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ASSESSMENT OF THE SOUTHERN GULF OF ST. LAWRENCE (NAFO DIV. 4T) SPRING AND FALL SPAWNER COMPONENTS OF ATLANTIC HERRING (*CLUPEA HARENGUS*) WITH ADVICE FOR THE 2018 AND 2019 FISHERIES

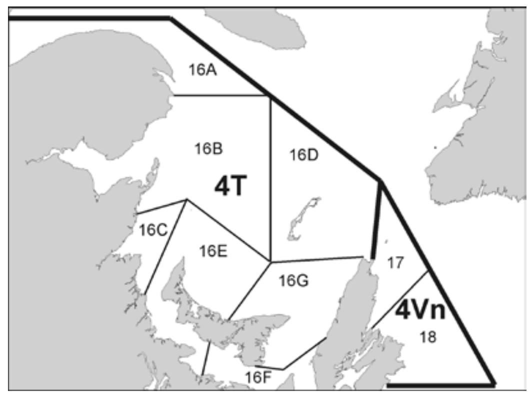

Figure 1. NAFO Divisions 4T and 4Vn and the corresponding herring fishery management zones.

Context:

The stock area for southern Gulf of St. Lawrence Atlantic Herring extends from the north shore of the Gaspe Peninsula to the northern tip of Cape Breton Island, including the Magdalen Islands (Fig. 1). Available information suggests that adults overwinter off the east coast of Cape Breton primarily in NAFO Division 4Vn. Southern Gulf of St. Lawrence herring are harvested by a fixed gear (gillnet) fleet on spawning grounds and a mobile gear (purse seine) fleet (vessels >65') in deeper water. The fixed gear fleet harvests almost exclusively the spring spawner component in the spring, except for June, and almost exclusively the fall spawner component in the fall. The mobile fleet harvests a mixture of spring and fall spawner components during their fishery. The proportions of spring and fall spawner components in the catch vary according to season. In recent years, spring herring have been sold primarily for bait but historically were also used for the bloater (smoked herring), and filet markets. Fall landings are primarily driven by the roe, bloater and filet markets. Annual quota management was initiated in 1972. In 2017, there were 2,339 fixed gear licenses and 8 seiner licenses.

Assessments of the spring and fall spawning herring from the southern Gulf of St. Lawrence (NAFO Div. 4T) are used to establish the total allowable catch. A meeting of the Regional Advisory Process was held March 15, 2018 in Moncton, N.B. to assess the status of the spring and fall spawner components of 4T herring and to provide advice for the 2018 and 2019 fisheries. Participants at the meeting included DFO Science (Gulf, Newfoundland and Labrador, Quebec Regions), DFO Fisheries Management (Gulf and Quebec Regions), provincial governments, the fishing industry, and aboriginal organizations.

SUMMARY

- Atlantic Herring in the southern Gulf of St. Lawrence are comprised of spring spawning and fall spawning components which are considered to be distinct stocks and as such are assessed separately.
- Fishery dependent indices are an important component of the assessment. Indices such as the commercial gillnet CPUE, may not be proportional to abundance due to changes in catchability over time. For example, catch rates can remain elevated despite decreases in abundance (increased catchability) due to contractions in stock distribution and targeting of aggregations by fishing fleets, as well as due to improved fishing technology and fishing practices.

Spring Spawner Component (SS)

- The preliminary estimated landings of SS herring in 2016 and 2017 were 966 t and 1,189 t, respectively, from annual total allowable catch values of 2,000 t.
- A virtual population analysis model that incorporated changes in catchability in the fixed gear fishery has been used since the last assessment.
- The estimates of Spawning Stock Biomass (SSB) at the beginning of 2017 and 2018 were 11,744 t (95% confidence interval: 6,463 – 28,171) and 12,446 t (95% CI: 6,418 – 30,365), respectively. The SSB has been in the critical zone of the Precautionary Approach framework since 2004 and the probabilities that SSB remained in the critical zone at the beginning of 2017 and 2018 were over 90%.
- The average fishing mortality rates on ages 6 to 8 for the SS exceeded $F_{0.1}$ (the removal reference level in the healthy zone, $F = 0.35$) during 2000 to 2011. F declined below $F_{0.1}$ in 2012, reaching its lowest value of 0.19. The fishing mortality rate during 2015 to 2017 averaged 0.24 (annual exploitation rate of 0.21).
- Due to variable recruitment in recent years, projections were conducted under three different recruitment scenarios during the projection period: (1) high recruitment, (2) low recruitment, and (3) mixed recruitment.
- SSB at the start of 2019 and 2020 was projected to increase slightly at annual catches less than 500 t, remain roughly stable at annual catches of 1,000 t, but decline at catches of 1,500 t or more. However, uncertainty in projected SSB is high. Even in the absence of any removals of SS herring in 2018 and 2019, the SSB is expected to only increase slightly with a high probability that the stock will remain in the critical zone.
- Since 2009, the TAC has been set to 2,000 t annually. At a catch of 2,000 t, the probability of an increase in SSB ranges from 0% (low recruitment scenario) to 19% (high recruitment scenario) with only a 10% chance of exceeding the LRP even under the high recruitment scenario.
- Elevated fishing mortality, declines in weights-at-age, and variable but low recruitment rates are further impeding the rebuilding of the stock.

Fall Spawner Component (FS)

- The preliminary estimated landings of the FS herring component in 2016 and 2017 were 24,677 t and 20,523 t respectively, from a total allowable catch of 35,000 t annually.

- Beginning in 2015, the FS herring assessment model incorporated the dynamics of three regional sub-stocks (North, Middle, South) which jointly comprise the NAFO Div. 4T stock. The catch options are evaluated at the level of the southern Gulf of St. Lawrence.
- Catchability to the fixed gear fishery was estimated to differ between regions and to have changed over time, being lowest with little variation in the North region in contrast to increases in the Middle and South regions over the time series.
- For the southern Gulf of St. Lawrence, the median estimate of SSB at the start of 2018 is 112,000 t. The probabilities that the SSB was below the Upper Stock Reference (USR) level of 172,000 t at the beginning of 2017 and 2018 were 98% and 97%, respectively.
- The average fishing mortality rate on ages 5 to 10 for the FS exceeded $F_{0.1}$ (the removal reference level in the healthy zone, $F = 0.32$) from 1994 to 2011 except in 2004, but declined from 2012 to attain the lowest levels in 2016. F averaged 0.20 during 2015 to 2017.
- Estimated abundances of age 4 herring at the start of 2017 and 2018 were very low, but with very large uncertainty.
- The median of the projected SSB at the start of 2019 and 2020 remains below the USR at all annual catch levels of 10,000 t or greater with a probability of at least 90%.
- At catches of 20,000 t (the catch in 2017) in 2018 and 2019, the probability of the SSB remaining under the USR in 2020 was estimated at 94%. At the 20,000 t catch level, the probability of the fishing mortality rate being above the removal rate reference was estimated at 46%. $F_{0.1}$ is a removal reference for when a stock is in the healthy zone of the Precautionary Approach.
- Current retrospective patterns indicate that the assessment model may overestimate the exploitable biomass. Consequently, harvest options presented may be optimistic relative to attainment of management objectives.
- When a stock is below the USR (in the cautious zone), consideration should be given to increasing the SSB. A 5% increase in SSB by 2020 would only be likely (greater than 50%) at annual catches below 16,000 t.
- Elevated fishing mortality, during the mid-1990s to 2010, declines in weights-at-age, and low recruitment rates are contributing to declines in SSB, further impeding the rebuilding of the stock.

INTRODUCTION

The Atlantic Herring (Clupea harengus) is a schooling pelagic species. Age at first spawning is typically four years. The herring population in the sGSL consists of two spawning components: spring spawners (SS) and fall spawners (FS). Spring spawning occurs primarily in April-May at depths <10 m. Fall spawning occurs from mid-August to mid-October at depths of 5 to 20 m. Herring also show high spawning site fidelity. In recent years, the largest spring spawning areas are in the Northumberland Strait and Chaleur Bay and the largest fall spawning areas are in coastal waters off Miscou and Escuminac N.B., North Cape and Cape Bear P.E.I., and Pictou, N.S. When spawned, the eggs are attached to the sea floor.

Herring fisheries in NAFO Div. 4T of the southern Gulf of St. Lawrence (sGSL) are managed across seven herring fishing areas within area 16 (A-G; Fig. 1). The SS and FS herring of the sGSL are considered distinct stocks and are assessed separately. For the fall spawner component, a regionally-disaggregated assessment model (North, Middle, South regions) was first used to update advice for the 2015 fishery (DFO 2015).

Fisheries

Over the period 1978 to 2017, total landings of Atlantic Herring from NAFO Div. 4T and 4Vn peaked at 93,471 t in 1995 and dropped to 20,523 t in 2017 (Fig. 2). A Total Allowable Catch (TAC) for the combined harvest of both components in 4T and 4Vn has been in place since 1972. The total landings have generally been less than the TAC since 1988. The TAC values in 2016 and 2017 were 37,000 t.

In the sGSL, herring are harvested by a gillnet fleet (referred to as “fixed” gear fleet) and a purse seine fleet (“mobile” gear fleet). The fixed gear fishery is focused in NAFO Div. 4T whereas the mobile gear fishery occurs in Div. 4T and occasionally in Div. 4Vn. As in previous years, 77% of the TAC for both seasons was allocated to the fixed gear fleet and 23% to the mobile gear fleet. The majority (73% to 97%) of the reported landings since 1981 have been from the fixed gear fleet with percentages in 2016 and 2017 of 94% and 99%, respectively (Fig. 2). Local stocks are generally targeted by the fixed gear fishery which takes place on the spawning grounds.

Separate TACs for the spring spawner component and for the fall spawner component have been established since 1985. The TACs are attributed to the fishing seasons. Reported landings from the fall season have represented the majority (65% to 98%) of the total landings of sGSL herring throughout the time series (Fig. 2). Landings in the fall fishing season were estimated to have represented 94% and 95% of the total herring harvested in 2016 and 2017, respectively.

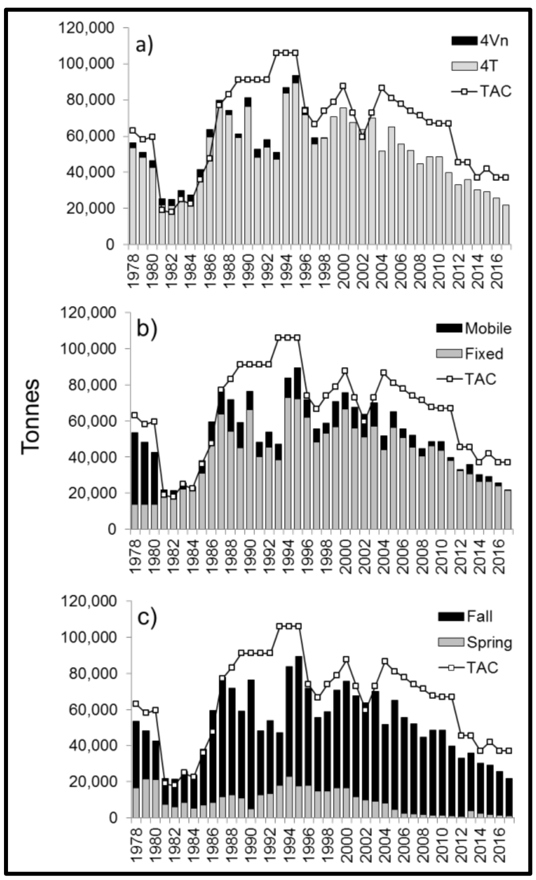

Figure 2. Reported landings (tonnes) of southern Gulf of St. Lawrence Atlantic Herring (spring and fall spawners combined) by NAFO Division (upper panel), by gear fleet (middle panel), and by fishing season (lower panel), 1978 to 2017. In all panels, the corresponding annual total allowable catch (TAC; tonnes) is shown. For landings by season, the landings in NAFO Div. 4Vn were attributed to the fall fishing season. Data for 2016 and 2017 are preliminary.

Spring spawners and fall spawners are not exclusively captured in their corresponding spawning seasons and the landings are attributed to spawning groups based on macroscopic characteristics of individual herring obtained from samples of the fishery catches.

Spring spawner component (SS)

The 2016 and 2017 TAC for the SS herring was set at 2,000 t annually, the same value since 2010 (Fig. 3). The preliminary estimated landings of SS herring in 2016 and 2017 were 966 t and 1,189 t, respectively. With few exceptions, most of the SS herring were estimated to have been landed in the fixed gear fleet over the 1981 to 2017 period. In 2016 and 2017, the fixed gear fleet was estimated to have landed 82% and 96%, respectively, of the total harvests of SS herring (Fig. 3). Generally more than 90% of the SS herring landed by the fixed gear fleet is landed during the spring fishing season, whereas most (> 75%) of the SS herring landed by the mobile fleet is landed in the fall season (Fig. 3).

