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Gulf Region

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Science Advisory Report 2020/029

ASSESSMENT OF THE SOUTHERN GULF OF ST. LAWRENCE (NAFO DIVISION 4T-4Vn) SPRING AND FALL SPAWNER COMPONENTS OF ATLANTIC HERRING (*CLUPEA HARENGUS*) WITH ADVICE FOR THE 2020 AND 2021 FISHERIES

Atlantic Herring (*Clupea harengus*)

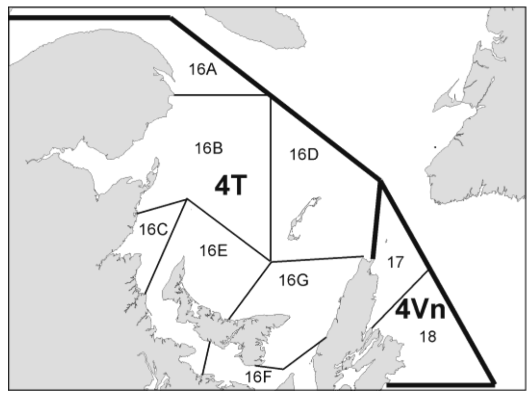

Figure 1. NAFO Divisions 4T and 4Vn and the corresponding herring fishery management zones.

Context:

The stock area for southern Gulf of St. Lawrence herring (NAFO Division 4T-4Vn) 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 herring are sold as roe, bloater, filet markets, and bait. Annual quota management was initiated in 1972. In 2019, there were 2,332 fixed gear licenses and 8 seiner licenses issued. Of these licences approximately 22% of fixed gear and 25% of seiner licences are active (at least one trip per season).

Assessments of the spring and fall spawning herring from the southern Gulf of St. Lawrence (NAFO Division 4T-4Vn) are used to establish the total allowable catch. A science peer review meeting of the Regional Advisory Process was held March 12-13, 2020 in Moncton, N.B. to assess the status of the spring and fall spawner components of NAFO Division 4T-4Vn herring and to provide advice for the 2020 and 2021 fisheries. Participants at the meeting included DFO Science (Gulf, Quebec, Newfoundland and Labrador regions), DFO Fisheries Management (Gulf, Quebec regions), provincial governments, the fishing industry, environmental non-government organizations, and Indigenous organizations.

SUMMARY

- Atlantic Herring in the southern Gulf of St. Lawrence (sGSL) are composed of spring spawning and fall spawning components which are genetically distinct stocks and as such assessed separately.
- Statistical Catch at Age models that incorporated time varying changes in catchability in the fixed gear fishery and changes in natural mortality have been used for the first time in this assessment.
- For both spring and fall spawners, the increasing trend in natural mortality of ages 7 to 11+ was correlated with the increase in indices of Grey Seal and Atlantic Bluefin Tuna abundance over the same time period.

Spring Spawner Component

- Based on the current stock assessment, the 2018 and 2019 estimate of Spawning Stock Biomass (SSB) of spring spawning herring has likely (>80%) remained in the Critical Zone of the Precautionary Approach Framework. The stock has been below the limit reference point (LRP) since 2002.
- Under current conditions of high natural mortality, declines in weight-at-age, and low recruitment, it is unlikely that SSB will increase in the short term (2021 and 2022) or the long term (2029) at all catch options between 0 and 1,250 t. Even in the absence of any fishery removals, it is very likely (> 90%) that the stock will remain in the Critical Zone.
- A directed fishery targets spring spawning herring with landings of 798 t and 1,047 t in 2018 and 2019, respectively. Fishing mortality in this stock has exceeded the provisional harvest decision rule of the Precautionary Approach Framework since 1999.
- Recruitment has remained stable at low values since 1994. This low recruitment corresponds with long-term environmental changes including temperature increases and changes in zooplankton abundance. Given the ongoing trend towards warmer environmental conditions, it is not expected that recruitment will improve in future years.
- Natural mortality estimates for ages 2 to 6 varied between 21% and 41% over the time series, however natural mortality for older fish (ages 7-11+) increased since 2011 to an estimated value of 64% in 2018 and 2019.

Fall Spawner Component

- The SSB of fall spawning herring in 2020 is virtually certain (100%) to be in the Cautious Zone of the Precautionary Approach Framework.
- Under current conditions of high natural mortality, constant fishing mortality, declines in weight-at-age, and low recruitment, it is unlikely that SSB will increase in the short term (2021 and 2022) or the long term (2029). Reducing fishing mortality will slightly reduce the probabilities of declines in the short and long term projections. It is unlikely (0-33%) that SSB will increase by 2022 at any catch option.
- The preliminary estimated landings of the fall spawning herring component were 16,742 t from a 25,000 t TAC in 2018 and 15,544 t from a 22,500 t TAC in 2019. Average fishing mortality exceeded the provisional harvest decision rule of the Precautionary Approach Framework for most of the 1990s and 2000s but is currently below the provisional harvest decision rule at stable levels.

- Recruitment has been declining since 2006 and reached the lowest levels of the time series in recent years. Environmental conditions that promote high recruitment require the synchronicity of temperature, zooplankton abundance, and timing of the release of herring larvae. The occurrence of future environmental conditions for successful fall spawning herring recruitment cannot be predicted.
- Natural mortality estimates for ages 2 to 6 decreased over the time series, with trends that matched the declines seen in the abundance of Atlantic Cod in the sGSL. For ages 7 to 11+, annual natural mortality estimates increased sharply in 2004 to reach a peak in the mid-2010s and has since stabilized at values of approximately 55%.

INTRODUCTION

Atlantic Herring (*Clupea harengus*) is a schooling pelagic species. Age at first spawning is typically four years. The herring population in the southern Gulf of St. Lawrence (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 Division 4T of the sGSL are managed across seven herring fishing areas within area 16 (A-G; Fig. 1). The SS and FS herring of the sGSL are genetically 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).

Herring is a vital pelagic prey species for numerous predators in the sGSL including Grey Seal (*Halichoerus grypus;* Hammill and Stenson 2000; Hammill et al. 2007, 2014), seabirds (Cairns et al. 1991), cetaceans (Fontaine et al. 1994; Benoît and Rail 2016), numerous groundfish including Atlantic Cod (*Gadus morua*; Hanson and Chouinard 2002), White Hake (*Urophycis tenuis*; Benoît and Rail 2016) and Atlantic Bluefin Tuna (*Thunnus thynnus*; Pleizier et al. 2012). Of these major predators, Grey Seal and Bluefin Tuna have increased, whereas cod abundance has decreased in the last decades in the sGSL (Benoît and Rail 2016). Major environmental changes have also occurred in the sGSL, including an increase in water temperature and associated shifts in the zooplankton abundance and composition (Blais et al. 2019; Galbraith et al. 2019). Recruitment success of spring spawners corresponds with cold water temperature and energy-rich cold-water copepods, while recruitment success of fall spawning herring has been associated with warmer water and small warm-water copepods (Melvin et al. 2009; Brosset et al. 2019).

Fisheries

Over the period 1978 to 2019, total landings of Atlantic Herring from NAFO Division 4T and 4Vn peaked at 93,471 t in 1995 and dropped to 16,591 t in 2019 (Fig. 2). A Total Allowable Catch (TAC) for the combined harvest of both components in NAFO Division 4T and 4Vn has been in place since 1972. The total landings have generally been less than the TAC since 1988. The TAC values were 25,500 t (25,000 t FS and 500 t interim SS) and 23,500 t (22,250 t FS and 1,250 t SS) in 2018 and 2019, 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 Division 4T whereas the mobile gear fishery occurs in Division 4T and occasionally in Division 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 99%) of the reported landings since 1981 have been from the fixed gear fleet with percentages in 2018 and 2019 of 89% and 93%, 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 90% and 97% of the total herring harvested in 2018 and 2019, respectively.

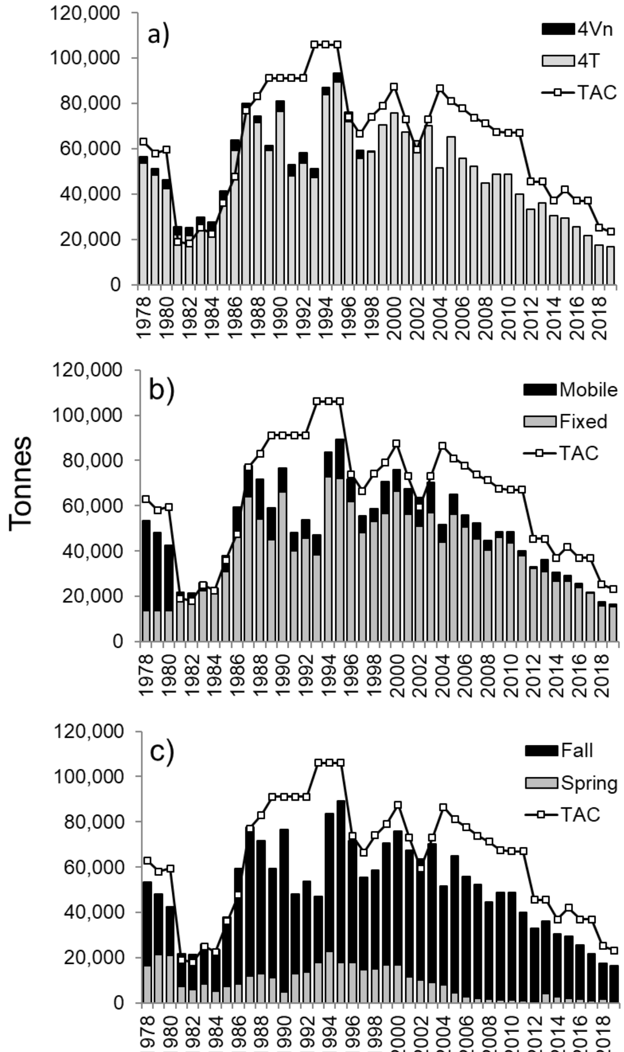

Figure 2. Reported landings (tonnes) of southern Gulf of St. Lawrence Atlantic Herring (spring and fall spawners combined) by NAFO Division (upper panel), by gear fleet (middle panel), and by fishing season (lower panel), 1978 to 2019. In all panels, the corresponding annual total allowable catch (TAC; tonnes) is shown. For landings by season, the landings in NAFO Division 4Vn were attributed to the fall fishing season. Data for 2018 and 2019 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)

In 2018, an interim TAC of 500 t was allocated for SS, however no official TAC was set. The 2019 TAC for the SS herring was set at 1,250 t (Fig. 3). The preliminary estimated landings of SS herring in 2018 and 2019 were 798 t and 1,047 t, respectively. In 2018, 160% of the SS interim TAC was attained, whereas 84% of the TAC was attained in 2019.

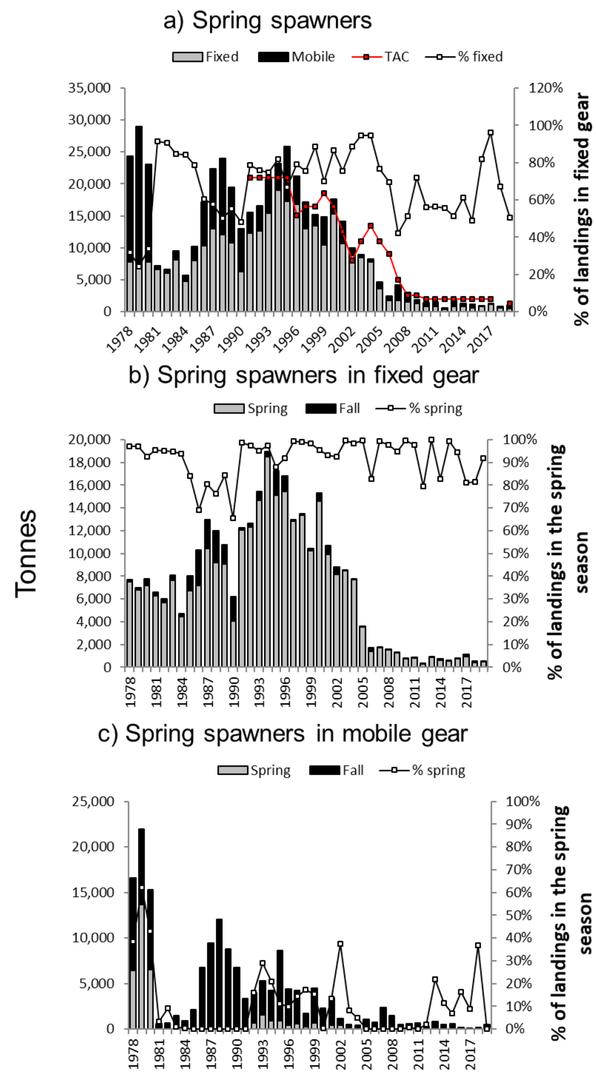

Figure 3. Estimated landings (tonnes) of the spring spawner component (SS) of Atlantic Herring from the southern Gulf of St. Lawrence, 1978 to 2019. The upper panel shows the estimated landings by gear type and the proportion of the landings attributed to the fixed gear fleet, and the SS herring TAC (red symbols) for 1991 to 2019. 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 bottom 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 Division 4Vn were attributed to the fall fishing season. Data for 2018 and 2019 are preliminary.

With few exceptions, most of the SS herring were estimated to have been landed in the fixed gear fleet over the 1981 to 2019 period. In 2018 and 2019, the fixed gear fleet was estimated to have landed 67% and 51%, 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).

Catch-at-age and weight-at-age

Catches-at-age for both gears combined are presented in Figure 4.

