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Canadian Science Advisory Secretariat
Gulf Region **Science Advisory Report 2016/036**

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 2016 AND 2017 FISHERIES

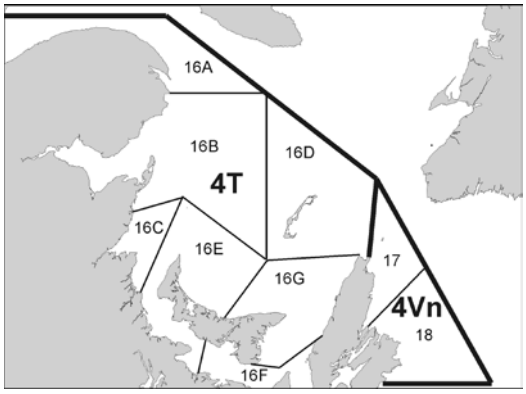

Figure 1. NAFO Divisions 4T and 4Vn and the corresponding herring fishery management zones.

Context:

The stock area for southern Gulf of St. Lawrence 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 solely the spring spawner component in the spring, except for June, and almost solely 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 2015, there were 3,054 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 and 16, 2016 in Moncton, N.B. to assess the status of the spring and fall spawner components of 4T herring and to provide advice for the 2016 and 2017 fisheries. Participants at the meeting included DFO Science (Gulf, Newfoundland and Labrador regions), DFO Fisheries Management (Gulf Region), 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 assessed separately.

Spring Spawner Component (SS)

- The preliminary estimated landings of SS herring in 2014 and 2015 were 1,251 t and 1,190 t, respectively, from annual total allowable catch values of 2,000 t.
- A revised virtual population analysis model that incorporated changes in catchability in the fixed gear fishery was used in this assessment. The model provides a better fit to observations and no longer has a severe retrospective pattern.
- Catchability to the fixed gear increased to the mid-2000s and declined to an intermediate value since 2010.
- The estimates of Spawning Stock Biomass (SSB) at the beginning of 2015 and 2016 were 9,076 t (95% confidence interval: 5,686 – 14,282) and 9,659 t (95% CI: 5,530 – 16,294), 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 start of 2015 and 2016 were almost 100%.
- Estimated fishing mortality (F) declined below the reference level (F = 0.35) in 2010, reaching a low value of 0.08 in 2012. The fishing mortality rate in 2013-2015 of herring aged 6-8 years old averaged 0.18 (exploitation rate of 0.16).
- SSB at the start of 2017 and 2018 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 2016 and 2017, the SSB is expected to only increase slightly with a very high probability (90%) that the stock will remain in the critical zone.
- Poor recruitment, resulting from low recruitment rates, is constraining the rebuilding of the stock out of the critical zone. Declines in weight-at-age are also exacerbating the low levels of SSB.

Fall Spawner Component (FS)

- The preliminary estimated landings of the FS herring component in 2014 and 2015 were 29,214 t and 28,138 t respectively, from a total allowable catch of 35,000 t in 2014 and 40,000 t in 2015.
- 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 South region.
- For the southern Gulf of St. Lawrence, the median estimate of SSB at the start of 2016 is 165,000 t. The probabilities that the SSB was below the Upper Stock Reference level of 172,000 t at the beginning of 2015 and 2016 were 22% and 60%, respectively.

- The average fishing mortality rate on ages 5 to 10 for the FS has declined to an average of 0.19 since 2012 (an exploitation rate of 17%). The probability that the fishing mortality rate for ages 5-10 in 2015 exceeded $F = 0.32$ (the reference removal rate in the healthy zone; exploitation rate of 27%) is essentially 0.
- Poor recruitments at age 4 in the last three years, resulting from low recruitment rates, have contributed to the decline in SSB.
- The median of the SSB estimate at the start of 2017 and 2018 was projected to be close to the USR at annual catch levels in 2016 and 2017 less than 10,000 t but the probability of the stock declining into the cautious zone at the start of 2018 was greater than 50% at catch options above 10,000 t. At catches of 28,000 t (the catch in 2015) in 2016 and 2017, the probability of the SSB being in the cautious zone was estimated at 76.5%.
- At the 28,000 t catch level, the probability of the fishing mortality rate being above the removal rate reference was estimated at 42%.

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 2015, total landings of Atlantic Herring from NAFO Div. 4T and 4Vn peaked at 93,471 t in 1995 and dropped to 29,328 t in 2015 (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 2014 and 2015 were 37,000 t and 42,000 t, respectively.

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 2014 and 2015 of 87% and 91%, 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 91% and 93% of the total herring harvested in 2014 and 2015, respectively.

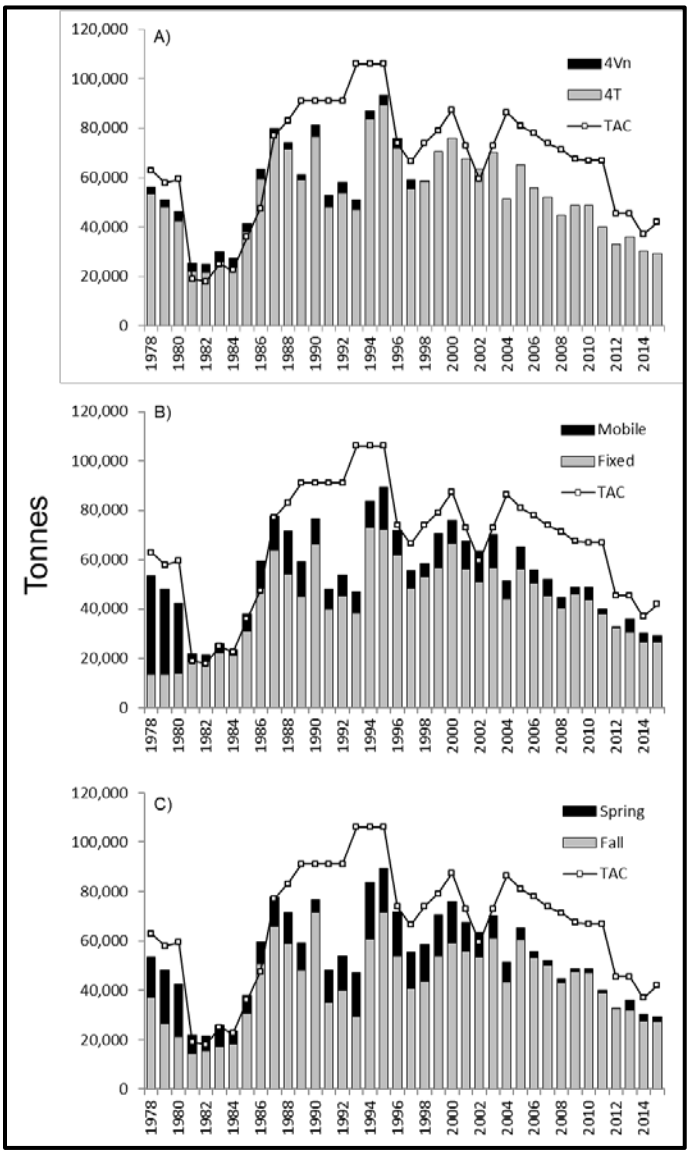

Figure 2. Reported landings (tonnes) of southern Gulf of St. Lawrence Atlantic herring (spring and fall spawners combined) by NAFO division (upper panel), by gear fleet (middle panel), and by fishing season (lower panel), 1978 to 2015. In all panels, the corresponding annual total allowable catch (TAC; tonnes) is shown. For landings by season, the landings in Div. 4Vn were attributed to the fall fishing season. Data for 2015 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 2014 and 2015 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 2014 and 2015 were 1,251 t and 1,190 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 2015 period. In 2014 and 2015, the fixed gear fleet was estimated to have landed 61% and 49%, 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).

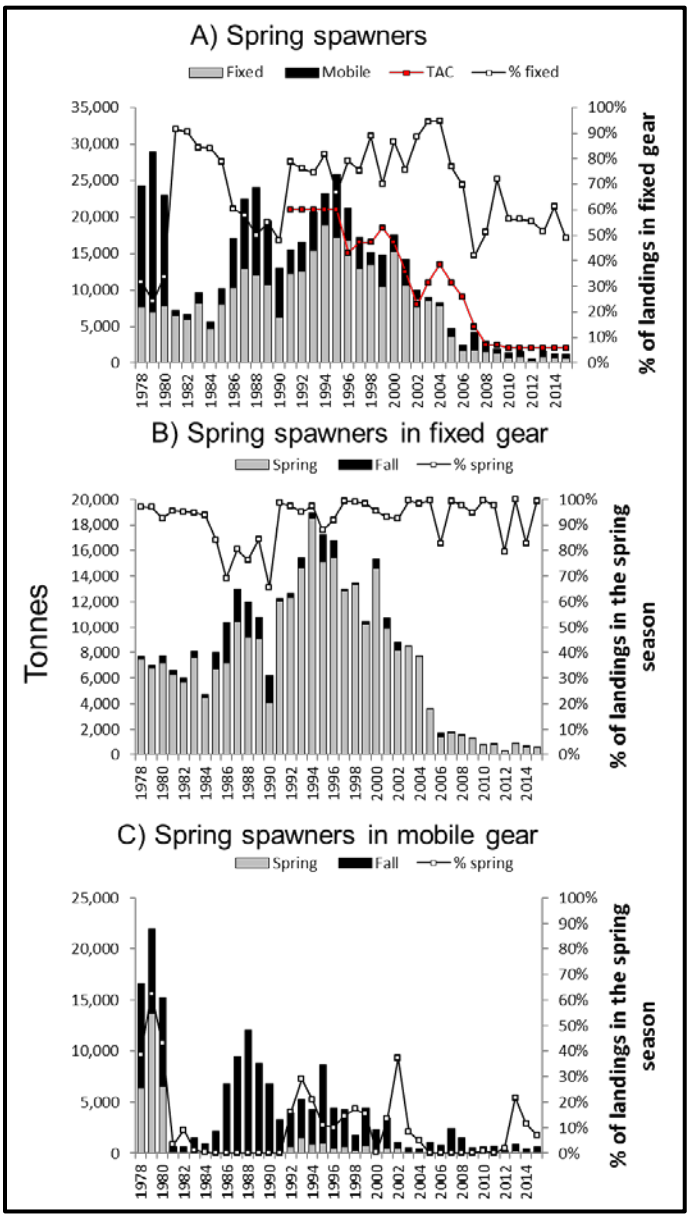

Figure 3. Estimated landings (tonnes) of the spring spawner component (SS) of Atlantic herring from the southern Gulf of St. Lawrence, 1978 to 2015. The upper panel shows the estimated landings by gear type and the proportion of the landings attributed to the fixed gear fleet. Also shown in the upper panel is the SS herring TAC (red symbols) for 1991 to 2015. 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 Div. 4Vn were attributed to the fall fishing season. Data for 2015 are preliminary.