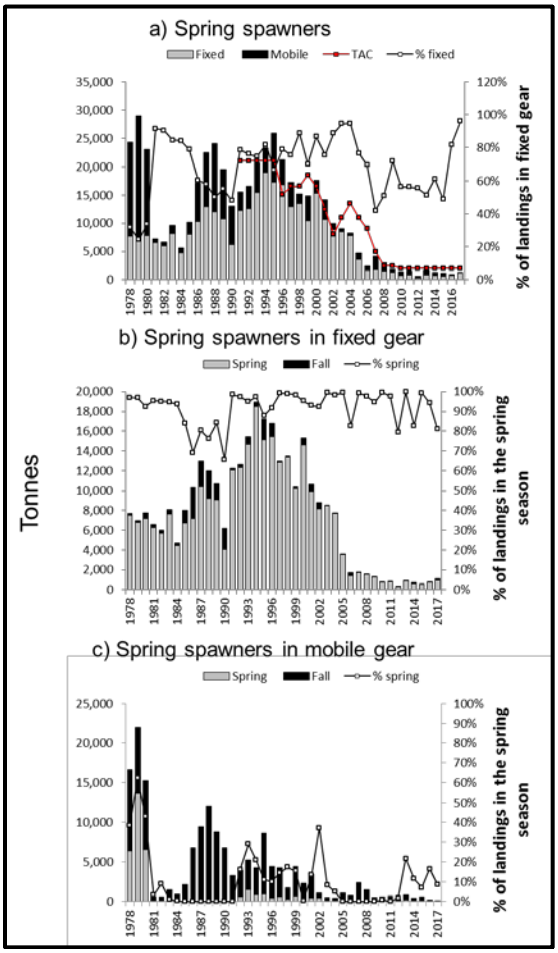

Figure 3. Estimated landings (tonnes) of the spring spawner component (SS) of Atlantic Herring from the southern Gulf of St. Lawrence, 1978 to 2017. The upper panel shows the estimated landings by gear type and the proportion of the landings attributed to the fixed gear fleet. Also shown in the upper panel is the SS herring TAC (red symbols) for 1991 to 2017. The middle panel shows the estimated landings of SS herring in the fixed gear fleet that occurred in the spring fishery season and the fall fishery season as well as the proportion of total SS herring landed by the fixed gear fleet in the spring fishing season. The lower panel shows the estimated landings of SS herring in the mobile gear fleet that occurred in the spring fishery season and the fall fishery season as well as the proportion of the total SS herring landed by the mobile gear fleet in the spring fishing season. For landings by season, the landings in NAFO Div. 4Vn were attributed to the fall fishing season. Data for 2016 and 2017 are preliminary.

Catch-at-age and weight-at-age

The dominant age in the 2016 SS catch was age 7 belonging to the 2009 year-class. In 2017 it was age 5, belonging to the 2012 year-class (Fig. 4).

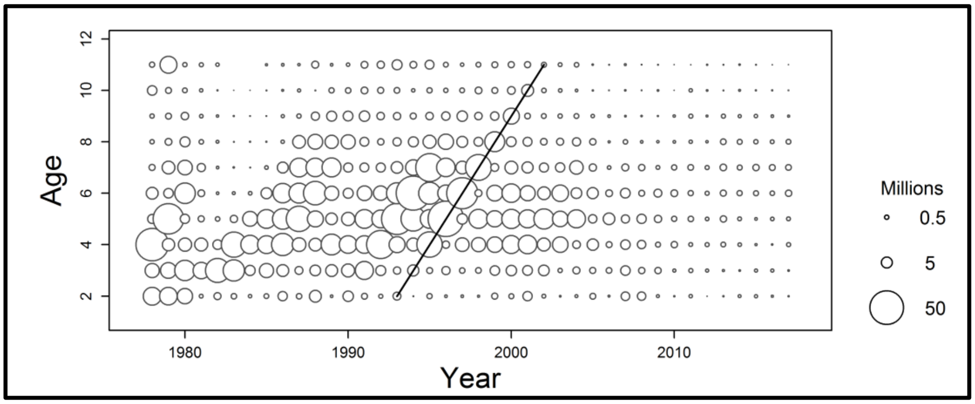

Figure 4. Catch-at-age of the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence fishery, all gears combined, 1978 to 2017. Size of the bubble is proportional to the catch numbers by age and year. The diagonal line tracks the most recent strong year-class (1991).

Mean weights-at-age of the SS caught in the mobile and fixed gears in the spring season have declined since the 1990s for mobile gear, and since the mid-1980s for the fixed gear (Fig. 5).

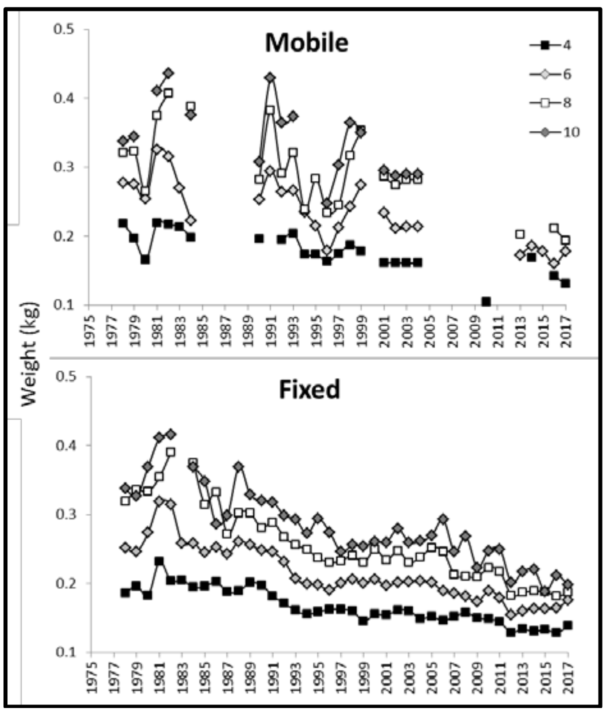

Figure 5. Mean weight (kg) for ages 4, 6, 8 and 10 years of the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence sampled from catches during the spring season in the mobile (upper panel) and fixed (lower panel) commercial gears, 1978 to 2017.

Fall spawner component (FS)

The fishery TAC for the fall spawner component is set for the NAFO Div. 4T stock unit. The preliminary estimated landings of FS herring in 2016 and 2017 were 24,677 t and 20,523 t respectively (Fig. 6). The TAC was 35,000 t in 2016 and 2017. With few exceptions, over the 1978 to 2017 period, most of the FS herring were estimated to have been landed in the fixed gear fleet. In 2016 and 2017, the fixed gear fleet was estimated to have landed 94% and 95%, respectively, of the total harvests of FS herring (Fig. 6). The majority (generally almost 100%) of the FS herring captured in the fixed gear fishery are landed during the fall fishing season. The mobile fleet has landed varying amounts of FS herring in the fall, 31% to 45% during 2016 to 2017 (Fig. 6).

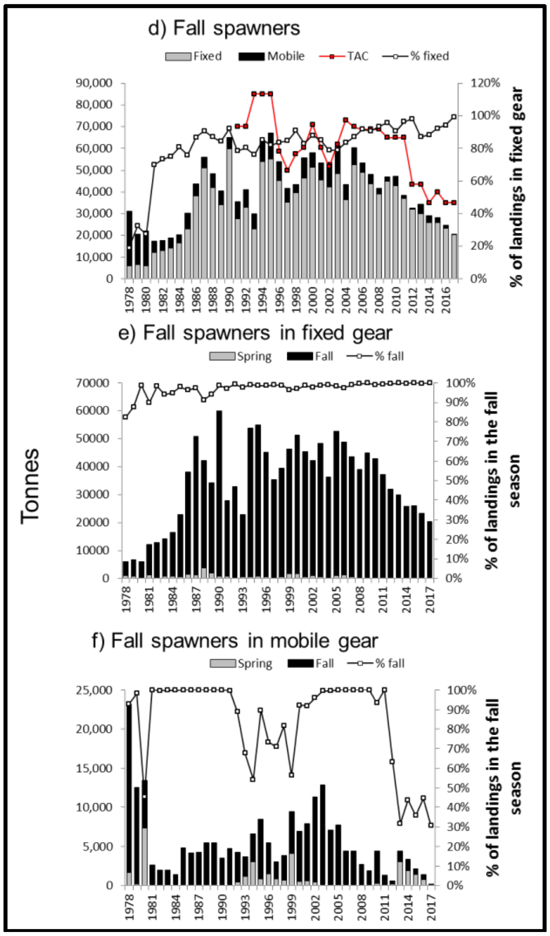

Figure 6. Estimated landings (tonnes) of the fall spawner component (FS) of Atlantic Herring from the southern Gulf of St. Lawrence, 1978 to 2017. The upper panel shows the estimated landings by gear type and the proportion of the landings attributed to the fixed gear fleet. Also shown in the upper panel is the FS herring TAC (red symbols) for 1991 to 2017. The middle panel shows the estimated landings of FS herring in the fixed gear fleet that occurred in the spring fishery season and the fall fishery season as well as the proportion of the total FS herring landed by the fixed gear fleet in the fall fishing season. The lower panel shows the estimated landings of FS herring in the mobile gear fleet that occurred in the spring fishery season and the fall fishery season as well as the proportion of the total FS herring landed by the mobile gear fleet in the fall fishing season. For landings by season, the landings from NAFO Div. 4Vn were attributed to the fall fishing season. Data for 2016 and 2017 are preliminary.

Catch-at-age and weight-at-age

Catches-at-age from the fisheries were compiled by region (North, Middle, South) and year. Catches from the fixed gear fleet were attributed to the region of capture. Catches by the mobile fleet in NAFO Div. 4T were attributed to the region which is most proximate to the location of capture. Catches made in NAFO Div. 4Vn during a winter seiner fishery (prior to 1999) were attributed to each region in proportion to the other catches from each region in the same year.

Catch-at-age and weight-at-age matrices for NAFO Div. 4T FS herring include catches made by both fixed and mobile gear fleets. These were derived using age-length keys and length-weight relationships from sampling for each principal fishing area and season.

Region-specific catches-at-age used in the model fitting for both gears combined are presented in Figure 7. The catches of younger ages (less than 6 years) have recently decreased in the fisheries consistent with the estimated changes in selectivity in the fixed gear fleet and changes in size-at-age of FS herring.

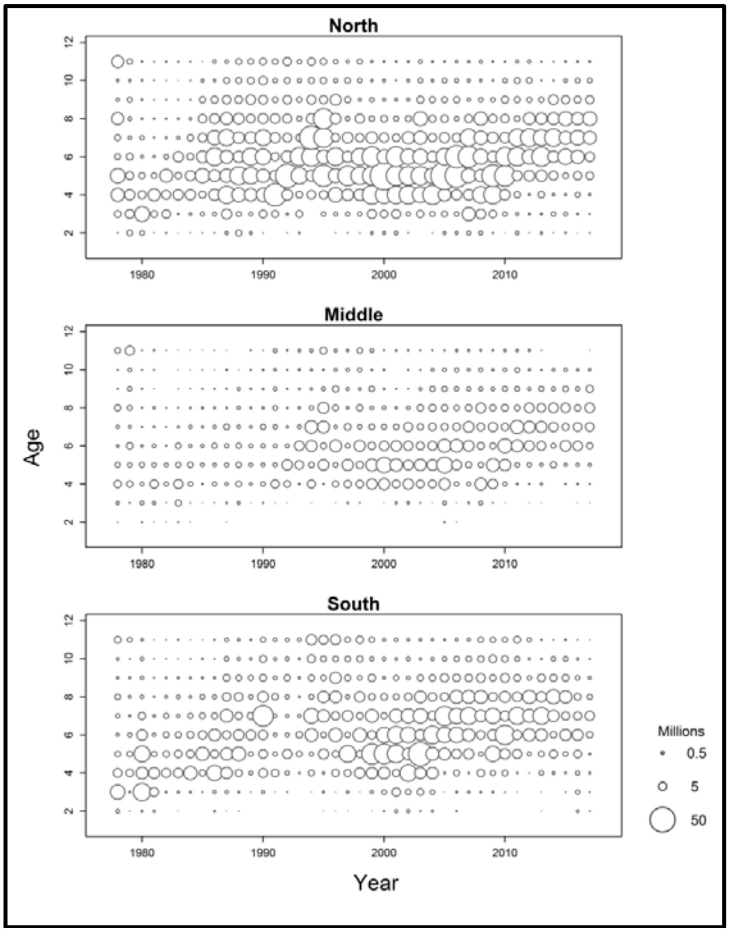

Figure 7. Bubble plots of fishery catch-at-age (number) of the fall spawner component of Atlantic Herring from the southern Gulf of St. Lawrence by region for mobile and fixed gears combined, 1978 to 2017. The size of the bubble is proportional to the number of fish in the catch by age and year. The values indicated at age 11 represent catches for ages 11 years and older.

