ASSESSMENT OF THE SOUTHERN GULF OF ST. LAWRENCE (NAFO DIVISION 4TVn) SPRING AND FALL SPAWNER COMPONENTS OF ATLANTIC HERRING (*CLUPEA HARENGUS*) WITH ADVICE FOR THE 2022 AND 2023 FISHERIES

*Atlantic Herring (*Clupea harengus*)*
Credit: Fisheries and Oceans Canada

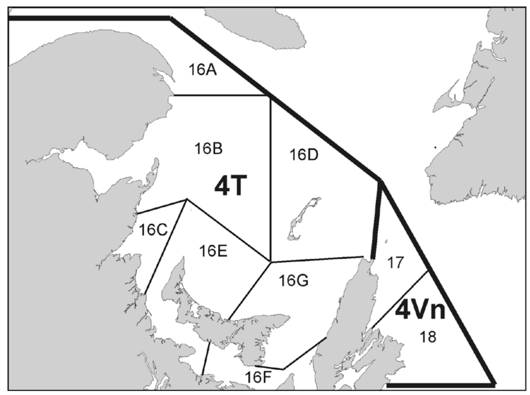

Figure 1. NAFO Divisions 4T and 4Vn and the corresponding herring fishery management zones.

Context:

The stock area for southern Gulf of St. Lawrence Herring (NAFO Division 4T) 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 2021, there were 3,001 fixed gear licenses and 20 seiner licenses. Of these licences approximately 9% of fixed gear and 6% of seiner licences were active (at least 1 trip/season).

Assessments of the spring and fall spawning Herring from the southern Gulf of St. Lawrence (NAFO Division 4TVn) are used to establish the total allowable catch. This Science Advisory Report is from the March 22-23, 2022 Regional Advisory Process to assess the stock status of Atlantic Herring from the sGSL (4T-4Vn) to 2021 and advice for the 2022 and 2023 fisheries. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule] as they become available. Participants at the meeting included DFO Science and Fisheries Management, provincial governments, the fishing industry, environmental non-government organizations, and aboriginal 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.
- The biomass index from a collaborative fishery-independent fall spawning ground acoustic survey has been used for the first time in this assessment.
- For both spring and fall spawning Herring, the trend in natural mortality of ages 7 to 11+ was correlated with the increases in Grey Seal, Atlantic Bluefin Tuna and Northern Gannet abundance over the same time period.

Spring Spawner Component

- Based on the current stock assessment, the median estimates of Spawning Stock Biomass (SSB) have been in the Critical Zone of the Precautionary Approach (PA) Framework since 2002. As of 2020 and 2021, estimated SSB of spring spawning Herring have likely (> 80%) remained in the Critical Zone.
- Under current conditions of high natural mortality, declines in weight-at-age, and low recruitment, the probabilities that SSB will increase by 2024 ranges from 44% at a catch of 0 tonnes (t) to 42% at a catch 1,250 t. Even in the absence of fishery removals, it is likely (> 80%) that the stock will remain in the Critical Zone by 2027.
- Spring spawning Herring are caught in a directed fishery as well as bycatch in the fall Herring fishery for total preliminary landings of 603 t and 403 t in 2020 and 2021, respectively. Fishing mortality in this stock has exceeded the provisional harvest decision rule of the PA Framework since 1999. Total bait removals and discards-at-sea are unknown.
- Recruitment has remained stable at low values since 1993. This low recruitment corresponds with long-term environmental changes including temperature increases and changes in zooplankton abundance and phenology. Given the ongoing trend towards warmer environmental conditions and zooplankton dynamics, it is not expected that recruitment will improve.
- Annual natural mortality estimates for ages 2 to 6 remained stable between 21% and 40% over the time series. However natural mortality for older fish (ages 7-11+) increased since 2010 to reach a maximum of 65% in 2018 before declining to 59% in 2020 and 2021. Based on dynamics in predator abundance, natural mortality is expected to remain high.

Fall Spawner Component

- Based on the current stock assessment, the estimated SSB of fall spawning Herring has been in the Cautious Zone of the PA Framework since 2017, and is virtually certain (100%) to remain there in 2022. The stock has declined over the last decade.
- Under current conditions of high natural mortality, declines in weight-at-age, and low recruitment, the probabilities that SSB will increase by 2024 range from 35 to 40% across all considered catch options (18,000 to 2,000 t). At all catch options, it is exceptionally unlikely (< 1%) that SSB will increase into the Healthy Zone or decline into the Critical Zone by 2027.
- The preliminary landings of the fall spawning Herring component in 2020 and 2021 were 10,065 t and 10,834 t, respectively, from a 12,000 t TAC. Fishing mortality exceeded the

provisional harvest decision rule of the PA Framework for most of the 1990s, early 2000s, and 2020-2021.

- Recruitment has been declining since 2006 to reach the lowest levels of the time series in recent years. The synchronicity of events and environmental conditions required to produce strong recruitment, including water temperature and zooplankton abundance, cannot be predicted, and therefore future recruitment is unknown.
- Annual natural mortality estimates for ages 2 to 6 decreased over the time series to very low values in 2021, although the absolute level remains uncertain. For ages 7 to 11+, annual natural mortality increased sharply since 1986 to reach a peak in mid-2010s (63%) before declining to stable values of approximately 49%. Based on dynamics in predator abundance, natural mortality is expected to remain high.

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 and fall spawners. 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). Spring and fall Herring spawners 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) has been used since 2015 (DFO 2015).

Fisheries

Over the period 1978 to 2021, total landings of Atlantic Herring from NAFO Division 4T and 4Vn peaked at 93,471 t in 1995 and dropped to 11,237 t in 2021 (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 were 12,500 t (500 and 12,000 t for spring and fall spawners, respectively) in 2020 and 2021.

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 2020 and 2021 of 95% and 99.9%, 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 95.8% and 96.4% of the total Herring harvested in 2020 and 2021, respectively.

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.

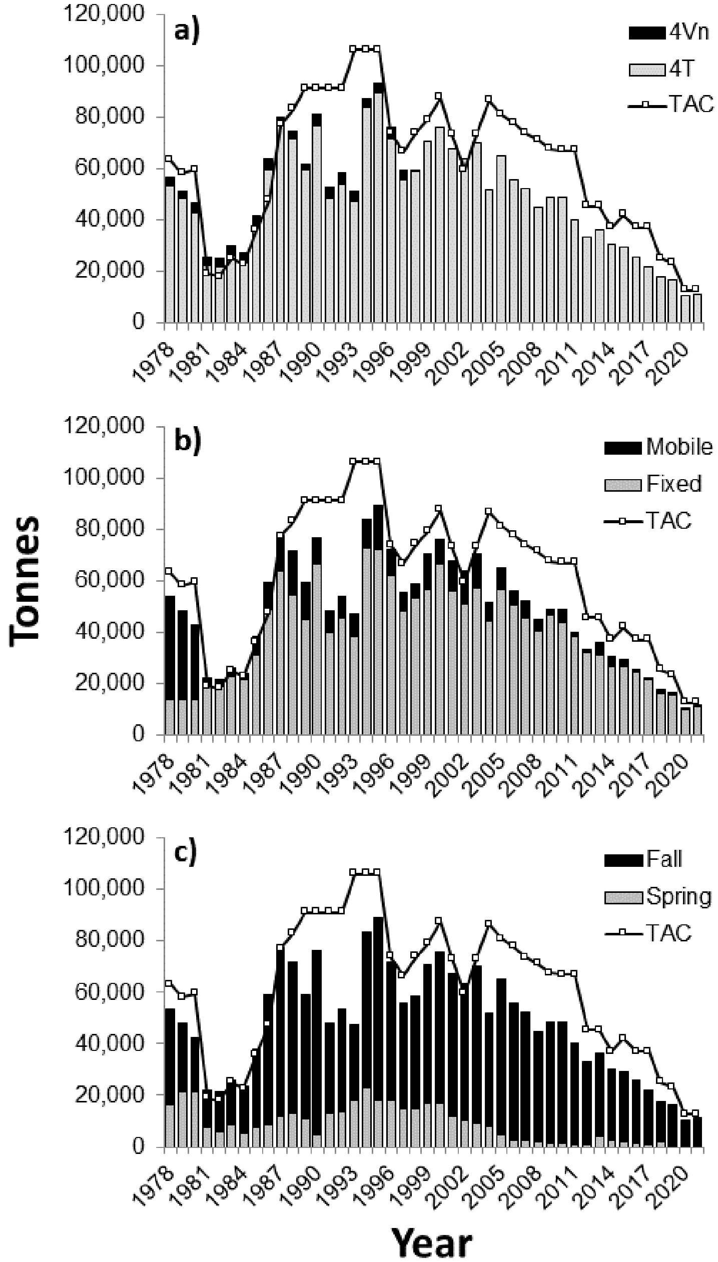

Figure 2. Reported landings (tonnes) of southern Gulf of St. Lawrence Atlantic Herring (spring and fall spawners combined) by NAFO division (upper panel), by gear fleet (middle panel), and by fishing season (lower panel), 1978 to 2021. In all panels, the corresponding annual total allowable catch (TAC; tonnes) is shown. For landings by season, the landings in Division 4Vn were attributed to the fall fishing season. Data for 2020 and 2021 are preliminary.

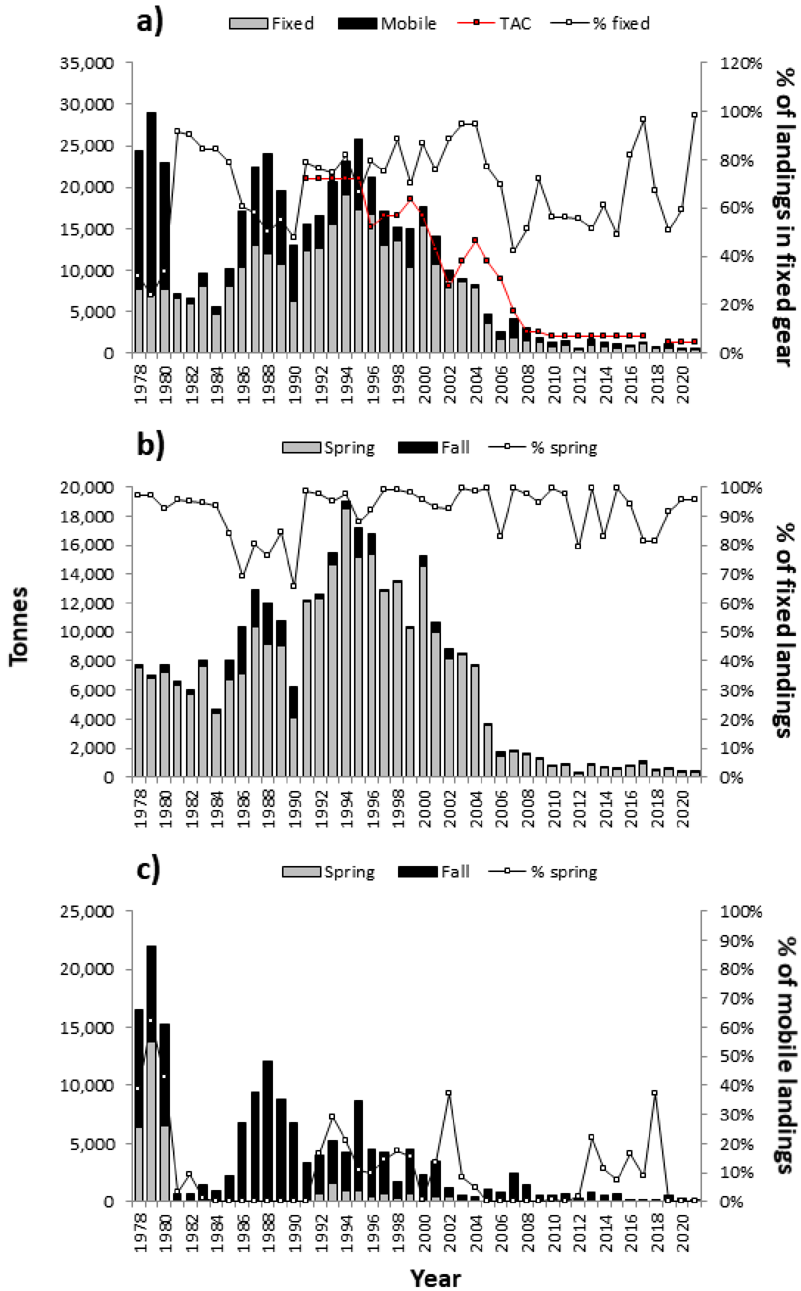

Figure 3. Estimated landings (tonnes) of the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence, 1978 to 2021. Estimated landings by gear type and the proportion of the landings attributed to the fixed gear fleet, and spring spawning Herring TAC (red symbols) for 1991 to 2021 (upper panel). Estimated landings of spring spawning 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 spring spawning Herring landed by the fixed gear fleet in the spring fishing season (middle panel). Estimated landings of spring spawning 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 spring spawning Herring landed by the mobile gear fleet in the spring fishing season (lower panel). For landings by season, the landings in Division 4Vn were attributed to the fall fishing season. Data for 2020 and 2021 are preliminary.

Spring spawner component

The 2020 and 2021 TAC for spring spawning Herring was set at 500 t (Fig. 3). The preliminary estimated landings in 2020 and 2021 were 603 t and 403 t, respectively. In 2020, 120.6% of the spring spawners TAC was attained compared to 80.6% in 2021.