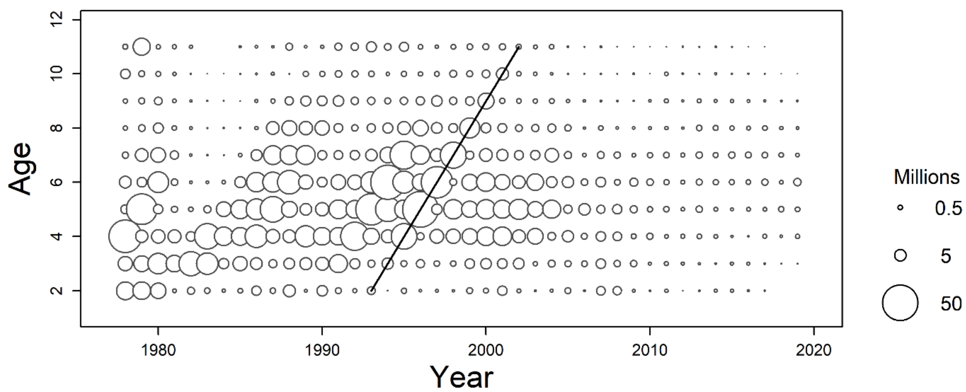

Figure 4. Catch-at-age of the spring spawner component from the fishery, all gears combined, 1978 to 2019. Size of the bubble is proportional to the catch numbers by age and year. The diagonal line tracks the most recent strong year-class (1991). The values indicated at age 11 represent catches for ages 11 years and older.

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). The average weight-at-age declined by 37% between 1978 and 2019. For a given number of fish, lower mean weights result in lower stock biomass when numbers are converted to weight.

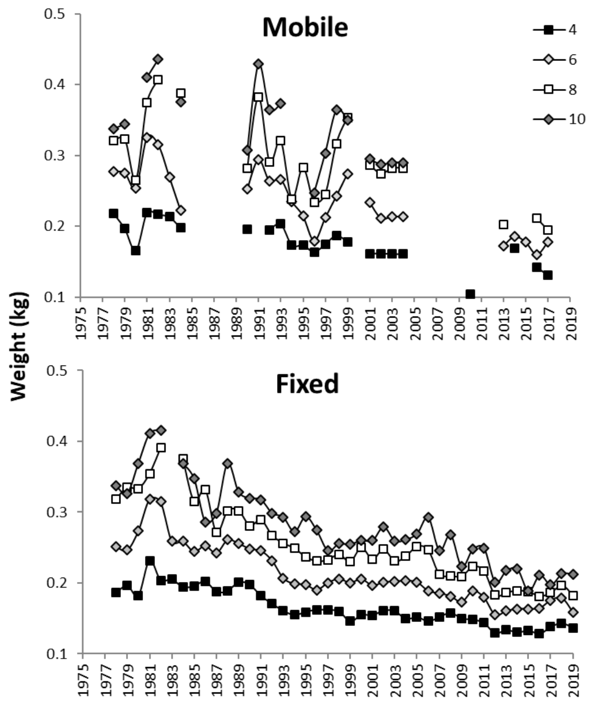

Figure 5. Mean weight-at-age for ages 4, 6, 8 and 10 years of spring spawner herring from the southern Gulf of St. Lawrence sampled from catches during the spring season in the mobile (upper panel) and fixed (lower panel) commercial gears, 1978 to 2019.

Fall spawner component (FS)

The fishery TAC for the fall spawner component is set for the NAFO Division 4TVn stock unit. The preliminary estimated landings of FS herring in 2018 and 2019 were 16,742 t and 15,544 t, respectively (Fig. 6). The TAC was 25,000 t in 2018 and 22,500 in 2019. In 2018, 66% of the FS TAC was attained. In 2019, 70% of the TAC was attained. With few exceptions, over the 1978 to 2019 period, most of the FS herring were estimated to have been landed by the fixed gear fleet. In 2018 and 2019, the fixed gear fleet was estimated to have landed 91% and 93%, 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, 22% to 100% during 2018 to 2019 (Fig. 6).

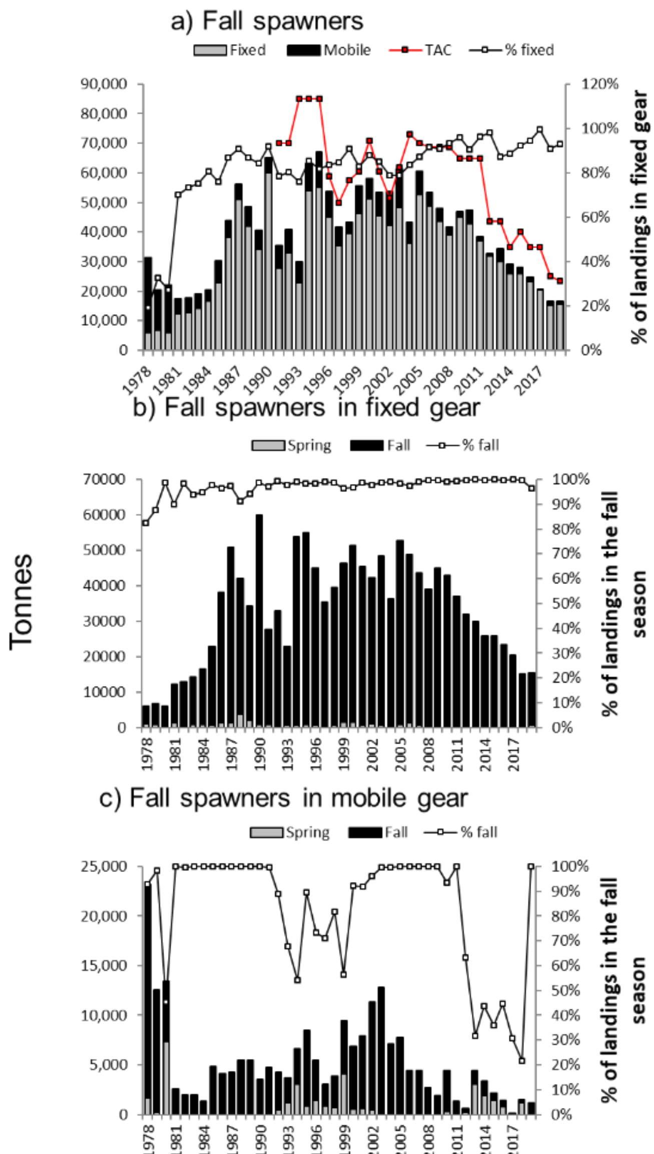

Figure 6. Estimated landings (tonnes) of the fall spawner component (FS) of Atlantic Herring from the southern Gulf of St. Lawrence, 1978 to 2019. The upper panel shows the estimated landings by gear type, the proportion of the landings attributed to the fixed gear fleet, as well as the FS herring TAC (red symbols) for 1991 to 2019. The middle panel shows the estimated landings of FS herring in the fixed gear fleet that occurred in the spring fishery season and in 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 Division 4Vn were attributed to the fall fishing season. Data for 2018 and 2019 are preliminary.

Catch-at-age and weight-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 NAFO Division 4T were attributed to the region which is most proximate to the location of capture. Catches made in NAFO Division 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 sGSL 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 for both gears combined are presented in Figure 7. The catches of younger ages (less than 6 years) have decreased in the last decade.

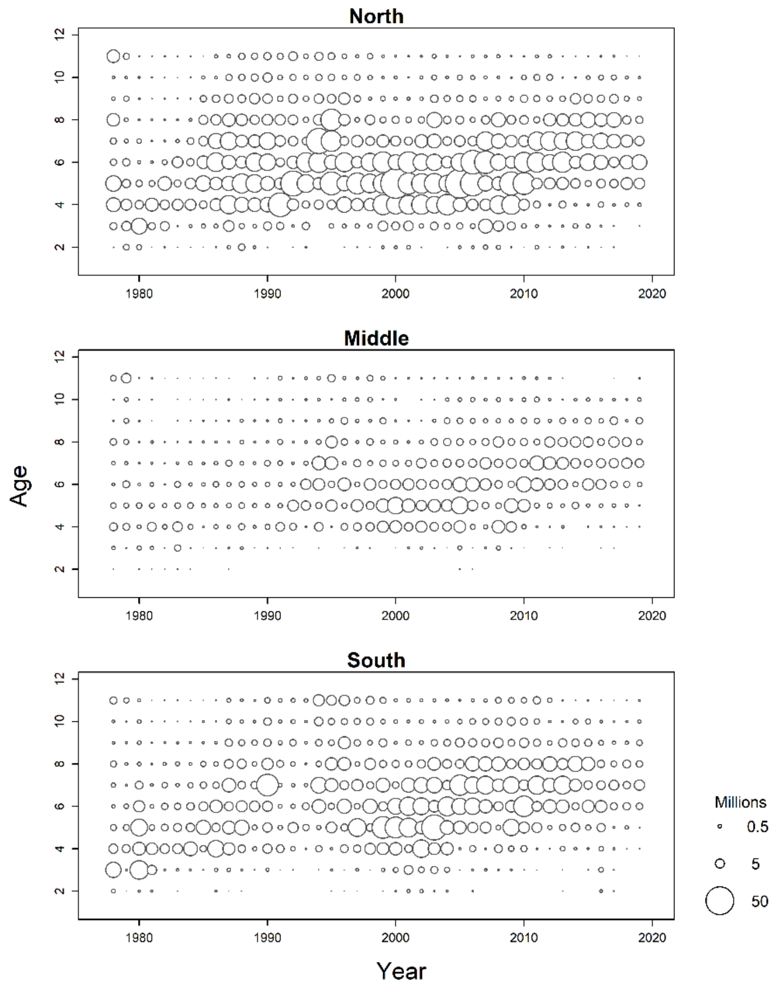

Figure 7. Bubble plots of fishery catch-at-age (number) by region for both mobile and fixed gear combined, 1978 to 2019. The size of the bubble is proportional to the number of fish in the catch by age and year. The values indicated at age 11 represent catches for ages 11 years and older.

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). The mean weight-at-age declined by 32% between 1978 and 2019. For a given number of fish, lower mean weights result in lower stock biomass when numbers are converted to weight.

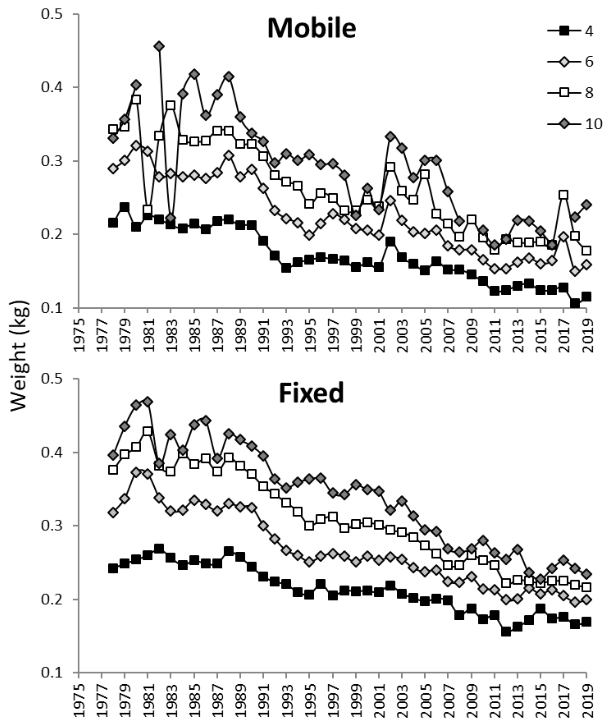

Figure 8. Mean weights-at-age for ages 4, 6, 8 and 10 years of fall spawner herring from the southern Gulf of St. Lawrence sampled from catches in the fall season by the mobile (upper panel) and fixed (lower panel) gear fleets, 1978 to 2019.

ASSESSMENT

The SS herring and FS herring of the sGSL are distinct stocks and are assessed separately. The assessments use Statistical Catch at Age (SCA) models based on fishery catch-at-age, fishery dependent, and fishery independent indices of biomass. The fishery TAC, and therefore the advice for catch options 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, spring fish harvesters felt that abundances had remained consistent with previous years, however for the fall fishery there was an overall sense that abundance decreased across regions.

Fishery independent acoustic survey (SS and FS herring)

An annual fishery-independent acoustic survey of early fall (September-October) aggregations of herring in the sGSL has been conducted since 1994. The standard annual survey area occurs in the NAFO Division 4Tmno areas (16B; Fig. 1) where sGSL herring aggregate in the fall.

The 2018 and 2019 acoustic biomass index of the surveyed area for SS and FS combined were 23,313 t, and 18,826 t, respectively. In 2018, the biomass was composed of 35% SS and 65% FS. In 2019, the biomass was composed of 38% SS and 62% FS.

Population models fit to proportions-at-age 4 to 8 for the SS herring component and to ages 2 and 3 for the FS herring component; the acoustic survey provides a useful abundance index of FS recruiting herring at ages 2 and 3 only. Populations models also fit to age-aggregated biomass indices for both components.

Fishery dependent commercial catch-per-unit-effort (CPUE) (SS and FS herring)

Fixed gear catch and effort data were used to construct age-aggregated biomass indices for SS herring and FS herring, expressed as catch-per-unit-effort (CPUE) with values in kg/net-haul/trip. Population models also fit to proportions-at-age 4 to 10 in the assessments of the SS herring and FS herring. For the SS herring, an index is estimated for the whole sGSL. For the FS herring, indices are calculated for each of the North, Middle, and South regions.

Fishery independent experimental gillnet indices (FS herring)

Experimental gillnets, consisting of multiple panels of varying mesh size, were fished approximately weekly by fish harvesters 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 mesh sizes that varied among fish harvesters. The nets were set during the commercial fishery on the fishing grounds.

A relative selectivity index was developed to account for changes in the proportion of 2⅝", and 2¾" meshes used by commercial fish harvesters, as well as changes in mean length-at-age which have generally decreased over time.

