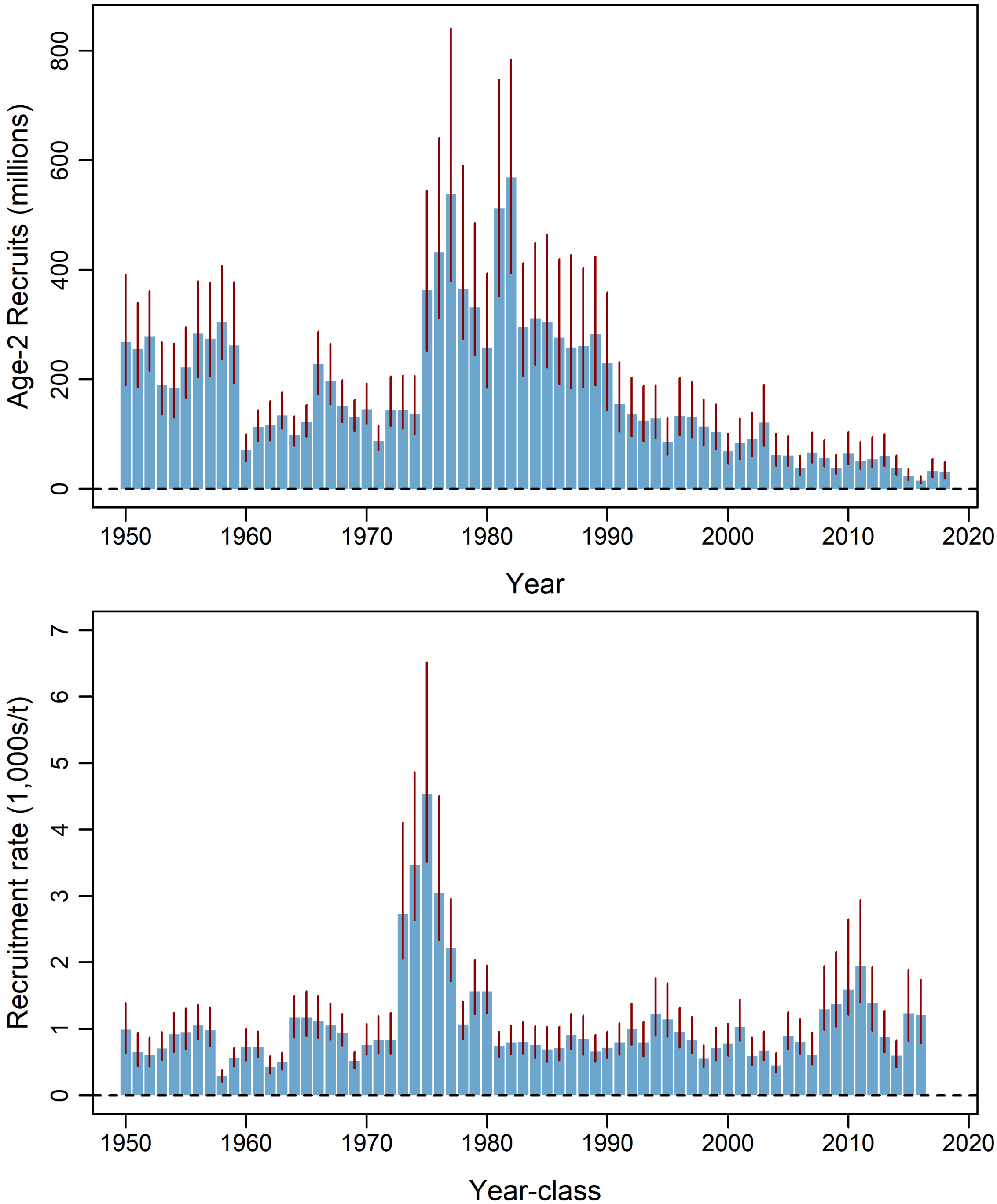

Figure 36. Model estimates of of recruit abundance (upper panel) and recruitment rate (lower panel) for southern Gulf of St. Lawrence Atlantic Cod. Bars are the median value and vertical lines the 95% credible intervals based on MCMC sampling.