Mean weights-at-age of FS herring from fixed and mobile gears have declined almost continuously over the period 1978 to 2011 and remain at low levels (Fig. 8). Lower mean weights have a consequence on the estimation of stock biomass when numbers are converted to weight.

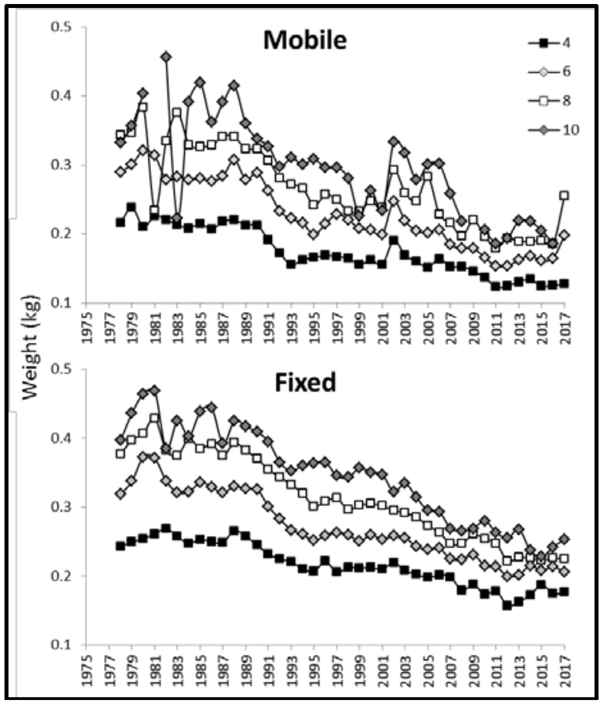

Figure 8. Mean weight (kg) for ages 4, 6, 8 and 10 years of the fall spawner component of Atlantic Herring from the southern Gulf of St. Lawrence sampled from catches in the fall season by the mobile (upper panel) and fixed (lower panel) gear fleets, 1978 to 2017.

ASSESSMENT

The SS herring and FS herring of NAFO Div. 4T are considered distinct stocks and are assessed separately. The assessments of abundance are made using Virtual Population Analysis (VPA) models based on catch-at-age, fishery dependent and fishery independent indices at age. The fishery TAC, and the analysis of catch options presented in this document, are for the spring spawner component and the fall spawner component separately and at the scale of the entire southern Gulf of St. Lawrence.

Indices of Abundance

Telephone survey

A telephone survey has been conducted annually since 1986 to collect information on the fixed gear fishery and opinions on abundance trends. The telephone survey responses include information on fishing effort, in terms of the number of nets, number of hauls, and mesh sizes used, which is used in the derivation of the commercial catch-per-unit-effort (CPUE) indices and in modelling relative fixed gear fishery selectivity in the fall spawner assessment model. The opinion of relative abundance is not used as an index in the population model. Overall, spring fishermen felt that abundances had remained consistent with the previous assessment, however for the fall fishery there was an overall sense of decreased abundance in all regions.

Fishery Independent Acoustic survey (SS and FS herring)

An annual fishery-independent acoustic survey of early fall (September-October) concentrations of herring in the sGSL has been conducted since 1991. The standard annual survey area occurs in the NAFO Div. 4Tmno areas (16B Fig. 1) where sGSL herring aggregate in the fall.

The 2015, 2016, and 2017 acoustic biomass indices for spawning groups combined were 169,635 t, 73,977 t, and 69,023 t, respectively. Based on biological samples, the biomasses in 2015 to 2017 were estimated to have been comprised of 19% SS and 81% FS herring.

Age-disaggregated acoustic indices for ages 4 to 8 are developed for the SS herring component. For the FS herring, the acoustic survey provides an abundance index of recruiting herring at ages 2 and 3 only.

Fishery Dependent Commercial Catch per Unit Effort (CPUE) (SS and FS herring)

Fixed gear catch and effort data were used to construct age-disaggregated abundance indices for SS herring and FS herring, expressed as catch per unit effort (CPUE) with values in kg/net-haul/trip. Age-specific CPUE indices for ages 4 to 10 are used in the assessments of the SS herring and FS herring stock. For the SS herring, an index is estimated for the whole stock area. For the FS herring, indices are calculated for each of the North, Middle, and South regions.

Fishery Independent Experimental Gillnet Indices (FS herring)

Catches from experimental nets are used to estimate the relative size-selectivity of gillnets of different mesh sizes and to produce age-disaggregated abundance indices, by region, as inputs to the fall spawner component assessment model.

Experimental gillnets, consisting of multiple panels of varying mesh size, were fished approximately weekly by fishermen during the fall fishing season. Each experimental gillnet had five panels of different mesh size, from a set of seven possible mesh sizes, ranging from 2” to 2¾” in ⅛” increments. All gillnets had panels with mesh sizes of 2½”, 2⅝”, and 2¾”, plus two smaller mesh sizes that varied among fishermen. The nets were set during the commercial fishery on the fishing grounds. The index is standardized to a one-hour soak time corresponding to the target fishing duration.

Fishery Independent September Bottom Trawl Survey (FS herring)

This sGSL index is used for the fall spawner population model. The annual multi-species bottom trawl survey, conducted each September since 1971, provides information on the relative abundance and distribution of NAFO Div. 4T herring throughout the sGSL. Since 1994, sampling of herring catches has been undertaken to disaggregate catches by spawner group and age. Spawning group assignment and age data were available for 1994 to 2017 for this assessment.

Spring Spawner Component (SS)

Indices of abundance

Acoustic survey

The acoustic survey provides catch rates (in numbers) of SS herring for ages 4 to 8 for 1994 to 2017 (Fig. 9). The combined index was highest in the mid-1990s and subsequently declined and remained at low levels in the 2000s.

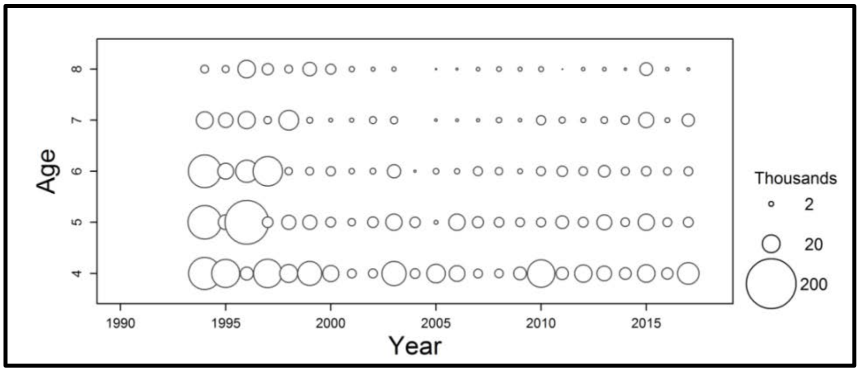

Figure 9. Bubble plot of abundance-at-age (number) from the fisheries-independent acoustic survey for herring spring spawners (SS; ages 4 to 8) in the southern Gulf of St. Lawrence, 1994 to 2017.

Commercial fixed gear catch per unit effort

The CPUE index for SS herring shows internal consistency as the abundance of cohorts is correlated between years, as shown for example for the sequence of catches of the 1988 year class (e.g., age 4 in 1992, age 5 in 1993, Fig. 10). Decreases in the CPUE of younger fish and increases in the CPUE of older fish are noted since 2011 (Fig. 10).

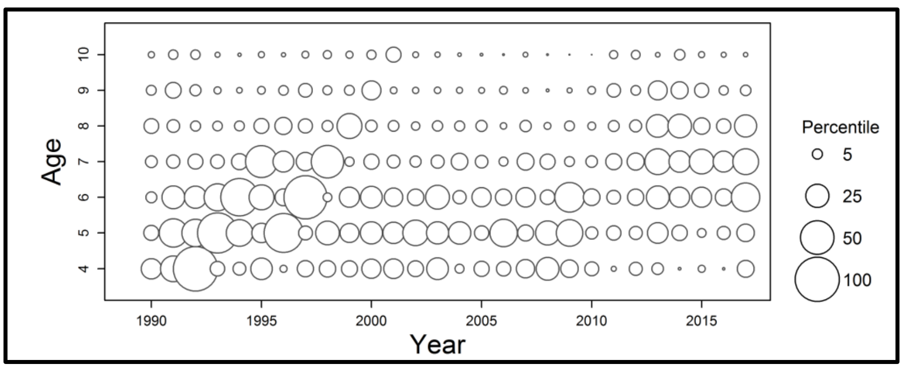

Figure 10. Bubble plot of spring spawner Atlantic Herring fixed gear catch per unit effort values (number per net-haul per trip) at age in the southern Gulf of St. Lawrence, 1990 to 2017. The size of the bubble is proportional to the maximum CPUE index value.

Population model

In the previous assessment (Swain, 2016), time-varying catchability was incorporated in the virtual population analysis (VPA) to improve the residual and retrospective patterns. Fishery dependent indices are an important component of the assessment. Indices such as the commercial gillnet CPUE, may not be proportional to abundance due to changes in catchability over time. Catchability to the fishery is defined as the proportion of the stock removed by one unit of fishing effort. If catchability doubles while abundance remains the same, CPUE will increase even though abundance did not. In the absence of correcting for changes in catchability, CPUE may bias the estimate of abundance.

The VPA model inputs include a natural mortality at all ages set at 0.2, a fishery catch-at-age 2 to 11+ (in numbers), fishery CPUE in numbers at ages 4 to 10 years from 1990 to 2017, and abundance indices at ages 4 and 8 from the fall acoustic survey (1994-2017). Catchability to the fishery, defined as the proportion of the stock removed by a unit of fishing effort, averaged about 0.006 in the 1990s, increasing to a peak of 0.032 from 2007 to 2017 (Fig. 11). Estimated catchability increased as the stock declined below 60,000 t of spawner biomass (Fig. 11).

Fishery catchability has been shown to increase as population size decreases for a number of stocks including herring (Winters and Wheeler, 1985). Reasons for this include:

- The area occupied by a stock usually decreases as stock size decreases, and because fish harvesters target fish aggregations (e.g., spawning aggregations), the proportion of the stock removed by a unit of fishing effort is expected to increase.
- In a gillnet fishery, net saturation at high abundance may also contribute to reduced catchability at high population size.

Independent of changes in SSB, catchability by fisheries may increase over time due to technological improvements and changes in fishing tactics. Other factors might result in declines in catchability, for example the changes in management measures that have occurred in the spring fishery since 2010. These measures included closures of some spawning areas and a requirement that gear be in the water by 6:00 PM and not retrieved before 4:00 AM the next day (preventing the targeting of aggregations overnight).

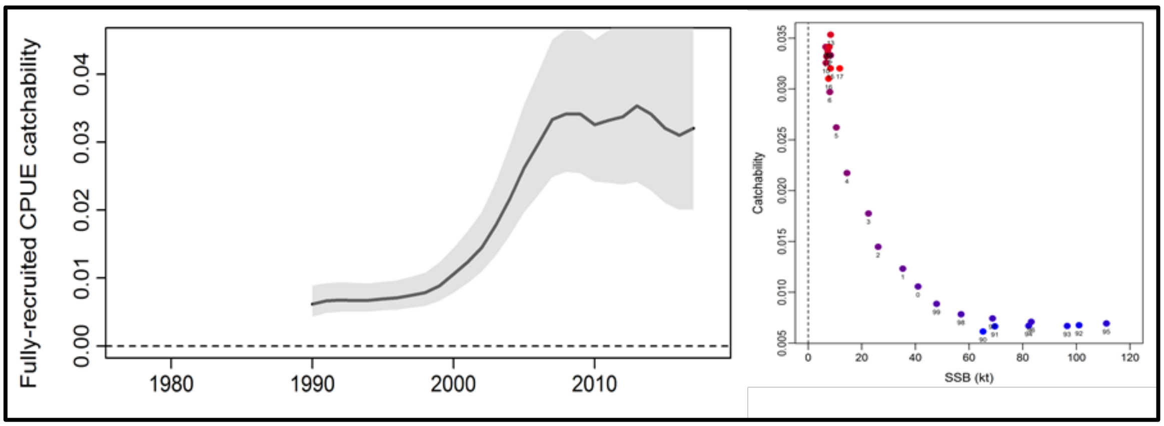

Figure 11. Estimated fully-recruited catchability to the CPUE index of the spring spawner component of Atlantic Herring (left panel) and fully-recruited catchability to the spring spawner gillnet fishery in relation to spring spawner SSB (right panel) for the southern Gulf of St. Lawrence. In the left panel, the line shows the median estimates and shading the 95% confidence intervals.