Previous assessments included region-specific age-disaggregated abundance indices from experimental net data. Preliminary work on SCA models showed that this index showed poor fit, some blocking in the residual proportions-at-age, and a lack of trend. The age-aggregated abundance index was thus not used in this assessment. However, the proportions-at-age information was used and the fall spawning herring population models fit to proportions-at-age 3 to 9 in the experimental nets catch.

Fishery independent September bottom trawl survey (FS herring)

This sGSL research vessel (RV) survey 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 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 2019 for this assessment. The fall spawning herring population models fit to proportions-at-age 4 to 6 and to the age-aggregated biomass index from this survey.

In the previous assessment, the index from the RV survey was calculated by first correcting for a diel effect in survey catches. In recent years, and following on the collapse of groundfish stocks, it was noted that herring remained associated with the bottom even at night (McQuinn 2009) and as a result the diel effect correction factor was generating very high and likely biased indices of abundance. For this assessment, stratified mean catch at age indices were calculated without the diel effect correction. The trends in this relative index are similar to the previous index (McDermid et al. 2018).

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 2019 (Fig. 9). The index was highest in the mid-1990s and subsequently declined and remained at low levels in the 2000s.

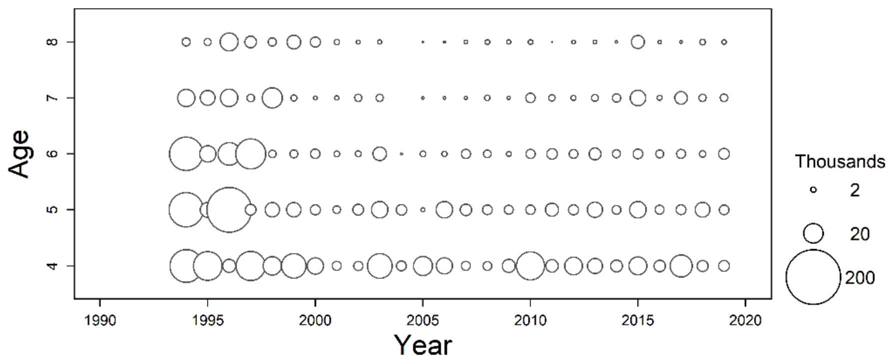

Figure 9. Bubble plot of abundance-at-age (number) from the fisheries-independent acoustic survey for herring spring spawners (SS; ages 4 to 8) in the southern Gulf of St. Lawrence, 1994 to 2019.

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).

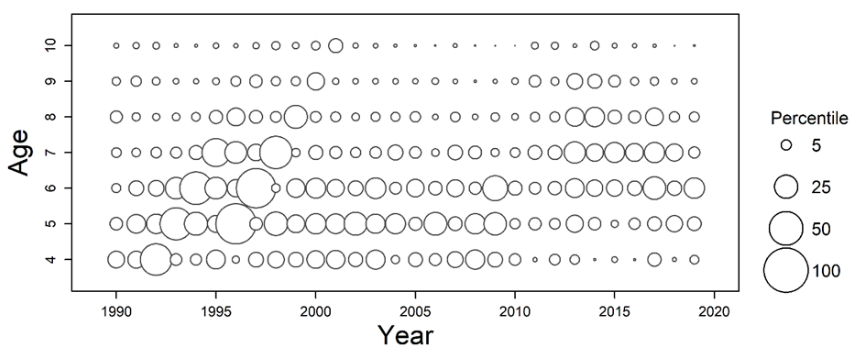

Figure 10. Bubble plot of spring spawning herring fixed gear catch-per-unit-effort values (number per net-haul per trip) at age in the southern Gulf of St. Lawrence, 1990 to 2019. The size of the bubble is proportional to the maximum CPUE index value.

Population model

For this assessment, a SCA model with time-varying natural mortality and time-varying catchability to the fixed gear fishery was used. The SCA model inputs include fishery catches at ages 2 to 11+ from 1978 to 2019 in proportions-at-age (PAA), catch-per-unit-effort (CPUE) index PAA, age-aggregated CPUE biomass index from 1990 to 2019 (ages 4 to 10), and fishery-independent acoustic survey index PAA and age-aggregated biomass index from 1994 to 2019 (ages 4 to 8).

Catchability to the fishery, defined as the proportion of the stock removed by a unit of fishing effort, averaged about 0.002 in the 1990s, increasing to 0.006 from 2006 to 2019 (Fig. 11). Estimated catchability increased as the stock declined (Fig. 11).

Figure 11. Estimated fully-recruited catchability (q) to the CPUE index of the spring spawner component of herring (left panel) and fully-recruited catchability to the spring spawner gillnet fishery in relation to spring spawner April 1 SSB (right panel). In the left panel, the line shows the median estimates and light shading the 95% confidence interval (50% confidence interval in darker shading).

Natural mortality estimates for ages 2-6 vary between 0.24 and 0.53 over the time series (between 21% and 41% annual mortality). For ages 7-11+, natural mortality increased gradually from 0.29 to 0.52 between 1978 and 2005 (between 25% and 41% annual mortality). Beginning in 2011, natural mortality increased sharply to peak at 1.03 in 2018 and 2019 (64% annual mortality; Fig. 12).

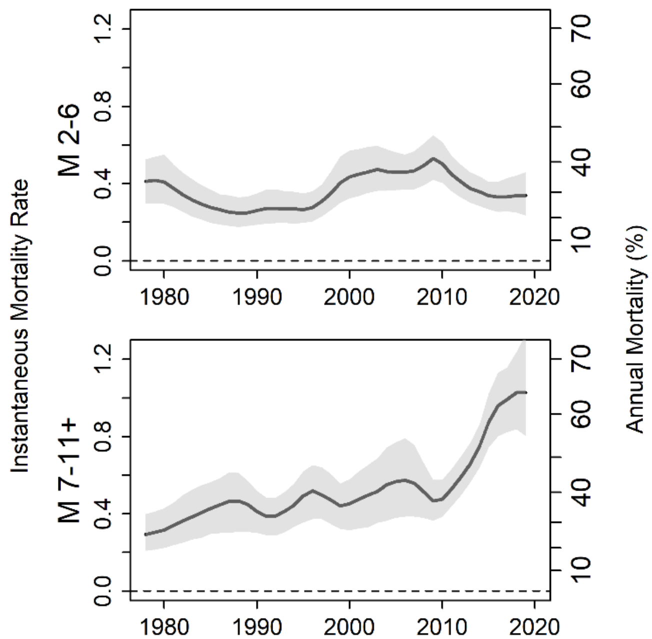

Figure 12. Estimated instantaneous natural mortality rate (left axis) and annual mortality (%, right axis) of spring spawning Atlantic Herring from the population model, for ages 2 to 6 (upper panel) and 7 to 11+ (lower panel). Lines show the median estimates and shading their 95% confidence interval based on MCMC sampling.

Recalculating the reference points

The limit reference point (LRP) for sGSL herring is $B_{recover}$, which is 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, 1980 to 1983 (DFO 2005). If the model changes, stock biomass may be re-scaled upwards or downwards. With the model change in 2020, SSB was scaled upwards. The revised LRP is 47,250 t, which is 245% higher than the former value of 19,250 t. The upper stock reference (USR) was re-scaled upwards by the same proportion as the LRP thus increasing the USR from 54,000 t to 132,546 t. The LRP and USR values were calculated to April 1 to account for three months of natural mortality for both age groups. The fishing removal reference in the Healthy Zone, previously defined as $F_{0.1}$ corresponding to F = 0.35, is unchanged from the previous assessment (DFO 2005).

Spawning stock biomass and exploitation rate

Estimates of Spawning Stock Biomass (SSB; ages 4+) in this assessment are presented for the start of the fishing season (April 1) to account for three months of natural mortality. SSB estimates were higher than those estimated in the previous assessment because natural mortality estimates from the SCA model are higher than the previously assumed value of M = 0.2 (DFO 2018; McDermid et al. 2018). However, the stock remains in the Critical Zone of the Precautionary Approach (Fig. 13). The estimates of SSB in 2018 and 2019 were 40,134 t (95% confidence interval: 26,119 – 63,709) and 33,010 t (95% CI: 21,014 – 53,709), respectively. The median estimate for 2019 is 70% of the LRP. The probabilities that the predicted SSB was under the LRP were 82% in 2018 and 91% in 2019 (Fig. 13).

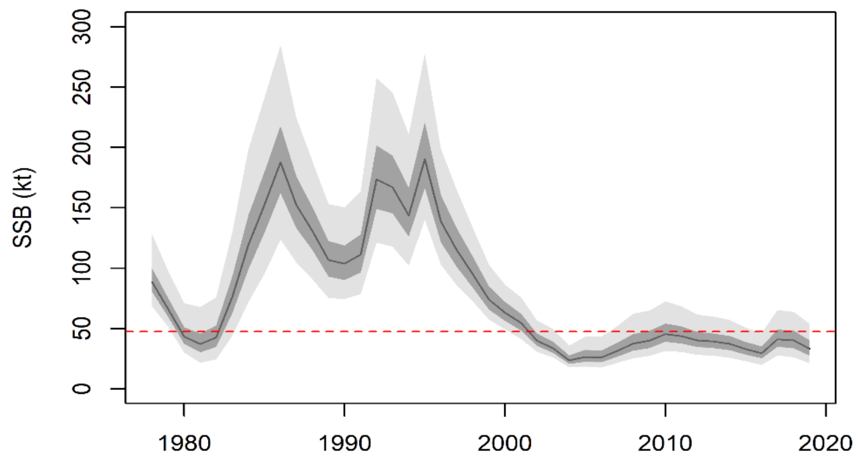

Figure 13. Estimated beginning of the fishing season (April 1) spawning stock biomass (SSB) of the spring spawner component of herring in the southern Gulf of St. Lawrence, 1978 to 2019. The solid line is the median MCMC estimate, the light shading its 95% confidence interval, and the dark shading the 50% confidence interval. The red horizontal dashed line is the Limit Reference Point (47,250 t of SSB).

Estimated exploitation rates were high in 1978 to 1980 and from 1999 to 2006. Since 2010, exploitation rates have remained at low levels (Fig. 14). Fishing mortality was 0.041 and 0.047 in 2018 and 2019, respectively (annual mortality 4% and 5%).

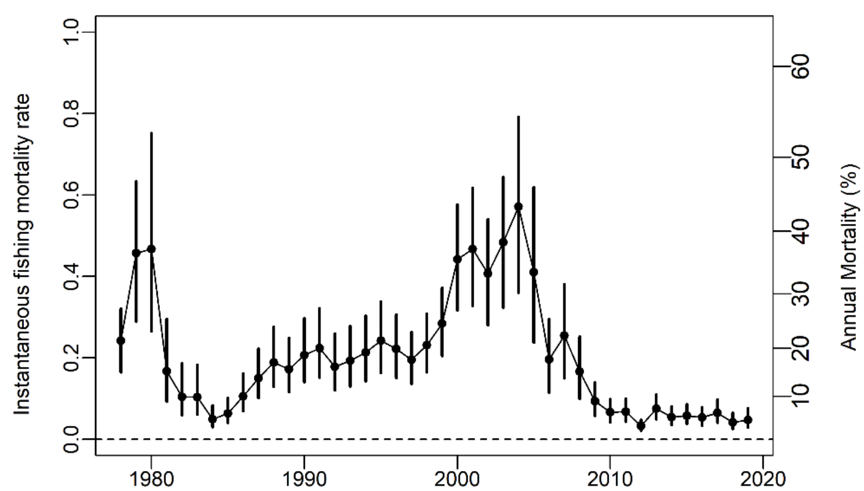

Figure 14. Estimated January 1 ages 6 to 8 fishing mortality ($F_{6\text{-}8}$, left axis; annual exploitation rate, right axis) of spring spawning herring in the southern Gulf of St. Lawrence. Circles are the median estimates and vertical lines their 95% confidence intervals.

Recruitment and recruitment rates

Estimated recruitment (number of age 2 fish) was highest in the early 1980s, 1990, and 1993 (Fig. 15). Recruitment has been relatively stable at lower values since 1993, with slightly higher values between 2005 and 2008. Recruitment declined to the lowest values of the time-series after 2008 up to 2019, except a small peak in 2015. Estimated abundances of age 4 herring were highest in the mid-1980s, 1992, and 1995 but have remained relatively low since 2000 (Fig. 15). The median estimate of spring spawner (4+) abundance for 2019 is 245.8 million herring (95% CI: 156.4 – 398.2), about 35% of the average spawner abundance in 1985 to 1995. Recruitment rates followed the same trend, declining from the mid-2000s to 2019, although not reaching the lowest level of the time-series which was estimated in 1992.

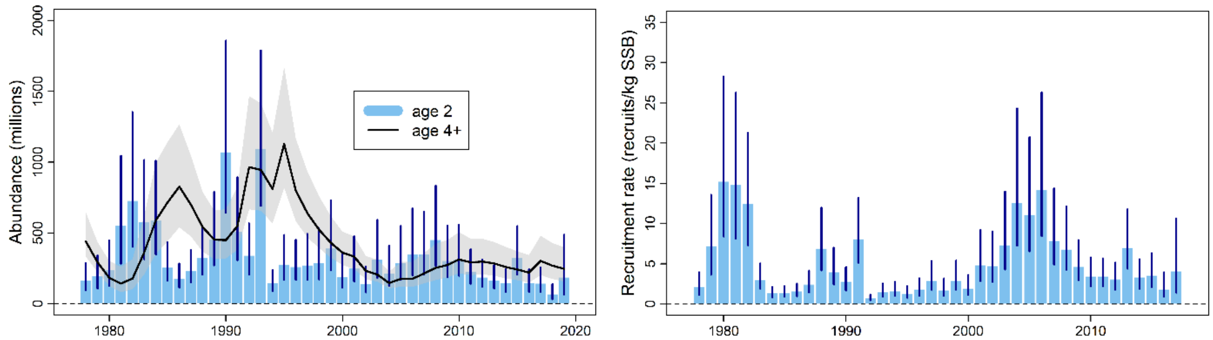

Figure 15. Left panel shows the estimated beginning-of-year (January 1) abundance of age 2 year old herring (blue bars), and herring age 4 years and older (black line) of the spring spawner component in the southern Gulf of St. Lawrence. The black line shows the median MCMC estimate and vertical lines and shading show the 95% confidence intervals. The right panel shows recruitment rates at age 2, as numbers per kg of SSB, for the 1978 to 2017 cohorts of spring spawning Atlantic Herring of the southern Gulf of St. Lawrence. The vertical lines indicate the 95% confidence intervals.