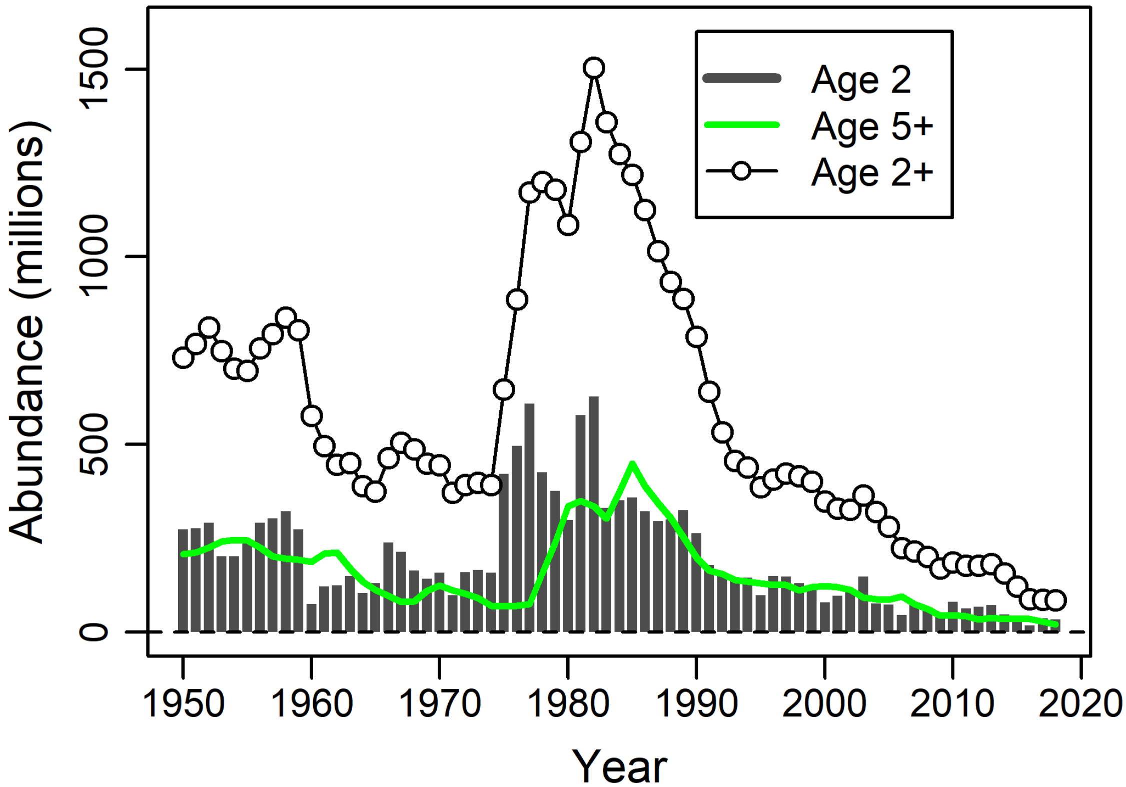

Figure 37. Model estimates of abundance at age 2 (bars), 2+ (circles) and 5+ (green line) for southern Gulf of St. Lawrence Atlantic Cod in 1950 to 2018.