Recalculating the Limit Reference Point

The limit reference point (LRP) for NAFO Div. 4T herring is based on $B_{recover}$, the lowest biomass from which the stock has been observed to readily recover, calculated as the average of the four lowest spawning stock biomass (SSB) estimates in the early 1980s (i.e., 1980-1983). Consequently, this value is model dependent. If the model changes, stock biomass may be re-scaled upwards or downwards. With the model change initiated in 2016 (DFO 2016) and retained in this assessment, there was a revised value for the biomass in the 1980s. Thus the LRP was re-calculated. The revised LRP is 19,250 t, slightly lower than the former value of 22,000 t.

Spawning Stock Biomass and Exploitation Rate

The estimates of Spawning Stock Biomass (SSB; age 4+) at the beginning of 2017 and 2018 were 11,744 t (95% confidence interval: 6,463 – 28,171 t) and 12,446 t (95% CI: 6,418 – 30,365 t), respectively. These biomasses are higher than the SSBs in 2015 and 2016, however, the stock remains in the critical zone of the Precautionary Approach (Fig. 12). The SSB estimate for 2018 is 65% of the LRP. The probabilities that the projected SSBs were above the LRP at the start of 2017 and 2018 were <11% and 15%, respectively (Fig. 12).

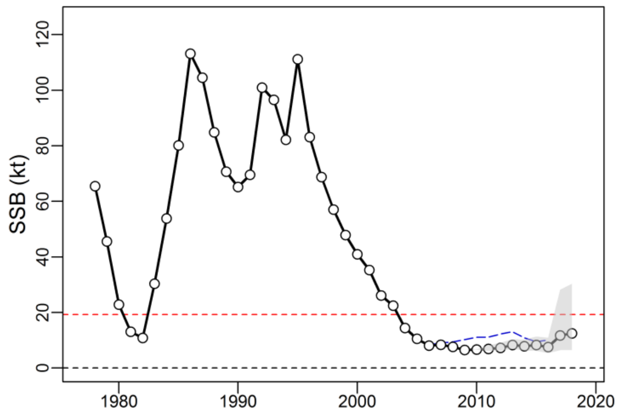

Figure 12. Estimated beginning of the year spawning stock biomass (SSB) of the spring spawner component of Atlantic Herring in the southern Gulf of St. Lawrence, 1978 to 2018. Circles show the maximum likelihood estimates, the solid line is the median of the Monte Carlo Markov Chain (MCMC) values and shading encompasses the 95% confidence interval. The red horizontal dashed line is the Limit Reference Point (19,250 t of SSB). The blue dashed line shows the SSB estimates from the 2016 assessment (DFO 2016).

Estimated fishing mortality rates were high in 1980 and in most years from 2000 to 2011 (Fig. 13), declined to a low value of 0.19 (annual exploitation rate of 0.16) and below the reference removal rate ($F_{0.1}$; F = 0.35 corresponding to exploitation rate of 0.30) in 2012, and has remained below $F_{0.1}$ in subsequent years, with the exception of 2013. Fishing mortality rates in 2015 to 2017 averaged 0.24 (annual exploitation rate of 0.21).

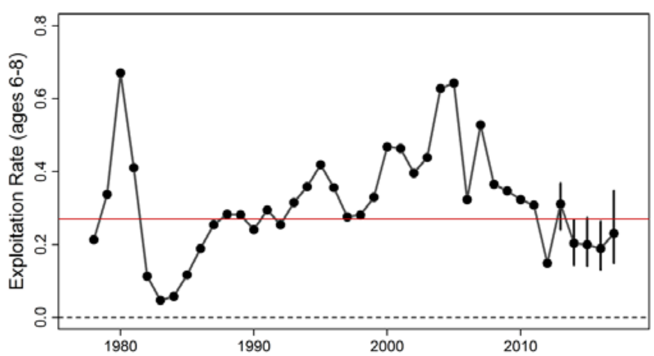

Figure 13. Estimated annual exploitation rates of spring spawning Atlantic Herring aged 6 to 8 years in the southern Gulf of St. Lawrence, 1978 to 2017. Circles are the median estimates and vertical lines their 95% confidence intervals. The red horizontal line shows the reference level annual exploitation rate (0.295 equivalent to F = 0.35) corresponding to $F_{0.1}$.

Recruitment and Recruitment Rates

Recruitment rates (the number of recruits divided by the SSB that produced them) were unusually high in the early 1980s (Fig. 14). Recruitment rates have been much lower since then, though periods of moderately high recruitment rates occurred in the late 1980s and early 1990s as well as during 2005 to 2011. Recruitment rates were lower in 2012 but appear high in 2013 though the uncertainties are very high (wide confidence intervals) for that year. Estimated abundances of age 4 herring at the start of 2017 and 2018 were higher than those since 2005 (Fig. 14). The age 4 abundance in 2018 depends on the assumption that recruitment rate for this cohort equals the average rate for the preceding five cohorts. Recruitment rates and uncertainty vary among these five cohorts resulting in very high uncertainty in age 4 abundance in 2018. If the recruitment rate of the 2013 cohort was instead low, like that of the previous cohort, age 4 abundance in 2018 would be similar to the low 2016 value.

The estimate of spring spawner (4+) abundance for 2017 is 82.9 million fish (Fig.14; median value of 80.2 million with 95% CI: 42.3 – 206.5 million), about 20% of the average spawner abundance during 1985 to 1995.

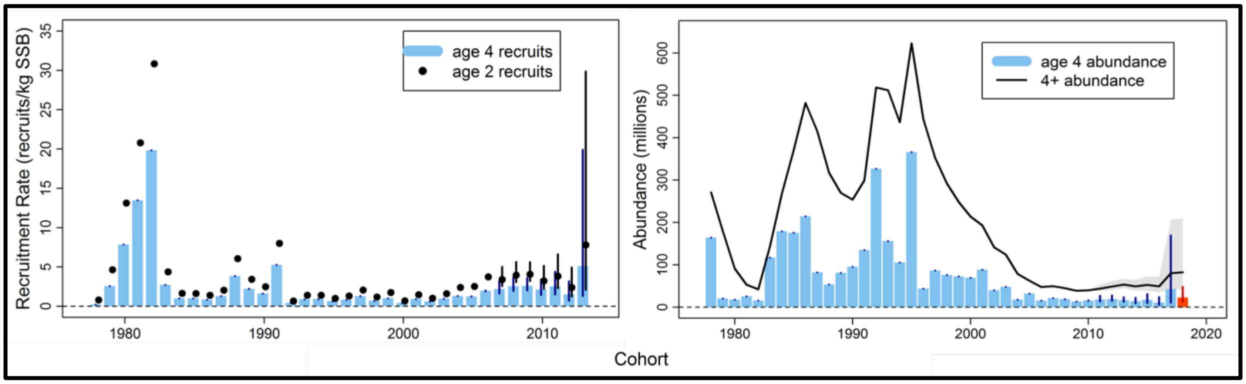

Figure 14. Recruitment rates and beginning of year abundances of the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence. The left panel shows recruitment rates at age 2 (circles) and at age 4 (bars) for the 1978 to 2013 cohorts with vertical lines indicating the 95% confidence intervals. The right panel shows the estimated beginning-of-year abundances of 4 year old herring (blue bars) and herring 4 years and older (line) for the spring spawner component of the southern Gulf of St. Lawrence. Bars and the line show the median estimate and vertical lines or shading the corresponding 95% confidence intervals. Age 4 abundance in 2018 (the red bar) was estimated assuming the recruitment rate for this cohort was the average of the rates of the preceding five cohorts.

Projections

The population model was projected forward for two years to the start of 2020 and 10 years to the start of 2027. These projections incorporated uncertainty in the estimates of abundance at age at the beginning of 2018, in the weights-at-age, partial recruitments to the fishery, and recruitment rates (to estimate ages 2 to 4). Projections were conducted at seven levels of annual catch (0 to 3,000 t in increments of 500 t) with the same catch level for the 2018 and 2019 fishing seasons. Projection results depend strongly on recruitment rates. Due to variable recruitment in recent years, projections were conducted for three recruitment scenarios during the projection period: (1) high recruitment rate scenario (2007 to 2012 cohorts), (2) low recruitment rate scenario (1999 to 2005 cohorts), and (3) mixed recruitment rate scenario (1999 to 2012 cohorts).

SSB was projected to increase slightly at annual catches of 0 and 500 t, remain roughly stable at a catch of 1,000 t, and decline at catches of 1,500 t or more (Fig. 15). However, uncertainty was high. The probability of an increase in SSB between the beginning of 2018 and the beginning of 2020 decreased from 80% at 0 t of catch to 49% at 1,000 t of catch and 11% at 2,500 t of catch under the high recruitment scenario. At the mixed and low recruitment scenarios, the probability of the SSB increasing in the absence of fishery removals (0 t) was 58% and 39%, respectively (Fig. 15; Table 1).

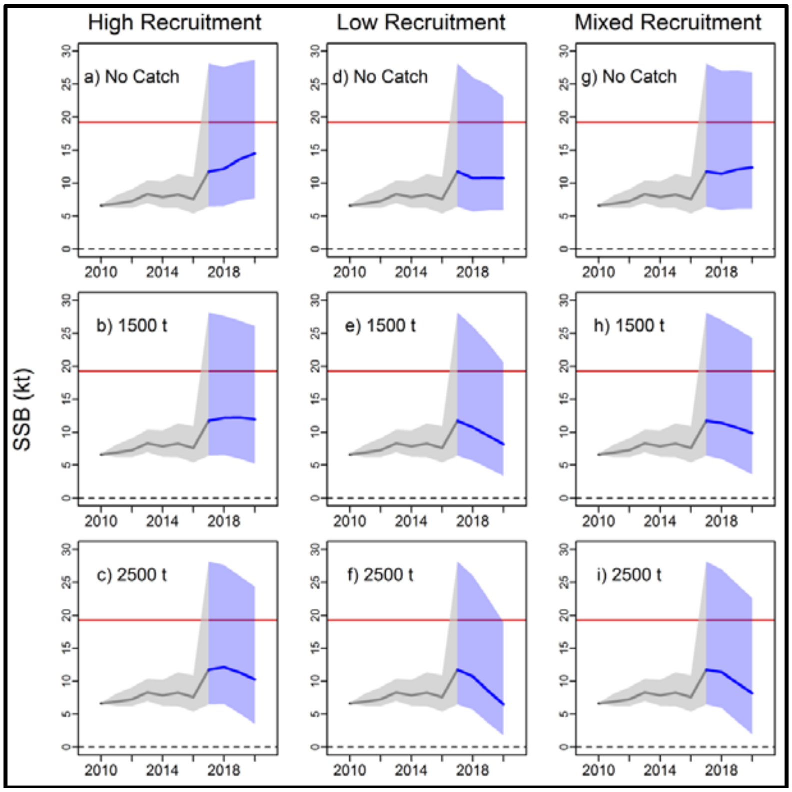

Figure 15. Projected spawning stock biomass (SSB in kt) of spring spawning Atlantic Herring from the southern Gulf of St. Lawrence for three recruitment scenarios (columns) and at various catch levels (rows) in 2018 and 2019. Lines show the median estimates of the beginning-of-year SSB and shading the 95% confidence intervals of these estimates (based on MCMC sampling). Grey shading indicates the historical period and blue shading indicates the projection period. The red horizontal line in each panel is the limit reference point (LRP) value of 19,200 t.

Risk analysis of catch options

All catch levels in 2018 and 2019 (including no catch) and recruitment rate scenarios indicate little probability that SSB would exceed the LRP at the start of 2020 (for high recruitment 20% at 0 t of catch, 8% at 2,500 t of catch; at low recruitment 6% at 0 t of catch, 2% at 2,500 t of catch) (Table 1). By 2027, the probability of exceeding the LRP was most favorable (>= 50%) under the high recruitment scenarios and low catches (<1,500 t), however at the low recruitment scenarios even with no catch there was only a 13% probability of SSB exceeding the LRP (Table 1).