Projections

The population model was projected forward to April 1 of 2021 and 2022, and 10 years forward to 2029. Projections were conducted at several levels of annual catch (0, 250, 500 and 1,250 t). Projections were conducted using the average recruitment values of the last five years (2015-2019). Natural mortality for ages 2-6 has been stable for the last five years. For ages 7-11+, natural mortality has increased in the last decade to highest values in 2018 and 2019. Projections were conducted using the average of the 2018-2019 M values for each age group.

SSB was projected to decline from 2020 to 2022 at all annual catch levels from 0 to 1,250 t (Fig. 16). The probability of a 5% or greater increase in SSB between 2020 and 2022 was 32% to 33% for all catch levels (Fig. 16; Table 1).

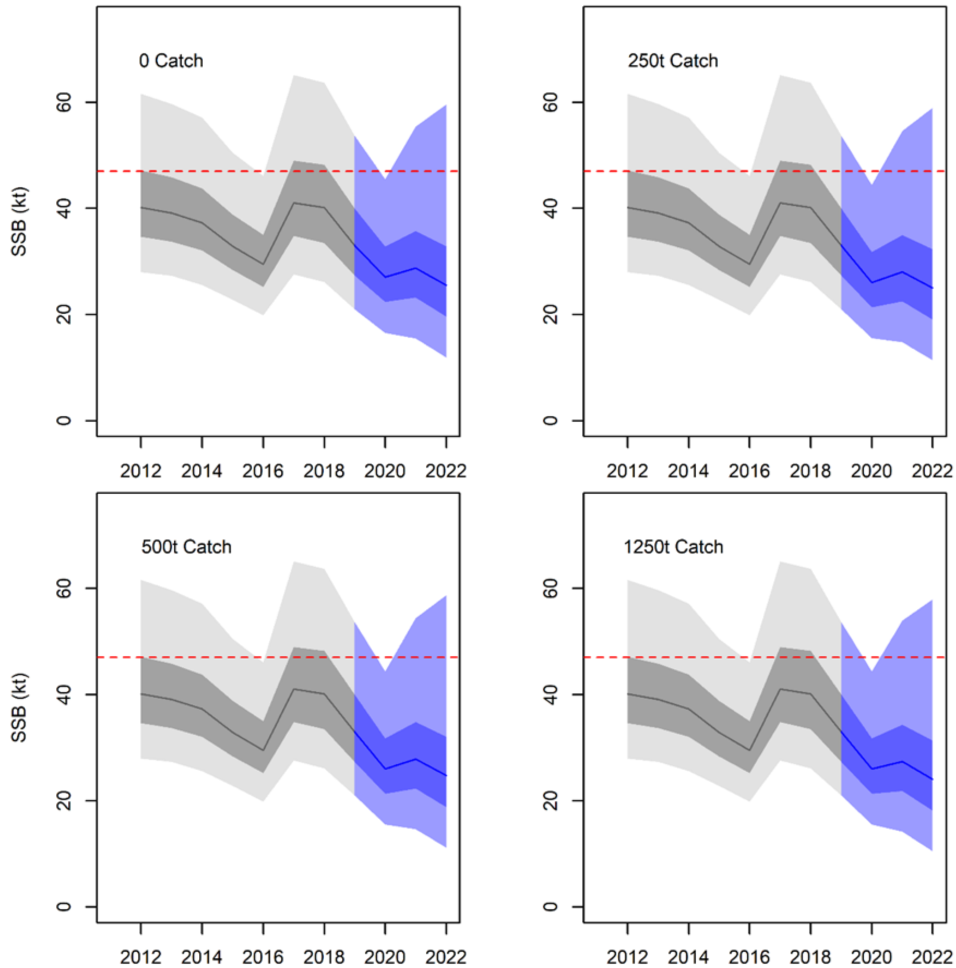

Figure 16. Projected spawning stock biomass (SSB in kt) of spring spawning Atlantic Herring from the southern Gulf of St. Lawrence at various catch levels in 2020 and 2021. Lines show the median estimates of the beginning of fishing season (April 1) SSB, light shading the 95% confidence intervals, and dark shading the 50% confidence intervals of these estimates (based on MCMC sampling). Black and grey indicate the historical period and blue the projection period. The red horizontal line is the limit reference point (LRP). SSB and LRP values are adjusted to April 1 by correcting for natural mortality estimates at age for 3 months.

Risk analysis of catch options

At all catch levels (including no catch) it was unlikely (0-33%) that SSB would exceed the LRP at the start of the 2022 spring fishing season (7% at 0 t of catch, 6% at 250 to 1,250 t) (Table 1). By 2029, the probability that SSB will exceed the LRP even with no catch is 0% (Table 1). There is 0% probability that SSB will be at or above the Upper Stock Reference (USR) in 2022 even with no catch (Table 1).

By 2021, the ages 6 to 8 fishing mortality increases from 0.02 at 250 t to 0.13 at 1,250 t.

Ten year projections in SSB show a constant decline over the period 2020 to 2029, with SSB values ranging between 200 t at annual catches of 1,250 t and 1,198 t at no catch by 2029 (Table 1). The downward trend in SSB started in 2010, at the time when natural mortality for the ages 7-11+ group started increasing. The decline in SSB has been constant, except for years with small recruitment peaks.

Table 1. Risk analysis table of annual catch options (between 0 and 1,250 tons) for 2020, 2021 and subsequent years until 2028 for the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence. The table summarizes the following: the projected April 1 adjusted SSB (kt, median) in 2021, 2022, and 2029; probabilities (%) of SSB being greater than the LRP; probabilities of an increase in SSB by 5%; and abundance weighted fishing mortality rate at ages 6 to 8 (median F_{6-8}).

Stock characteristic	Year	Catch option (t)			
		0	250	500	1,250
SSB (kt)	2021	28.2	28.0	27.9	27.4
	2022	25.2	25.0	24.8	24.0
	2029	1.2	1.0	0.7	0.2
SSB > LRP	2021	7%	6%	6%	6%
	2022	7%	6%	6%	6%
	2029	0%	0%	0%	0%
At least 5% increase in SSB	2021	54%	53%	53%	50%
	2022	32%	33%	33%	32%
F_{6-8}	2020	0	0.02	0.04	0.10
	2021	0	0.02	0.05	0.13

Fall Spawner Component (FS)

The FS herring assessment considers three regions (North, Middle, South) which cover the entire NAFO Division 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. 17). 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.

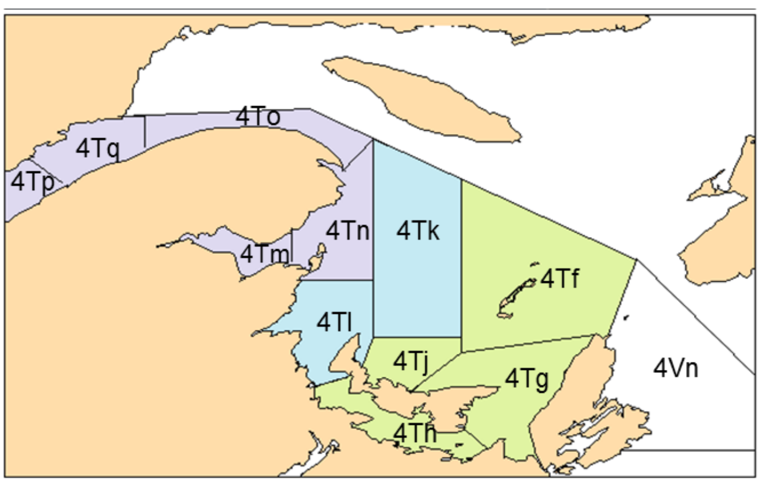

Figure 17. Correspondence between the herring fishing areas and the three regional groups (North in purple, Middle in blue, South in green) used in the assessment of the fall spawner component of Atlantic Herring from the southern Gulf of St. Lawrence. Fishing areas in each region are described in the 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 sGSL (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 and three year olds in 2019 was among the lowest of record (Fig. 18).

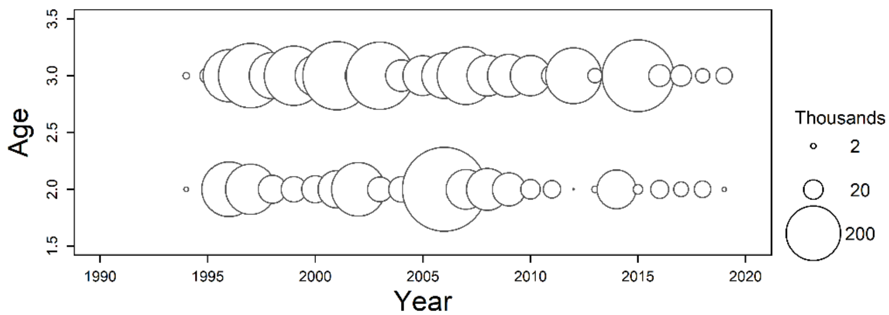

Figure 18. Bubble plot of the index of abundance of fall spawning herring at ages 2 and 3, from the fisheries-independent acoustic survey, 1994 to 2019.

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. 19). Declines in size at age contribute to some of these changes. In the North region, CPUE indices for ages 6 to 8 in 2018 and 2019 remained similar to recent years. CPUE values in the Middle region were higher in 2018 and 2019 than in 2017. In the South region, CPUE values were very low in 2018 but higher in 2019.

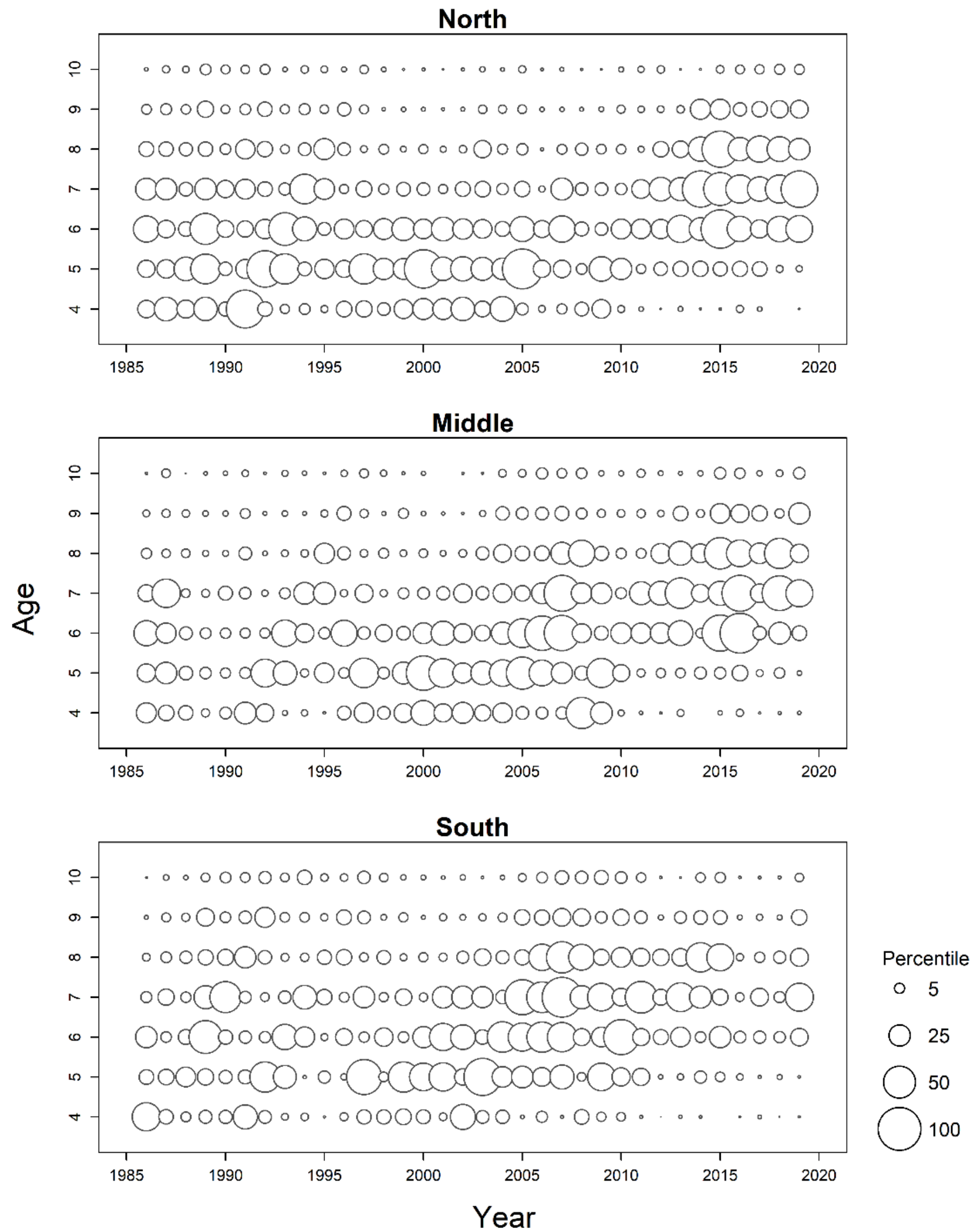

Figure 19. Fall spawner (FS) herring fixed gear age-disaggregated catch-per-unit-effort values (number per net-haul per trip) by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 1986 to 2019. The size of the bubble is proportional to the CPUE index value.