Catch-at-age

The dominant age in the 2014 SS catch was age 6 and in 2015 it was age 7, corresponding to the 2008 year-class in both years (Fig. 4).

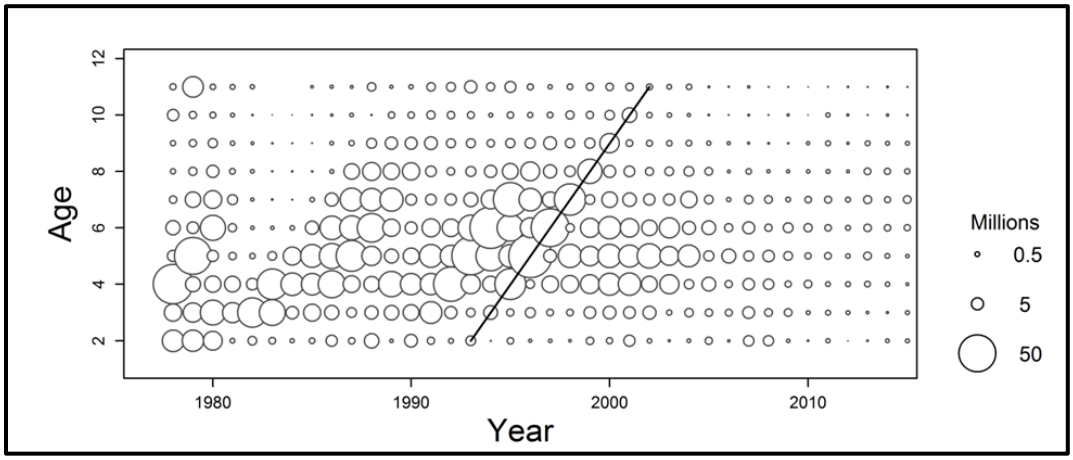

Figure 4. Catch-at-age of the spring spawner component from the fishery, all gears combined, 1978 to 2015. Size of the bubble is proportional to the catch numbers by age and year. The diagonal line tracks the most recent strong year-class (1991).

Weight-at-age

Mean weight-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).

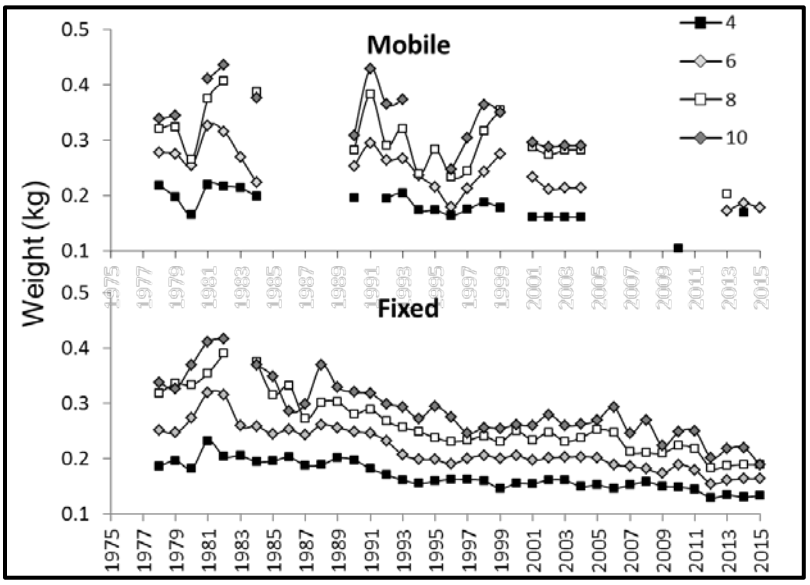

Figure 5. Mean weight-at-age for ages 4, 6, 8 and 10 years of spring spawner herring from the southern Gulf of St. Lawrence sampled from catches during the spring season in the mobile (upper panel) and fixed (lower panel) commercial gears, 1978 to 2015.

Fall spawner component (FS)

The fishery TAC for the fall spawner component is set for the NAFO Div. 4T stock unit. The 2014 TAC was 35,000 t while in 2015, the TAC was 40,000 t. The preliminary estimated landings of FS herring in 2014 and 2015 were 29,214 t and 28,138 t respectively (Fig. 6). With

few exceptions, over the 1978 to 2015 period, most of the FS herring were estimated to have been landed in the fixed gear fleet. In 2014 and 2015, the fixed gear fleet was estimated to have landed 89% and 92%, 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, 32% to 44% during 2013 to 2015 (Fig. 6).

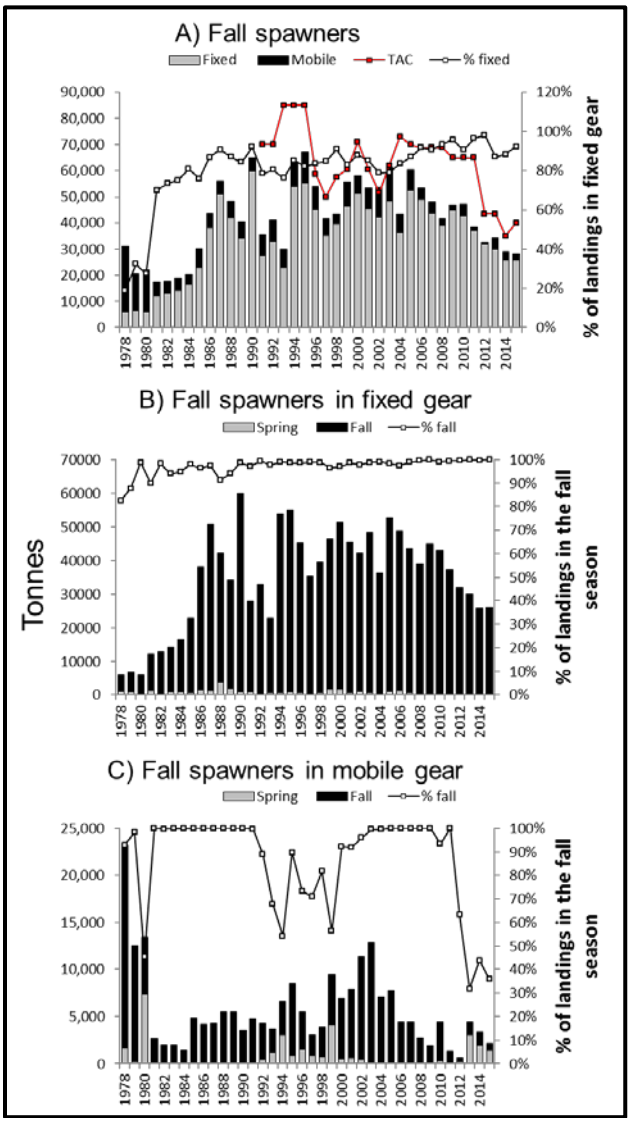

Figure 6. Estimated landings (tonnes) of the fall spawner component (FS) of Atlantic herring from the southern Gulf of St. Lawrence, 1978 to 2015. The upper panel shows the estimated landings by gear type and the proportion of the landings attributed to the fixed gear fleet. Also shown in the upper panel is the FS herring TAC (red symbols) for 1991 to 2015. 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 Div. 4Vn were attributed to the fall fishing season. Data for 2015 are preliminary.

Catch-at-age

Catch-at-age from the fishery was 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 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 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. For FS, the dominant age was 8 in both 2014 and 2015, thus 2006 and 2007 year-classes. 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.

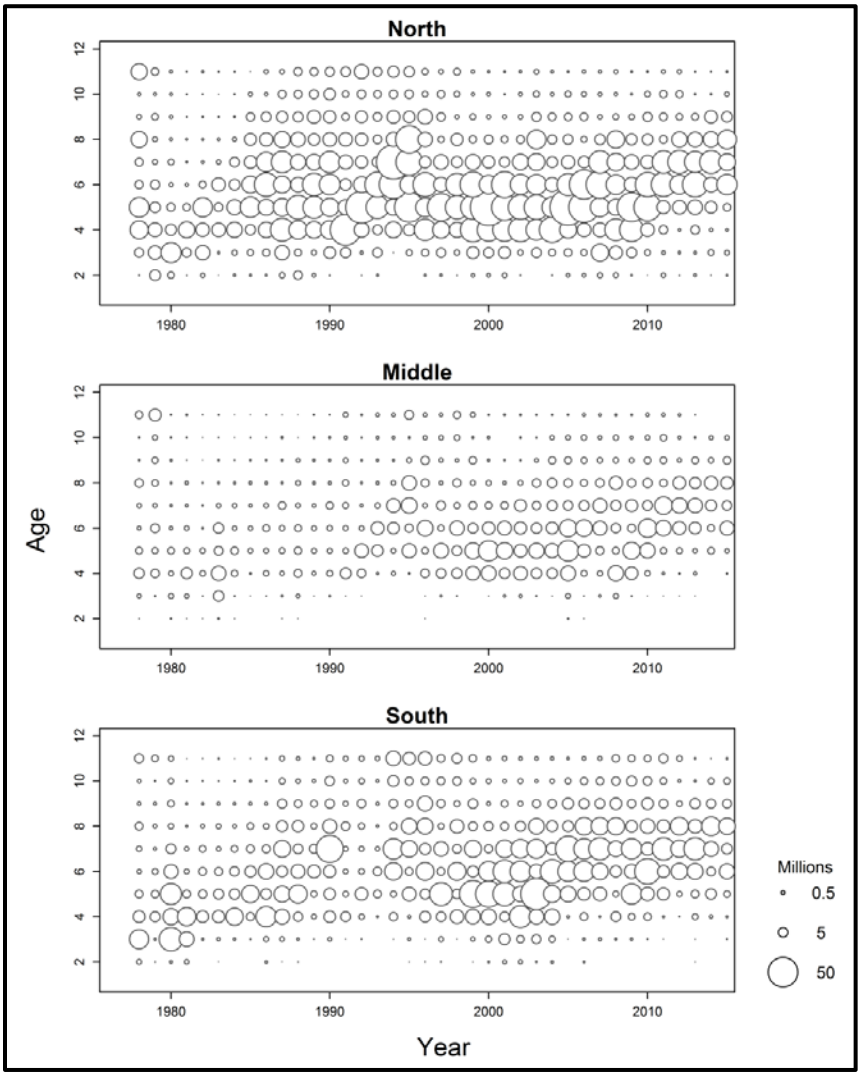

Figure 7. Bubble plots of fishery catch-at-age (number) by region for both mobile and fixed gear combined, 1978 to 2015. The size of the bubble is proportional to the number of fish in the catch by age and year. The values indicated at age 11 represent catches for ages 11 years and older.