Most of the spring spawning Herring were estimated to have been landed in the fixed gear fleet over the 1981 to 2021 period. In 2020 and 2021, the fixed gear fleet was estimated to have landed 59% and 98%, respectively, of the total harvests of spring spawning Herring (Fig. 3). Historically and on average, more than 80% of the spring spawning Herring landed by the fixed gear fleet has been landed during the spring fishing season, whereas more than 80% of the spring spawning Herring landed by the mobile fleet has been 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. The dominant age in the 2020 spring spawners catch was age 7 belonging to the 2013 year-class. In 2021 the dominant age was the same year-class, now age 8.

Mean weight-at-age of the spring spawning Herring 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 39.6% between 1978 and 2021. For a certain number of fish, lower mean weights generates lower estimations of stock biomass when numbers are converted to weight.

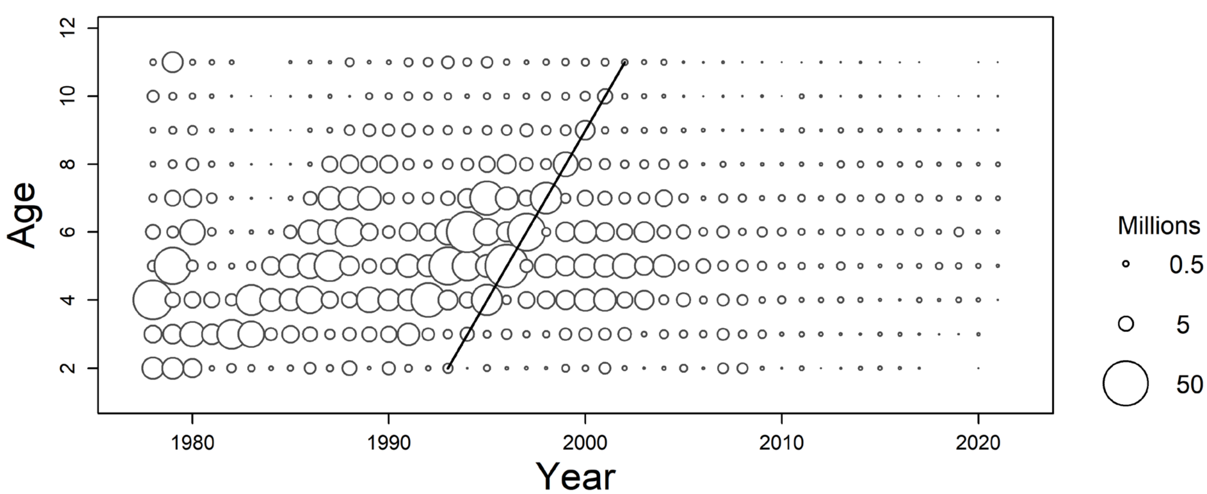

Figure 4. Catch-at-age of the spring spawner component from the fishery, all gears combined, 1978 to 2021. Size of the bubble is proportional to the catch numbers by age and year. The diagonal line tracks the most recent strong year-class (1991). The values indicated at age 11 represent catches for ages 11 years and older.

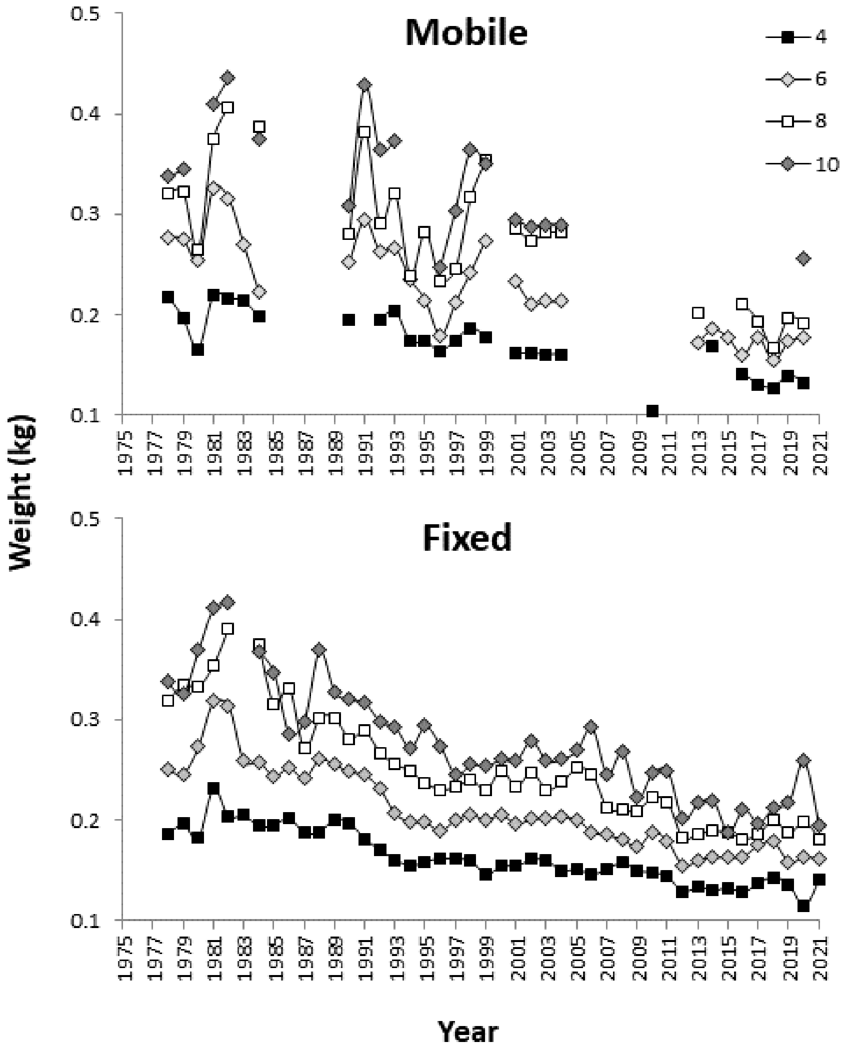

Figure 5. Mean weight-at-age for ages 4, 6, 8 and 10 years of spring spawner Herring from the southern Gulf of St. Lawrence sampled from catches during the spring season in the mobile (upper panel) and fixed (lower panel) commercial gears, 1978 to 2021.

Fall spawner component

The 2020 and 2021 TAC for fall spawning Herring in NAFO Division 4T was set at 12,000 t. The preliminary estimated landings in 2020 and 2021 were 10,065 t and 10,834 t respectively (Fig. 6). In 2020, 84% of the fall spawners TAC was attained compared to 90% in 2021. Over the 1978 to 2021 period, most of the fall spawning Herring have been landed in the fixed gear fleet. In 2020 and 2021, the fixed gear fleet was estimated to have landed 97% and 99.9%, of the total harvests of fall spawning Herring, respectively (Fig. 6). The majority (nearly 100%) of the fall spawning Herring captured in the fixed gear fishery are landed during the fall fishing season. Of all the fall spawners landed by the mobile fleet, 100% were landed in the fall fishing season in 2020 and 2021 (Fig. 6).

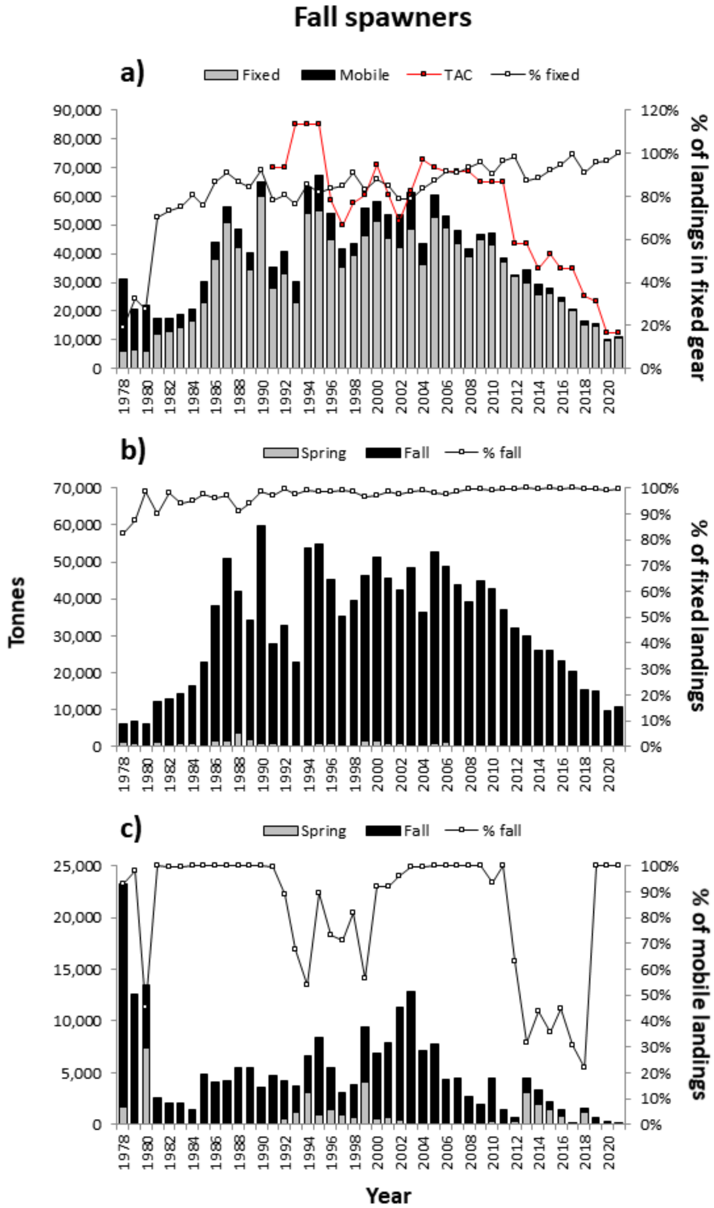

Figure 6. Estimated landings (tonnes) of the fall spawner component of Atlantic herring from the southern Gulf of St. Lawrence, 1978 to 2021. Estimated landings by gear type and the proportion of the landings attributed to the fixed gear fleet, and fall spawning Herring TAC (red symbols) for 1991 to 2021 (upper panel). Estimated landings of fall spawning 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 fall spawning Herring landed by the fixed gear fleet in the fall fishing season (middle panel). Estimated landings of fall spawning 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 fall spawning Herring landed by the mobile gear fleet in the fall fishing season (lower panel). For landings by season, the landings in Division 4Vn were attributed to the fall fishing season. Data for 2020 and 2021 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

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 Division 4T fall spawning 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. For fall spawners, the dominant age was 7 (2020) and 8 (2021) in the North (2013-2014 cohorts), age 8 in the Middle for both years (2011-2012 cohorts), ages 7 to 8 in 2020 (2013 to 2012 cohorts) and age 8 in 2021 (2013 cohort) in the South The catches of younger ages (less than 6 years) have decreased in the last decade of the fisheries.

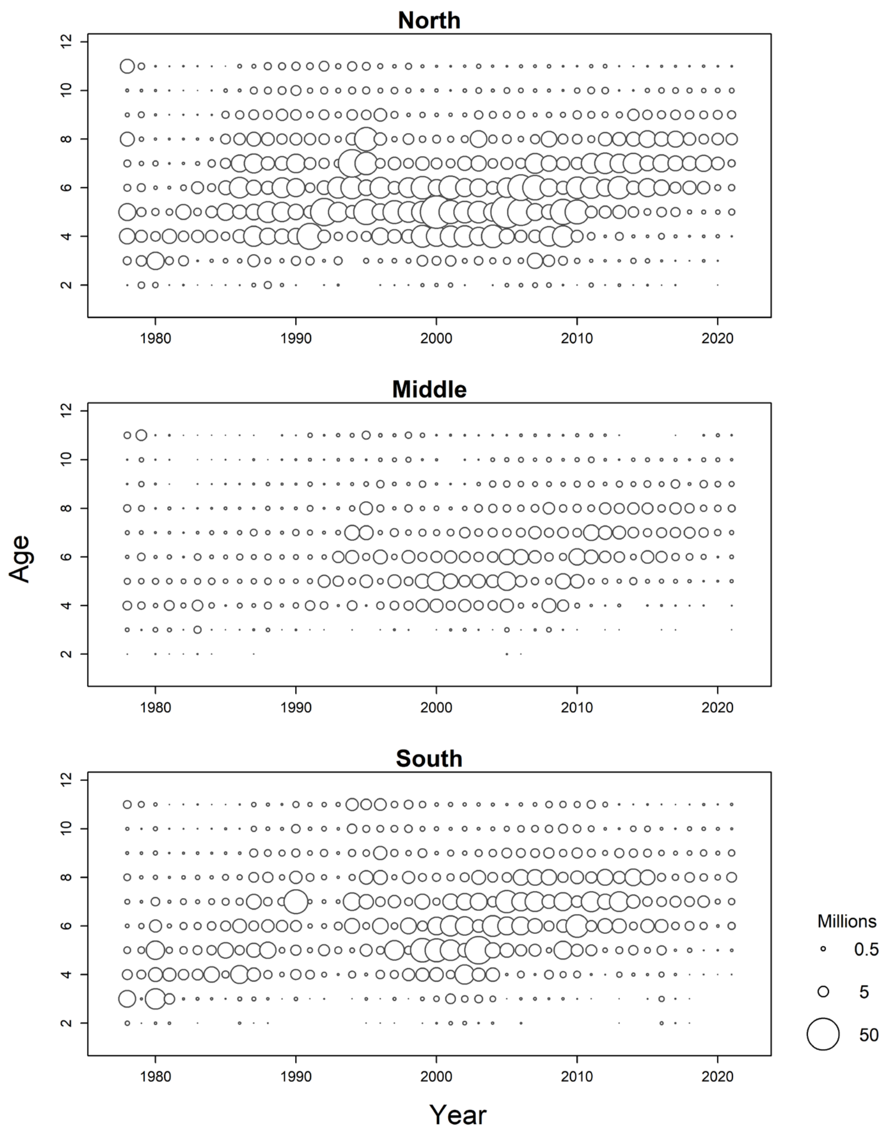

Figure 7. Bubble plots of fishery catch-at-age (number) by region for both mobile and fixed gear combined, 1978 to 2021. The size of the bubble is proportional to the number of fish in the catch by age and year. The values indicated at age 11 represent catches for ages 11 years and older.