Experimental gillnet indices

Dominant ages in the experimental nets catches for all regions were ages 6 and 7 in 2018 and 2019 (Fig.20).

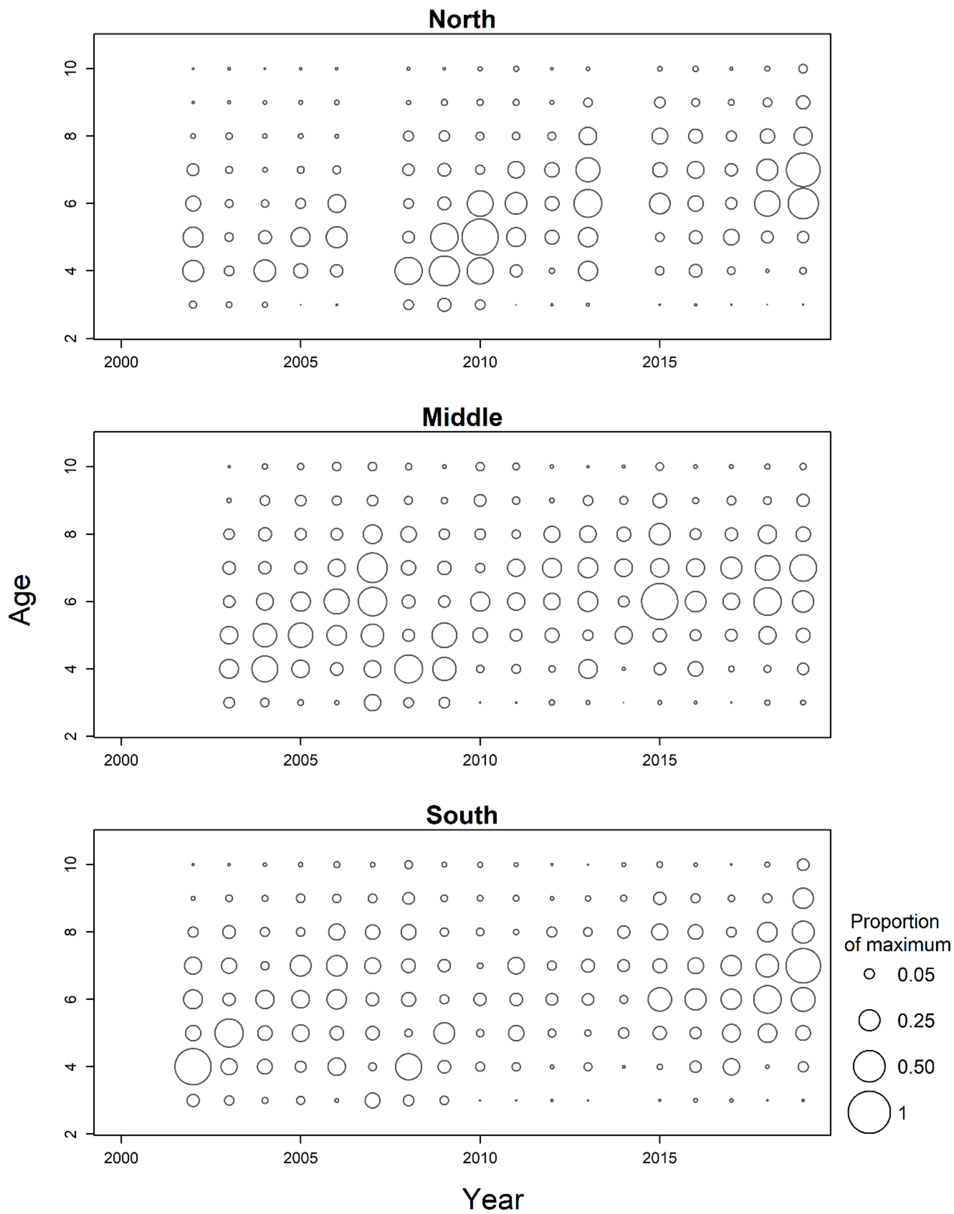

Figure 20. Bubble plots of catch-at-age indices (number) of fall spawning herring from the experimental gillnets by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 2002 to 2019. The size of the bubble is proportional to the index value.

Fishery independent September bottom trawl survey

The index suggests low abundances in the late 1990s, higher abundances of ages 4 and 5 during 2000 to 2005, a decline and low abundances until 2009, high values of ages 4 to 6 during 2010 to 2014, and a steady decline of all ages until 2019 (Fig. 21).

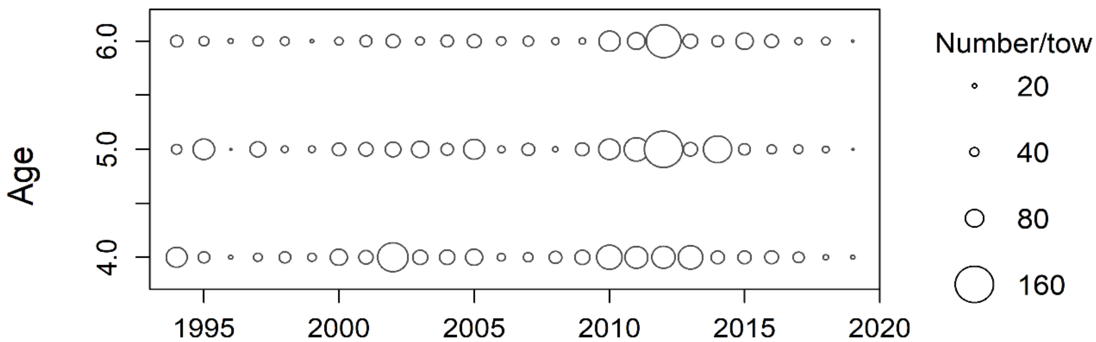

Figure 21. Multispecies bottom trawl survey abundance index (number of fish per standardized tow) for fall spawning herring ages 4 to 6 years in the southern Gulf of St. Lawrence, 1994 to 2019.

Population model

In this assessment, the fall spawning herring component is assessed using two statistical catch-at-age (SCA) models. The first model incorporated time-varying catchability to the fixed gear fishery (qSCA model), and the second model incorporated time-varying catchability and time-varying natural mortality (qmSCA model). Data inputs were fishery catches at age 2 to 11+ by region from 1978 to 2019, in proportions-at-age (PAA), catch-per-unit-effort (CPUE) PAA index and age-aggregated CPUE biomass index by region from 1986 to 2019 (ages 4 to 10), proportions-at-age in experimental nets by region from 2002 to 2019 (ages 3 to 9), fishery-independent acoustic survey PAA and age-aggregated biomass index from 1994 to 2019 (ages 2 and 3), multispecies bottom trawl survey (RV survey) PAA index and age-aggregated biomass index across the sGSL from 1994 to 2019 (ages 4 to 6). 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 2⅝" mesh in each region in each year (Fig. 22) and relative selectivity to the gillnet fishery by age, year, and mesh size. As a result of the changes in size at age over time, the relative selectivity in the two main gillnet mesh sizes used in the fixed gear fishery have also changed over time.

Figure 22. Variations by region in the proportions of gillnets with mesh sizes 2⅝" used in the fall herring fishery season in the southern Gulf of St. Lawrence, 1986 to 2019. It is assumed that all other nets used were of mesh size 2¾".

Time-varying natural mortality (M) and catchability to the CPUE gillnet fishery (q) were estimated independently for each region (North, Middle, South) using the same method described for the spring spawner model.

The two SCA models were peer-reviewed in a separate meeting. A best model could not be identified based on model diagnostics, as the qmSCA showed better fit to indices, but the qSCA showed lesser retrospective patterns. Hence, both models are shown in the assessment, but their respective weaknesses need to be considered. The qSCA model may result in biased estimates of SSB as it does not account for changes in natural mortality, which is estimated to have occurred over the time series. This model then provides over-optimistic SSB projections in the short-term, as natural mortality removals are underestimated. Also, this model showed important retrospective patterns in the North and Middle regions. The qmSCA model is also biased as SSB is underestimated every year, as seen in the retrospective analysis pattern.

Estimated changes in catchability (q) to the gillnet fishery are generally higher in the qSCA, compared to the qmSCA model (Fig. 23).

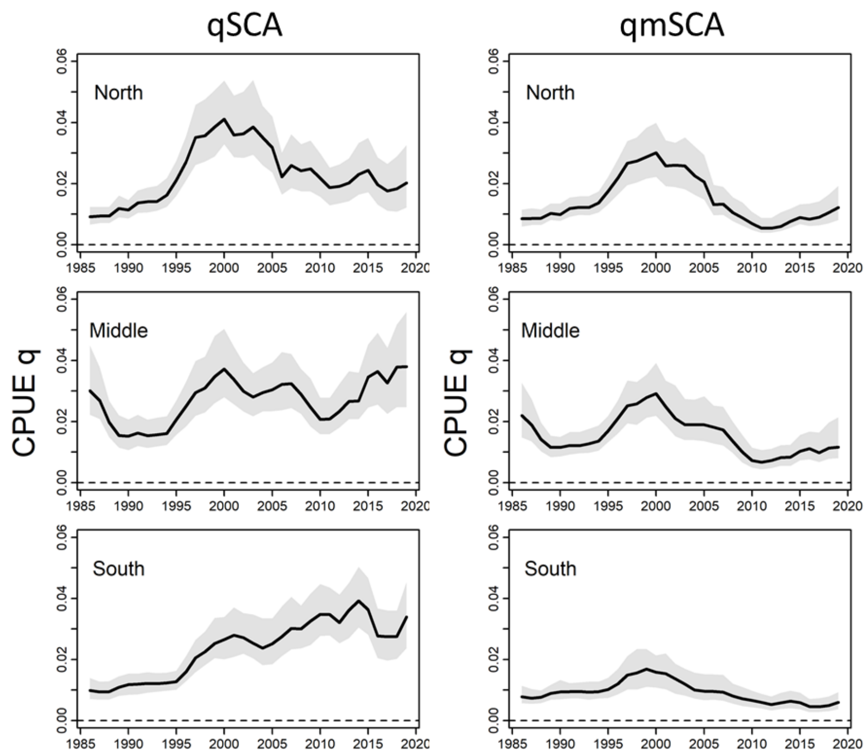

Figure 23. Estimated fully-recruited catchability (q) of fall spawner herring to the fall gillnet fishery in three regions (North, Middle and South) of the southern Gulf of St. Lawrence, 1986 to 2019 for the qSCA (left panel) and qmSCA (right panel) models. Lines show the median estimates and shading their 95% confidence intervals based on MCMC sampling.

Natural mortality (M) was fixed at 0.2 for the qSCA model. For the qmSCA model, estimated M trends over time are similar within age groups among regions (Fig. 24). For ages 2-6 natural mortality is lowest in the North region. M is stable in the early time series at 0.2 in the North and 0.4 in the Middle and South, followed by a gradual decline around 1990, to reach similarly low values in all regions in 2019. For the 7-11+ age group, estimates from all regions increase gradually from around 0.2 at the beginning followed by a sharp increase starting in 2004 to reach maximum values of 0.98 in the North in 2017, 0.75 in the Middle in 2016, and 0.99 in the

South region in 2016. Estimated values declined slightly but remained at high levels in recent years in all regions (between 48% and 58% annual mortality).

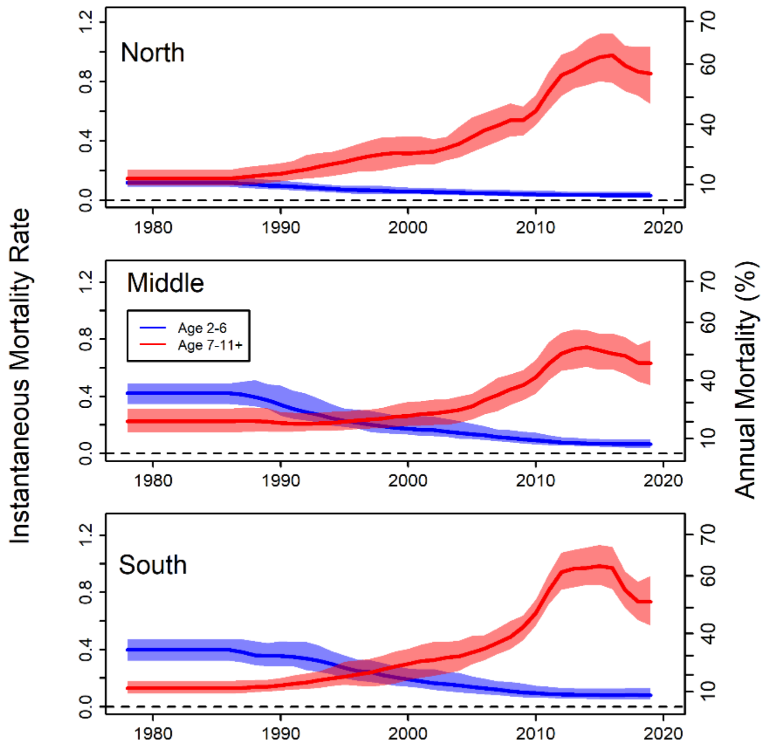

Figure 24. Estimated instantaneous natural mortality rate (left axis) and annual mortality (%, right axis) of fall spawning Atlantic Herring for three regions (North, Middle, South) of the southern Gulf of St. Lawrence, from the qmSCA population model. The estimates for ages 2 to 6 are shown in blue and the estimates for ages 7 to 11+ are shown in red. The lines are the median estimates and the shading their 95% confidence interval based on MCMC sampling.