Weight-at-age

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

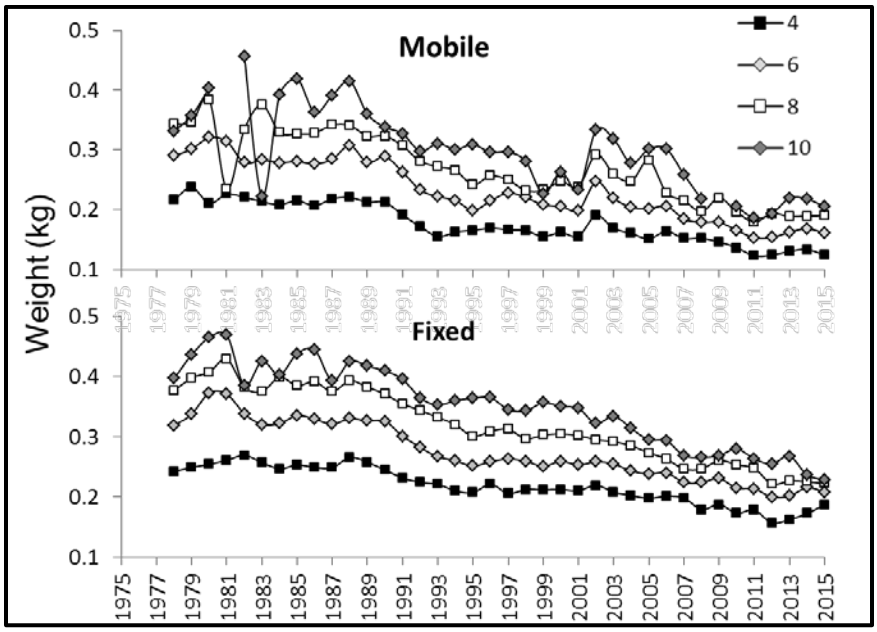

Figure 8. Mean weights-at-age for ages 4, 6, 8 and 10 years of fall spawner herring from the southern Gulf of St. Lawrence sampled from catches in the fall season by the mobile (upper panel) and fixed (lower panel) gear fleets, 1978 to 2015.

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 therefore the TAC advice presented in this document, is for the spring spawner component and the fall spawner component separately and at the scale of the entire southern Gulf of St. Lawrence for both spawner components.

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, fishermen felt that abundances in the 2015 spring fishery were lower than in 2014, whereas for the fall fishery there was an overall sense of increased abundance in the North and Middle regions and a decrease in the South region.

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 Div. 4Tmno areas (see Fig. 16) where sGSL herring aggregate in the fall.

The 2014 acoustic biomass index for spawning groups combined was 67,378 t. The biomass index estimate for 2015 was not available at the time of this report. Based on biological samples, the biomass in 2014 was estimated to have been comprised of 14% SS and 86% 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 a useful 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 abundance and distribution of 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 2011 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 2014 (Fig. 9). The combined index was highest in the mid-1990s and subsequently declined and remained at low levels in the 2000s.

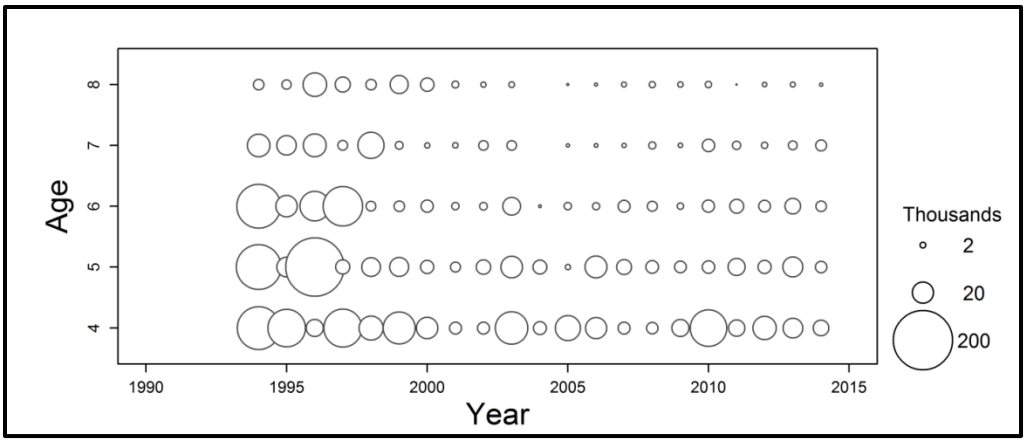

Figure 9. Bubble plot of abundance-at-age (number) from the fisheries-independent acoustic survey for herring spring spawners (SS; ages 4 to 8) in the southern Gulf of St. Lawrence, 1994 to 2014. The data for 2015 were not available at the time of the assessment.

Commercial fixed gear catch per unit of 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 (age 4 in 1992, age 5 in 1993, etc; Fig. 10). Decreases in the CPUE of younger fish and increases in the CPUE of older fish are noted since 2011 (Fig. 10).

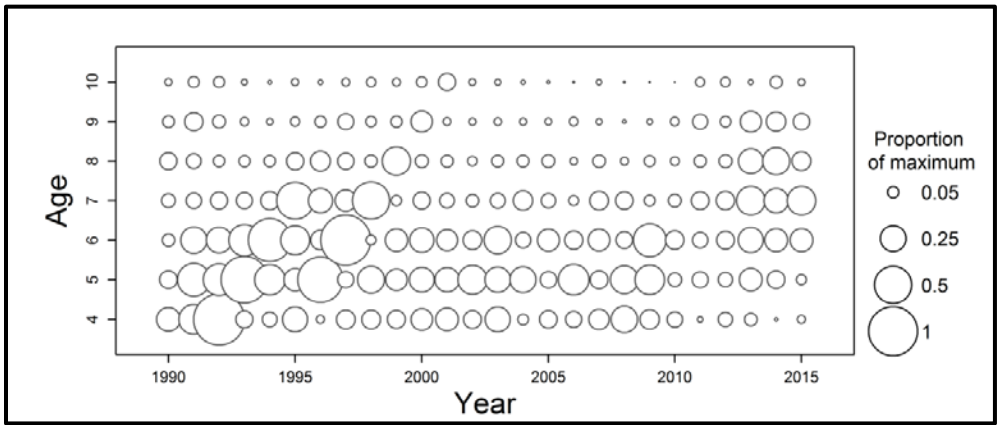

Figure 10. Bubble plot of spring spawner herring fixed gear catch-per-unit-effort values (number per net-haul per trip) at age in the southern Gulf of St. Lawrence, 1990 to 2015. The size of the bubble is proportional to the maximum CPUE index value.

Population model

In the most recent assessment of the Div. 4T spring spawner component (DFO 2014; LeBlanc et al. 2015), model fits to the CPUE indices were poor, with a pattern of blocks of residuals and a strong retrospective pattern in the estimates of spawning stock biomass (SSB) that systematically overestimated SSB. These results suggested that the model failed to incorporate one or more non-stationary processes in the population dynamics of this stock or in the observation model relating indices of abundance to population abundance.

Three population models were examined in this assessment (Swain 2016). Model 1 corresponds to the model used in the last assessment (DFO 2014; LeBlanc et al. 2015). Model 2 has the same structure as Model 1 except that the instantaneous rate of natural

mortality (*M*) is allowed to vary over time. Model 3 is like Model 1, except that catchability in the fixed gear fishery (q) is allowed to vary over time. In models 1 and 3, natural mortality at all ages is set at 0.2.

Diagnostic analyses indicated that Model 3 provided a better fit (residual patterns) and model reliability (i.e., a reduced and non-directional retrospective pattern). The improved performance of Model 3 was associated with an interpreted change in catchability to the fixed gear fishery. 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 0.026 in 2000 and then declining to an average value of 0.017 in 2010 to 2015 (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).

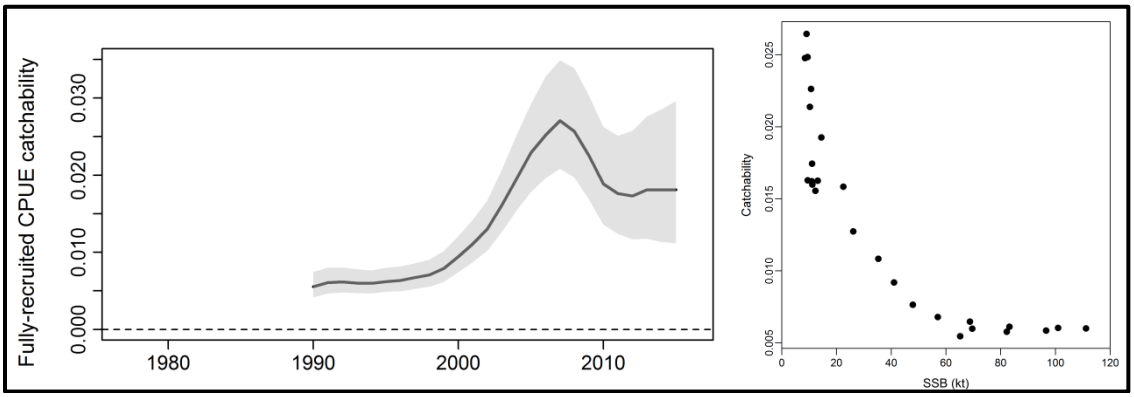

Figure 11. Estimated fully-recruited catchability to the CPUE index of the spring spawner component of herring based on Model 3 (left panel) and fully-recruited catchability to the spring spawner gillnet fishery in relation to spring spawner SSB (right panel). In the left panel, the line shows the median estimates and shading their 95% confidence interval.