Mean weight-at-age of fall spawning Herring from fixed and mobile gears has declined almost continuously over the time period 1978 to 2015 and has then stabilized until 2021 (Fig. 8). The mean weight-at-age declined by 30.2% between 1978 and 2021. For a certain number of fish, lower mean weights generates lower estimations of stock biomass when numbers are converted to weight.

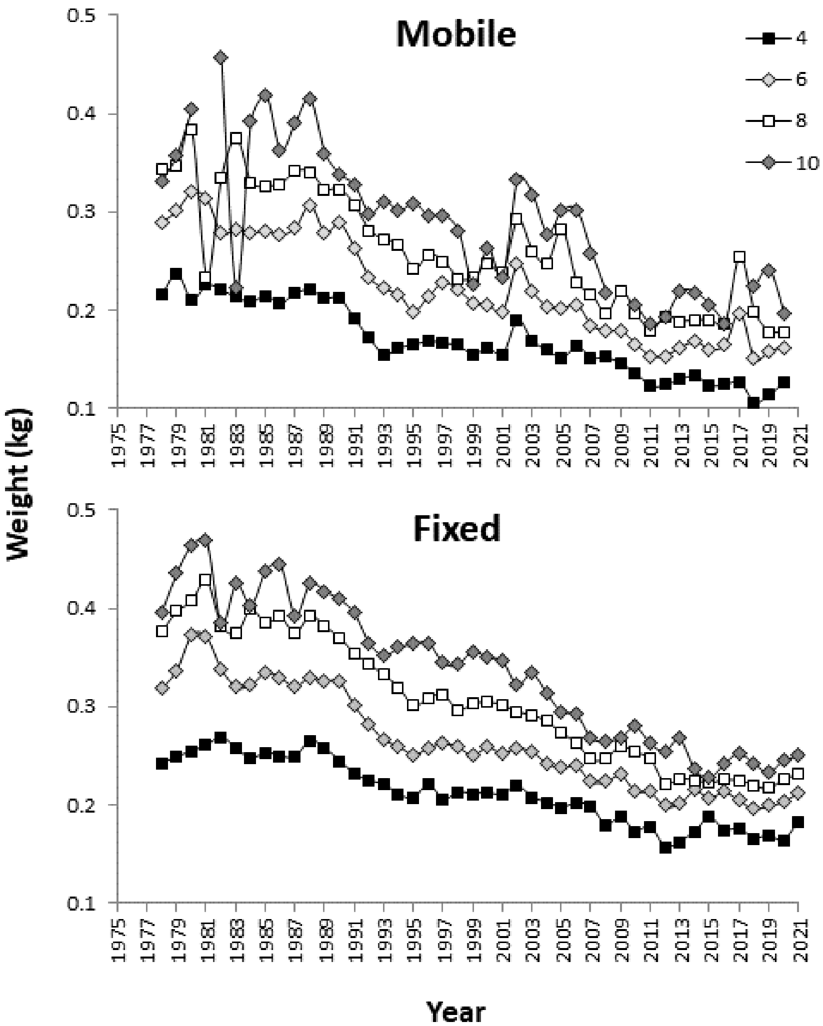

Figure 8. Mean weights-at-age for ages 4, 6, 8 and 10 years of fall spawner Herring from the southern Gulf of St. Lawrence sampled from catches in the fall season by the mobile (upper panel) and fixed (lower panel) gear fleets, 1978 to 2021.

ASSESSMENT

Spring and fall spawning Herring of NAFO Division 4T are distinct stocks and are assessed separately. Both 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.

Spring Spawning Herring

Indices of abundance

Acoustic survey

The acoustic survey provides catch rates (in numbers) of spring spawning Herring for ages 4 to 8 for 1994 to 2021 (Fig. 9). For 2020 and 2021, the rate were overall slightly higher than those observed in 2018 and 2019. The index was highest in the mid-1990s and subsequently declined and remained at low levels in the 2000s.

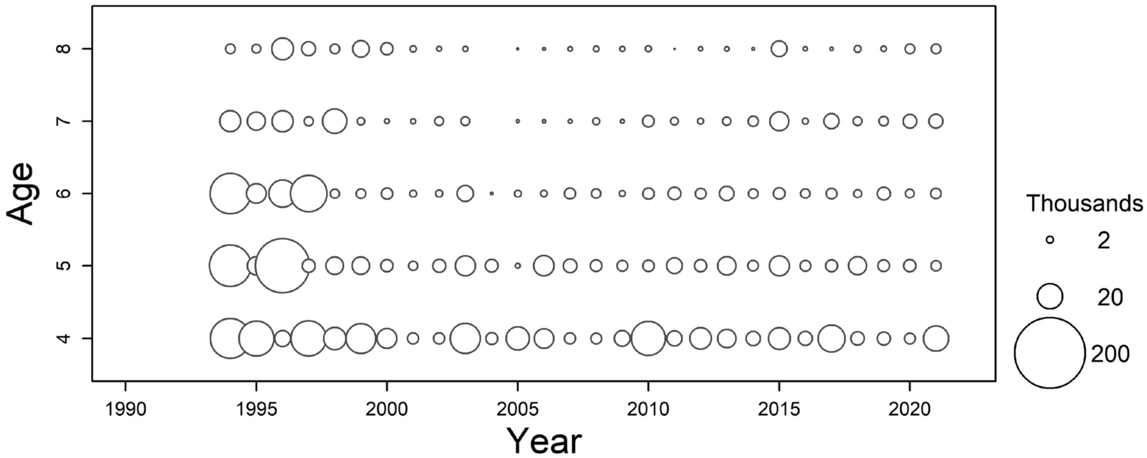

Figure 9. Bubble plot of abundance-at-age (number) from the fisheries-independent acoustic survey for Herring spring spawners (SS; ages 4 to 8) in the southern Gulf of St. Lawrence, 1994 to 2021.

Commercial fixed gear catch per unit of effort

The CPUE index for spring spawning 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). For 2020 and 2021 the CPUE has increased compared to the low values of 2018-2019 and the dominant ages were 7 and 8 in 2021.

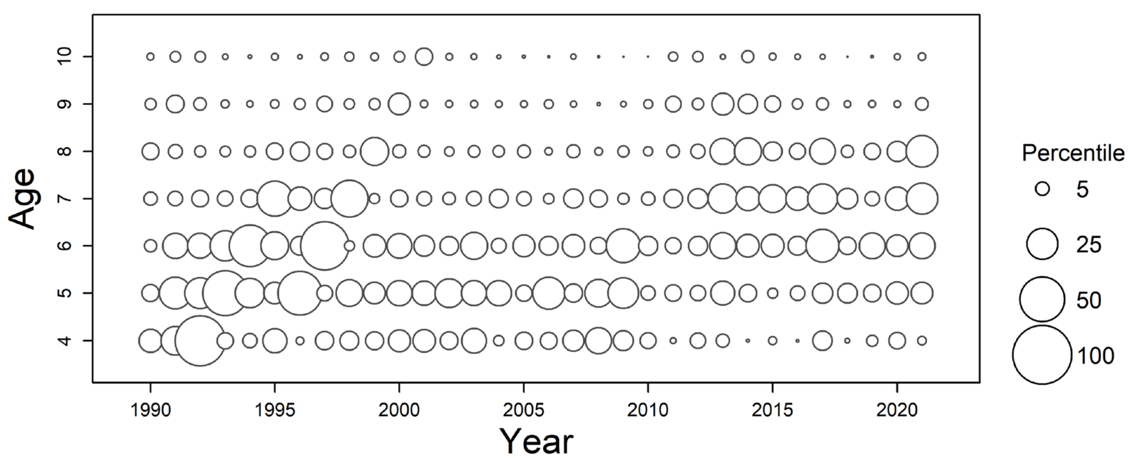

Figure 10. Bubble plot of spring spawning Herring fixed gear catch-per-unit-effort values (number per net-haul per trip) at age in the southern Gulf of St. Lawrence, 1990 to 2021. The size of the bubble is proportional to the maximum CPUE index value.

Population model

A SCA model with time-varying natural mortality and time-varying catchability to the fixed gear fishery was used. The model inputs include fishery catches at ages 2 to 11+ from 1978 to 2021 in proportions-at-age (PAA), catch-per-unit-effort (CPUE) index PAA, age-aggregated biomass index from 1990 to 2021 (ages 4 to 10) and fishery-independent acoustic survey index PAA and age-aggregated biomass index from 1994 to 2021 (ages 4 to 8).

Catchability to the fishery, defined as the proportion of the stock removed by a unit of fishing effort, averaged about 0.0019 in the early 1990s, increasing to a peak of approximately 0.0062 in 2007-2008, and stabilizing at 0.0056 on average between 2017 and 2021 (Fig. 11). Estimated catchability increased as the stock declined (Fig. 11).

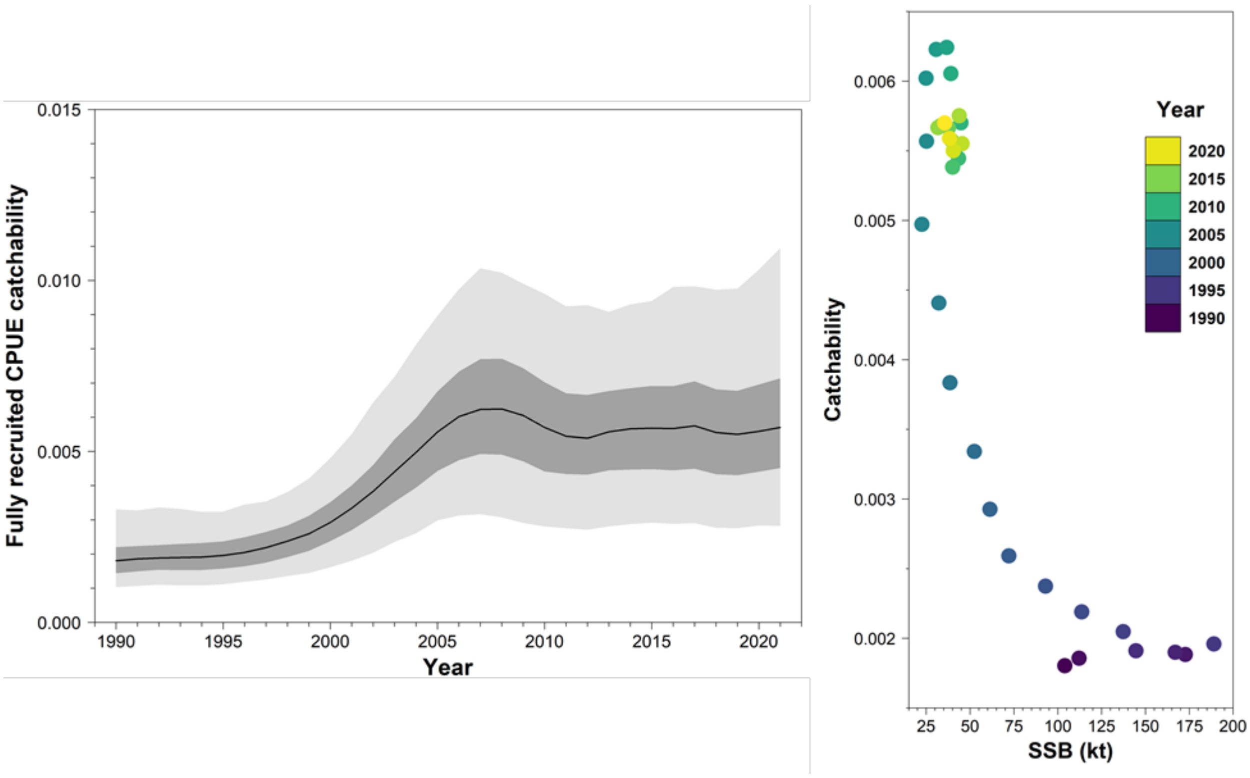

Figure 11. Estimated fully-recruited catchability (q) to the CPUE index of spring spawning Herring (left panel) and fully-recruited catchability to the spring spawning gillnet fishery in relation to the spring spawning April 1st SSB (right panel). In the left panel, the line shows the median estimates and shading their 95% confidence interval.

Natural mortality estimates for the age group 2-6 varied between 0.24 and 0.51 (between 21% and 40% annual mortality) over the time series (Fig. 12). For the age group 7-11+, *M* increased gradually from 0.30 to 0.56 (between 26% and 43% annual mortality) between 1978 and 2006, before decreasing down to 0.47 (37% annual mortality) in 2009 (Fig. 12). Starting in 2010, estimates sharply increased to reach a maximum of 1.05 (65% annual mortality) in 2018 before decreasing down to a mean value of 0.9 (59% annual mortality) in 2020 and 2021.