Recalculating the reference points

The limit reference point (LRP) for sGSL fall spawning herring is $B_{recover}$, which is 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, 1980 to 1983 (DFO 2005). If the model changes, stock biomass may be re-scaled upwards or downwards. With the model change in 2020, SSB was scaled upwards. Consequently, this value is model dependent. If the model changes, stock biomass may be re-scaled upwards or downwards. With the model change in this assessment, there was a change in biomass in the 1980s in both models, as expected. The revised LRP from the qSCA model is 45,589 t, a lower value than the former value of 58,000 t. The revised LRP from the qmSCA model is 52,825 t.

The previously defined USR value of 172,000 t represented 60% of maximum SSB, therefore 60% of maximum SSB was used to calculate a revised USR of 120,034 t for the qSCA model. For the qmSCA model, USR was calculated as 60% of maximum SSB for two time periods: a lower mortality period (1978 to 2001) and a high natural mortality period (2002 to 2019). The USR for the low mortality period is 141,730 t of SSB and the USR for the high mortality period is 335,345 t. The LRP and USR were adjusted to August 1, corresponding to the beginning of the fall spawner fishery, to account for seven months of natural mortality for both age groups. The fishing removal reference in the Healthy Zone was previously defined as $F_{0.1}$ and this assessment used a value of F = 0.32 as in previous assessments (DFO 2005).

Spawning stock biomass and exploitation rate

Estimated August 1 SSB trends are similar between models before the 2000s, but differ afterwards (Fig. 25). In the North region, SSB 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. The SSB increased slightly between 2000 and 2016 in the qSCA but declined over the period 2017 to 2019. In the qmSCA model, SSB increased during 2008 to 2013 but declined rapidly during 2014 to 2019. In the Middle region, estimated SSB increased gradually from 1980 to the late 2000s, but declined consistently during 2010 to 2019. SSB in the South region was at a relatively high level from about the mid-1980s to the late 2000s. In the South region, the qSCA, model estimated a decrease in SSB beginning in 2004 to low levels in 2019. In the qmSCA model, SSB was estimated to have increased to a maximum in 2010 before decreasing rapidly to a low level in 2019.

Summed over the three regions, the qSCA model median estimate of total August 1 SSB in 2018 was 79,989 t (95% CI: 68,248 – 98,523 t) and 63,478 t in 2019 (95% CI: 52,374 – 80,692 t). The 2019 SSB was 138% of the LRP. For the qmSCA model, the median estimate of total SSB in 2018 was 211,069 t (95% CI: 167,960 – 256,845 t) and 174,161 t in 2019 (95% CI: 135,029 – 212,670 t). The 2019 SSB was 330% of the LRP. The estimated probabilities that total SSB was above the USR was 0% in 2019 and 2020 for both models. The estimated probabilities that total SSB was below the LRP was 0% in 2019 and 2020 for both models. Both models indicate that the stock is in the Cautious Zone.

The trend in estimated beginning-of-the-year fishing mortality for ages 5 to 10 ($F_{5\text{-}10}$) is similar for the qSCA and qmSCA models (Fig. 26). As SSB estimates are higher in the qmSCA model, $F_{5\text{-}10}$ estimates are therefore lower. Fishing mortality has declined in the North region since 2008, but in the Middle and South regions $F_{5\text{-}10}$ remained relatively high and consistent until 2019. The average $F_{5\text{-}10}$ over all three regions (weighted by regional abundance of 5 to 10 year olds) was highest in 1980, declined in the early 1980s until the early 1990s, to increase again to reach 0.78 in 1995. Total average $F_{5\text{-}10}$ then declined until 2019.

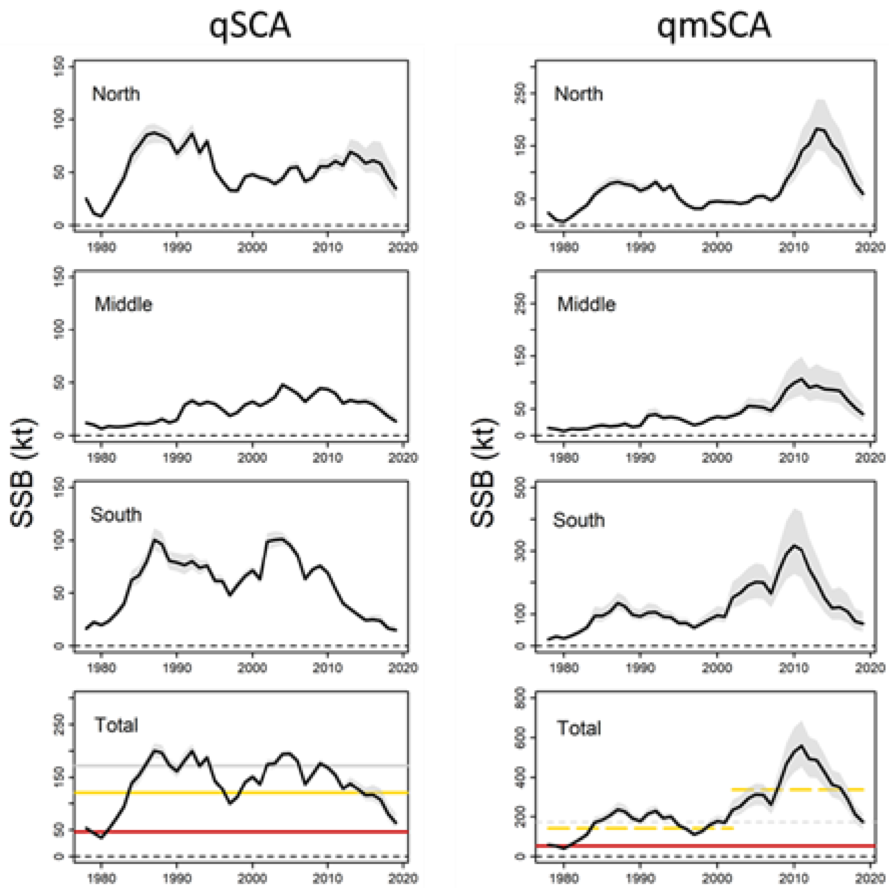

Figure 25. Estimated beginning of fishing season (August 1) spawning stock biomass (SSB) of fall spawning herring by region and overall (Total) for the southern Gulf of St. Lawrence for the qSCA (left panel) and qmSCA (right panel) models. The line shows the median estimates and the shading their 95% confidence intervals. In the bottom panels for Total, the solid and dashed yellow horizontal lines represent the upper stock reference level (USR) and the red horizontal line is the limit reference point (LRP). The grey horizontal line is the USR from the previous assessment. SSB, USR and LRP values are adjusted to August 1 using natural mortality estimates at age for 7 months.

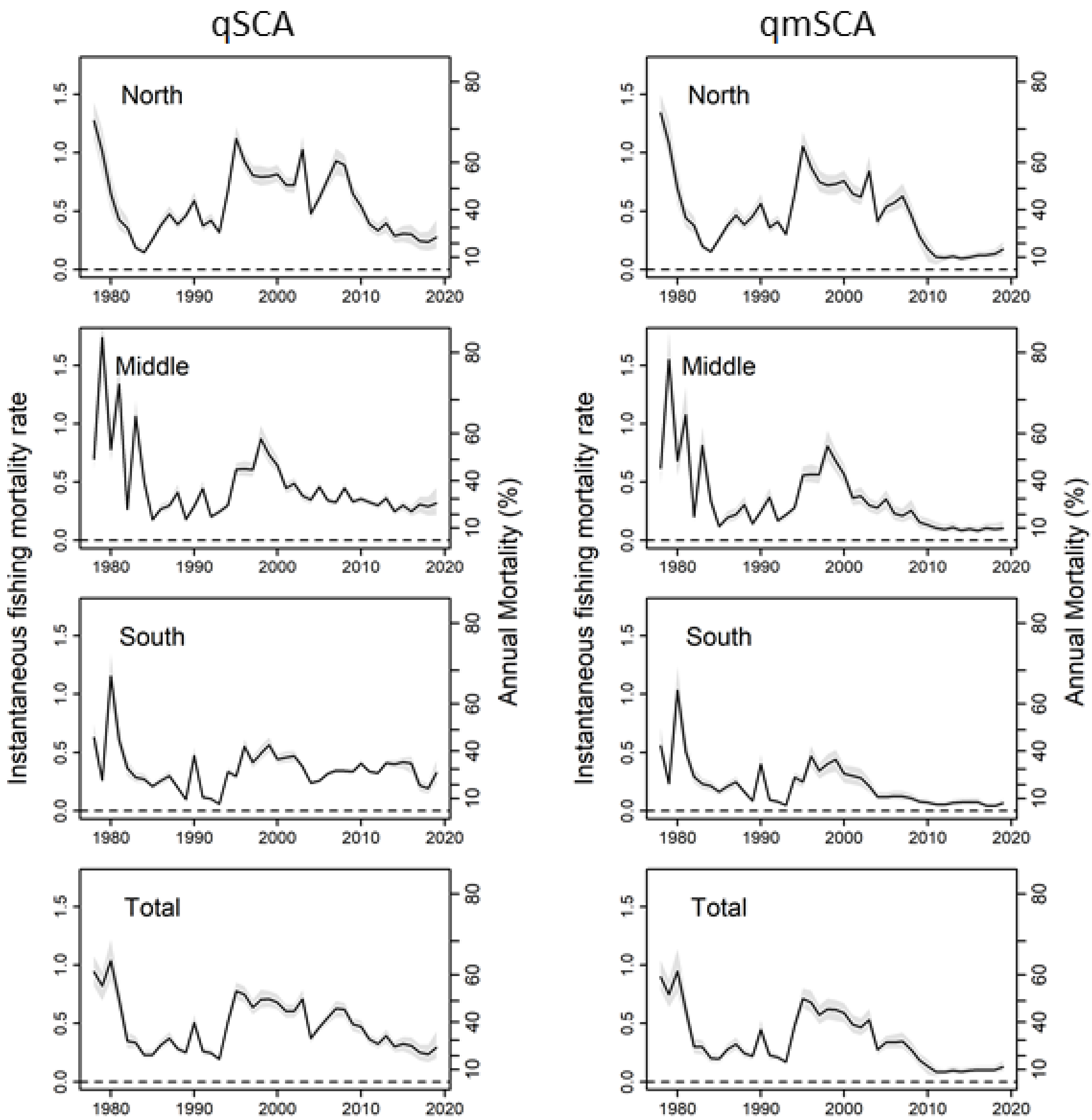

Figure 26. Estimated beginning-of-the-year (Jan. 1) age 5 to 10 fishing mortality ($F_{5\text{-}10}$, left axis; annual exploitation rate, right axis) of fall spawning herring by region and averaged over regions (weighted by region-specific abundances at ages 5-10 years) in the southern Gulf of St Lawrence for the qSCA (left panel) and qmSCA (right panel) models. Lines show the median estimates and shading their 95% confidence intervals.

Recruitment and recruitment rates

The most recent estimates of recruitment (number of age 2 fish) were among the lowest observed over the time series in all three regions in both the qSCA and qmSCA models (Fig. 27). Uncertainty is high in the age 2 recruit estimates for 2019. Estimated abundances of FS age 4 and older have declined in all regions and for both models since 2007 (Fig. 27). To a large extent, this reflects reductions in the recruitment of 2-year-old herring. The recruitment rate declines followed the same trends in the last decade. For the qSCA model, the median MCMC estimate for spawner abundance (age 4+) in 2019 was 357 million fish (95 % CI : 258 to

503 million). For the qmSCA model, the median MCMC estimate for spawner abundance (age 4+) in 2019 was 966 million fish (95% CI : 654 to 1,424 million).

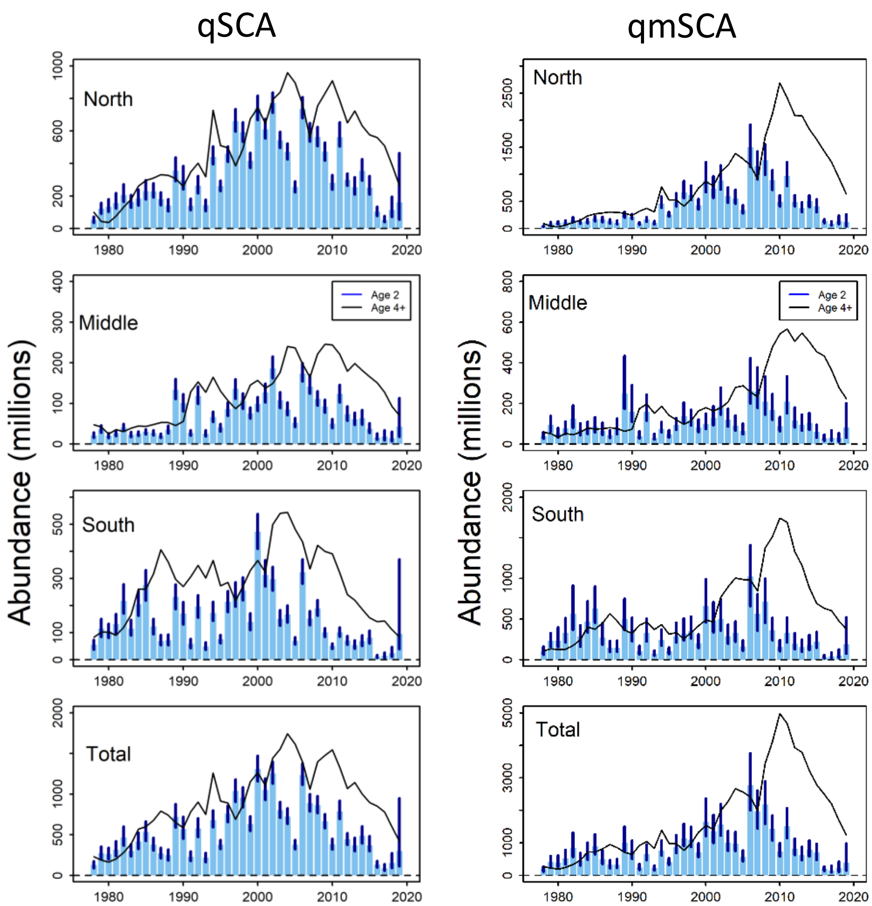

Figure 27. Estimated beginning-of-the-year (Jan. 1) recruitment of age 2 fish (bars, abundance in millions) and age 4+ (line) for fall spawning herring by region and summed (Total) over regions in the southern Gulf of St. Lawrence, for 1978 to 2019 for the qSCA (left panel) and qmSCA (right panel) models. Vertical lines are the 95% confidence intervals.