There is no chance that the population would be at or above the Upper Stock Reference (USR) in 2020 even with no catch regardless of the recruitment rate scenario. At the high recruitment rate scenario, there is an 11% probability of SSB exceeding the USR by 2027 with no catch whereas at the low recruitment rate there is 0% chance (Table 1).

For the low recruitment rate scenario, the probability that age 6 to 8 fully recruited *F* in 2019 would be greater than the removal rate reference level of $F_{0.1}$ (0.35) was essentially zero at 1,000 t or less of catch, increasing to 9% at 1,500 t of catch, and rising to 57% at 2,500 t of catch.

Since 2009, the TAC has been set to 2,000 t annually. At a catch of 2,000 t, the probability of an increase in SSB after 2019 ranges from 0% (low recruitment rate) to a high of 19% (high recruitment rate) depending on the recruitment rate scenario. At 2,000 t of annual catch, there is at most a 10% chance of exceeding the LRP and the probability of SSB exceeding the LRP by 2027 ranges from 2% (low recruitment) to 38% (high recruitment). Furthermore at 2,000 t there is at best a 4% chance of reaching the USR by 2027 (Table 1).

Table 1. Risk analysis table of probabilities (%) of increases in SSB, of SSB being greater than the LRP (i.e., the SSB not in the critical zone), of SSB being greater than the USR (i.e., the SSB in the healthy zone), and of fully-recruited fishing mortality rate ($F_{6\text{-}8}$) being above $F_{0.1}$ for differing fixed catch options in 2018, 2019, and 2027 for the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence according to three recruitment rate scenarios. The recruitment rate scenarios are: A) High recruitment rate scenario (2007-2012 cohorts), B) low recruitment rate scenario (1999-2005 cohorts), and C) mixed recruitment rate scenario (1999-2012 cohorts). nd means not considered.

			Catch option (t)						
Scenario	State of stock	Year	0	500	1,000	1,500	2,000	2,500	3,000
A	SSB increasing	2018	91%	80%	63%	44%	28%	16%	nd
		2019	80%	66%	49%	32%	19%	11%	nd
	SSB > LRP	2019	16%	15%	13%	12%	11%	10%	nd
		2020	20%	17%	14%	11%	10%	8%	nd
		2027	87%	76%	63%	50%	38%	29%	21%
	SSB > USR	2019	0%	0%	0%	0%	0%	0%	nd
		2020	0%	0%	0%	0%	0%	0%	nd
		2027	11%	9%	6%	5%	4%	3%	2%
	$F_{6\text{-}8} > 0.35$	2018	0%	0%	0%	4%	22%	48%	71%
		2019	0%	0%	0%	3%	18%	39%	60%
		2027	0%	0%	1%	10%	30%	51%	69%
B	SSB increasing	2018	53%	25%	8%	1%	0%	0%	nd
		2019	39%	18%	5%	1%	0%	0%	nd
	SSB > LRP	2019	7%	6%	6%	5%	5%	5%	nd
		2020	6%	5%	4%	3%	3%	2%	nd
		2027	13%	7%	4%	3%	2%	1%	1%
	SSB > USR	2019	0%	0%	0%	0%	0%	0%	nd
		2020	0%	0%	0%	0%	0%	0%	nd
		2027	0%	0%	0%	0%	0%	0%	0%
	$F_{6\text{-}8} > 0.35$	2018	0%	0%	0%	6%	31%	58%	78%
		2019	0%	0%	0%	9%	33%	57%	74%
		2027	0%	0%	29%	73%	91%	96%	98%
C	SSB increasing	2018	68%	52%	37%	23%	13%	7%	nd
		2019	58%	43%	28%	17%	10%	5%	nd
	SSB > LRP	2019	11%	10%	9%	8%	7%	7%	nd
		2020	12%	10%	8%	7%	6%	5%	nd
		2027	54%	40%	28%	19%	12%	9%	6%
	SSB > USR	2019	0%	0%	0%	0%	0%	0%	nd
		2020	0%	0%	0%	0%	0%	0%	nd
		2027	2%	1%	1%	1%	1%	0%	0%
	$F_{6\text{-}8} > 0.35$	2018	0%	0%	0%	5%	26%	53%	75%
		2019	0%	0%	0%	6%	26%	49%	68%
		2027	0%	0%	7%	35%	62%	79%	90%

Fall Spawner Component (FS)

The FS herring assessment considers three regions (North, Middle, South) which cover the entire NAFO Div. 4T area as three independent populations. The regions are defined on the basis of traditional herring spawning beds and fishing areas: North (Gaspe and Miscou; 4Tmnopq), Middle (Escuminac-Richibucto and west Prince Edward Island; 4Tkl) and South (east Prince Edward Island and Pictou; 4Tfghj) (Fig. 16). The choice of three regions was dictated by geographic proximity of spawning beds and is the finest level of disaggregation that can presently be supported by the available data.

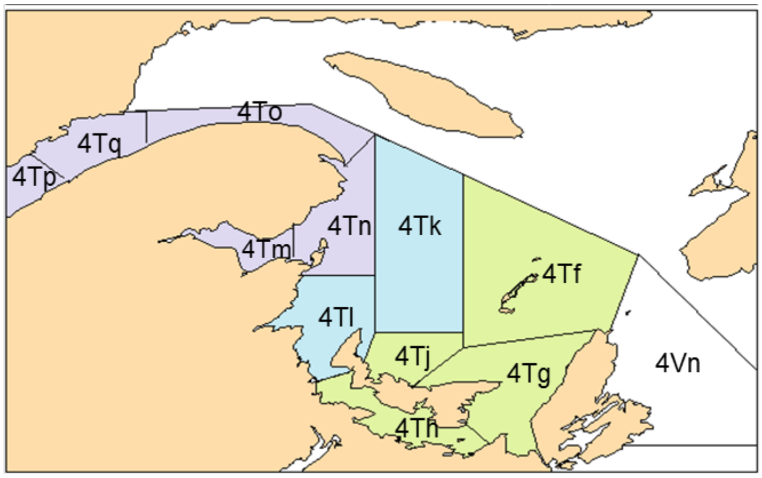

Figure 16. Correspondence between the herring fishing areas and the three regional groups (by colour shading) used in the assessment of the fall spawner component of Atlantic herring from the southern Gulf of St. Lawrence. Fishing areas in each region are described in the text above.

Indices of abundance

Acoustic survey

For the FS assessment model, the acoustic survey provides a useful abundance index of recruiting herring (ages 2 and 3) for the entire NAFO Div. 4T stock unit (LeBlanc et al. 2015). It is not considered a useful abundance index for older ages given that the survey is limited to a restricted portion of the sGSL at a time when older herring are distributed and spawning in areas throughout the sGSL. The index of three year olds was relatively high in 2015, with relatively smaller abundances for both age classes in 2016 and 2017 (Fig. 17).

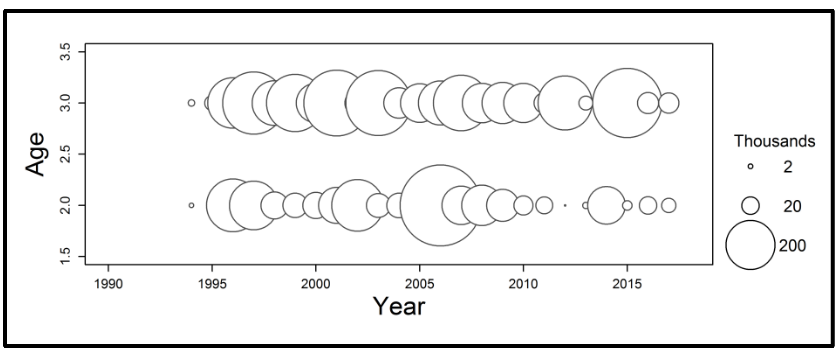

Figure 17. Bubble plot of the index of abundance (number of fish) of fall spawning herring at age 2 and 3, from the fisheries-independent acoustic survey for fall spawners, 1994 to 2017.

Commercial fixed gear catch per unit effort

Decreases in the CPUE of younger fish and increases in the CPUE of older fish were noted for the FS herring (Fig. 18). In the North region, CPUE indices for ages 6 to 8 in 2016 and 2017 were lower than in previous recent years. CPUE values in the Middle region were higher in 2016 than in the previous recent years but declined in 2017. CPUE values in the South region were higher in 2017 than in 2016 but both years were lower than most of the previous years.

In the North and Middle regions, catches of FS in 2016 were dominated by age 6 and 7 and in 2017 by ages 7 and 8 (2009 and 2010 year-classes). In the South region, catches of FS in 2016 and 2017 were dominated by age 7 and 8 respectively (2009 year-class).

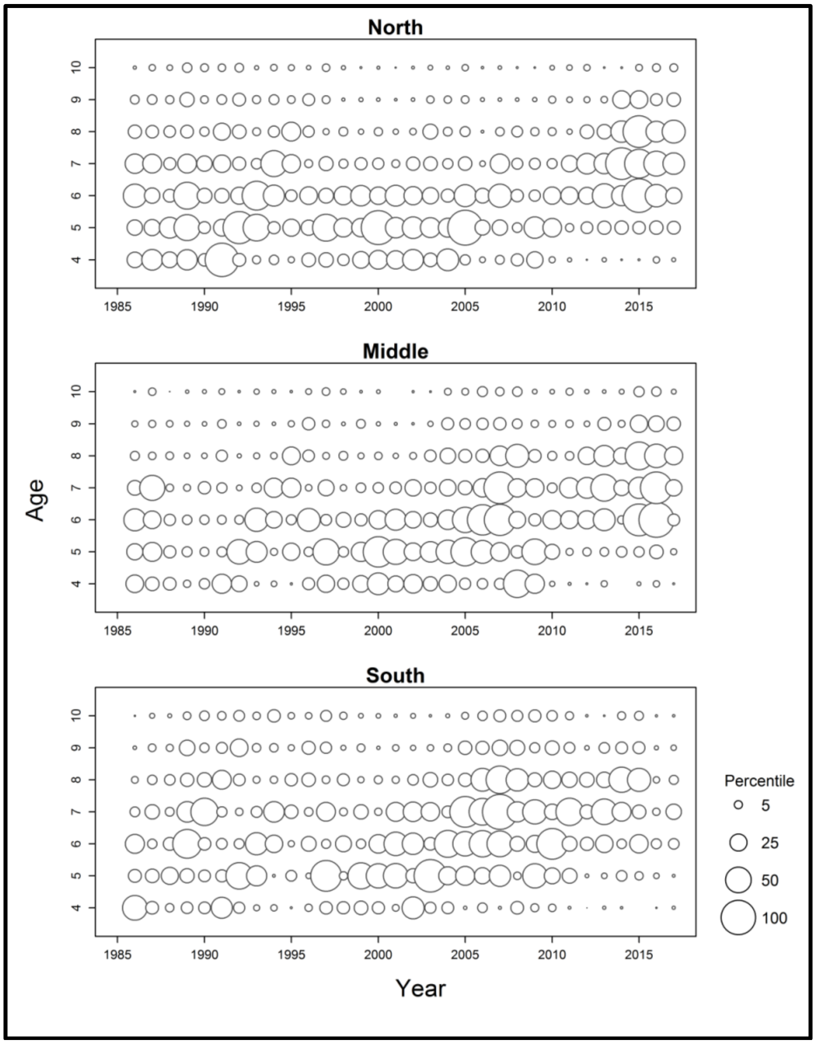

Figure 18. Fall spawner (FS) herring fixed gear age-disaggregated catch per unit effort values (number per net-haul per trip) by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 1986 to 2017. The size of the bubble is proportional to the CPUE index value.

Experimental gillnet indices

The experimental gillnet indices suggest an increase in young herring (ages 2 to 4) until 2009, after which the numbers declined, with proportional catches of herring 5 to 9 generally increasing from 2010 to 2017, in all regions (Fig. 19).