Spawning Stock Biomass and Exploitation Rate

Estimates of Spawning Stock Biomass (age 4+) from Model 3 in this assessment were lower for recent years (since 2004) than those estimated in the 2014 assessment (using Model 1) and the status of the stock relative to the Precautionary Approach has also changed (Fig. 12). The estimates of SSB at the beginning of 2015 and 2016 were 9,076 t (95% confidence interval: 5,686 – 14,282) and 9,659 t (95% CI: 5,530 – 16,294), respectively. The SS herring SSB has been in the critical zone since 2004 and the probabilities that SSB was below the Limit

Reference Point (LRP, 22,000 t of SSB) at the start of 2015 and 2016 were >99% in both years (Fig. 12).

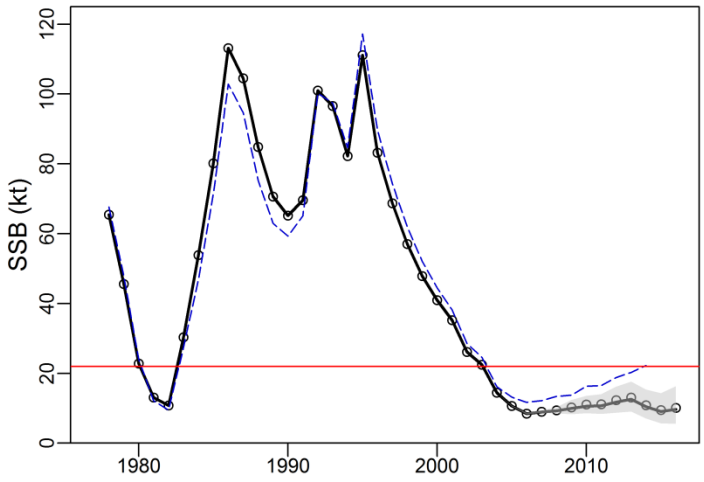

Figure 12. Estimated beginning of the year spawning stock biomass (SSB) of the spring spawner component of herring in the southern Gulf of St. Lawrence, 1978 to 2016. Circles show the maximum likelihood estimates, the solid line is the median MCMC estimate and shading its 95% confidence interval. The red horizontal dashed line is the Limit Reference Point (22,000 t of SSB). The blue dashed line shows the SSB estimates from the 2014 assessment (DFO 2014).

Estimated fishing mortality rates were high in 1980 and in most years from 2000 to 2007 (Fig. 13) but declined below the reference removal rate (F = 0.35) level in 2010, reaching a low value of 0.08 (annual exploitation rate of 0.07) in 2012. Fishing mortality rates in 2013 to 2015 averaged 0.18 (annual exploitation rate of 0.16).

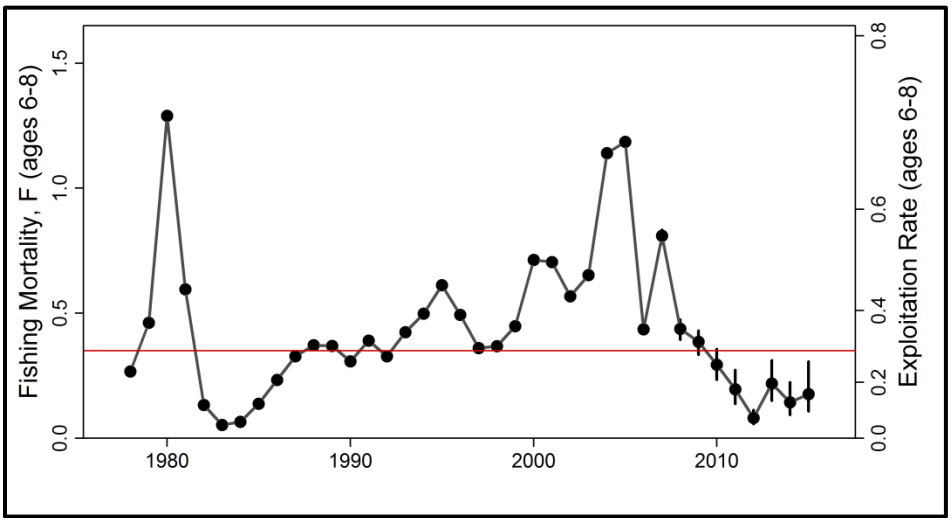

Figure 13. Estimated instantaneous rates of fishing mortality (F) (left axis) and corresponding annual exploitation rate values (right axis) of spring spawning herring aged 6 to 8 years in the southern Gulf of St. Lawrence. Circles are the median estimates and vertical lines their 95% confidence intervals. The red horizontal line shows the reference level of F = 0.35 (annual exploitation rate of 0.295) 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 and between 2005 and 2009. Recruitment rates for the 2010 and 2011 cohorts were among the lowest observed. Estimated abundances of four-year-old herring at the start of 2014 and 2015 (the 2010 and 2011 year-classes) were the lowest on record (Fig. 14). The age-4 abundance in 2016 is greater than these very low values, however, this value depends on the assumption that recruitment rate for this cohort is the average of the rate for the preceding five cohorts. Recruitment rates have varied widely among these five cohorts; thus, the uncertainty in age-4 abundance in 2016 is very high. If recruitment rate of the 2012 cohort was instead very low, like that of the 2010 and 2011 cohorts, age-4 abundance in 2016 would resemble the very low 2014 and 2015 values.

The estimate of spring spawner (4+) abundance for 2015 is 51.4 million herring (95% CI: 32.0 – 83.1 million), about 13% of the average 4+ abundance in 1985 to 1995 (Fig. 14). Only the 2005 and 1982 values were lower than the median estimate for 2015.

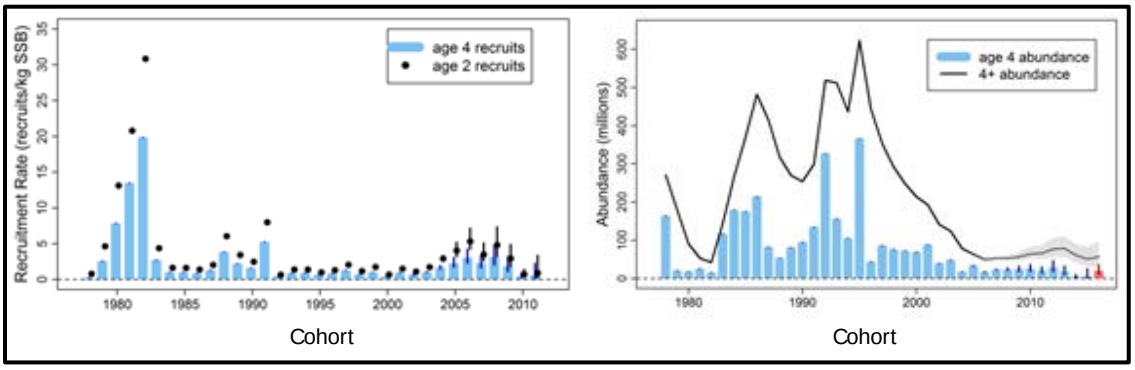

Figure 14. Left panel shows recruitment rates at age 2 (circles) and at age 4 (bars) for the 1978 to 2011 cohorts of spring spawning herring from the southern Gulf of St. Lawrence. Vertical lines indicate 95% confidence intervals. The right panel shows the estimated beginning-of-year abundances of 4 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 its 95% confidence interval. Age-4 abundance in 2015 (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 to the start of 2018. These projections incorporated uncertainty in the estimates of abundance at age at the beginning of 2016, in the weights-at-age, partial recruitments to the fishery, and recruitment rates (to estimate ages 2 to 4). Projections were conducted at six levels of annual catch (0 to 2,500 t in increments of 500 t) with the same catch level for the 2016 and 2017 fishing seasons.

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 a decline in SSB between 2016 and 2018 increased from 34% at 0 t to 49% at 1,000 t to 69% at 2,500 t (Fig. 15).

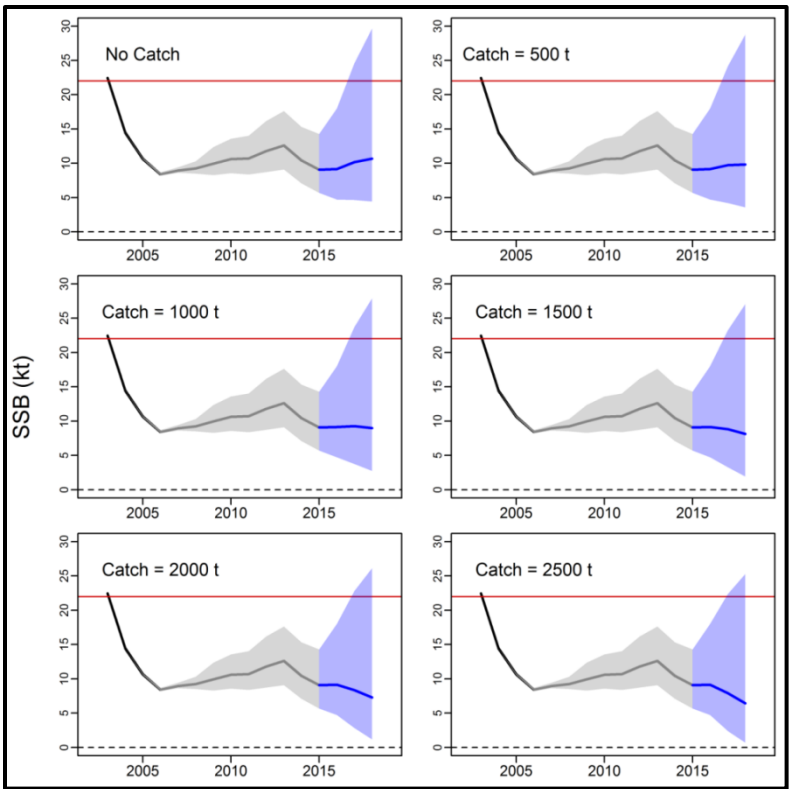

Figure 15. Projected beginning of year spawning stock biomass (SSB) of the spring spawner component of Atlantic herring from the southern Gulf of St. Lawrence at various annual catch levels in 2016 and 2017. Lines show the median estimates of beginning-of-year SSB and shading the 95% confidence intervals of these estimates. Black and grey indicate the historical period and blue the projection period. The red horizontal line is the LRP.

Risk analysis of catch options

The probability of a 5% increase in SSB decreased from 60% at 0 t to 48% at 1,000 t and 27% at 2,500 t (Table 1). The probability of a 5% decline in SSB increased from 23% at 0 t to 47% at 1,000 t and 65% at 2,500 t. For all catch levels (including no catch), there was a high probability that SSB would remain below the LRP at the start of 2018 (Table 1). There was no chance that the population would be at or above the Upper Stock Reference (USR) in 2018 even with no catch. The probability that age 6-8 *F* would be greater than the *F* = 0.35 reference level was small (6%) at 1,000 t, increasing to 29% at 1,500 t and 70% at 2,500 t.