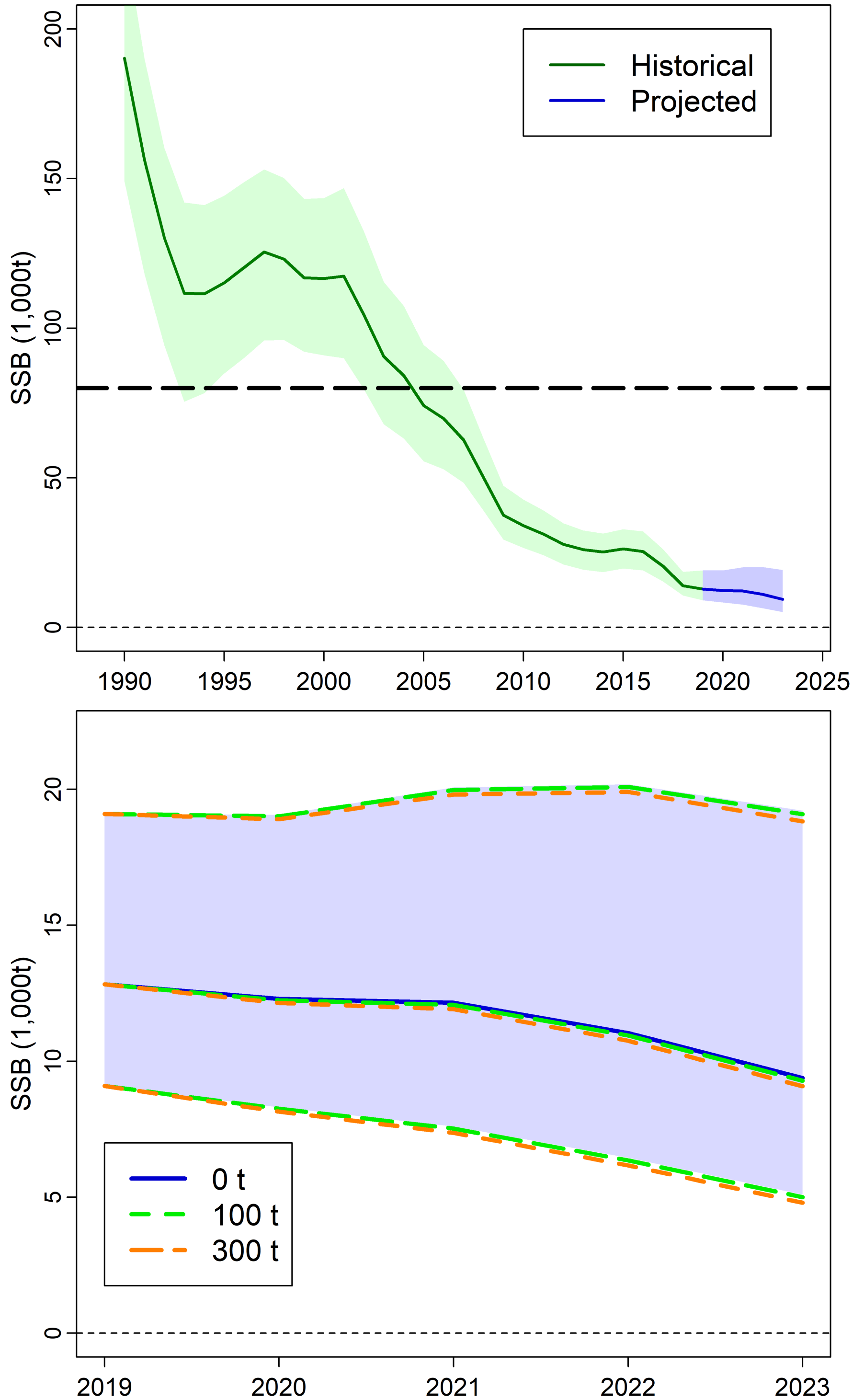

Figure 38. Estimated (green) and projected (blue) SSB of Atlantic Cod from the southern Gulf of St. Lawrence based on the population model. Projections assume that recent productivity conditions persist during the projection. Lines show the median estimate and shading the 95% credible intervals based on MCMC sampling of the posterior distribution. Line colour indicates the annual catch during the projection. The heavy black horizontal line is the Limit Reference Point (LRP). The lower panel focuses on the 5-year projection period.