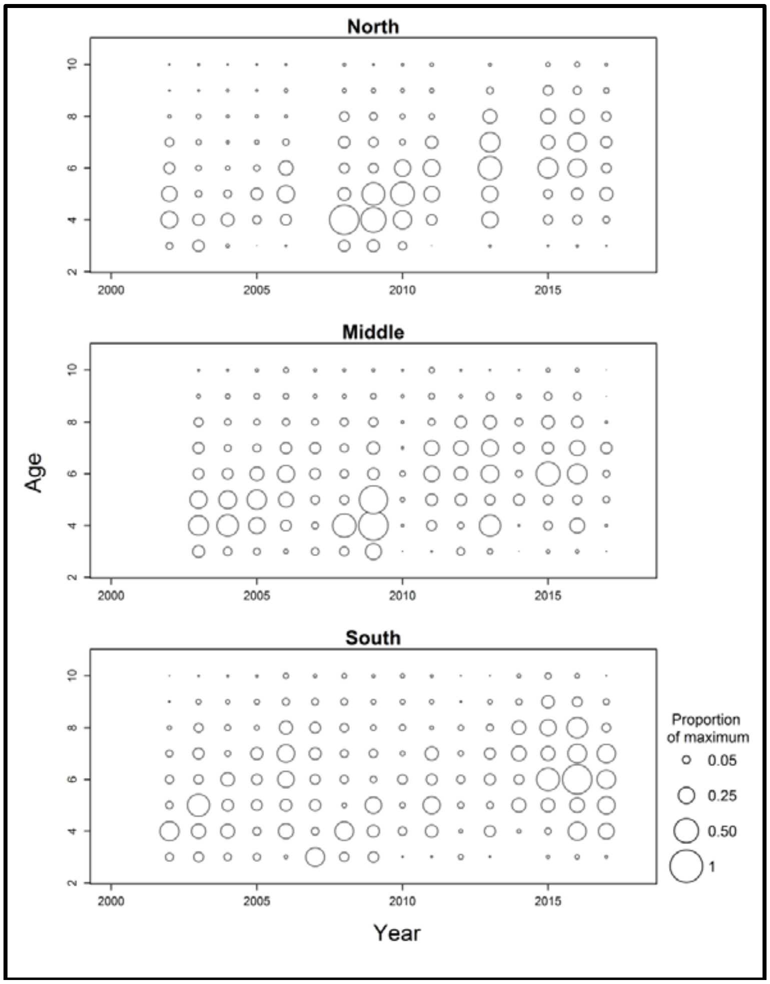

Figure 19. Bubble plots of catch-at-age indices (number) of fall spawner herring from the experimental gillnets by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 2002 to 2017. The size of the bubble is proportional to the index value.

Fishery Independent September Bottom Trawl Survey

The index suggests an increasing trend in four year old FS herring from the mid-1990s to 2011, and generally higher abundance of six year old FS herring in the 2000s compared to the 1990s (Fig. 20).

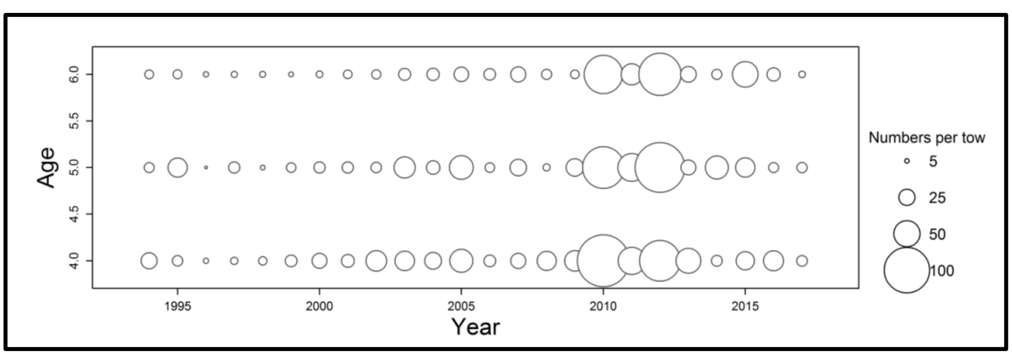

Figure 20. Multispecies bottom trawl survey abundance index (number of fish per standardized tow) for fall spawning herring ages 4 to 6 years in the southern Gulf of St. Lawrence, 1994 to 2017.

Population model

A virtual population analysis (VPA) as described in DFO (2015) was conducted for three regions and then combined to estimate the overall FS herring abundance in NAFO Div. 4T. Natural mortality at all ages and in all regions was set at 0.2. Data inputs were fishery catches at ages 2 to 11+ (in numbers), fishery CPUE in numbers at ages 4 to 10 years from 1986 to 2017, catch rates at age in experimental nets (ages 3 to 9 or 10, 2002 or 2003 to 2017, with indices missing in some years in some regions), abundance indices at ages 2 and 3 from the fall acoustic survey (1994 to 2017), and catch rates at ages 4 to 6 in the September bottom trawl survey. Separate fishery catch-at-age, CPUE indices from the gillnet fishery, and indices from the experimental nets were derived for each of the three regions. The acoustic and bottom trawl survey indices were considered abundance indices for the sum of the three regions.

Additional inputs included the proportion of gillnets with 2 $^{5}/_{8}$ inch mesh in each region in each year (Fig. 21) and relative selectivity to the gillnet fishery by age, year, and mesh size (Fig. 22). As a result of the changes in size at age over time, the relative selectivities in the two main gillnet mesh sizes used in the fixed gear fishery have also changed over time, generally declining over the time series for ages 4 to 6 and declining since the late 1990s for ages 8 and 10 in the 2 ¾ inch mesh gear (Fig. 22).

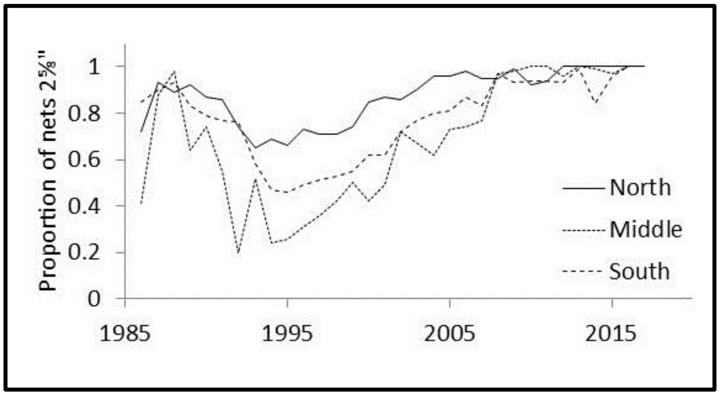

Figure 21. Variations by region in the proportions of gillnets with mesh sizes 2 $^{5}/_{8}$ inches used in the fall herring fishery season in the southern Gulf of St. Lawrence, 1986 to 2017. It is assumed that all other nets used were of mesh size 2 ¾.

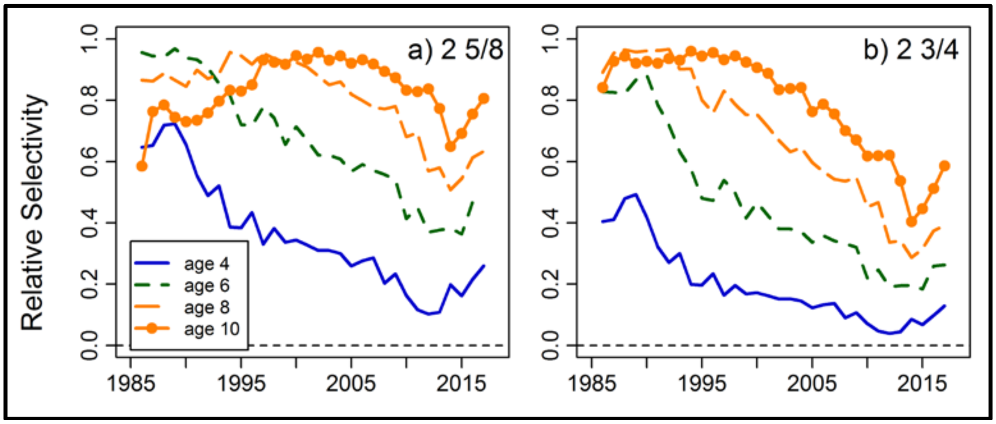

Figure 22. Changes in relative selectivity of fall spawning herring aged 4, 6, 8 and 10 years to gillnets with mesh sizes of 2 $^{5}/_{8}$ inches (left panel) or 2 ¾ inches (right panel) in the fall herring fishery of the southern Gulf of St. Lawrence, 1986 to 2017.

Similar to the results for 2016 (DFO 2016), the model diagnostics indicated an adequate fit to the observations. There was no severe blocking of residuals for the commercial CPUE indices. Fits to the CPUE indices were reasonably good, with predicted values consistent with the general trends in the indices. Retrospective patterns were present but negligible for the Middle region and greatest for the North region, though not in a consistent direction.

Estimated changes in catchability (*q*) to the gillnet fishery differed between regions (Fig. 23). Catchability was lowest and varied little over time in the North region. Catchability in the South region increased over time, primarily between 1995 and 2010 but has decreased recently. Estimated catchability was greatest in the Middle region except for a brief period in the mid-2000s.

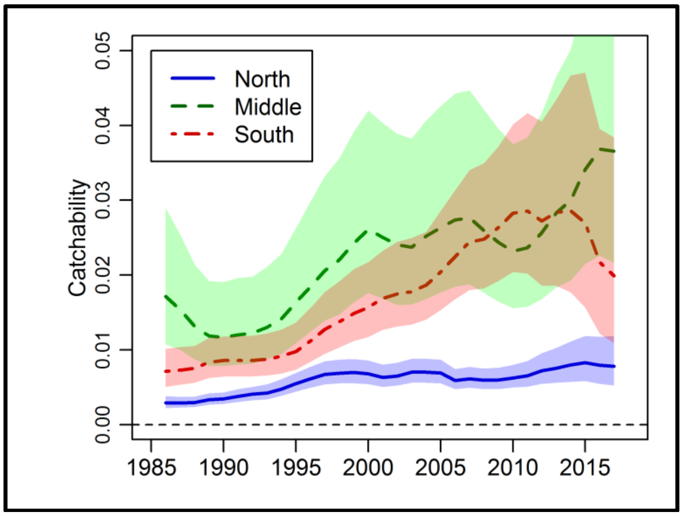

Figure 23. Estimated fully-recruited catchability (q) of fall spawner herring to the fall gillnet fishery in three regions (North, Middle and South) of the southern Gulf of St. Lawrence, 1986 to 2017.

Catchability to fisheries is expected to change over time for a number of reasons including a common inverse relationship between catchability and population size, and improvements in fishing technology and tactics. Variation in *q* within the Middle and South regions was independent of variations in stock biomass suggesting that much of the increase in *q* in these two regions is related to technological improvements and changes in fishing tactics.

Recalculating the Limit Reference Point

The limit reference point (LRP) in 4T herring is $B_{recover}$, the lowest biomass from which the stock has been observed to readily recover, and it is calculated as the average of the four lowest spawning stock biomass (SSB) estimates during the early 1980s (i.e., 1980-1983). Consequently, this value is model dependent. If the model changes, stock biomass may be re-scaled upwards or downwards. With the model change initiated in 2015 (DFO 2015) and retained in this assessment, there was a revised value for the biomass in the 1980s. Thus the LRP was re-calculated and the revised LRP is 58,000 t, slightly greater than the former value of 51,000 t.

Spawning Stock Biomass and Exploitation Rate

Estimated SSB in the North region was at a high level from the mid-1980s to the early 1990s and declined to a moderate level from the mid-1990s to the late 2000s (Fig. 24). Estimated SSB in this region declined continuously during 2012 to 2018, with the median estimate reaching low levels not observed since the early-1980s. In the Middle region, estimated SSB increased gradually from 1980 to the late 2000s, but declined by about 60% during 2009 to 2018. SSB in the South region was at a relatively high level from about the mid-1980s to the late 2000s, however, estimated SSB declined during 2009 to 2015. In 2016, SSB began to increase in the South region, however, the estimate has very high uncertainty in this region. Summed over the three regions, the median estimate of total SSB at the start of 2018 is 112,000 t. The estimated probabilities that total SSB was below the USR of 172,000 t at the beginning of 2017 and 2018 are 98% and 97%, respectively.