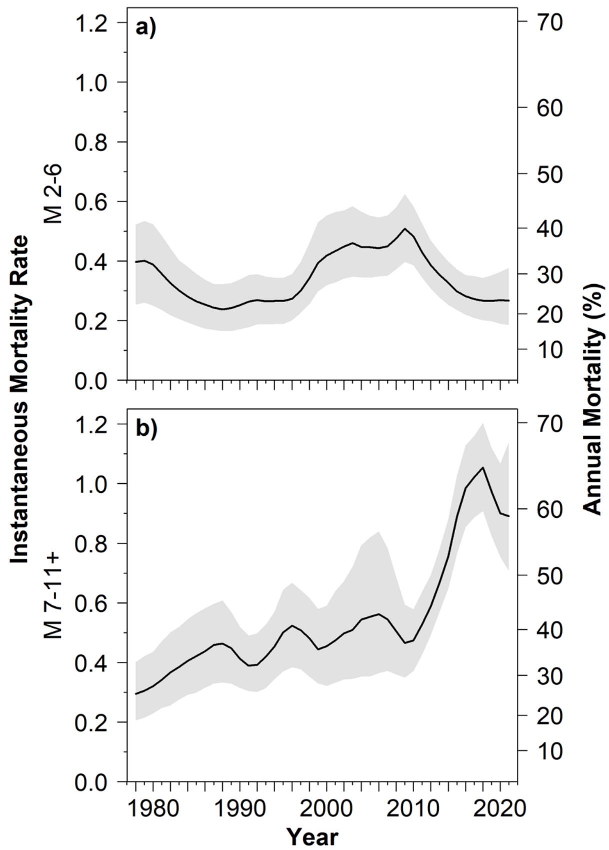

Figure 12. Estimated instantaneous natural mortality rate (left axis) and annual mortality (%, right axis) of spring spawning Herring from the population model, for ages 2 to 6 (upper panel) and 7 to 11+ (lower panel). Lines show the median estimates and shading their 95% confidence interval based on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

Recalculating the Reference Points

The limit reference point (LRP) in 4T Herring is $B_{recover}$, which is the lowest biomass from which the stock has been observed to readily recover. It is calculated as the average of the 4 lowest SSB estimates in the early 1980s (i.e., 1979-1982). Consequently, this value is model dependent. If the model changes, stock biomass may be re-scaled upwards or downwards. For this assessment, the LRP was estimated to be 46,340 t which is ~1.9% lower than the 47,250 t presented in the last assessment. The upper stock reference (USR) was scaled downwards by the same proportion as the LRP to reach a value of 129,994 t. The LRP and USR were calculated to April 1st to account for three months of natural mortality for both age groups. The fishing removal reference in the Healthy Zone was defined as $F_{0.1}$ and this assessment used the same value of 0.35 as used in previous assessments.

Spawning Stock Biomass and Exploitation Rate

Estimates of Spawning Stock Biomass (age 4+) is presented at the start of the fishing season (April 1st) to account for three months of natural mortality at age 7 to 11+. Estimated SSB in 2020 and 2021 were 38,402 t (95% confidence interval: 23,771 – 69,893) and 35,626 t (95% CI: 22,012 – 66,950), respectively. The estimate for 2021 is 77% of the LRP. The stock remains in the Critical Zone of the Precautionary Approach (Fig. 13). The probabilities that April 1st SSB was under the LRP were 23% in 2020 and 30% in 2021.

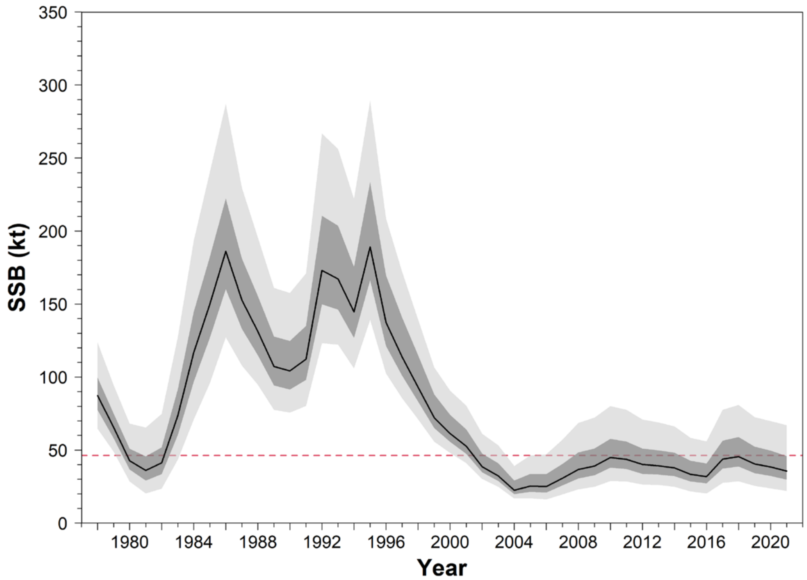

Figure 13. Estimated beginning of the fishing season (April 1st) spawning stock biomass (SSB) of the spring spawner component of Herring in the southern Gulf of St. Lawrence, 1978 to 2021. The solid line is the median MCMC estimate and light shading its 95% confidence interval and dark shading is 50% CI. The red horizontal dashed line is the Limit Reference Point (46,340 t of SSB).

Estimated exploitation rates were high from 1979 to 1980 and from 1999 to 2006. Since 2010, exploitation rates have remained at low levels (Fig. 14). Fishing mortality was 0.025 and 0.018 in 2020 and 2021, respectively (annual mortality 2.5% and 1.8%).

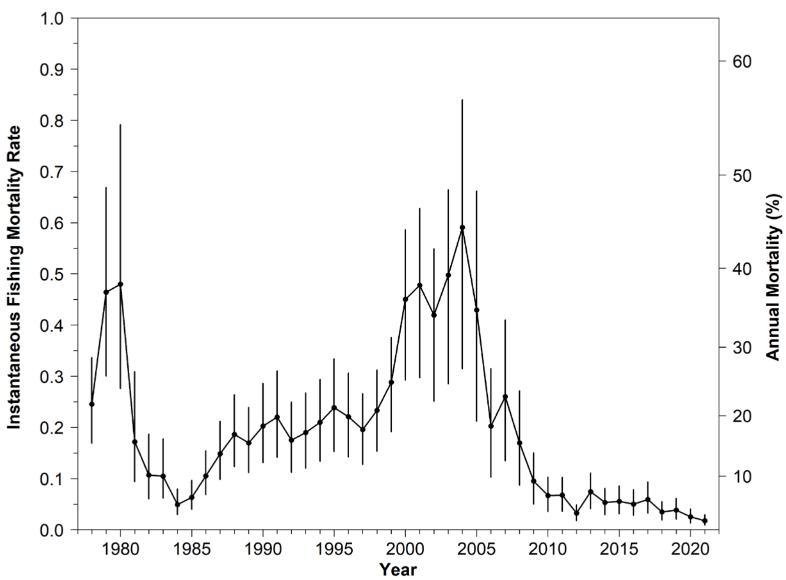

Figure 14. Estimated January 1st age 6 to 8 fishing mortality ($F_{6\text{-}8}$, left axis; annual exploitation rate, right axis) of spring spawning Herring in the southern Gulf of St. Lawrence. Circles are the median estimates and vertical lines their 95% confidence intervals.

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 2006 and 2008. Recruitment declined to lowest values of the time-series after 2008 up to 2020, except a small peak in 2015. Estimated abundances of age 4 Herring was highest in the mid-1980s, 1992, and 1995 but has remained relatively low since 2000 (Fig. 15). The median estimate of spring spawner (4+) abundance for 2021 is 250.2 million Herring (95% CI: 155.5 – 469.5), about 34.2% of the average spawner abundance in 1985 to 1995. Recruitment rate was highest in the early 1980s and around 2005, and at its lowest between 1992 and 2000. Since 2006, recruitment rates have declined to low values except for a small peak in 2013 and another in 2019.

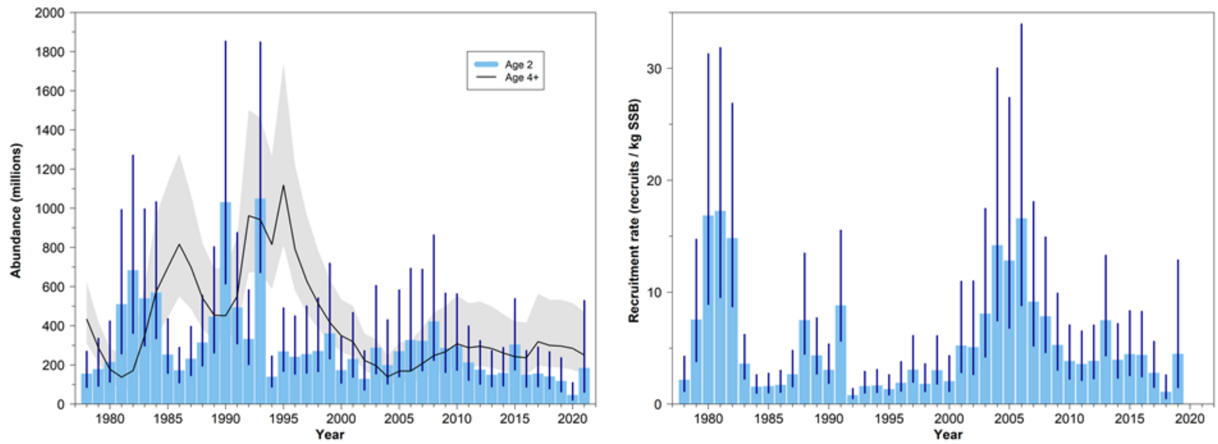

Figure 15. Left panel shows the estimated beginning-of-year (January 1st) abundance of age 2 (blue bars), and 4 years and older (black line) of the spring spawner component in the southern Gulf of St. Lawrence. Black line show the median MCMC estimate and vertical lines and shading show 95% confidence interval. The right panel shows recruitment rates for age 2 recruits for the 1978 to 2019 cohorts of spring spawning Atlantic Herring in NAFO Division 4T. Vertical lines indicate 95% confidence intervals.

Projections

The population model was projected forward to April 1st, of 2023 and 2024 and 6 years forward to 2027. Projections were conducted at several levels of annual catch (0, 250, 500 and 1,250 t) and using random recruitment values of the last five years (2017-2021). 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 and slightly decrease in 2020 and 2021. Projections were conducted using the average of the 2017-2021 *M* values for each age groups.

SSB was projected to increase slightly from 2022 to 2023, and to remain stable from 2023 to 2024 at all annual catch levels from 0 to 1,250 t (Fig. 16). The probability of an increase in SSB between April 1 2022 and April 1 2023 was between 64.5 and 68.5% at all catch levels. The probability of a greater than 5% increase in SSB between April 1 2023 and April 1 2024 was between 42.3% and 44.3% at all catch levels (Fig. 16; Table 1).

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 2024 spring fishing season (20.8% at 0 t of catch down to 17.8% 1,250 t). By 2023, the age 6 to 8 fully recruited fishing mortality increases from 0.02 at 250 t to 0.08 at 1,250 t (Table 1). The probability of a greater than 5% increase in SSB between April 1 2023 and April 1 2024 was between 42.3% and 44.3% at all catch levels. All catch levels (including no catch) resulted in under a 20% probability that SSB would exceed the LRP to reach the

Cautious Zone in 2024. In the short term, there is no chance that the population would reach the USR by 2024.

Six years projections in SSB show no changes from 2022 to 2027. By 2027, the probability of exceeding the LRP was between 15.8 and 20.4% at all catch levels (Table 1), with SSB values ranging between 32,477 and 35,445 tonnes.