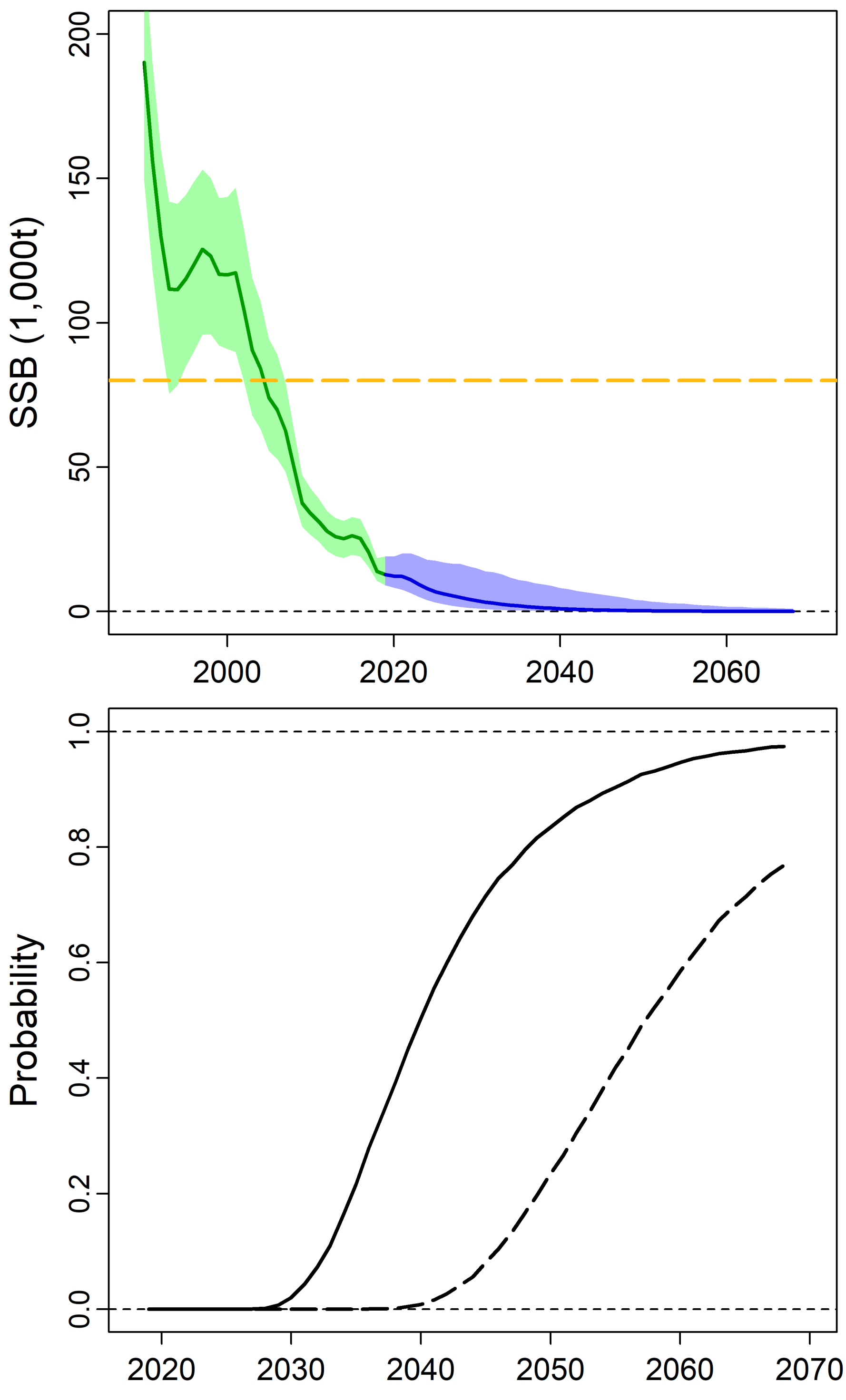

Figure 39. Projected SSB of Atlantic Cod from the southern Gulf of St. Lawrence over a 50-year projection (upper panel) and the probability that SSB declines below extinction proxies (lower panel). Projections assume that recent productivity conditions persist during the projection and that fishery catch is nil over the projection period. In the upper panel, lines and shading show the median estimate of SSB and its 95% credible interval, colour denotes the historical (green) and projection (blue) periods, and the horizontal line is the LRP. In the lower panel, the lines show the probability that SSB is below 1,000 t (solid line) or 100 t (dashed line) extinction proxies.

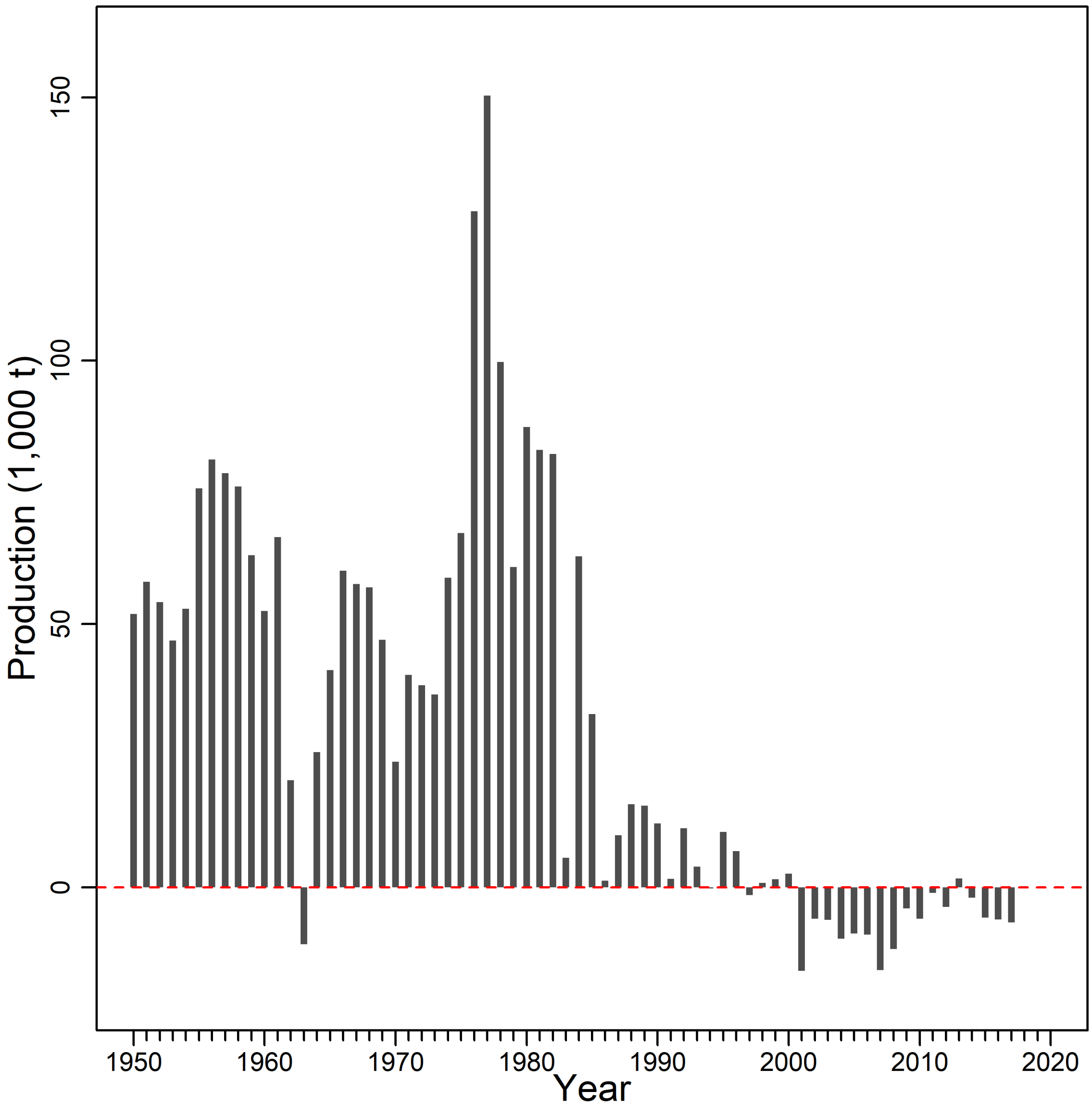

Figure 40. Model estimates of annual biomass production by the southern Gulf of St. Lawrence Atlantic Cod population, 1950 to 2017.