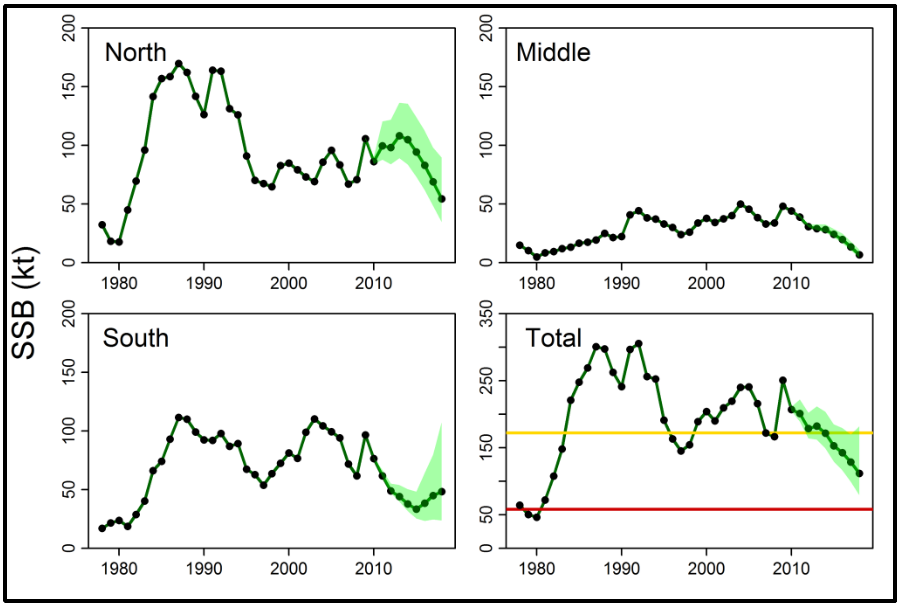

Figure 24. Estimated spawning stock biomass (SSB) of fall spawning herring by region and overall (Total) for the southern Gulf of St. Lawrence, at the beginning of the year 1978 to 2018. The line and circles show the median estimates and the shading their 95% confidence intervals. In the bottom right panel for Total, the yellow horizontal line is the upper stock reference level (USR) and the lower red horizontal line is the limit reference point (LRP).

Estimated fishing mortality rates (*F*; ages 5 to 10) declined to a relatively low level in the North (0.22 in 2017) region but in the Middle and South regions they remained relatively high and consistent until 2017 (Fig. 25). In the Middle region, *F* increased sharply to 0.95 in 2017, whereas in the South region it decreased to 0.10 in 2017 (Fig. 25). The average fishing mortality rate on ages 5 to 10 over all three regions (weighted by region-specific abundances of 5 to 10 year olds) exceeded $F_{0.1}$ (F = 0.32; the reference level in the healthy zone) during 1994 to 2011, except in 2004, but declined after 2011 to attain its lowest levels in 2016 (F = 0.18; Fig. 25). The probability that the overall *F* for ages 5 to 10 exceeded the $F_{0.1}$ value in 2017 was 20%.

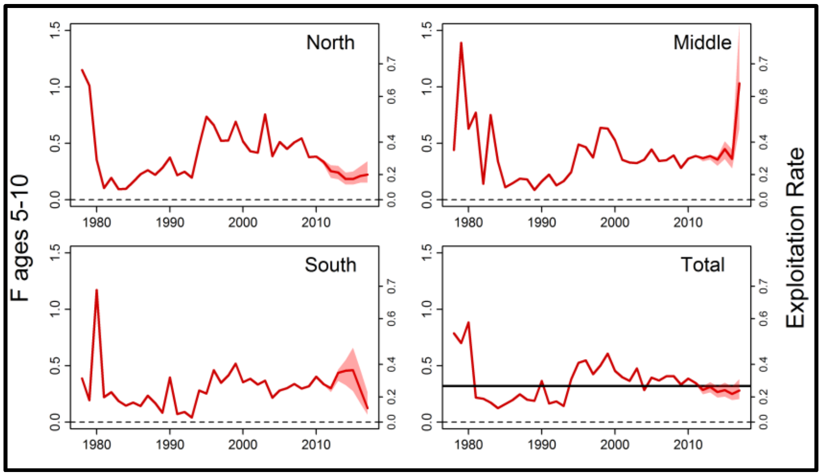

Figure 25. Estimated age 5 to 10 fishing mortality rates (instantaneous rate F in left axes and as annual exploitation rate in right axes) of fall spawning herring by region and averaged over regions (weighted by region-specific abundance at ages 5 to 10 years) in the southern Gulf of St Lawrence, 1978 to 2017. Lines show the median estimates and shading their 95% confidence intervals. The horizontal line in the bottom right panel (Total) shows the reference removal rate level of $F_{0.1}$ (F = 0.32, an exploitation rate of 27% annually) applicable in the healthy zone.

Recruitment and Recruitment Rates

The three most recent estimates of recruitment rate (2012 to 2014 cohorts; recruit abundance divided by the SSB producing them) were among the lowest observed in the North and Middle regions. The estimates for these three cohorts were average in the South region, though the estimates were extremely uncertain (Fig. 26). Summed over all three regions, total recruitment rates for the 2012 to 2014 cohorts were among the lowest observed.

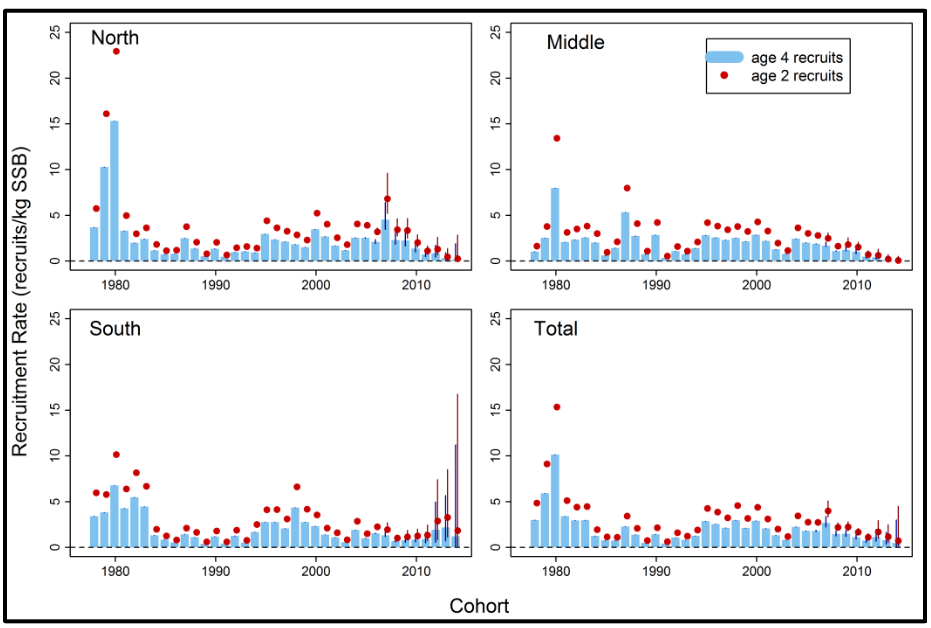

Figure 26. Estimated recruitment rates to age 2 (circles) and age 4 (bars) for fall spawning herring by region and summed (Total) over regions in the southern Gulf of St. Lawrence, for the 1978 to 2014 cohorts. Vertical lines are the 95% confidence intervals.

Estimated abundances of FS age 4 and older have declined in the North and Middle regions since 2013 and 2009, respectively (Fig. 27). In the South region, the abundances declined during 2004 to 2015 but increased recently, however, the estimates have very high uncertainty in this region since 2015 (Fig. 27).To a large extent, this reflects reductions in the recruitment of 4-year-old herring. In all three regions, estimated abundances of age 4 herring for the last three years (2016 to 2018) are among the lowest observed and comparable to the low levels estimated for the late 1970s.

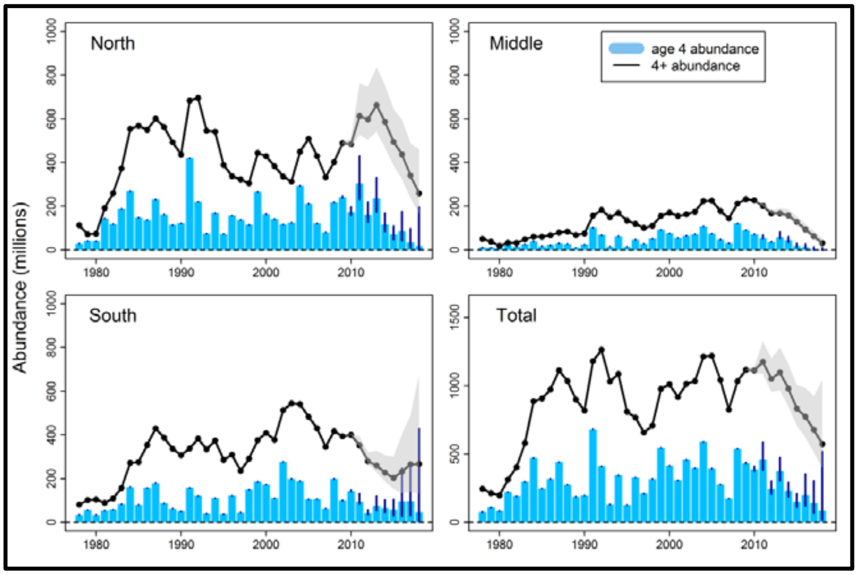

Figure 27. Estimated abundances of fall spawning herring at ages 4 and for ages 4+ by region and for the entire (Total) southern Gulf of St. Lawrence at the beginning of the year, 1978 to 2018. Line and circles (age 4+) and bars (age 4) show the median estimates and shading or vertical lines show the 95% confidence intervals.

Projections

The fishery TAC for the fall spawner component is set at the level of the entire NAFO Div. 4T stock unit. The three region-specific models were projected forward to the start of 2020. Uncertainties incorporated in projections included estimates of abundance at age at the beginning of 2018, weights-at-age, partial recruitment to the fishery, and recruitment rates (to estimate age 2 abundance). Summed over all three regions, the median estimate of SSB at the start of 2020 was projected to be below the USR at all catch levels between 10,000 and 50,000 t (Fig. 28).

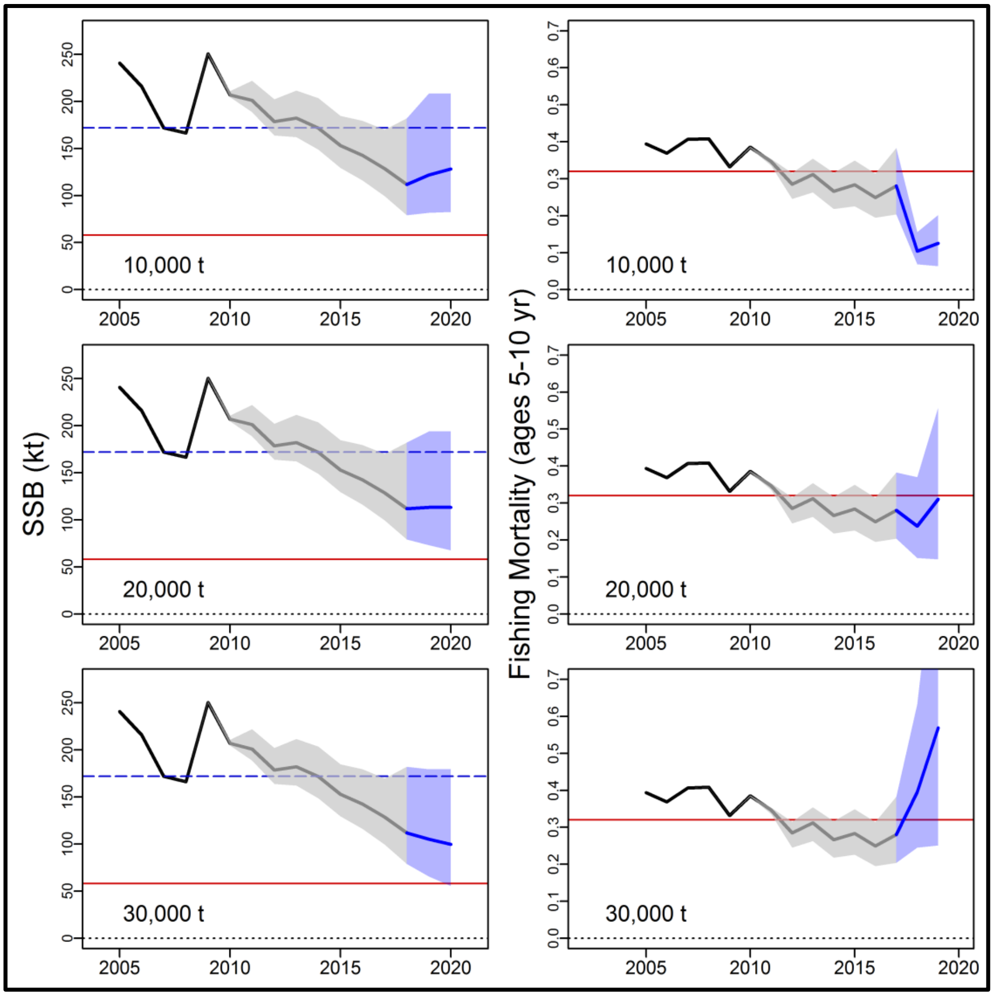

Figure 28. Spawning stock biomass (SSB in kt; left panels) and ages 5 to 10 fishing mortality rates (F; right panels) of fall spawner Atlantic herring from the southern Gulf of St. Lawrence for three catch levels in 2018 and in 2019. In all panels, lines show the median estimates and shading the 95% confidence intervals of these estimates (based on MCMC sampling). Black lines and grey shading indicate the historical period whereas blue lines and shading show the projection period, respectively. In the left panels, the blue dashed line is the upper stock reference (USR) and the red horizontal line is the limit reference point (LRP). In the right panels, the red horizontal line is the removal rate reference level ($F_{0.1}$; F = 0.32).