Table 1. Risk analysis table of probabilities (%) of increases or decreases in SSB, of SSB being less than the LRP (i.e., the SSB in the critical zone), and of fully-recruited fishing mortality rate ($F_{6\text{-}8}$) being above $F_{0.1}$ for differing fixed catch options in 2016 and 2017 for the for spring spawner component of Atlantic herring from the southern Gulf of St. Lawrence.

Catch option (t)	5% or greater increase in SSB	5% or greater decline in SSB	SSB < LRP	$F_{6\text{-}8} > F_{0.1}$
0	60%	23%	90%	0
500	53%	41%	91%	0
1,000	48%	47%	93%	6%
1,500	41%	52%	94%	29%
2,000	34%	58%	95%	53%
2,500	27%	65%	95%	70%

Fall Spawner Component (FS)

The FS herring assessment considers three regions (North, Middle, South) which cover the entire Div. 4T area as three independent populations. The regions are defined on the basis of traditional herring spawning beds and fishing areas: North (Gaspé 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.

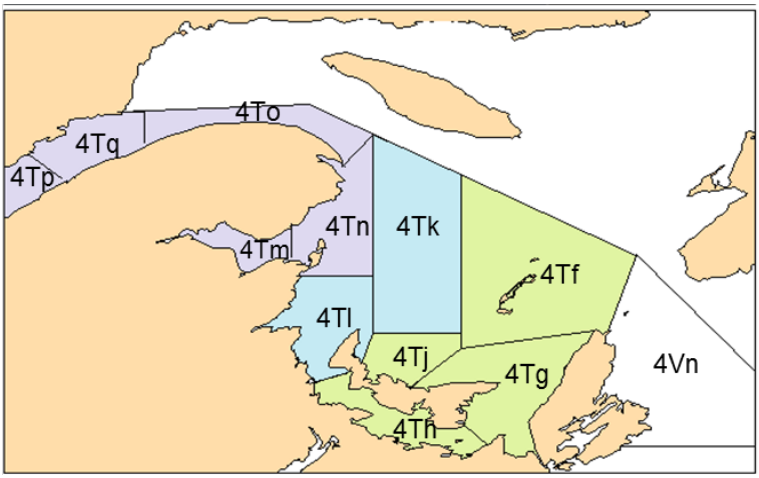

Figure 16. Correspondence between the herring fishing areas and the three regional groups (by colour shading) used in the assessment of the fall spawner component of Atlantic herring from the southern Gulf of St. Lawrence. Fishing areas in each region are described in the text above.

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 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 in areas throughout the sGSL spawning. The index of two year olds was relatively high in 2014 (Fig. 17).

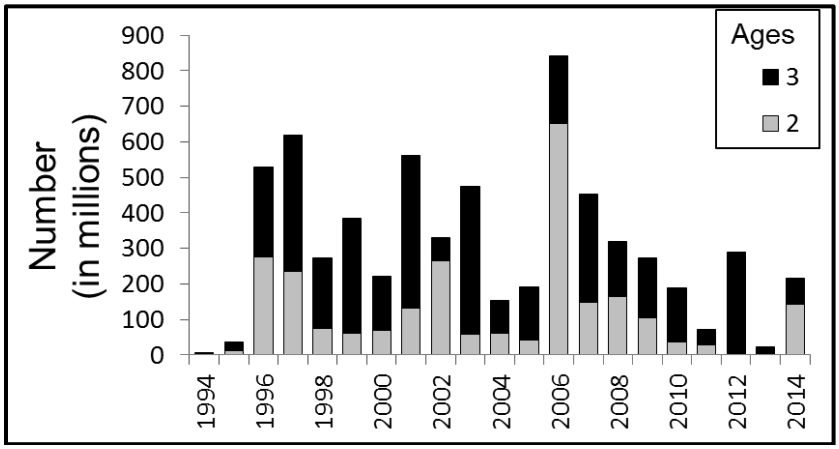

Figure 17. Stacked bar plots of the index of abundance (number in millions) of fall spawner herring at age 2 and 3 years from the fisheries-independent acoustic survey for fall spawners, 1994 to 2014.

Commercial fixed gear catch per unit of 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 were up in 2014 and 2015 for ages 6 to 8, and catches of FS herring in 2014 were dominated by age 7 and 8 (2006 and 2007 year-classes) and in 2015 by age 6 (2009 year-class). Similar higher CPUE values in 2015 were noted in the Middle region, where catches in 2014 were dominated by age 7 (2007 year-class) and in 2015 by ages 6 and 8 (2007 and 2009 year-classes). Age 8 FS herring was the most abundant component in the South region in 2015 (Fig. 18) and CPUE values in 2014 and 2015 were below the peak values noted in 2007.

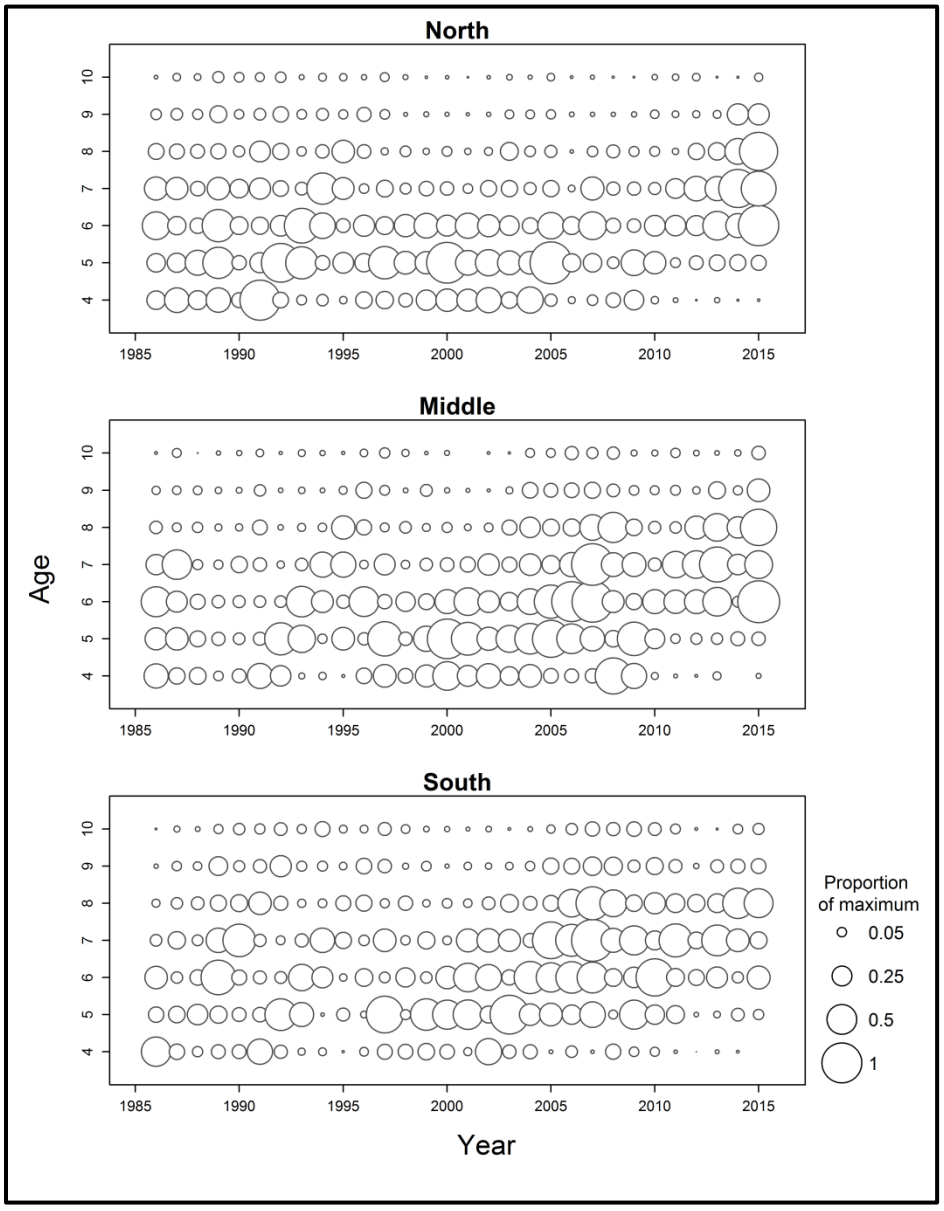

Figure 18. Fall spawner (FS) herring fixed gear age-disaggregated catch-per-unit-effort values (number per net-haul per trip) by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 1986 to 2015. The size of the bubble is proportional to the CPUE 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, and with no major trend over time for older ages (Fig. 19).