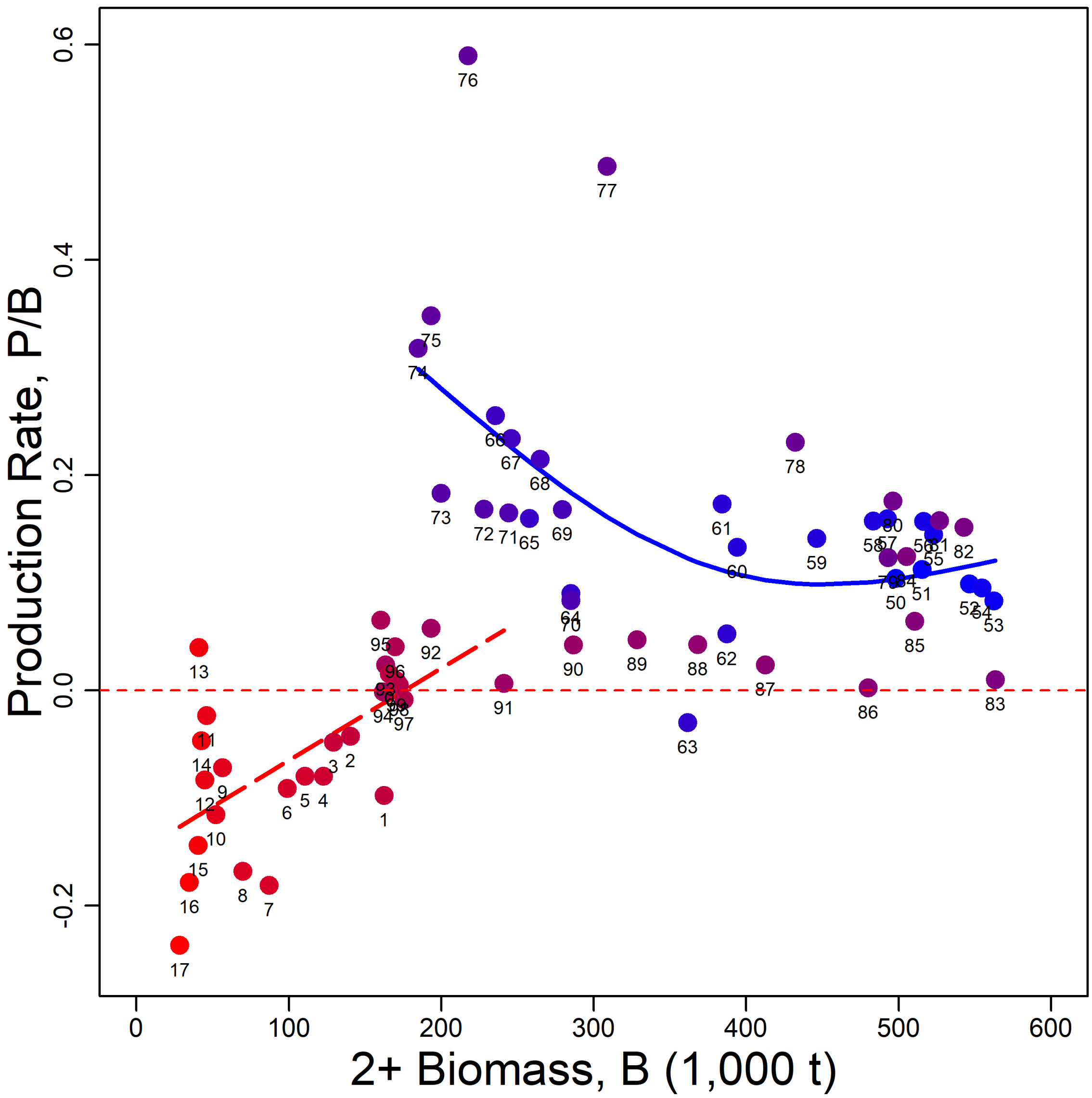

Figure 41. Annual rate of production (P/B, population production of biomass per unit of population biomass) by southern Gulf of St. Lawrence Atlantic Cod, 1950 to 2017. Circle colour indicates year (1950–blue, 2017–red). Circles are also annotated by year. The relationship between population biomass and the rate of population production is shown by the solid blue line for the 1950 to 1990 period and the dashed red line for the 1991 to 2017 period.