Risk analysis of catch options

The probability that SSB would be below the USR at the start of 2020 increases from 90% at 10,000 t of catch to 99% at 50,000 t of catch. At a catch of 20,000 t (the catch in 2017) in 2018 and 2019, this probability would be 94% (Fig. 29). At catch levels from 10,000 to 20,000 t in 2018 and 2019, the median value of weighted average *F* for ages 5 to 10 over all regions in 2019 was less than 0.32, i.e. the probability that F would exceed $F_{0.1}$ < 50%.

The probability that SSB would be below the LRP in 2020 ranged from 0% at 10,000 t to 17% at 50,000 t. A 5% increase in SSB by 2020 would only be likely at catches below 16,000 t whereas a decrease in SSB is probable at catches of 24,000 t and above.

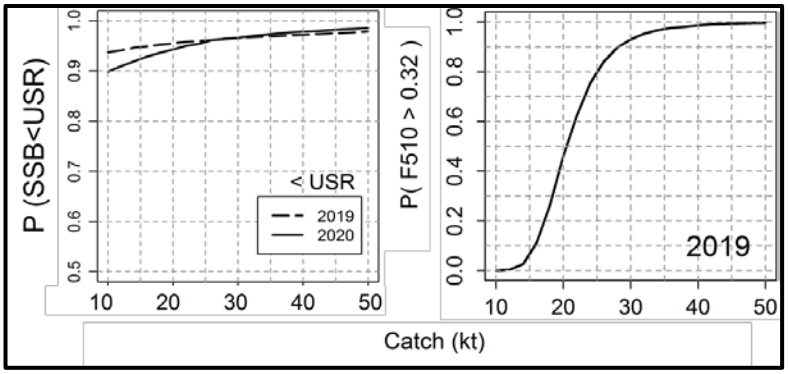

Figure 29. Risk analysis of annual fixed catch options for 2018 and 2019 for the FS herring component of the southern Gulf of St. Lawrence. The left panel shows probabilities that total SSB at the start of 2019 and 2020 will be below the USR. The right panel shows probability profile of average F for ages 5 to 10 in 2019 being greater than the reference level F = 0.32 ($F_{0.1}$).

Sources of Uncertainty

Fishery dependent indices, such as the commercial gillnet CPUE indices, may not be proportional to abundance due to changes in catchability over time. On one hand, catch rates can remain elevated despite decreases in abundance (increased catchability) due to contractions in stock distribution and targeting of aggregations by fishing fleets, as well as due to improved fishing technology and fishing practices. On the other hand, catch rates can be negatively affected by boat limits, saturation of nets at high abundance, and closure of prime fishing areas that redirect fishing effort to other locations. Catch rates calculated on the basis of realized landings and available fishing effort information would be subject to such effects. The estimation of time-varying catchabilities in the SS and FS assessments accounts for some of the effects listed above.

The commercial CPUE calculations are subject to uncertainty. The estimates are based on regional average seasonal values of fishing effort data (number of nets, number of hauls, and net length of gillnets) from the telephone survey rather than trip specific information. Trips with no catch were not documented prior to 2006 and therefore are not incorporated in the effort data. No information is collected on the soak time of nets. There are also potential inconsistencies in the reporting of effort data within and among regions and seasons.

The new modelling approach considers the dynamics of fall spawning herring in three regions. The dynamics are modelled independently among regions and assume closed populations after recruitment at age 2. This is a strong assumption that can have consequences on region-specific estimates of abundance and dynamics. Empirical evidence for spawning bed fidelity has been documented in fall spawning herring based on tagging studies. Nevertheless, elemental analyses of otolith structures did not detect region-specific differences among fall spawners despite showing distinct differences between spring spawners and fall spawners in the sGSL. Genetic research has been unable to identify population-level differences between regions for fall spawners.

The weight-at-age of herring has declined and remains at near record low levels. The causes of these declines in weight-at-age and the consequences to recruitment rate are unknown.

Catches of herring in bait fisheries are presently not accounted for in the assessments of either spring or fall spawner components. Catches in these fisheries are meant to be recorded in harvester logbooks but compliance with the requirement to complete and return logbooks is low. Catches of herring in the bait fishery are expected to be much lower than landings in the commercial fishery, nonetheless this unaccounted fishing mortality constitutes a source of uncertainty in the total fishing mortality.

Uncertainty in recruitment rate in both the SS and FS leads to uncertainty in projections as these are heavily reliant on the recruitment rate selected. In this assessment, three recruitment scenarios were used for the SS assessment to account for variation in recruitment rates among years. In the FS assessment, an intermediate recruitment rate value was used as it appears that the most recent estimates of recruitment rate were biased low and would result in overly pessimistic projections.

The model assumes that natural mortality was constant over time. Retrospective patterns from previous assessments indicated a change in dynamics over time which could be associated with changes in catchability of the commercial cpue index (q) or natural mortality (M). A model that incorporated time varying change in q rather than M resolved the non-stationarity problem. This does not mean that M did not change but the current data and information used in the model only resolve one or the other. Future research should also consider whether M has changed in this ecosystem and what information could be used to incorporate this dynamic in the population model.

In the previous assessment, the fall spawner abundances were declining with the estimate at the end of 2015 just below the USR. In this assessment, the median of the 2014 and 2015 estimates are below the USR. The declining trend in status has continued into 2018. Given this decline in absolute level of abundance from the previous assessment, it is possible that the current biomass values from the model are overestimated. This overestimation of the biomass will result in an underestimate of the risk of failing to achieve defined management objectives for different catch options for 2018 and 2019 although the extent of the bias is not known.

CONCLUSIONS AND ADVICE

Spring Spawner Component (SS)

The spring spawner component trajectory with respect to spawning stock biomass and fishing mortality levels is shown in Figure 30. The stock has been in the critical zone (SSB < LRP = 19,250 t) since 2004 with fishing mortalities above the $F_{0.1}$ level until 2010. Since 2010 F has decreased and remained at levels below $F_{0.1}$.

SSB at the start of 2019 and 2020 was projected to increase slightly at annual catches less than 500 t, remain roughly stable at annual catches of 1,000 t, but decline at catches of 1,500 t or more. However, uncertainty in projected SSB is high. Even in the absence of any removals of SS herring in 2018 and 2019, the SSB is expected to only increase slightly with a very high probability (90%) that the stock will remain in the critical zone.

Fishing mortality on the SS herring in recent years was estimated at 0.24, low relative to the history of the fishery but still high for a stock in the critical zone. Elevated fishing mortality and declines in weight-at-age are also exacerbating the reductions in SSB.

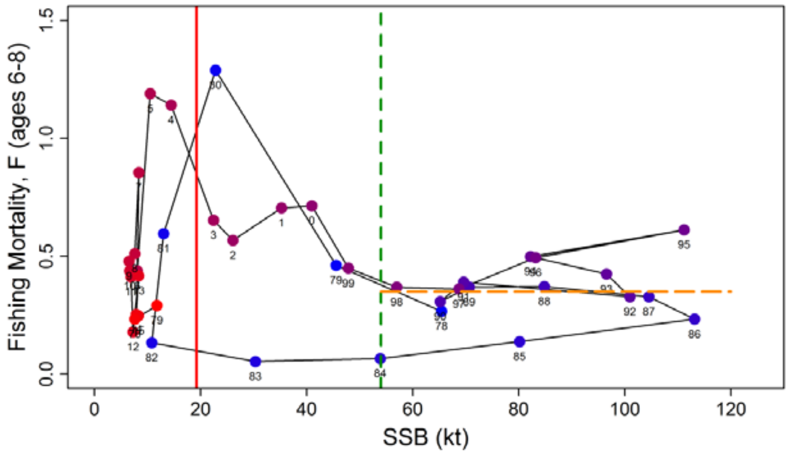

Figure 30. The southern Gulf of St. Lawrence Atlantic Herring spring spawner component trajectory in relation to spawning stock biomass (SSB, kt = thousand t) and fishing mortality rates for ages 6 to 8 years. The solid red vertical line is the LRP (19,250 t), the green dashed vertical line is the Upper Stock Reference (USR = 54,000 t), and the dashed horizontal line is the removal rate reference value ($F_{0.1}$ = 0.35). Point labels are years (83 = 1983, 0 = 2000). Colour coding is from blue in the 1970s and early 1980s to red in the 2000s.

Fall Spawner Component (FS)

The fall spawner component trajectory with respect to spawning stock biomass and fishing mortality levels is shown in Figure 31. The median estimate of the SSB has generally been in the healthy zone (SSB > 172,000 t) over its history with few exceptions but the median estimate of SSB has been in the cautious zone since 2015. Fishing mortality rates generally exceeded the removal rate reference from the mid-1990s to 2011 but were below the reference level from the early 1980s to the mid-1990s and since 2011.

The median SSB estimate at the start of 2019 and 2020 was projected to remain in the cautions zone (below the USR) even at catch levels of 10,000 t. At a catch of 20,000 t (the catch in 2017) in 2018 and 2019, the probability of the SSB being in the cautious zone in 2020 was estimated at 94%, and the probability of the fishing mortality rate being above the removal rate reference was estimated at 46%.

Fishing mortality on the FS herring averaged 0.20 since 2012, just over half of the $F_{0.1}$ removal reference level.

Declining abundance at age 4 in recent years, resulting from declining recruitment rates, has contributed to the decline in SSB for this stock. The causes of the low recruitment rates for the FS herring component are unknown. Declines in weight-at-age are also exacerbating the reductions in SSB. Fishing mortality rates in excess of $F_{0.1}$ from the mid 1990’s to 2010 have also contributed to reductions in SSB.

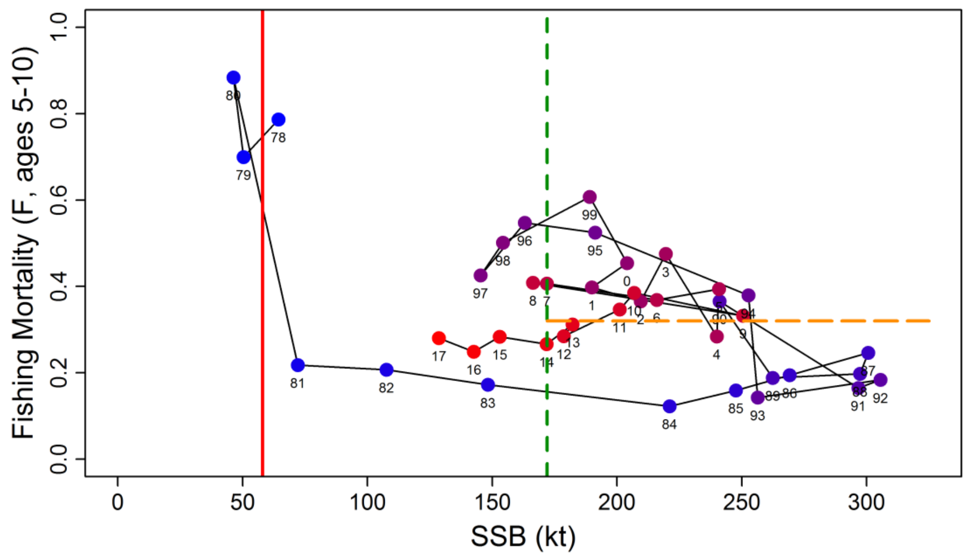

Figure 31. The southern Gulf of St. Lawrence Atlantic Herring fall spawner component trajectory in relation to spawning stock biomass (SSB, kt = thousand t) and fishing mortality reference levels. The solid red vertical line is the LRP (58,000 t), the green dashed vertical line is the Upper Stock Reference (USR = 172,000 t), and the dashed horizontal line is the removal rate reference value ($F_{0.1}$ = 0.32). Point labels are years (83 = 1983, 0 = 2000). Colour coding is from blue in the 1970s and early 1980s to red in the 2000s.

SOURCES OF INFORMATION

This Science Advisory Report is from the March 15, 2018 regional science peer review meeting on the Assessment of stock status of Atlantic herring (*Clupea harengus*) from the southern Gulf of St. Lawrence (NAFO Div. 4T-4Vn) to 2017 and advice for the 2018 and 2019 fisheries. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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