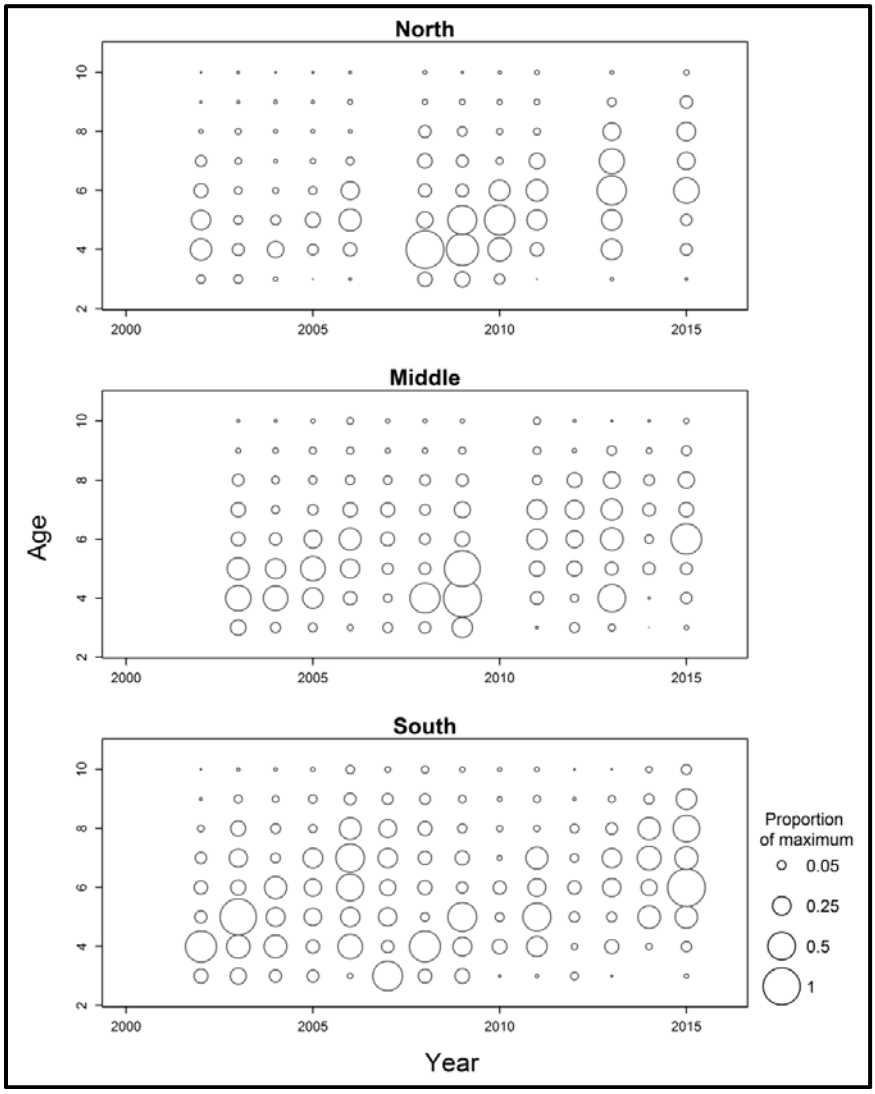

Figure 19. Bubble plots of catch-at-age indices (number) of fall spawner herring from the experimental gillnets by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 2002 to 2015. The size of the bubble is proportional to the index value.

Fishery Independent September Bottom Trawl Survey

Data were available from 1994 to 2011. The indices suggest 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).

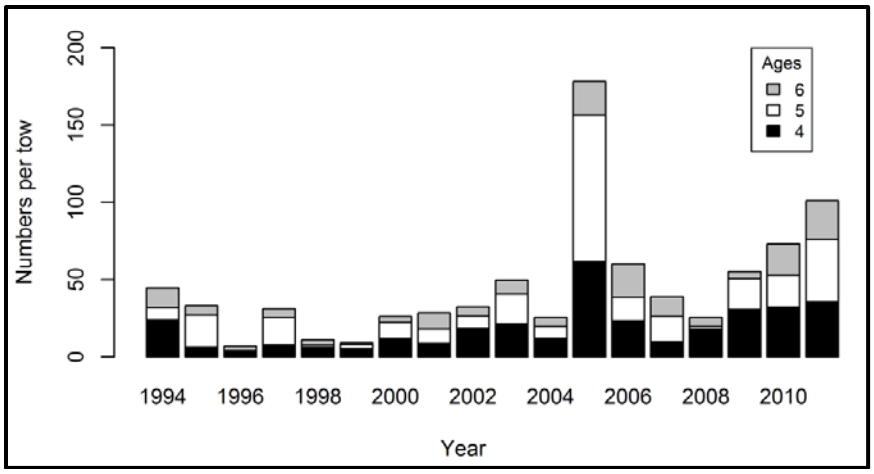

Figure 20. Multispecies bottom trawl survey abundance index (number of fish per standardized tow) for fall spawning herring ages 4 to 6 years in the southern Gulf of St. Lawrence, 1994 to 2011.

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 2015, catch rates at age in experimental nets (ages 3 to 9 or 10, 2002 or 2003 to 2015, with indices missing in some years in some regions), abundance indices at ages 2 and 3 from the fall acoustic survey (1994-2014), 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).

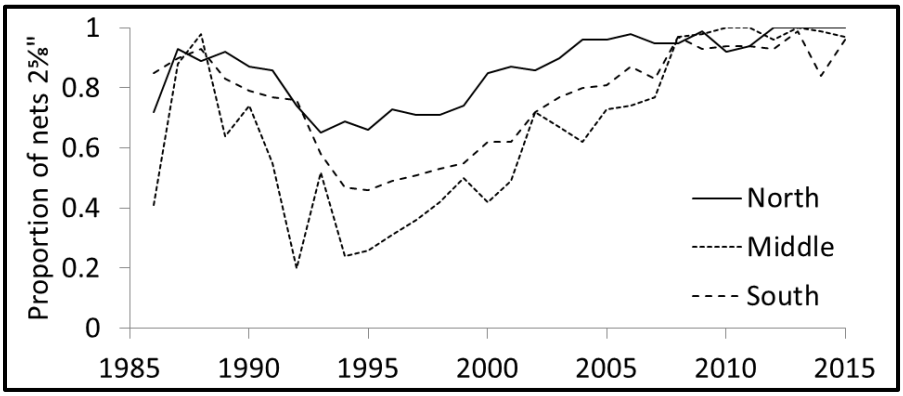

Figure 21. Variations by region in the proportions of gillnets with mesh sizes 2 $^{5}/_{8}$ inches used in the fall herring fishery season in the southern Gulf of St. Lawrence, 1986 to 2015. It is assumed that all other nets used were of mesh size 2 ¾.

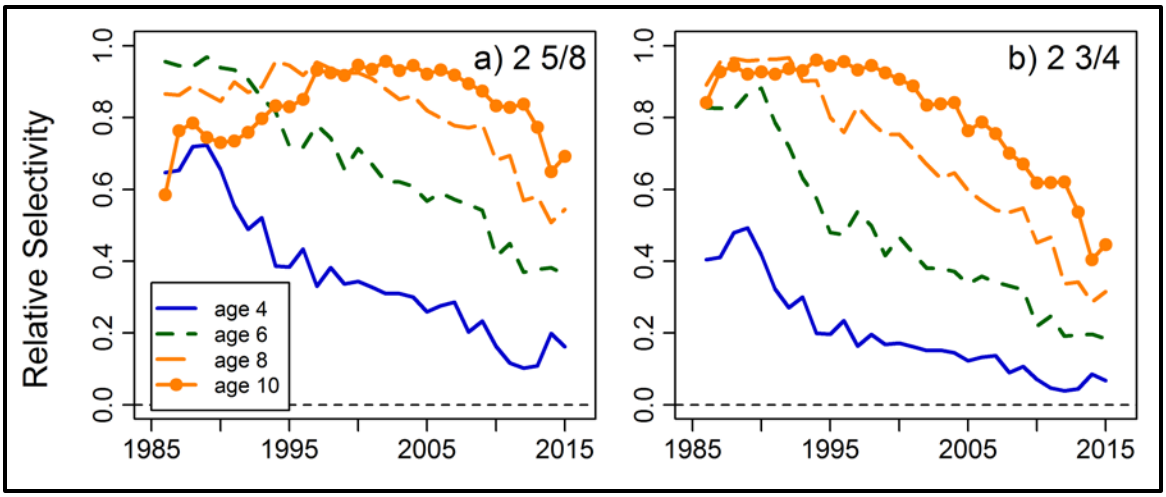

Figure 22. Changes in relative selectivity of fall spawning herring aged 4, 6, 8 and 10 years to gillnets with mesh sizes of 2 $^{5}/_{8}$ inches (left panel) or 2 ¾ inches (right panel) in the fall herring fishery of the southern Gulf of St. Lawrence, 1986 to 2015.

Similar to the results for 2015 (DFO 2015), 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. In this region, q has been 3.5 times greater since 2010 than prior to 1995. Estimated catchability was greatest in the Middle region until the mid-2000s when it was surpassed by catchability in the South region. In the Middle region, fully-recruited q was at its lowest around 1990, and then increased to a level about twice as high by 2000, where it has since remained.

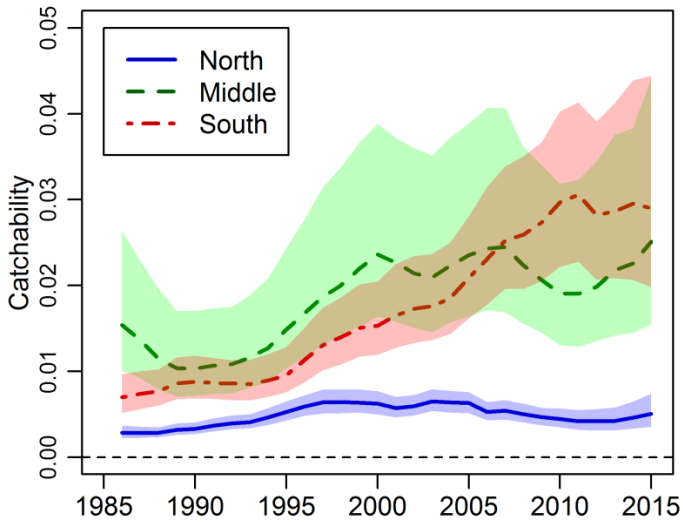

Figure 23. Estimated fully-recruited catchability (q) of fall spawner herring to the fall gillnet fishery in three regions (North, Middle and South) of the southern Gulf of St. Lawrence, 1986 to 2015.

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.

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, declined to a lower level from the mid-1990s to the late 2000s and then returned to a higher level (Fig. 24). Estimated SSB in this region declined substantially from 2013 to 2016, but the median estimate remained above the average level of 1995 to 2008. In the Middle region, estimated SSB increased gradually from 1980 to the late 2000s, but declined by about 60% between 2009 and 2016. SSB in the South region was at a relatively high level from about the mid-1980s to the late 2000s. However, estimated SSB has been in decline since 2009, with the median estimate at the start of 2016 at 40% of the 2009 value. Summed over the three regions, the median estimate of total SSB at the start of 2016 is 165,000 t. The estimated probabilities that total SSB was below the USR of 172,000 t at the beginning of 2015 and 2016 are 22% and 60%, respectively.