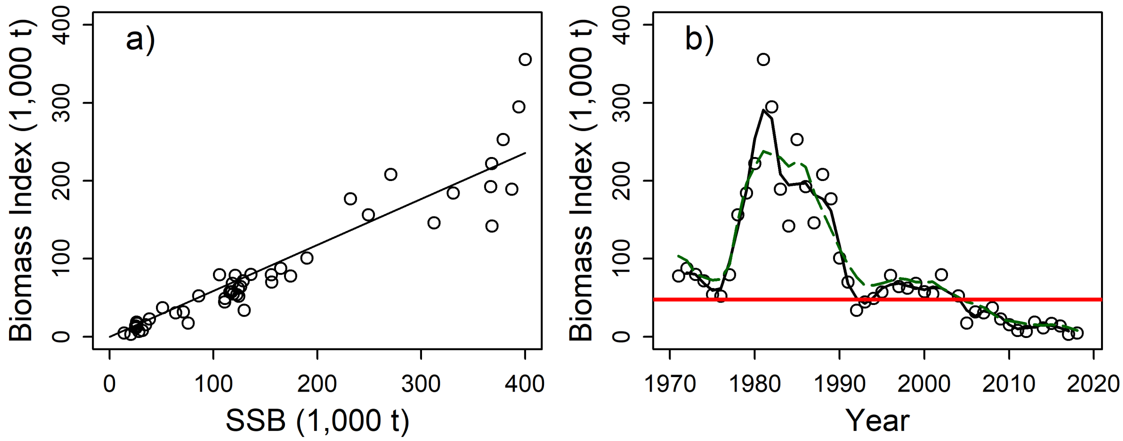

Figure 42. Re-scaling the LRP to the scale of the RV biomass index for Atlantic Cod 42 cm and larger from the southern Gulf of St. Lawrence. The left panel (a) shows the biomass index at the scale of trawlable biomass versus estimated spawning stock biomass (SSB) from the model. Circles are the observed index and the line shows the predicted index. The right panel (b) shows the 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). The horizontal red line in panel b) is the value of the limit reference point (LRP) at the scale of the biomass index, expressed as trawlable biomass.

APPENDIX A. LANDINGS BY MONTH AND GEAR

Table A.1. Landings (tonnes) by month and gear for southern Gulf of St. Lawrence Atlantic Cod in 2015. Landings are for NAFO Divs. 4T and 4Vn.

Month	Trawl	Seine	Gillnet	Longline	Handline	Misc.	Total
1	-	-	-	0.05	-	-	0.05
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	0.00	0.54	-	-	0.55
5	-	6.12	0.41	1.69	-	-	8.22
6	0.09	3.36	0.45	3.28	-	-	7.19
7	1.78	0.68	0.13	9.94	-	-	12.52
8	2.73	0.01	0.08	47.09	-	0.001	49.91
9	2.12	-	0.20	5.36	-	0.026	7.70
10	-	0.16	0.02	2.67	-	-	2.85
11	-	-	-	4.04	-	-	4.04
12	-	-	-	0.02	-	-	0.02
Total	6.73	10.32	1.28	74.68	-	0.03	93.05

Table A.2. Landings (tonnes) of the southern Gulf of St. Lawrence Atlantic Cod from NAFO Division 4T in 2015 in the Sentinel Survey.

Month	Longline	Trawl-lined	Total
7	0.96	-	0.96
8	2.61	5.65	8.26
9	1.62	-	1.62
10	0.50	-	0.50
11	0.03	-	0.03
12	-	-	0.00
Total	5.72	5.65	11.36

Table A.3. Landings (tonnes) by month and gear for southern Gulf of St. Lawrence Atlantic Cod in 2016. Landings are for NAFO Divs. 4T and 4Vn.

Month	Trawl	Seine	Gillnet	Longline	Handline	Misc.	Total
1	-	-	-	-	-	-	-
2	-	-	-	0.29	-	-	0.29
3	-	-	-	0.49	-	-	0.49
4	-	-	0.02	16.04	-	-	16.06
5	-	3.03	0.25	2.28	-	-	5.56
6	1.07	3.15	0.27	2.70	-	-	7.20
7	2.08	0.07	0.25	20.64	-	0.01	23.05
8	0.14	0.01	0.93	34.09	-	-	35.16
9	-	0.03	0.07	6.42	-	0.04	6.56
10	-	-	-	-	-	-	-
11	-	-	-	3.75	-	-	3.75
12	-	-	-	0.50	-	-	0.50
Total	3.30	6.29	1.79	87.19	-	0.04	98.61

Table A.4. Landings (tonnes) of the southern Gulf of St. Lawrence Atlantic Cod from NAFO Division 4T in 2016 in the Sentinel Survey.