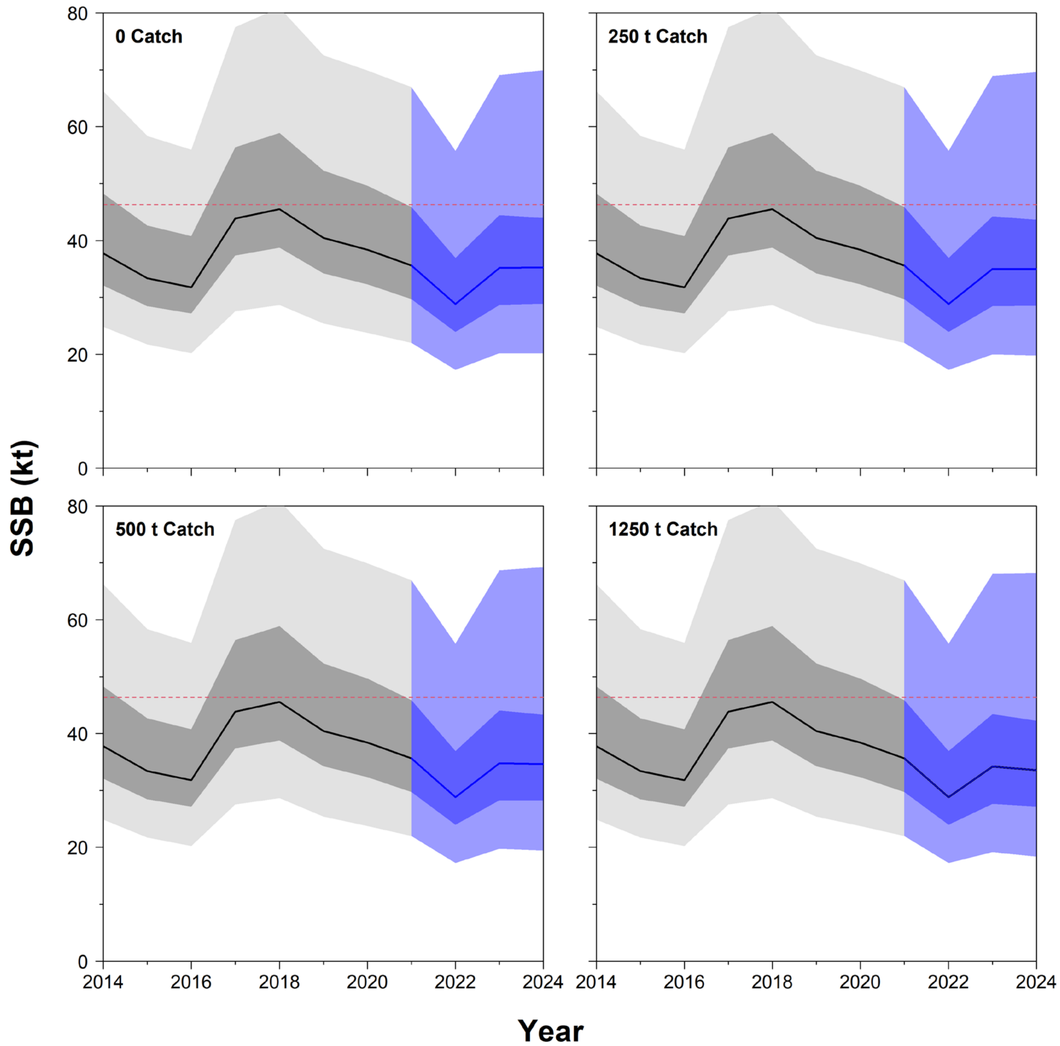

Figure 16. Projected spawning stock biomass (SSB in kilotonnes (kt)) of spring spawning Atlantic Herring from the southern Gulf of St. Lawrence at various catch levels in 2022 to 2024. Lines show the median estimates of the beginning of fishing season (April 1st) SSB, light shading the 95% confidence 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 1st using natural mortality estimates at age for 3 months.

Table 1. Risk analysis table of annual catch options (between 0 and 1,250 tonnes) for 2022 and 2024 and subsequent years until 2027, with predicted resulting SSB (kt) in 2023, 2024 and 2027, resulting probabilities (%) of SSB being greater than the LRP, resulting probabilities of increases in SSB by 5%, and resulting fully-recruited fishing mortality rate ($F_{6\text{-}8}$) for the spring spawner component of Atlantic Herring from the southern Gulf of St. Lawrence.

	Year	Catch options (t)			
		0	250	500	1,250
SSB (kt)	2023	35.2	35.0	34.8	34.2
	2024	35.3	34.9	34.6	33.6
	2027	35.4	34.9	34.3	32.5
SSB > LRP (%)	2023	21.7	21.4	20.9	19.8
	2024	20.8	20.2	19.4	17.8
	2027	20.3	19.2	18.3	15.8
5% increase in SSB (%)	2023	68.5	67.8	67.0	64.5
	2024	44.3	43.7	43.4	42.3
$F_{6\text{-}8}$	2022	0	0.02	0.03	0.09
	2023	0	0.02	0.03	0.08

Fall Spawning Herring

The fall spawning Herring assessment considers three regions (North, Middle, South), which cover the entire 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.

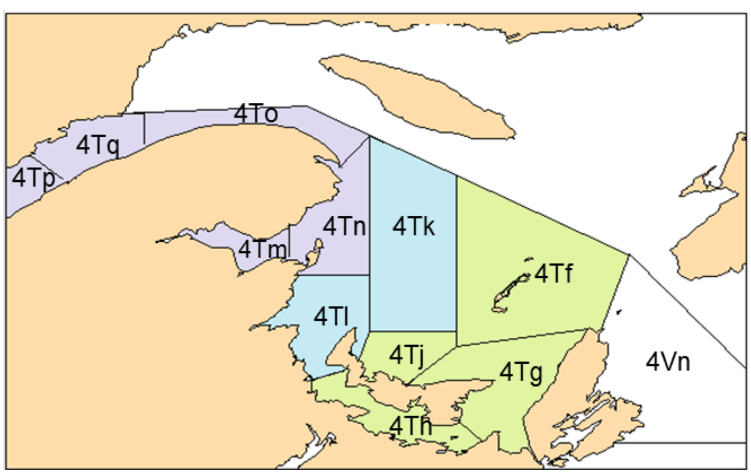

Figure 17. Correspondence between the Herring fishing areas and the three regional groups (North in purple, Middle in blue, South in green) used in the assessment of the fall spawner component of Atlantic Herring from the southern Gulf of St. Lawrence. Fishing areas in each region are described in the text above.

Indices of abundance

Acoustic survey

The acoustic survey provides a useful abundance index of recruiting Herring (ages 2 and 3) for the entire Division 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 ages 2 and 3 were much higher in both 2020 and 2021 than those of 2019 (Fig. 18).

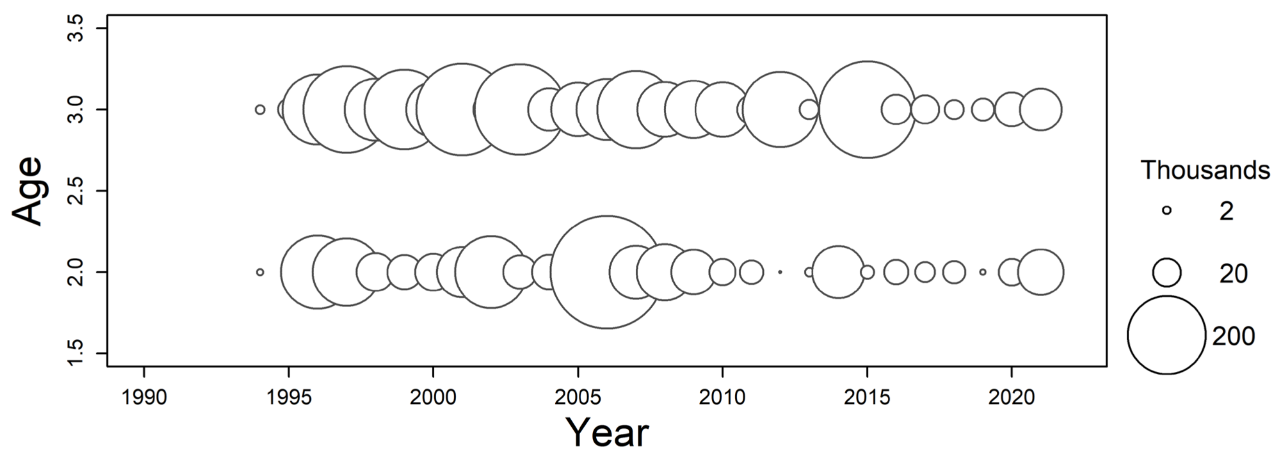

Figure 18. Bubble plot of the index of abundance of fall spawning Herring at age 2 and 3, from the fisheries-independent acoustic survey for fall spawners, 1994 to 2021.

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 fall spawning Herring (Fig. 19). Declines in size-at-age contribute to these changes. The CPUE indices increased in 2020 for both the North and Middle regions but decrease in the South region. In 2021, the CPUE decreased in the North, but increased in the Middle and South regions. Across regions, the CPUE of fall spawning younger fish (ages 4 and 5) has remained low since 2011, although the values are slightly higher for both North and Middle regions compared to 2018-2019

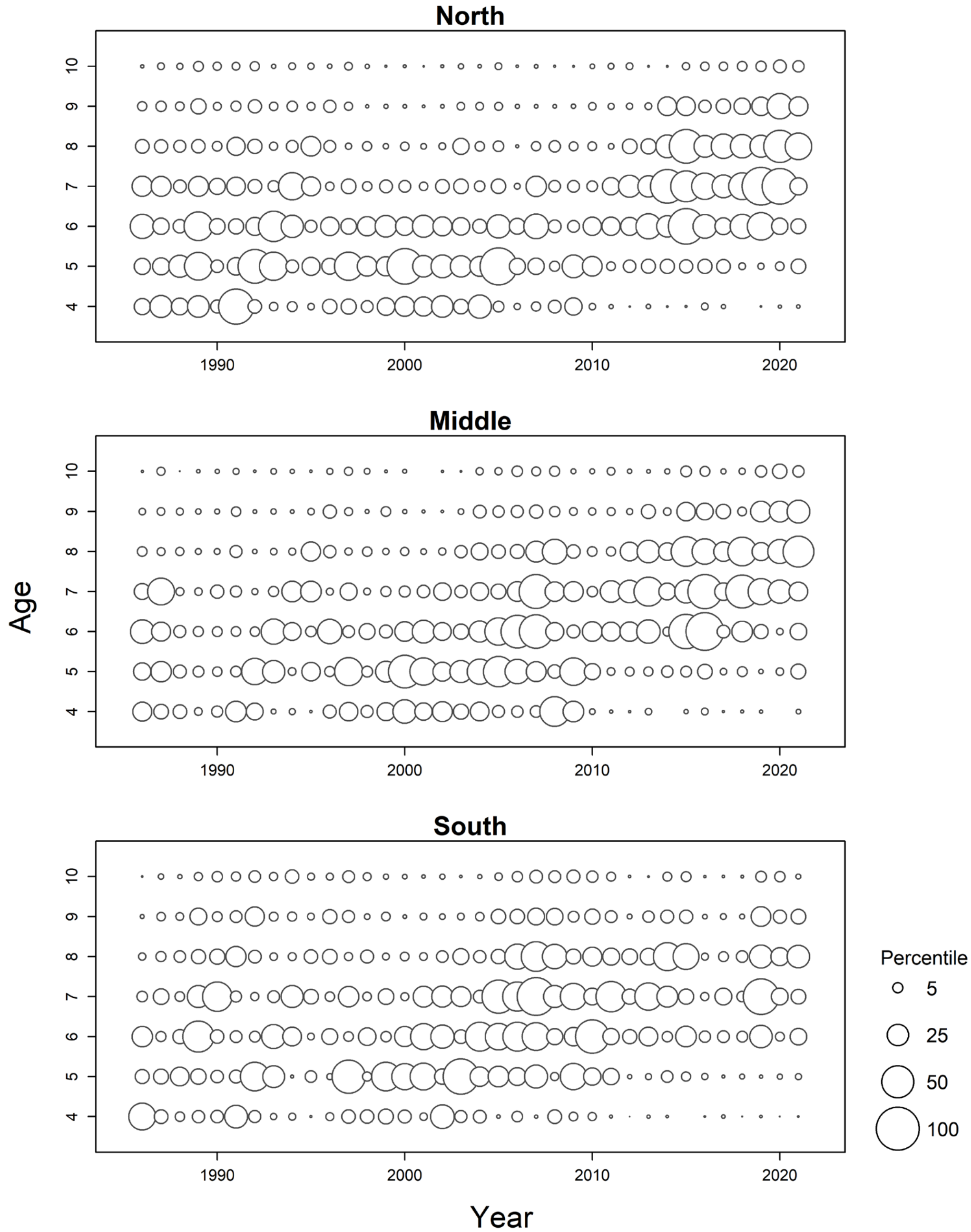

Figure 19. Fall spawning Herring fixed gear age-disaggregated catch-per-unit-effort values (number per net-haul per trip) by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 1986 to 2021. The size of the bubble is proportional to the CPUE index value.

Experimental gillnet indices

No data was available for the North region in 2021 and in 2020 the proportion in the catch-at-age was much less than what was observed in 2018 and 2019. For both middle and south regions, proportions in the catch-at-age show greater catches of fish ages 5 to 8 (Fig. 20).