Projections

The projections of the qmSCA model are more precautionary and more realistic given our knowledge of predator abundance and the likely consequences on natural mortality. Advice for catch options is provided based on the qmSCA model. The fishery TAC for the fall spawner component is set at the level of the entire sGSL. The population models were projected forward for two years to the start of the 2021 and 2022 fishing seasons (August 1) and 10 years forward to 2029. Projections were conducted at annual catch options between 2,000 and 24,000 t (Fig. 28). These projections incorporated uncertainty in parameter estimates. Projections were conducted using the average recruitment values of the last five years (2015 to 2019). For the qmSCA, natural mortality for ages 2-6 has been stable for the last five years. Projections were conducted using the average of the 2018 and 2019 M values of each age group.

In the qSCA projections, SSB was expected to increase slightly from 2020 to 2021 at all catch levels with probabilities of at least a 5% increase in SSB of 52% to 94%, and to decrease from 2021 to 2022 at all catch levels with probabilities of 5% increase in SSB of 24% to 47%

(Fig. 28). In the qmSCA projections, SSB was expected to decrease at all catch levels from 2020 to 2022 with probabilities of 5% increase in SSB of 23% to 29% (Fig. 28; Table 2).

Risk analysis of catch options

The probability of SSB being in the Healthy Zone (SSB > USR) by 2022 was 0% at all catch levels. The probability of the SSB being in the Critical Zone (SSB < LRP) by 2022 was low at catches under 24,000 t (0%). At all catch levels, it is unlikely (23% to 29%) that SSB will increase by 5% by 2022 (Table 2). At landings equal to the 2019 catch of 16,000 t, projected $F_{5\text{-}10}$ is 0.11 in 2020 and 0.18 in 2021 (Table 2).

Ten years projections in SSB show a constant decline from 2020 to 2029. Both models predict SSB will be in the Critical Zone (SSB < LRP) by 2025.

Table 2. Risk analysis table from the qmSCA model of annual catch options (between 2,000 and 24,000 t) in 2020, 2021, and subsequent years until 2028 for the fall spawner component of Atlantic Herring from the southern Gulf of St. Lawrence. The table summarizes the following: the projected August 1 adjusted SSB (kt, median) in 2021, 2022, and 2029; probabilities (%) of SSB being greater than the LRP; probabilities of an increase in SSB equal to or greater than 5%; and abundance weighted fishing mortality rate at ages 5 to 10 (median, $F_{5\text{-}10}$).

Stock characteristic	Year	Catch option (t)						
		2,000	4,000	8,000	12,000	16,000	20,000	24,000
SSB (kt)	2021	144.4	143.3	141.2	139.5	137.4	135.5	133.6
	2022	131.2	129.4	126.8	123.1	119.9	116.9	114.1
	2029	2.6	1.7	0.6	0.3	0.2	0.1	0.1
SSB > LRP	2021	100%	100%	100%	100%	100%	100%	100%
	2022	100%	100%	100%	100%	100%	100%	100%
	2029	0%	0%	0%	0%	0%	0%	0%
5% increase in SSB	2021	29%	27%	25%	23%	22%	19%	17%
	2022	29%	28%	28%	27%	25%	25%	23%
$F_{5\text{-}10}$	2020	0.01	0.03	0.06	0.08	0.11	0.14	0.18
	2021	0.02	0.04	0.08	0.13	0.18	0.24	0.30

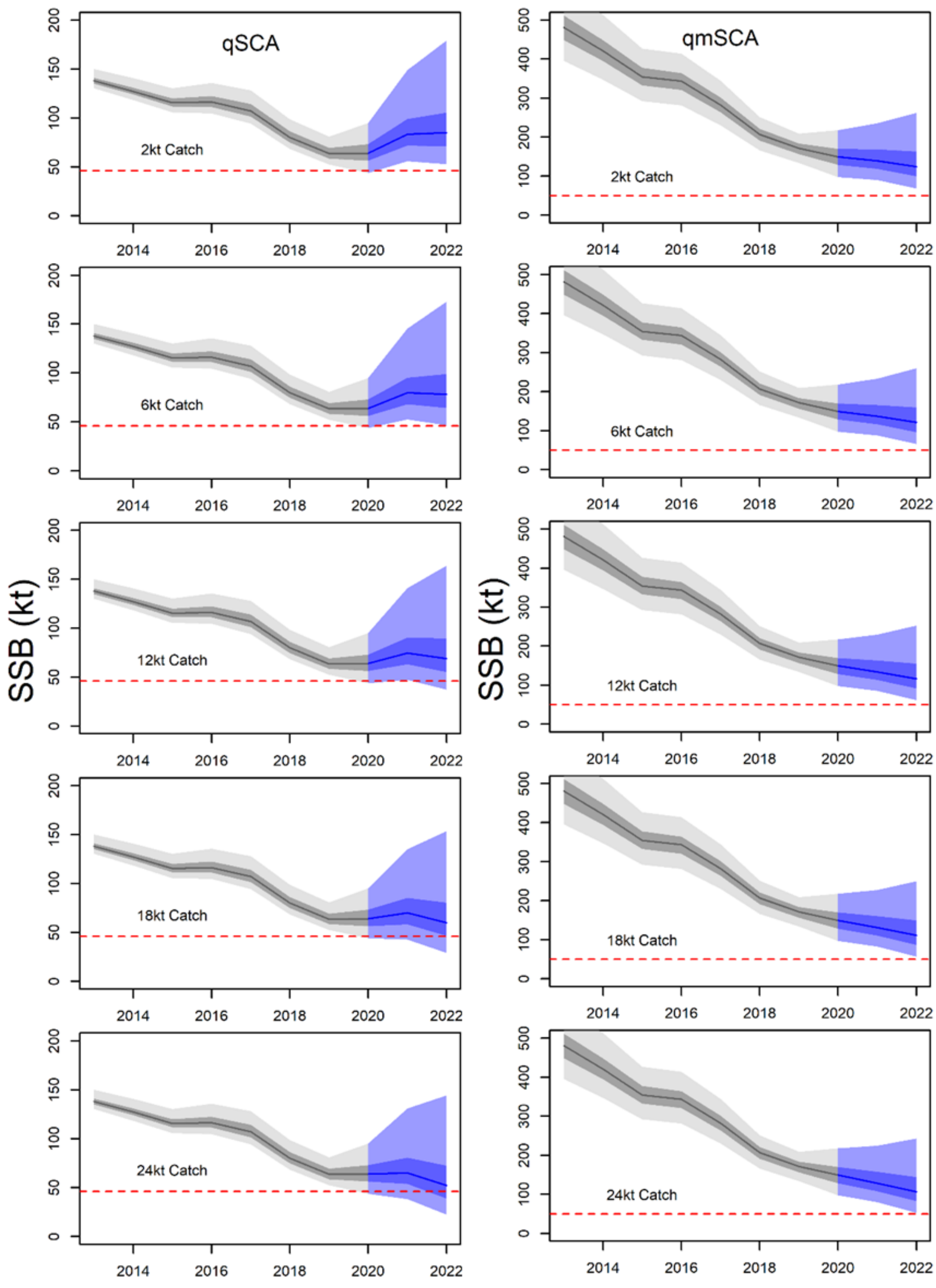

Figure 28. Projected spawning stock biomass (SSB in kt) of fall spawner Atlantic Herring from the southern Gulf of St. Lawrence at various catch levels in 2020 and 2021 for the qSCA (left panel) and qmSCA (right panel) models. Lines show the median estimates of the beginning of fishing season (August 1) SSB, light shading the 95% confidence intervals, and dark shading the 50% confidence intervals of these estimates (based on MCMC sampling). Black and grey indicate the historical period and blue the projection period. The red horizontal line is the limit reference point (LRP). SSB and LRP values are adjusted to August 1 using natural mortality estimates at age for 7 months.

ECOSYSTEM CONSIDERATIONS

Natural Mortality

Natural mortality incorporates predation by all sources, disease, and unreported catches (bait). Herring is a vital pelagic prey species for numerous predators in the sGSL including Grey Seal, seabirds, cetaceans, numerous groundfish including Atlantic Cod and White Hake, and Atlantic Bluefin Tuna (Benoît and Rail 2016). Of these major predators, cod, Grey Seal and Bluefin Tuna abundances have undergone large changes in the sGSL in the past decades. Consequently, natural mortality of herring is expected to also have changed over time. For both the spring spawning and fall spawning components, the estimated increases in natural mortality for ages 7 to 11+ correspond to the increases in the indices of abundance of Grey Seal and Bluefin Tuna in the sGSL, the two most important herring consumers in the sGSL in recent years (Benoît and Rail 2016; Fig. 29). Natural mortality was independently estimated for the three regions in the fall model and for ages 7 to 11+ the pattern in natural mortality was nearly identical across the regions. For the fall spawners, natural mortality of ages 2 to 6 in the three regions correlated with the declining trend seen in the abundance of Atlantic Cod in the sGSL (Fig. 29).

The harvesters have observed high incidences of predation by Grey Seal and Bluefin Tuna on herring. For the fall spawners, the trend in natural mortality for ages 7 to 11+ matched the summed relative abundance indices of grey seal and bluefin tuna (Fig. 29). Furthermore, this pattern was similar to the natural mortality pattern in spring spawning herring.

Recruitment

Pelagic fish such as herring often exhibit sporadic recruitment peaks, making long term projections highly uncertain. However, recruitment is currently low for both spring and fall spawner components. For the spring spawners, recruitment has been stable at low values since 1994. The low recruitment of spring spawners corresponds with long-term environmental changes in the sGSL including temperature increases, declining abundance of cold-water copepods, and increasing abundance of small warm-water copepods (Melvin et al. 2009; Brosset et al. 2018). The current abundance of large, energy-rich cold-water copepods in the GSL during the spring season (Blais et al. 2019) may not be sufficient to support strong recruitment events for spring spawners. Given the ongoing trend towards warmer conditions in the sGSL (Fig. 30; Blais et al. 2019; Galbraith et al. 2019), spring spawning herring recruitment is not expected to increase in future years. Fall spawner recruitment has been declining since 2006 to reach the lowest levels of the time series in recent years. Variability in fall herring recruitment is also correlated with water temperature and zooplankton community composition. High recruitment occurs in warm water conditions and higher abundance of small copepods. In recent years, these environmental conditions did not align and recruitment has been weak (Brosset et al. 2018). The occurrence of future environmental conditions for successful fall spawning herring cannot be predicted. Hence, prospects for this stock to rebuild are uncertain. As the sGSL ecosystem is changing, the synchronicity of the required zooplankton abundance and quality with the timing of the release of herring larvae is unpredictable. As a consequence, exploitation of this stock should be cautious until high recruitment is observed for consecutive years.

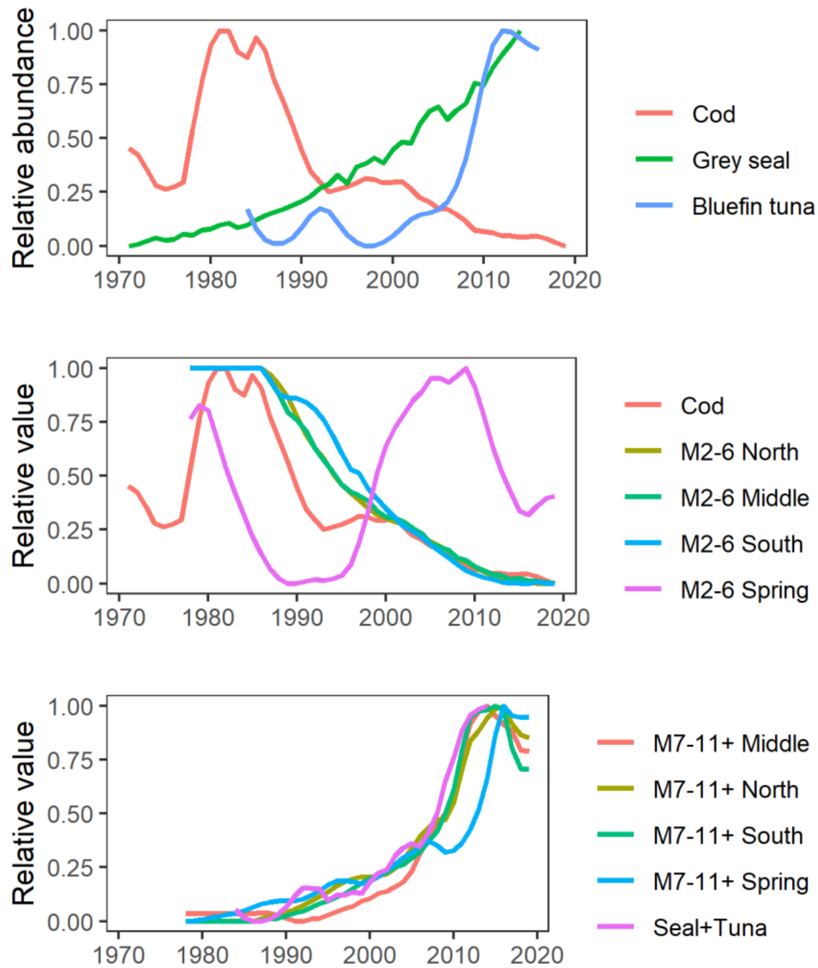

Figure 29. Scaled (0-1) relative abundance indices for major predators of herring (Atlantic Cod, Grey Seal, Atlantic Bluefin Tuna) during 1970 to 2019, where available (upper panel). The middle panel shows the scaled relative index of sGSL Atlantic Cod and natural mortality estimates for age group 2-6 (M2-6) from the qmSCA spring and fall herring SCA models. The lower panel shows the scaled relative value of the summed sGSL indices of abundance for Grey Seal and Atlantic Bluefin Tuna, and the natural mortality estimates for age group 7-11+ (M7-11+) from the qmSCA spring and fall herring SCA models (lower panel). Natural mortality estimates shown are the medians of the MCMC estimates.