Month	Longline	Trawl-lined	Total
7	2.21	-	2.21
8	5.09	3.00	8.09
9	4.28	-	4.28
10	2.44	-	2.44
11	0.25	-	0.25
12	-	-	0.00
Total	14.27	3.00	17.27

Table A.5. Landings (tonnes) by month and gear for southern Gulf of St. Lawrence Atlantic Cod in 2017. Landings are for NAFO Divs. 4T and 4Vn.

Month	Trawl	Seine	Gillnet	Longline	Handline	Misc.	Total
1	-	-	-	-	-	-	-
2	-	-	-	0.13	-	-	0.13
3	-	-	-	0.05	-	-	0.05
4	-	-	0.04	3.05	-	-	3.09
5	-	1.48	0.40	3.39	-	-	5.27
6	0.06	2.53	0.70	3.69	-	-	6.97
7	0.04	0.28	1.05	7.88	0.45	0.01	9.71
8	0.02	0.15	0.08	13.86	0.06	-	14.16
9	-	0.20	0.13	4.00	-	0.05	4.38
10	-	-	-	1.94	-	-	1.94
11	-	-	0.07	0.17	-	-	0.23
12	-	-	-	0.32	-	-	0.32
Total	0.12	4.63	2.46	38.47	0.51	0.06	46.25

Table A.6. Landings (tonnes) of the southern Gulf of St. Lawrence Atlantic Cod from NAFO Division 4T in 2017 in the Sentinel Survey.

Month	Longline	Trawl-lined	Total
7	1.74	-	1.74
8	4.20	1.73	5.93
9	3.05	-	3.05
10	1.79	-	1.79
11	0.34	-	0.34
12	-	-	0.00
Total	11.12	1.73	12.85

Table A.7. Landings (tonnes) of the southern Gulf of St. Lawrence Atlantic Cod from NAFO Division 4T in 2018 in the Sentinel Survey.

Month	Longline	Trawl-lined	Total
7	0.30	-	0.30
8	3.35	0.84	4.19
9	2.84	-	2.84
10	3.00	-	3.00
11	0.70	-	0.70
12	-	-	0.00
Total	10.19	0.84	11.03

APPENDIX B. AGE-LENGTH KEYS USED TO CALCULATE THE CATCH-AT-AGE

Table B.1. Age-length keys that were used in the calculation of the 2015 catch-at-age for southern Gulf of St. Lawrence Atlantic Cod. Gear Type Abbreviations: OTB = Otter Trawl, SNU = Seine, GN = Gillnet, LL = Longline, LHP = Handline. Length/Weight Coefficients (sexes combined) from Mission T533 (Sept. 2015): $a = 7.393546e\text{-}06$*,* $b = 3.041236$*.*

Key	Fishery	Lengths (N)	Ages (N)	Landings (t)
1	OTB/SNU - Bycatch Apr - Dec (No liner)	826	301	17.054
2	GN/LL/LHP - Bycatch Apr - Dec	480	240	75.912
3	LL - Sentinel Survey Jul - Nov	3644	863	5.716
4	OTN - Sentinel Survey Aug. (Liners)	4482	1154	5.647
Total		-	-	104.329

Table B.2. Landings (numbers) at age by gear in 2015. The age-key numbers correspond with Table B.1 (Comm. = Commercial, Sent. = Sentinel, Comb. = Commercial & Sentinel, L=Liner, NoL=No Liner).

Age	OTB/SNU Comm.(NoL)	GN/LL/LHP Comm.	LL Sent	OTB Sent. (L)	Unsampled	Total
2	0	0	0	77	0	77
3	0	23	14	644	0	681
4	16	4958	153	1981	4	7112
5	196	9310	672	2165	7	12351
6	911	11068	954	1488	9	14428
7	1458	9304	961	1145	8	12875
8	1241	2872	421	153	3	4690
9	1413	3603	341	107	4	5469
10	1153	4906	291	73	5	6428
11	105	1246	90	15	1	1457
12	79	994	81	21	1	1176
13	62	94	28	5	0	189
14	97	3	37	0	0	137
15	0	0	11	0	0	11
16+	0	0	4	0	0	4
Total (all)	6731	48382	4058	7874	42	67087
Total (3+)	6731	48382	4058	7797	42	67010

Table B.3. Age-length keys that were used in the calculation of the 2016 catch-at-age for southern Gulf of St. Lawrence Atlantic Cod. Gear Type Abbreviations: OTB = Otter Trawl, SNU = Seine, GN = Gillnet, LL = Longline, LHP = Handline. Length/Weight Coefficients (sexes combined) from Mission T661 (Sept. 2016): $a = 7.681694e\text{-}06$*,* $b = 3.022402$*.*

Key	Fishery	Lengths (N)	Ages (N)	Landings (t)
1	OTB/SNU - Bycatch Apr - Dec (No liner)	198	175	9.586
2	GN/LL/LHP - Bycatch Apr - Dec	955	504	88.207
3	LL - Sentinel Survey Jul - Nov	9223	1423	14.671
4	OTN - Sentinel Survey Aug. (Liners)	3309	655	2.999
Total		-	-	115.463

Table B.4. Landings (numbers) at age by gear in 2016. The age-key numbers correspond with Table B.3 (Comm. = Commercial, Sent. = Sentinel, Comb. = Commercial & Sentinel, L=Liner, NoL=No Liner).