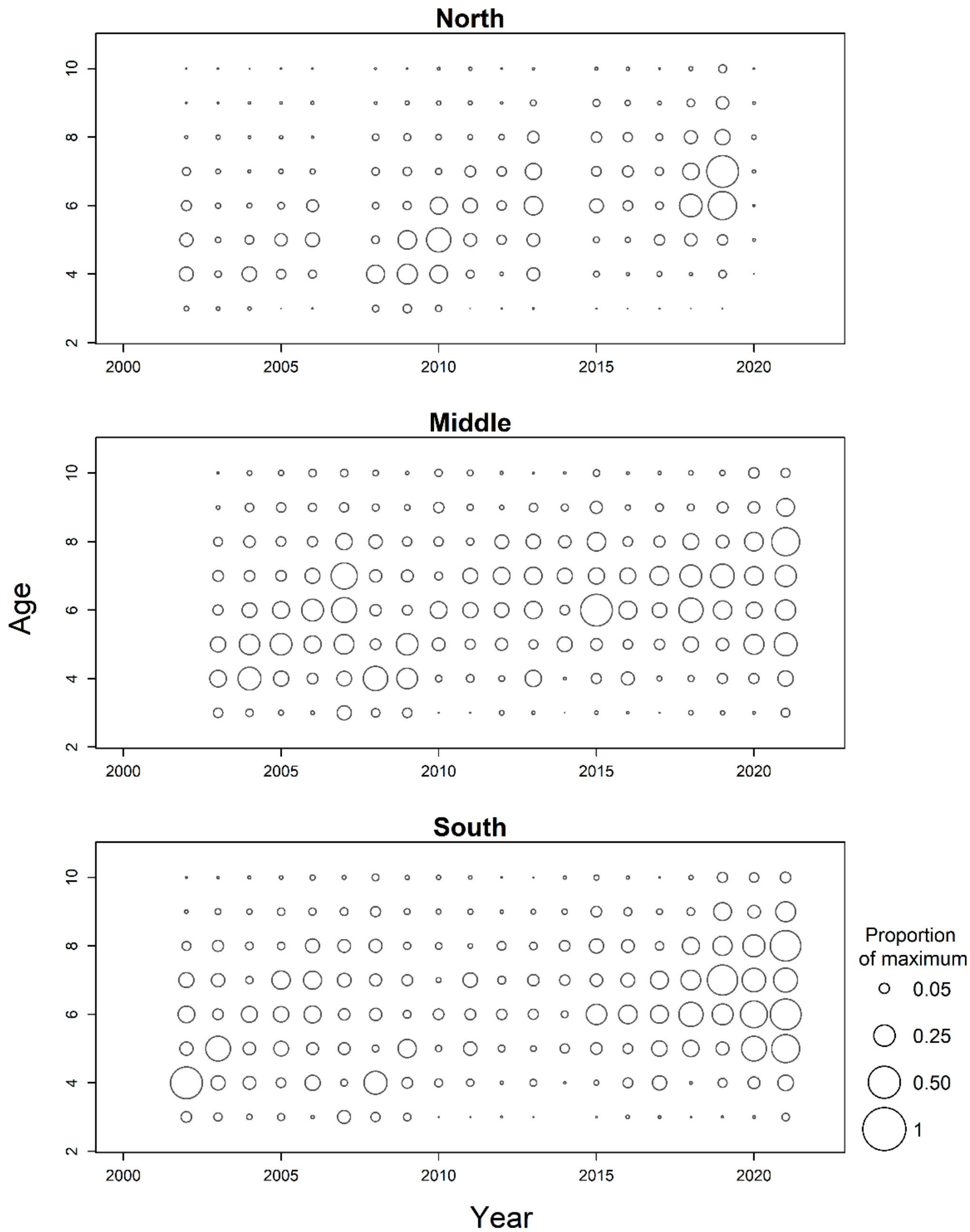

Figure 20. Bubble plots of catch-at-age indices (number) of fall spawning Herring from the experimental gillnets by region (upper panel North, middle panel Middle, and lower panel South) in the southern Gulf of St. Lawrence, 2002 to 2021. The size of the bubble is proportional to the index value.

Fishery Independent September Bottom Trawl Survey

The index suggests low abundances in the late 1990s, higher abundances of ages 4 and 5 between 2000-2005, a decline and low abundances until 2009, high values of ages 4 to 6 between 2010-2014, and a steady decline of all ages until 2021 (Fig. 21).

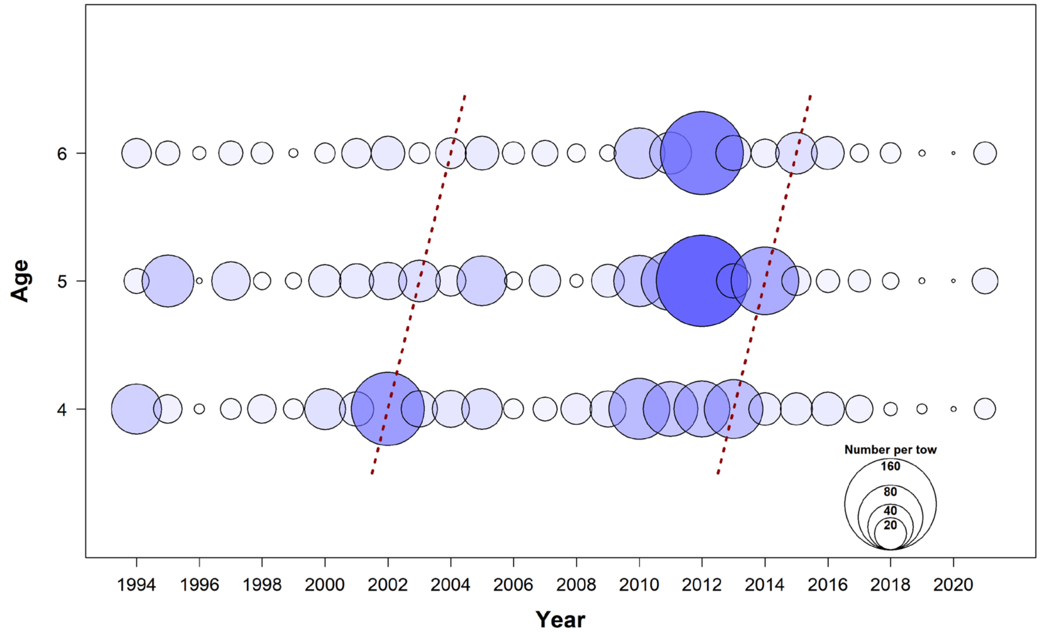

Figure 21. Multispecies bottom trawl survey abundance index (number of fish per standardized tow) for fall spawning Herring ages 4 to 6 years in the southern Gulf of St. Lawrence, 1994 to 2021.

Population model

The fall spawning Herring component is assessed using a SCA model with time-varying catchability and time-varying natural mortality. Data inputs were fishery catches at age 2 to 11+ by region from 1978 to 2021, in proportions-at-age (PAA), catch-per-unit-effort (CPUE) PAA index and age-aggregated CPUE biomass index by region from 1986 to 2021 (ages 4 to 10), PAA in experimental nets (ages 3 to 9) and the average nightly biomass from the spawning grounds acoustic survey by region from 2015 to 2021, fishery-independent acoustic survey PAA and age-aggregated biomass index from 1994-2021 (ages 2 and 3), multispecies bottom trawl survey (RV survey) PAA index and age-aggregated biomass index across the sGSL from 1994 to 2021 (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 2 $^{5}/_{8}$ inch 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.

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 spawning Herring model.

Variation in estimated catchability (*q*) to the gillnet fishery was greatest in the North region, intermediate in the Middle region, and lesser with lower values in the South region. For both North and South regions, the catchability increased as SSB declined, but seemed to be less dependent of SSB in the South region (Fig. 23).

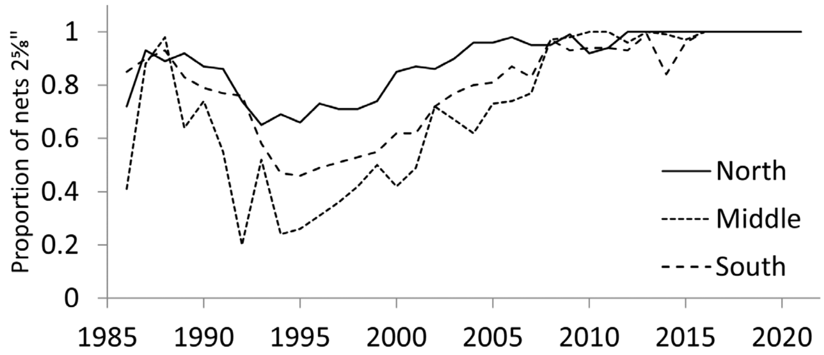

Figure 22. Variations by region in the proportions of gillnets with mesh sizes 2 ⅝ inches used in the fall Herring fishery season in the southern Gulf of St. Lawrence, 1986 to 2021. It is assumed that all other nets used were of mesh size 2 ¾ inches.

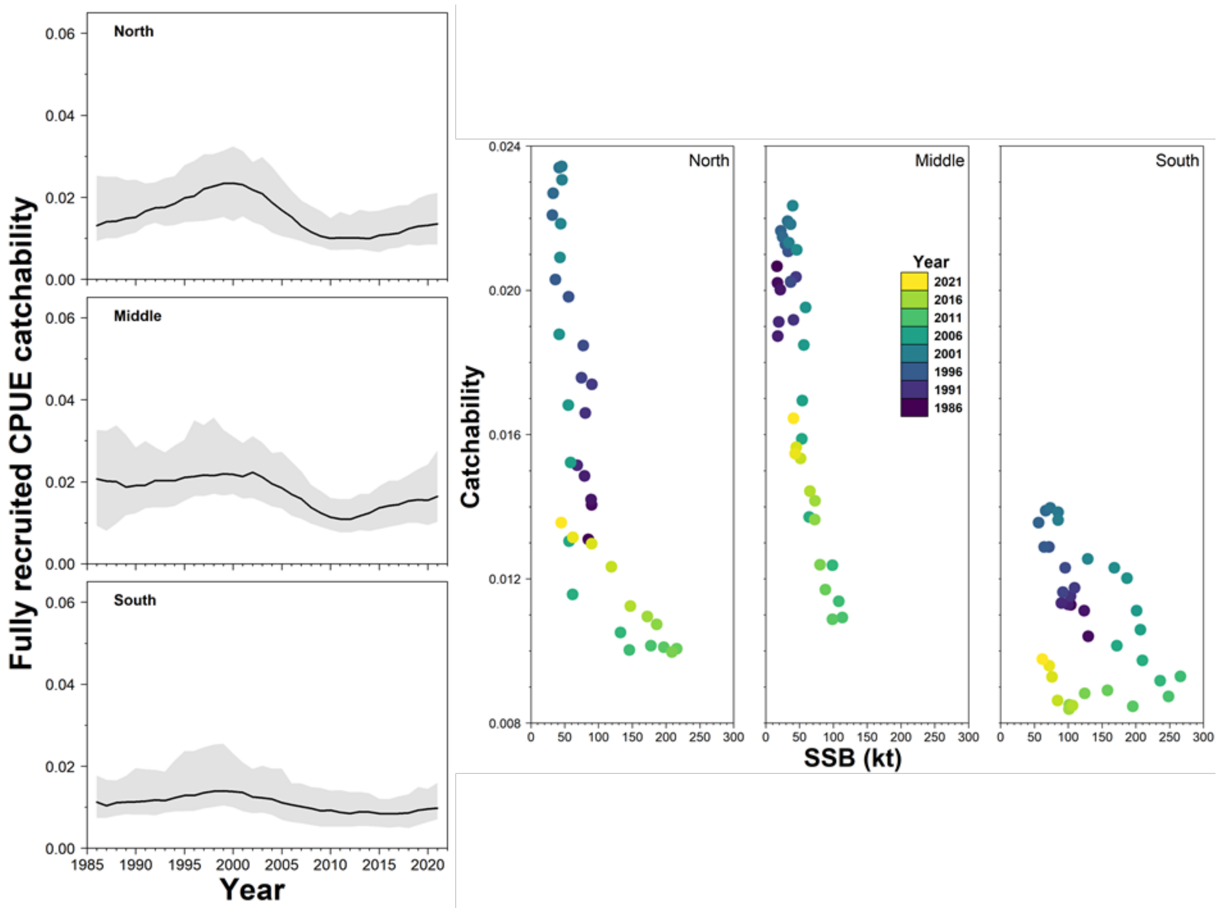

Figure 23. Estimated fully-recruited catchability (q) of fall spawner Herring to the fall gillnet fishery in three regions (North, Middle and South) (left panel) and fully-recruited catchability to the fall spawning gillnet fishery in relation to the fall spawning August 1st SSB (right panel). In the left panel, the line shows the median estimates and shading their 95% confidence interval.

Natural mortality (*M*) trends are similar within age groups among regions (Fig. 24). For ages 2-6, estimated *M* was stable early in the time series at a level near 0.2 (North) or 0.4 (Middle, South). *M* estimates then began to decline near 1990, reaching very low levels in recent years (around

0.05 in all regions). For the age group 7-11+, estimates from all regions were stables at around 0.15 until 1986 before rapidly increasing to reach extreme values of 1.1 (North), 0.8 (Middle) and 1.0 (South). Values then declined to reach 0.9, 0.5 and 0.6 in 2021 for the North, Middle and South regions, respectively. Estimated values remained at a high level in recent years in all regions (between 37% and 58% annual mortality in 2021).

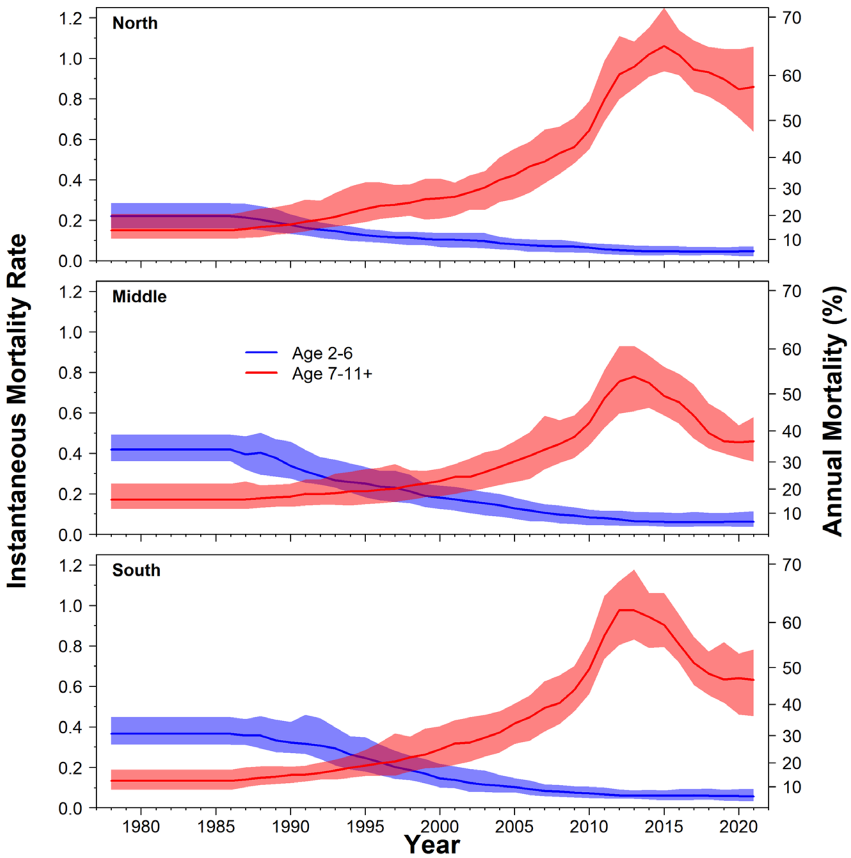

Figure 24. Estimated instantaneous natural mortality rate (left axis) and annual mortality (%, right axis) of fall spawning Herring for three regions of the sGSL (North, Middle, South) from the population model, for ages 2 to 6 (blue) and 7 to 11+ (red). Lines show the median estimates and shading their 95% confidence interval based on MCMC sampling.