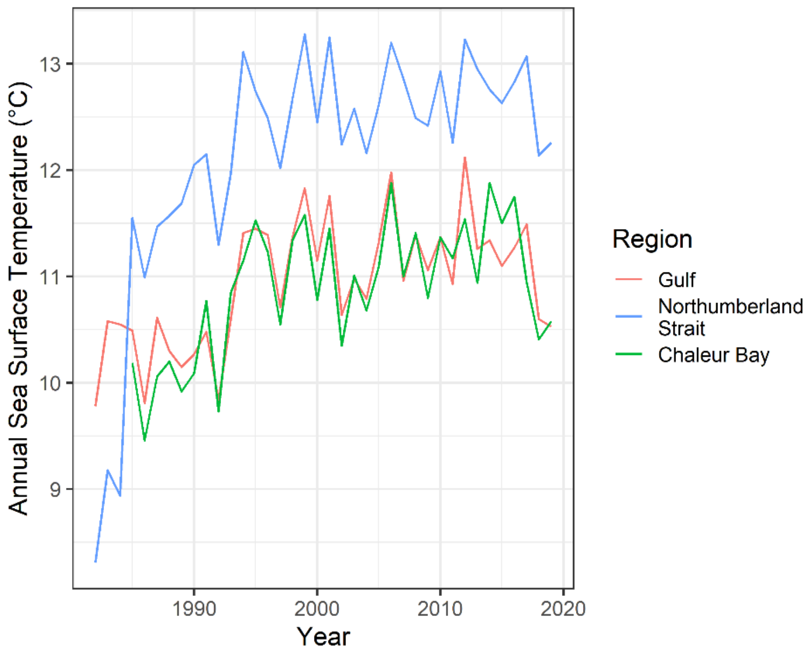

Figure 30. Annual average sea surface temperature in the Gulf of Saint-Lawrence, in the Northumberland Strait area and in the Chaleur Bay areas. Data are from the AZMP monitoring program (Galbraith et al.2019)

SOURCES OF UNCERTAINTY

Fishery-dependent indices such as the commercial gillnet CPUE, may not be proportional to abundance due to changes in catchability over time and can bias estimates of abundance. This has been addressed in the models by estimating time-varying catchability.

Fisheries stock assessments are often based on the assumption that natural mortality is constant through time, yet numerous examples show that predator-prey interactions are dynamic. Failure to account for increases in natural mortality due to changes in predator-prey interactions in stock assessments can result in biased estimates of population parameters and vital rates. To address this, the models in this assessment incorporated time-varying natural mortality. Natural mortality also incorporates disease mortality and unreported catches, including the bait fishery removals, for which no information is available.

The weight-at-age of herring has declined and remains at near record low levels. With this declining trend and increasing studies showing enhanced reproductive potential of older and larger spawners, there is uncertainty in the reproductive output of herring over time.

Historically, catches of herring in bait fisheries were 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 for fishing mortality constitutes a source of uncertainty in the total fishing mortality. This is now accounted for in the models through the incorporation of time-varying natural mortality.

The two models used in the fall spawner assessment have different assumptions on variations in natural mortality over time. The assumption of constant mortality in the qSCA model is inconsistent with changes in the ecosystem, of both predators and prey, and of changes in natural mortality described in other species. Conversely, the incorporation of time-vayring natural mortality in the qmSCA model shows a lag in abundance estimation over time, with abundance in the current year underestimated relative to estimates as additional years of data are included in the model (retrospective pattern). Despite the differences in model structure and differences in estimates of absolute abundance between the two models, the trends in abundance are similar and show a strong decline over the past decade.

Reference points in these stocks were developed in 2005 based on ecosystem conditions in the 1980s and 1990s. With changes in models, in particular the qmSCA model with time-varying natural mortality, the reference points for abundance and fishing removals based on constant mortality assumptions are not likely applicable. Appropriate reference points will need to be developed to account for the ecosystem changes.

CONCLUSIONS AND ADVICE

For spring spawners, the assessment to the end of 2017 fishing year indicated that the stock had been in the Critical Zone since 2004 and that even in the absence of any removals of SS herring in 2018 and 2019, there was a high probability that the stock would remain in the Critical Zone (DFO 2018). For fall spawners, there was greater than 95% probabilities of SSB in 2016 and 2017 being below the USR and there was a high probability (>90%) of the SSB at the start of 2019 and 2020 being below the USR at annual catch levels of 10,000 t or greater (DFO 2018). This assessment confirmed the status of previous years and the expectations of abundance in 2018 and 2019 of both spring and fall spawners.

Spring Spawner Component (SS)

The spring spawner component trajectory with respect to spawning stock biomass and fishing mortality rates is shown in Figure 31. The stock has been in the Critical Zone (SSB < LRP) since 2002 and experienced fishing mortalities above the provisional harvest decision rule of the Precautionary Approach Framework since 1999. For the short term projections, it was very unlikely (7% or less) at all catch levels (including no catch) that SSB would exceed the LRP to reach the Cautious Zone by 2022. In reference to the specific requests from DFO Fisheries Management for spring spawners, there are no catch options that would provide a greater than 75% probability of the SSB exceeding the LRP within six years. An annual catch option of 500 t offers 0% probability of SSB exceeding the USR. The prognosis for this stock is that even in the absence of fisheries removals, the stock will decline further in the Critical Zone into 2029. As described in the PA policy, when a stock is in the Critical Zone, removals by all human sources must be kept to the lowest possible level and there is no tolerance for preventable declines (DFO 2009).

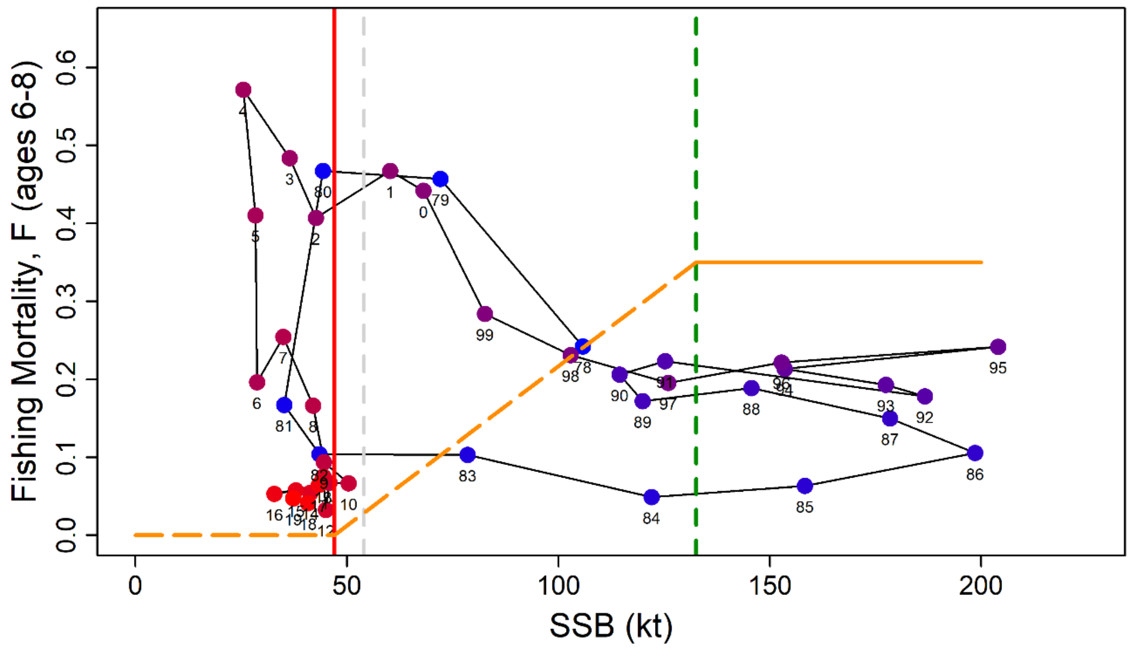

Figure 31. The southern Gulf of St. Lawrence Atlantic Herring spring spawner component trajectory in relation to spawning stock biomass (SSB, kt = thousand t) and fishing mortality rates for ages 6 to 8 years. The solid red vertical line is the Limit Reference Point (LRP) and the green dashed vertical line is the Upper Stock Reference (USR). The solid orange horizontal line is the removal rate reference value ($F_{0.1}$ = 0.35) in the Healthy Zone and the dashed orange line is the provisional harvest decision rule of the Precautionary Approach Framework. 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 projections of the qmSCA model are more precautionary and more realistic given our knowledge of predator abundance and the likely consequences on natural mortality. Advice for catch options are provided based on the qmSCA model.

The fall spawner component trajectory with respect to spawning stock biomass and fishing mortality rates is shown in Figure 32. The median estimate of the SSB has been in the Cautious Zone (LRP < SSB < USR) since 2017. Fishing mortality exceeded the default harvest decision rule of the Precautionary Approach Framework for most of the 1990s and 2000s but has generally remained stable and below the default harvest decision rule since 2008. From the mid-2000s, fishing mortality remained stable as SSB declined and natural mortality increased rapidly to reach a peak in the mid-2010s. Low recruitment, high natural mortality, decreasing weight-at-age, and constant fishing mortality can only result in a decrease in SSB. Under current conditions of low recruitment and high natural mortality, the decline in SSB is very likely to continue. Reducing fishing mortality will slightly reduce the probabilities of decline in the short and long term projections. The catch option that gives the greatest probability of increasing SSB by 2022 is 2,000 t.

In reference to the specific requests from DFO Fisheries Management for fall spawners, there are no fixed annual catch options that would provide probabilities greater than 60% of the stock being above the USR within six years. At any catch level, including zero, the probabilities of SSB in 2021 and 2022 being equal to or above the USR are essentially zero. Dependent on the model, there is a low probability of increases in SSB from 2019 even at low to zero catch level. There is no expectation of the stock being in the healthy zone, in 2020 and 2021, hence reference to fishing removals at the $F_{0.1}$ value is not appropriate. As the expectation is that the stock will be near or declining into the critical zone, fishing removals should be as low as possible.

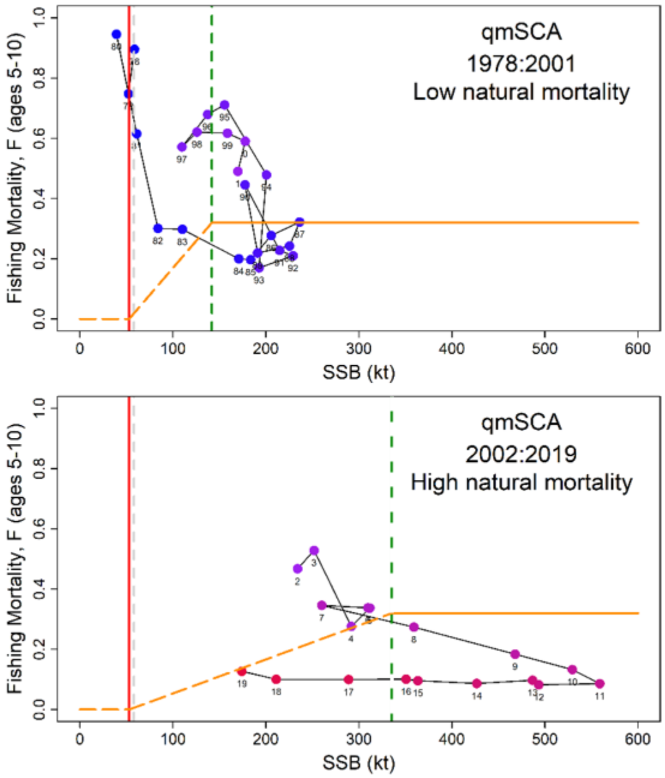

Figure 32. The southern Gulf of St. Lawrence Atlantic Herring fall spawner component trajectory in relation to spawning stock biomass (SSB) and fishing mortality rates for ages 5 to 10 years for 1978 to 2001 (lower natural mortality, upper panel) and 2002 to 2019 (higher natural mortality, lower panel) from the qmSCA population model. The solid red vertical line is the LRP and the green dashed vertical line is the Upper Stock Reference. The solid orange horizontal line is the removal rate reference value ($F_{0.1}$ = 0.32) in the Healthy Zone and the dashed orange line is the provisional harvest decision rule of the Precautionary Approach Framework. The dashed vertical grey line is the previously defined LRP. Point labels are years (83 = 1983, 0 = 2000). Colour coding is from blue in the 1970s and early 1980s to red in the 2000s.

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SOURCES OF INFORMATION

This Science Advisory Report is from the March 12-13, 2020 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 2019 and advice for the 2020 and 2021 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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