Age	OTB/SNU Comm.(NoL)	GN/LL/LHP Comm.	LL Sent	OTB Sent. (L)	Unsampled	Total
2	0	0	9	75	0	84
3	0	7	244	669	0	920
4	0	1890	1042	1230	13	4176
5	17	5564	1863	1021	39	8504
6	265	13072	2722	662	94	16815
7	967	10749	2276	364	82	14439
8	1311	10228	1183	236	81	13039
9	532	3086	483	68	25	4194
10	0	2771	345	28	19	3163
11	376	2411	223	20	20	3048
12	60	840	55	8	6	968
13	40	385	53	2	3	482
14	0	1	31	0	0	32
15	25	0	17	0	0	42
16+	0	0	3	0	0	3
Total (all)	3593	51003	10549	4406	384	69934
Total (3+)	3593	51003	10540	4306	384	69825

Table B.5. Age-length keys that were used in the calculation of the 2017 catch-at-age for southern Gulf of St. Lawrence Atlantic Cod. Gear Type Abbreviations: OTB = Otter Trawl, SNU = Seine, GN = Gillnet, LL = Longline, LHP = Handline. Length/Weight Coefficients (sexes combined) from Mission T777 (Sept. 2017): $a = 5.954514e\text{-}06$, $b = 3.10324$.

Key	Fishery	Lengths (N)	Ages (N)	Landings (t)
1	OTB/SNU - Bycatch Apr - Dec (No liner)	182	141	4.747
2	GN/LL/LHP - Bycatch Apr - Dec	325	235	41.267
3	LL - Sentinel Survey Jul - Nov	8317	1161	10.788
4	OTN - Sentinel Survey Aug. (Liners)	2258	477	1.732
Total		-	-	58.534

Table B.6. Landings (numbers) at age by gear in 2017. The age-key numbers correspond with Table B.5 (Comm. = Commercial, Sent. = Sentinel, Comb. = Commercial & Sentinel, L=Liner, NoL=No Liner).

Age	OTB/SNU Comm.(NoL)	GN/LL/LHP Comm.	LL Sent	OTB Sent. (L)	Unsampled	Total
2	0	0	0	145	0	145
3	0	0	158	182	0	340
4	0	535	683	527	2	1747
5	16	1682	1525	655	7	3884
6	145	3499	2027	524	15	6210
7	201	4989	1369	248	21	6828
8	433	3708	958	163	17	5278
9	529	2701	744	63	13	4050
10	134	887	111	17	4	1153
11	53	640	114	4	3	814
12	18	138	43	5	1	204
13	12	178	4	1	1	195
14	22	0	7	0	0	29
15	18	68	9	0	0	94
16+	11	0	0	0	0	11
Total (all)	1591	19024	7750	2688	84	31137
Total (3+)	1591	19024	7750	2388	84	30837

Table B.7. Age-length keys that were used in the calculation of the 2018 catch-at-age for southern Gulf of St. Lawrence Atlantic Cod. Gear Type Abbreviations: OTB = Otter Trawl, SNU = Seine, GN = Gillnet, LL = Longline, LHP = Handline. Length/Weight Coefficients (sexes combined) from Mission T896 (Sept. 2018): $a = 7.105257e\text{-}06$, $b = 3.04503$.

Key	Fishery	Lengths (N)	Ages (N)	Landings (t)
1	OTB/SNU - Bycatch Apr - Dec (No liner)	45	43	2.245
2	GN/LL/LHP - Bycatch & Sentinel Survey Apr - Dec	383	281	55.651
3	OTN - Sentinel Survey Aug. (Liners)	1814	455	0.839
Total		-	-	58.735

Table B.8. Landings (numbers) at age by gear in 2018. The age-key numbers correspond with Table B.7 (Comm. = Commercial, Sent. = Sentinel, Comb. = Commercial & Sentinel, L=Liner, NoL=No Liner).

Age	OTB/SNU Comm.(NoL)	GN/LL/LHP Comb.	OTB Sent. (L)	Unsampled	Total
2	0	0	230	0	230
3	0	0	461	0	461
4	0	237	229	1	467
5	0	1938	254	10	2202
6	34	5499	155	28	5716
7	141	9502	154	49	9845
8	192	7464	82	39	7775
9	277	4648	31	25	4981
10	68	2099	38	11	2216
11	17	153	3	1	174
12	21	375	2	2	399
13	0	0	0	0	0
14	17	0	0	0	17
15	0	0	0	0	0
16+	0	134	0	1	134
Total (all)	766	32048	1655	165	34633
Total (3+)	766	32048	1408	165	34387