Recalculating the Reference Points

The limit reference point (LRP) in 4T 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 4 lowest August 1st SSB estimates at the beginning of the time series (i.e., 1978-1981). Consequently, this value is model dependent. If the model changes, stock biomass may be re-scaled upwards or downwards. For this assessment, the LRP was estimated to be 53,154 t which is ~0.6% higher than the 52,825 t presented in the last assessment.

The USR is equivalent to 60% of the maximum August 1st SSB of the time series and is estimated to be 307,000 t. The fishing removal reference in the Healthy Zone was defined as $F_{0.1}$ and this assessment used the same value of 0.32 as used in previous assessments.

Spawning Stock Biomass and Exploitation Rate

Estimated SSB trends were mostly similar between regions (Fig. 25), increasing from lowest values in 1980 to high values from the mid-1980s to the early 1990s, before declining to a moderate level in the mid-90s. Values then increased to reach the maximum of the time series between 2008 and 2013. SSB has since been declining rapidly to a low level by 2021. The median estimate of total August 1st SSB in 2020 and 2021 were 168,849 t (95% CI: 140,076 – 211,198) and 144,007 t (95% CI: 116,994 – 185,443), respectively. The estimate for 2021 was 171% of the LRP. The probabilities that August 1st SSB was under the LRP (in the Critical Zone of the Precautionary Approach) were 0% in 2020 and 0% in 2021. The probabilities that August 1st SSB was above the USR (in the Healthy Zone of the Precautionary Approach) were 0% in 2020 and 0% in 2021. SSB has been declining since 2011.

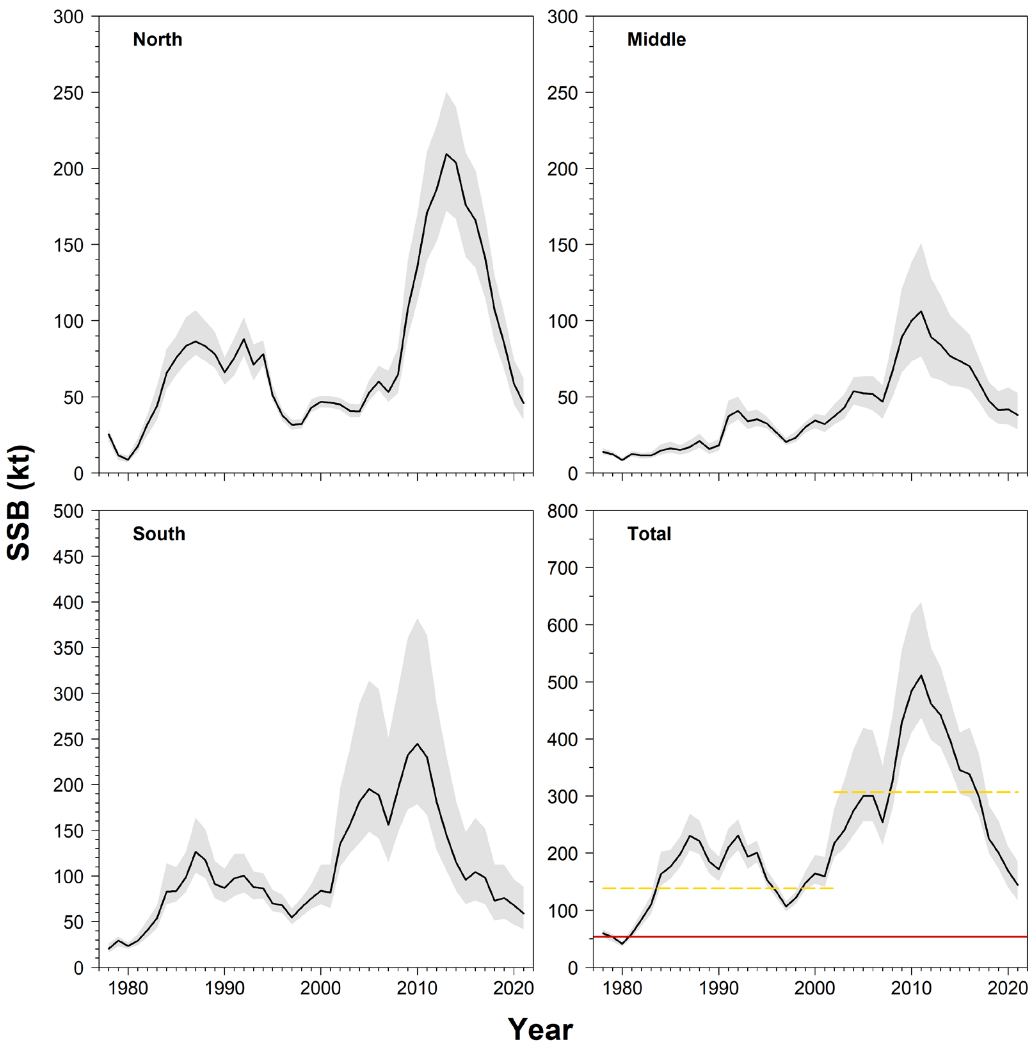

Figure 25. Estimated beginning of fishing season (August 1st) spawning stock biomass (SSB) of fall spawning Herring by region and overall (Total) for the southern Gulf of St. Lawrence from the SCA population model. The black line shows the median estimates of the MCMC sampling and the shading their 95% confidence intervals. In the bottom right panel for Total, the solid and dashed yellow horizontal lines represent the USR level and the red horizontal line is the LRP. SSB, USR and LRP values are adjusted to August 1st using natural mortality estimates at age for 7 months.

At the scale of the sGSL, estimated beginning-of-the-year fishing mortality for ages 5 to 10 (F_{5-10}) was at its highest in the early 1980s (55.5% annual mortality) before declining to stable low levels between 1984 to 1993 (Fig. 26). Starting in 1994 F_{5-10} increased until 2003 before rapidly declining to reach the lowest estimated average value in 2020 and 2021 (8.6% annual mortality). Since 2018, F_{5-10} for the North region showed a positive trend moving from a value 8.6% annual mortality in 2018 to a value of 13.9% annual mortality in 2021. Meanwhile for the Middle region the trend is negative moving from a value of 9.5% annual mortality in 2019 to 5.8% annual mortality in 2021. The South region had the lowest estimated F_{5-10} with a mean value of 5.1% annual mortality for the period 2017 to 2021.

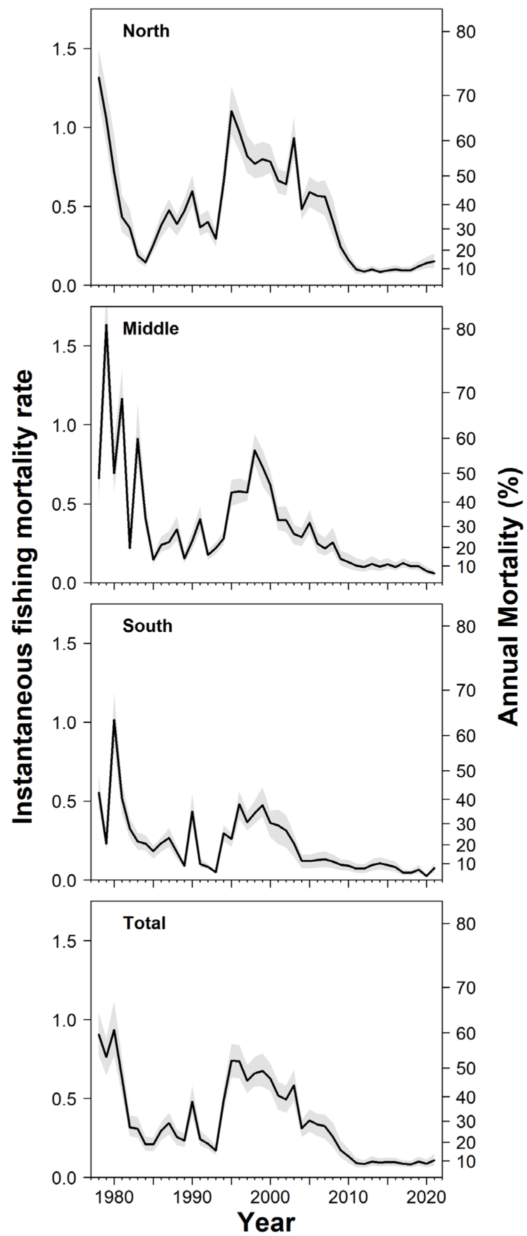

Figure 26. Estimated beginning-of-the-year age 5 to 10 fishing mortality (F_{5-10}, left axis; annual exploitation rate, right axis) of fall spawning Herring by region and averaged over regions (weighted by region-specific abundance at ages 5-10 years) in the southern Gulf of St Lawrence from the SCA population model. 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 (Fig. 27). Uncertainty is high in 2021 age 2 recruits estimates. Estimated abundance of fall spawning Herring age 4 and older has declined across regions and models since 2007. To a large extent, this reflects reductions in the recruitment of 2-year-old Herring. The recruitment rates declined in the same trend in the last decade (Fig. 27).

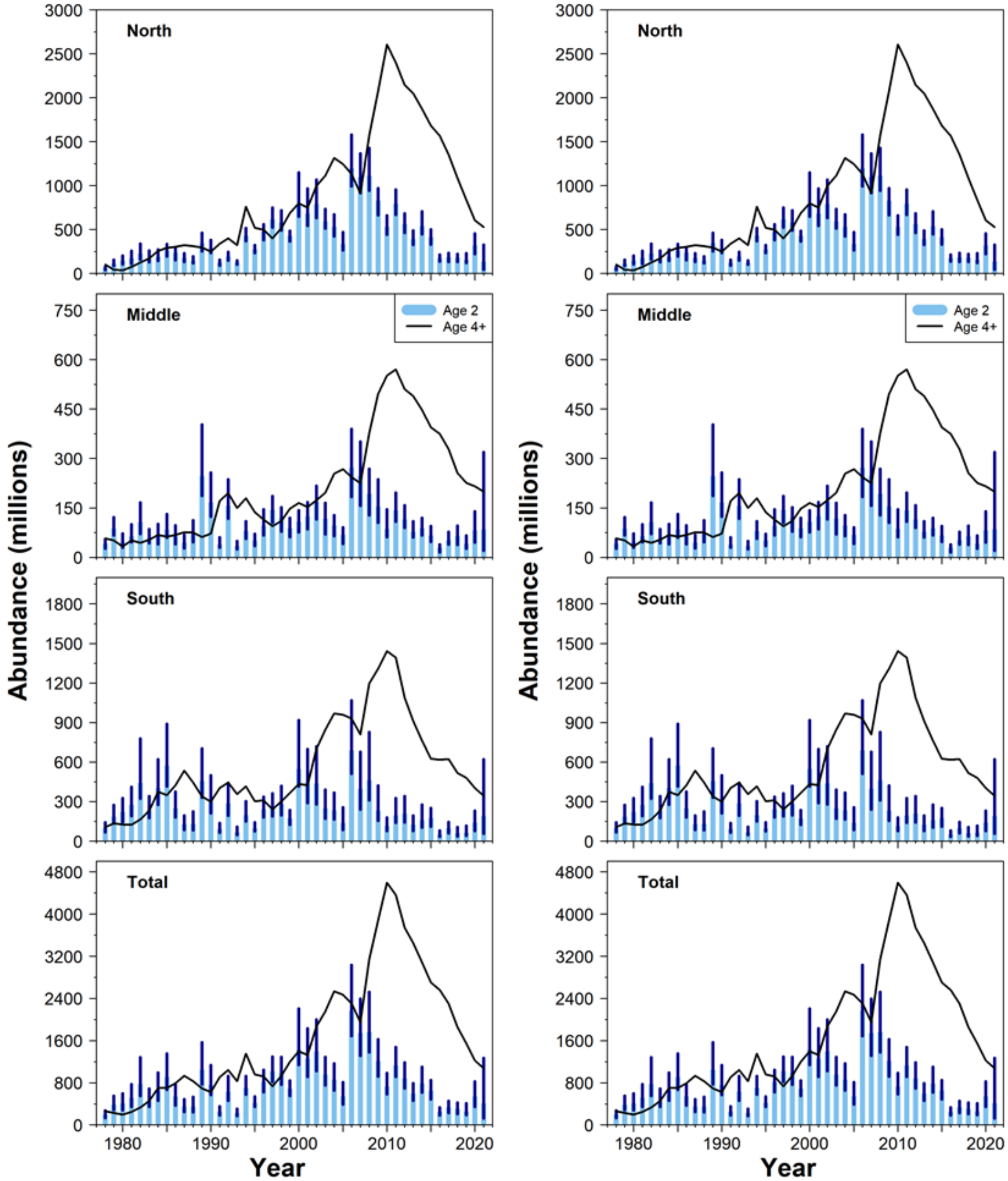

Figure 27. Estimated beginning-of-the-year recruitment of age 2 fish (bars, abundance in millions) and age 4+ (line) (left panel) and recruitment rate (recruits per kg of SSB) for fall spawning Herring by region and summed (Total) (right panel) over regions in the southern Gulf of St. Lawrence. Vertical lines are 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 population model was projected forward for two years to the start of the 2022 fishing season (August 1st) and six years forward to 2027. Projections were conducted at annual catch between 0 and 18,000 t (Fig. 28). These projections incorporated uncertainty in parameter estimates. Considering that the recruitment has been stable at low values over the past 5 years, projections were conducted using random recruitment deviations in the last five years (2017-2021).