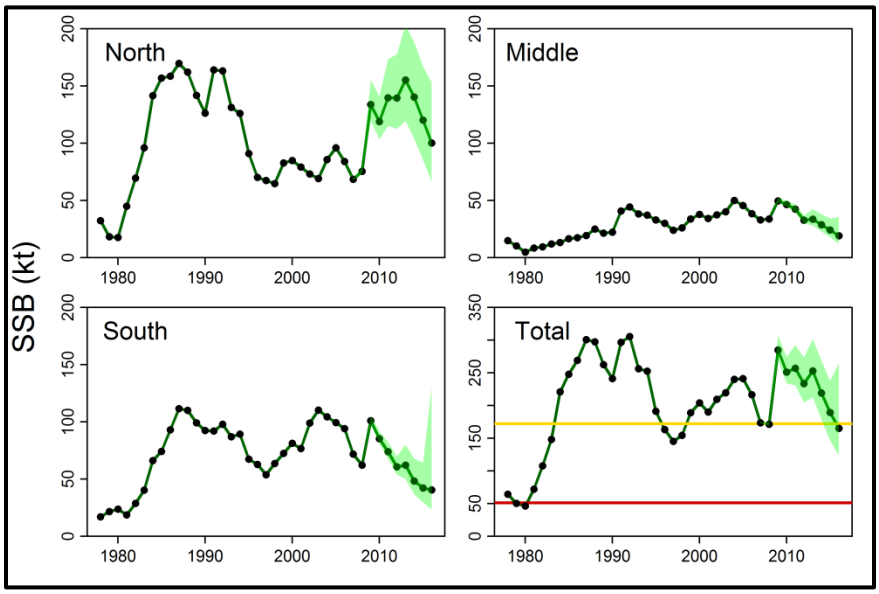

Figure 24. Estimated spawning stock biomass (SSB) of fall spawning herring by region and overall (Total) for the southern Gulf of St. Lawrence, at the beginning of the year 1978 to 2016. The line and circles show the median estimates and the shading their 95% confidence intervals. In the bottom right panel for Total, the yellow horizontal line is the upper stock reference level (USR) and the red horizontal line is the limit reference point (LRP).

Estimated fishing mortality (*F*; ages 5 to 10) has declined to a relatively low level in the North (0.13 in 2015) region but has remained higher in the Middle (0.33 in 2015) and South (0.26 in 2015) regions (Fig. 25). The average fishing mortality rate on ages 5 to 10 over all three regions (weighted by region-specific abundance of 5 to 10 year olds) has generally declined since 2008, from about 0.40 (annual exploitation rate of 0.33) to an average of 0.19 (annual exploitation rate of 0.17) since 2012. The probability that overall *F* for ages 5 to 10 exceeded 0.32 (the reference removal rate in the healthy zone) in 2015 is essentially 0 (0.02%).

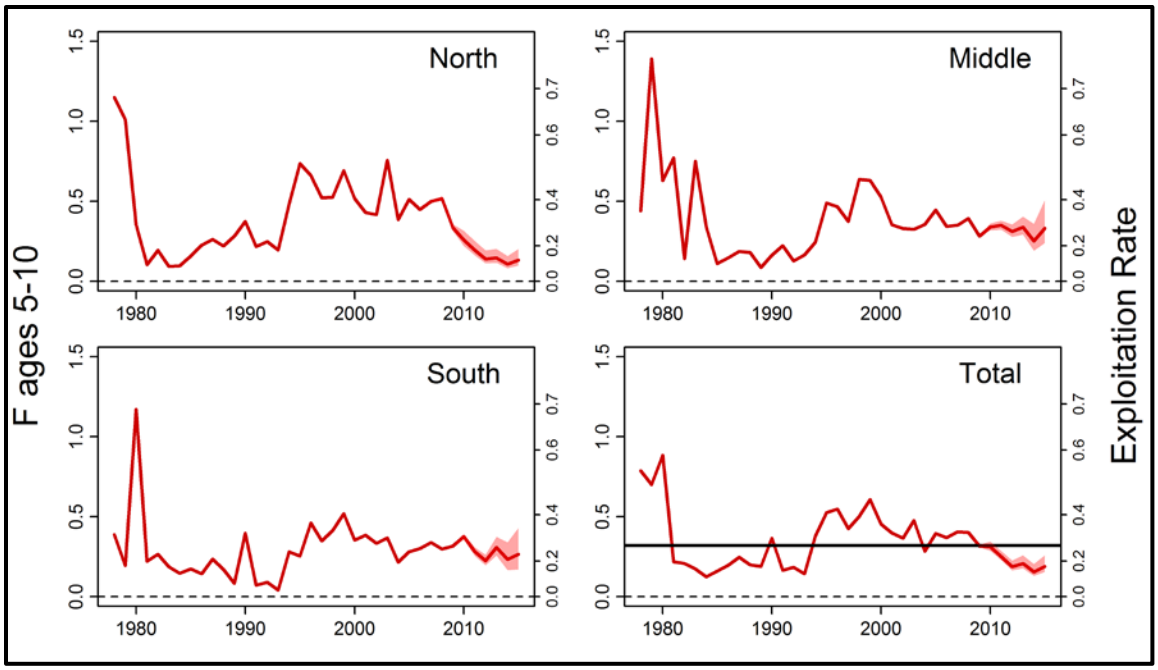

Figure 25. Estimated age 5 to 10 fishing mortality (as an instantaneous rate F in left axes and as annual exploitation rate in right axes) of fall spawning herring by region and averaged over regions (weighted by region-specific abundance at ages 5-10 years) in the southern Gulf of St Lawrence. Lines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

Recruitment and Recruitment Rates

The three most recent estimates of recruitment rate (2010 to 2012 cohorts; recruit abundance divided by the SSB producing them) were among the lowest observed in the North and Middle regions. In the South region, recruitment rates for these cohorts were also very low, though the estimate for the 2012 cohort was slightly greater than the 2010 and 2011 estimates. However, uncertainty in the 2012 estimate is very high. Summed over all three regions, recruitment rates for the 2010 to 2012 cohorts were among the lowest observed (Fig. 26). Only the estimates for the 1989 and 1991 cohorts were as low.

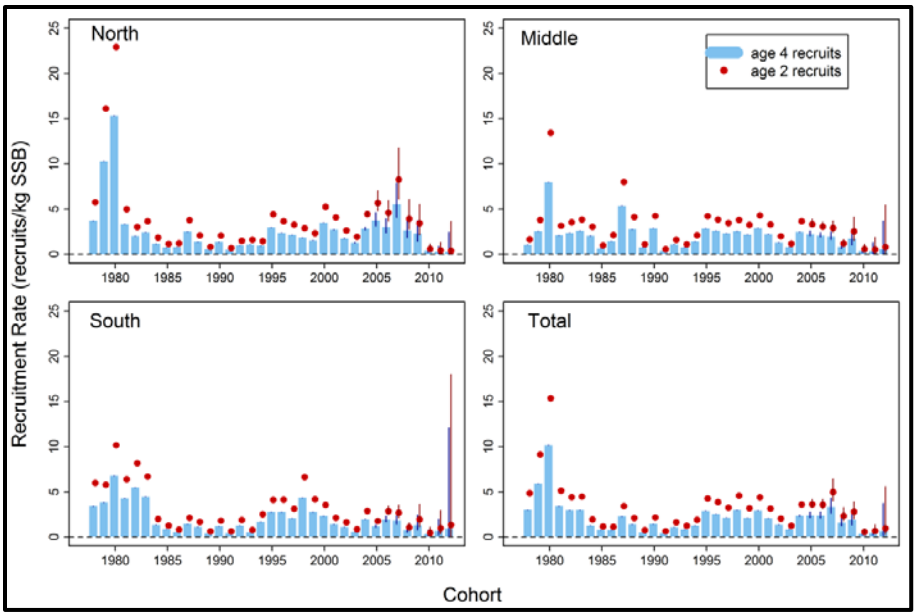

Figure 26. Estimated recruitment rates to age 2 (circles) and age 4 (bars) for fall spawning herring by region and summed (Total) over regions in the southern Gulf of St. Lawrence, for the 1978 to 2012 cohorts. Vertical lines are the 95% confidence intervals.

Estimated abundance of fall spawning herring 4 years of age and older has declined in all three regions in recent years (Fig. 27). To a large extent, this reflects reductions in the recruitment of 4-year-old herring. In all three regions, estimated abundances of 4-year-old herring for the last three years (2014 to 2016) are among the lowest observed, comparable to the low levels estimated for the late 1970s.

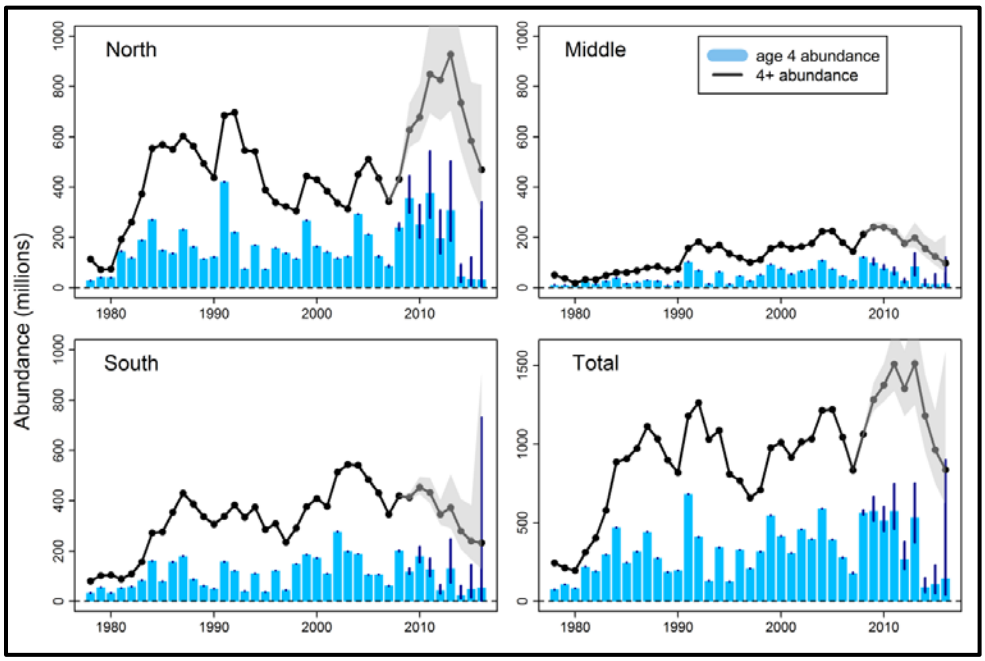

Figure 27. Estimated abundance of fall spawning herring at ages 4 and for ages 4+ by region and for the entire (Total) southern Gulf of St. Lawrence at the beginning of the year, 1978 to 2016. Line and circles (age 4+) and bars (age 4) show the median estimates and shading or vertical lines show the 95% confidence intervals.

Projections

The fishery TAC for the fall spawner component is set at the level of the entire 4T stock unit. The three region-specific models were projected forward to the start of 2018. Uncertainties incorporated in projections included estimates of abundance at age at the beginning of 2016, 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 2018 was projected to be below the USR at all catch levels between 10,000 and 50,000 t (Fig. 28).

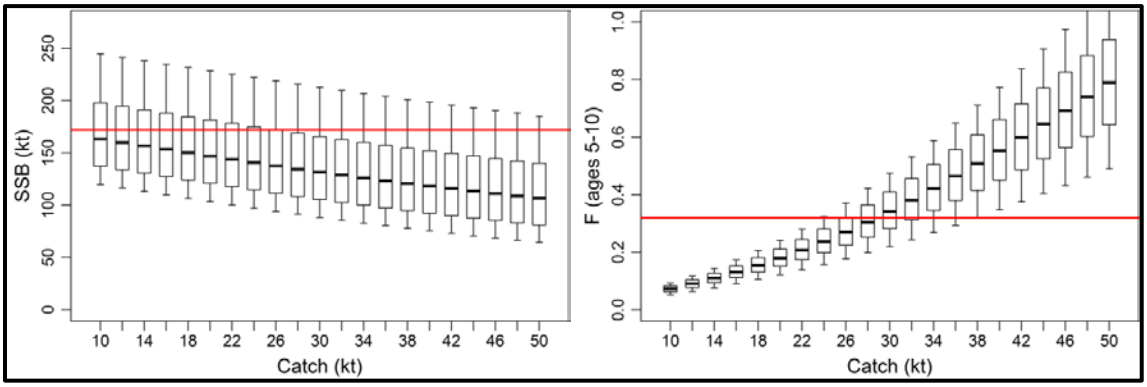

Figure 28. Projected SSB of fall spawner herring from the southern Gulf of St. Lawrnece at the start of 2018 (left panel) and fishing mortality for ages 5 to 10 in 2017 (right panel) at various annual catch levels in 2016 and 2017. The heavy horizontal lines in each box are the median estimate, the box extends from the 25th to 75th percentiles of the estimates, and the error bars show the 80% confidence intervals (10 to 90th percentiles). The horizontal line in each panel shows the reference level for SSB (USR left panel) and removal rate ($F_{0.1}$; right panel).

Risk analysis of catch options

The probability that SSB would be below the USR at the start of 2018 increased from 57% at 10,000 t of catch to 87% at 50,000 t of catch. At a catch of 28,000 t (the catch in 2015) in 2016 and 2017, this probability would be 76.5% (Fig. 29). The probability that *F* would be greater than the *F* = 0.32 removal rate reference level in 2017 was 0 at 10,000 t of catch, increasing to > 90% at 40,000 t of catch. For a TAC in 2016 and 2017 set to be equivalent to the landings in 2015 (28,000 t) the probability of exceeding the removal rate reference values was estimated at 42%. The chance that SSB would be in the critical zone in 2018 was 0 at catches of 20,000 t or less, <1% at catches of 22,000 to 40,000 t and 1 to 3% at annual catches of 42,000 to 50,000 t.

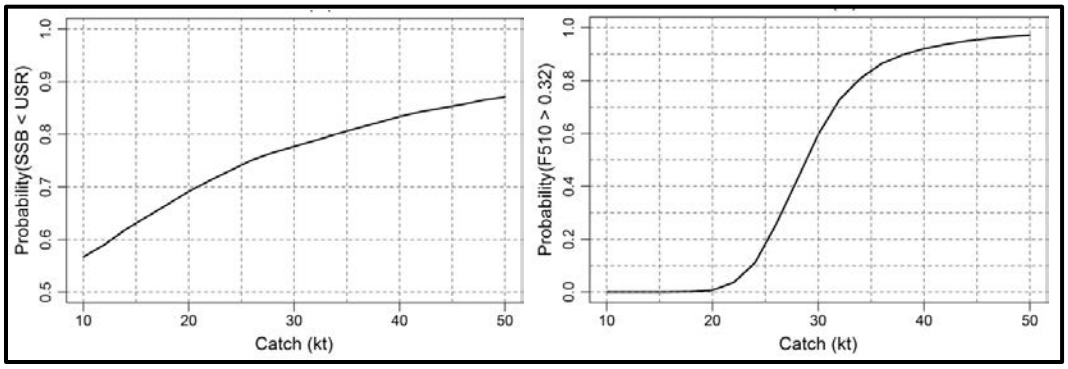

Figure 29. Risk analysis of annual fixed catch options for 2016 and 2017 for the FS herring component of the southern Gulf of St. Lawrence. The left panel shows probabilities that total SSB at the start of 2018 will be below the USR. The right panel shows probabilities that average F for ages 5 to 10 in 2017 will be greater than the reference level F = 0.32.

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 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, i.e., SSB in each region produces recruitment and future SSB to that region. 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. There is ongoing research using genetics to determine if there are population-level differences between regions for fall spawners.

Changes in natural mortality of adult herring in the southern Gulf of St. Lawrence are not apparent from exploration of variants of population models. The lack of recovery for the spring spawners and the continued decline of the fall spawners appear to be associated with low recruitment rates, particularly of the 2010 to 2012 year-classes. The causes of these low recruitment rates are unknown.

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.

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 < 22,000 t) since 2004 but experienced fishing mortalities above the $F_{0.1}$ level until 2010. Since 2010 F has decreased and remained below $F_{0.1}$.

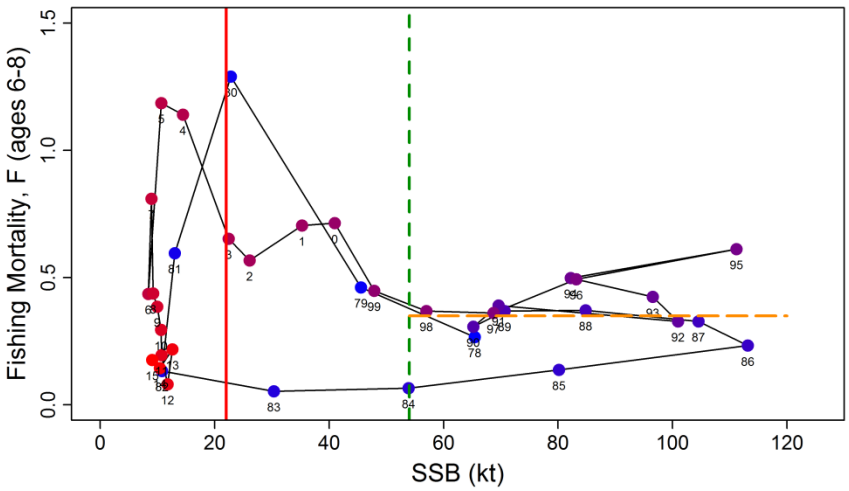

Figure 30. The southern Gulf of St. Lawrence Atlantic herring spring spawner component trajectory in relation to spawning stock biomass (SSB, kt = thousand t) and fishing mortality rates for ages 6 to 8 years. The solid red vertical line is the LRP (22,000 t), the green dashed vertical line is the Upper 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.

SSB at the start of 2017 and 2018 was projected to increase slightly at annual fixed catches less than 500 t, and remain roughly stable at a catch of 1,000 t, but decline at catches of 1,500 t or more. However, uncertainty is high. The probability of no decline in SSB between 2016 and 2018 decreased from 66% at 0 t to 51% at 1,000 t of catch and 31% at 2,500 t of catch. Even in the absence of any removals of SS herring in 2016 and 2017, 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 0.15, low relative to the history of the fishery but still high for a stock in the critical zone.

Poor recruitment, resulting from low recruitment rates, is constraining the rebuilding of the stock out of the critical zone. Low recruitment rates and declines in abundance of spring spawning herring have been observed in other areas of eastern Canada, potentially resulting from warmer environmental conditions and a mismatch with plankton production for this spawning strategy (Bourne et al. 2015). Declines in weight-at-age are also exacerbating the reductions in SSB.

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 was in the cautious zone at the start of 2016. Fishing mortality rates generally exceeded the removal rate reference from the mid-1990s to 2010 but were below the reference level from the early 1980s to the mid-1990s and since 2011.

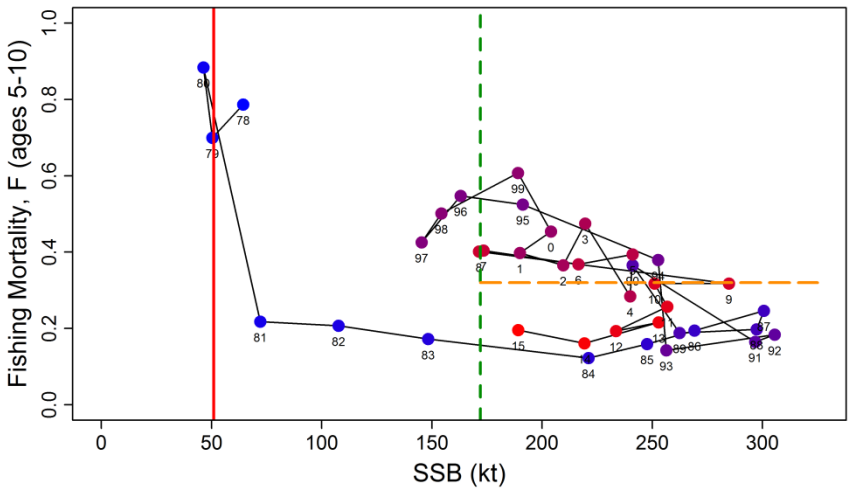

Figure 31. The southern Gulf of St. Lawrence Atlantic herring fall spawner component trajectory in relation to spawning stock biomass (SSB, kt = thousand t) and fishing mortality reference levels. The solid red vertical line is the LRP (51,000 t), the green dashed vertical line is the Upper Stock Reference (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.

The median SSB estimate at the start of 2017 and 2018 was projected to be close to the USR at catch levels in 2016 and 2017 of 10,000 t, but the probability of being in the cautious zone at the start of 2018 was greater than 50% at catch options greater than 10,000 t. At a catch of 28,000 t (the catch in 2015) in 2016 and 2017, the probability of the SSB being in the cautious zone was estimated at 76.5%, and the probability of the fishing mortality rate being above the removal rate reference was estimated at 42%.

Fishing mortality on the FS herring averaged 0.19 since 2012, just over half of the removal reference level.

Poor recruitment at age 4 in the last three years, resulting from low recruitment rates, has contributed to the decline in SSB for this stock. Similarly low recruitment rates and declines in abundance were noted for the spring spawner component of the southern Gulf of St. Lawrence. 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.

SOURCES OF INFORMATION

This Science Advisory Report is from the March 15 and 16, 2016 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) to 2015 and advice for the 2016 and 2017 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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