Natural mortality for age group 2-6 has been stable for the last 5 years. Projections were conducted using the average of the 2017-2021 *M* values for each age group. Under a 0 catch scenario, predicted August 1st SSB in 2022 was 172,426 t (95% CI: 125,807 – 260,255), keeping the stock in the Cautious Zone of the Precautionary Approach. For 2023, predicted August 1st SSB was 182,029 t (95% CI: 114,796 – 327,860).

Risk analysis of catch options

SSB is expected to increase slightly from 2022 to 2023 at catch levels below 10,000 t (probabilities of ≥ 5% increase in SSB between 50 and 54%), and decrease at all catch levels from 2023 to 2024 (probabilities of ≥ 5% increase in SSB between 35 and 40% (Table 2). At the target catch level in 2021 (~12,000 t), the probabilities of a ≥ 5% increase in SSB between 2022 and 2023 are 49%, and 37% between 2023 and 2024. At a catch level of 2,000 t, the probabilities of a ≥ 5% increase in SSB between 2022 and 2023 are 54%, and 40% between 2023 and 2024.

The Probabilities of SSB being in the Critical Zone (under the LRP) by 2023 and 2024 were 0% for all catch options (Table 2). In the short term, probabilities of SSB being in the Healthy Zone (SSB > USR) by 2024 were between 1 and 2% for all catch options.

Table 2. Risk analysis table from the SCA population model of annual catch options (between 2,000 and 18,000 t) for 2022 and 2023 and subsequent years until 2027, with predicted resulting SSB (kt) in 2023, 2024 and 2027, resulting probabilities (%) of SSB being lower than the LRP, resulting probabilities of increases in SSB by 5%, and resulting fully-recruited fishing mortality rate (F_{5-10}) for the fall spawner component of Atlantic Herring from the southern Gulf of St. Lawrence.

	Year	Catch options (t)								
		2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000
SSB (kt)	2023	186.3	185.5	184.3	183.3	181.7	181.1	179.7	178.3	177.6
	2024	184.0	182.1	180.0	178.8	176.7	175.2	172.8	171.0	169.0
SSB < LRP	2023	0	0	0	0	0	0	0	0	0
	2024	0	0	0	0	0	0	0	0	0
	2027	0	0	0	0	0	0	0	0	0
5% increase in SSB (%)	2023	54	53	52	51	50	49	47	45	46
	2024	40	39	38	38	38	37	36	36	35
F_{5-10}	2022	0.01	0.03	0.04	0.06	0.07	0.09	0.1	0.12	0.13
	2023	0.01	0.03	0.04	0.06	0.07	0.09	0.11	0.12	0.14

Six-year SSB projections show a small increase until 2023 followed by a sharp decline until 2027 for all catch options. The probabilities that the stock will reach the Healthy Zone (above the USR) under all catch options is 1%. By 2027, at all catch levels, the probability of SSB being in the Critical Zone (under the LRP) was 0% (Table 2).

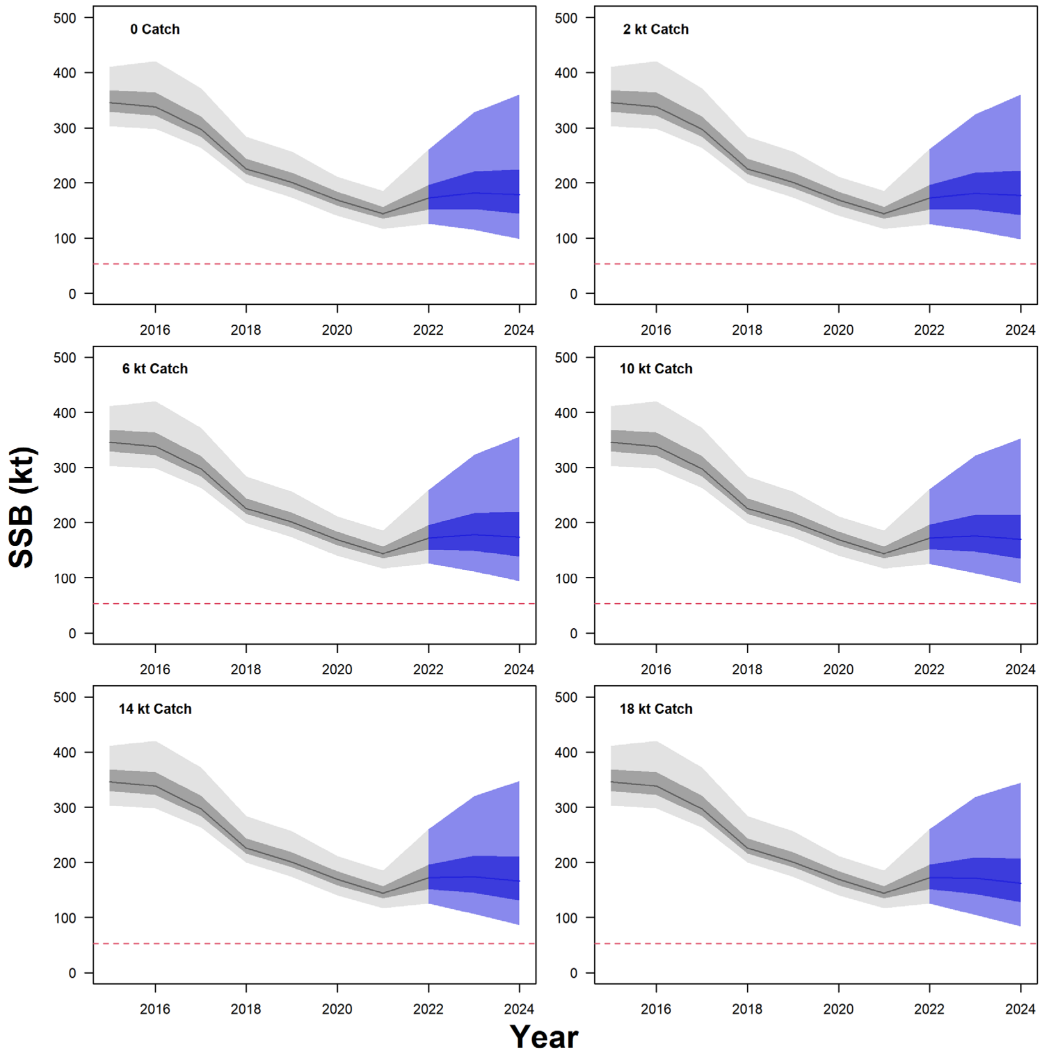

Figure 28. Projected SSB (in kt) of fall spawning Atlantic Herring from the southern Gulf of St. Lawrence at various catch levels in 2022 and 2023, under a 5 recent years average recruitment and 2 recent years average natural mortality scenario. Lines show the median estimates of August 1st SSB, dark shading the 95% confidence intervals and light shading the 50% confidence interval (based on MCMC sampling). Black and grey indicate the historical period and blue the projection period. The red horizontal line is the LRP.

ECOSYSTEM CONSIDERATIONS

Natural mortality

The general decline in both sGSL Herring stocks not only has negative impacts on the fishery, but is likely to have negative impacts on the ecosystem as well. For many predators, forage fish constitute a substantial percentage of their diet, possibly making them vulnerable to reductions or fluctuations in forage fish biomass (Pikitch et al. 2014).

Herring natural mortality includes predation by all sources, disease and unreported catch (bait). Natural mortality estimates of both stocks are expected to be mostly predation driven. Herring is an important pelagic prey species for numerous predators in the sGSL including Grey Seal (*Halichoerus grypus*; Hammill and Stenson 2000; Hammill et al. 2007, 2014), seabirds (mostly Northern Gannets (Cairns et al. 1991)), cetaceans (Fontaine et al. 1994; Benoît and Rail 2016), 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; Varela et al. 2020; Turcotte et al. 2021a). Of these major predators, Atlantic Cod, Grey Seals, Atlantic Bluefin Tuna and Northern Gannets have undergone large changes in abundance in the sGSL in the last decades. Consequently, natural mortality of Herring has likely to have changed over time.

For both Herring stocks, the increase in natural mortality for the age group 7-11+ correlated with the increases in the abundance indices of Grey Seal, Atlantic Bluefin Tuna and Northern Gannets, the most important Herring consumers in the sGSL (Benoit and Rail 2016; Turcotte et al. 2021b) (Fig. 29). Changes in natural mortality of younger Herring (ages 2-6) over the time-series were of a lesser magnitude, but fall spawning Herring changes in M correlated with decline in Atlantic Cod and White Hake abundance (Fig. 29). Further analysis of predator abundance, spatial distribution, size distribution, diet and functional response of predators to prey will be necessary to quantify the effects of the different predators on spring and fall spawning Herring natural mortality.

Recruitment

Pelagic fish such as Herring often exhibit sporadic recruitment peaks, making long term projections highly uncertain. However, recruitment is currently low in both spring and fall spawners.

Spring spawning Herring recruitment abruptly shifted from a cold water/high recruitment regime (1978-1991) to a warmer water/low recruitment regime (1992-2017) in the early 1990s. Spring spawning Herring recruitment can be predicted by a model using three zooplankton abundances/phenology variables, explicitly linking ecosystem changes to Herring population dynamics. Given the ongoing trend towards warmer conditions and changes in the zooplankton community in the sGSL (Blais et al. 2021; Galbraith et al. 2021), 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.

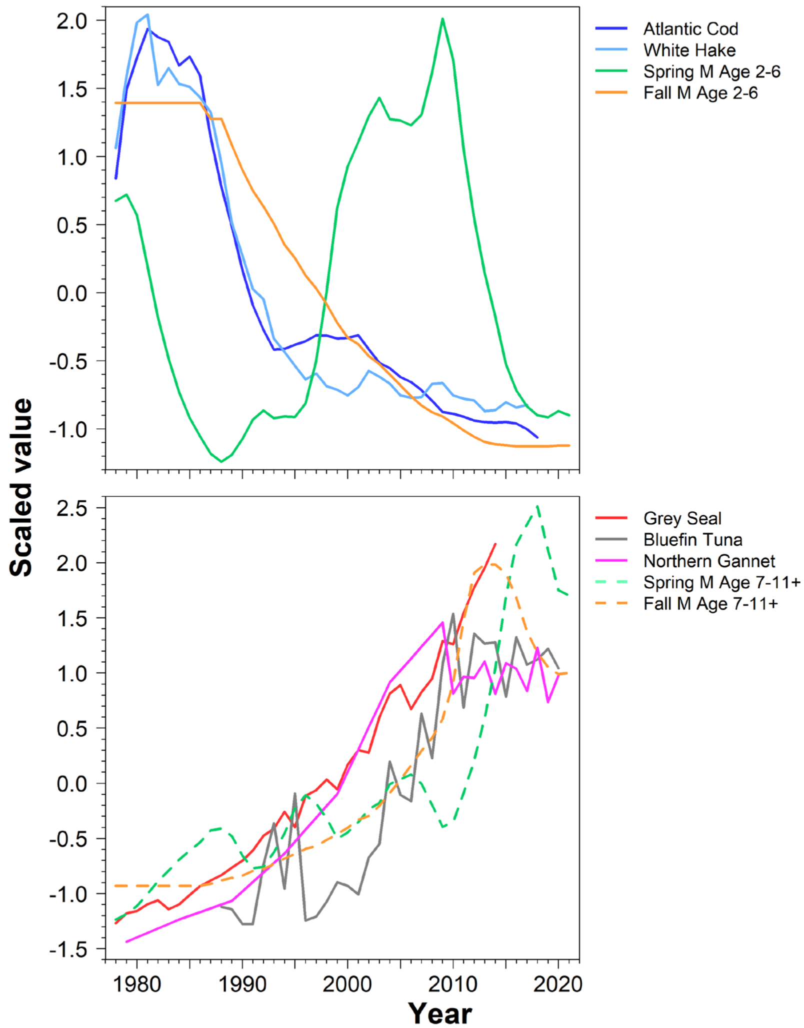

Figure 29. Scaled relative abundance indices for Herring major predators (Atlantic Cod, White Hake, Grey Seal, Atlantic Bluefin Tuna, Northern Gannet) between 1970-2021 alongside with natural mortality (M) estimates for age groups 2-6 (M2-6) and 7-11+ (M7-11) from the SCA spring and fall Herring stock models. Natural mortality estimates are median MCMC estimates.

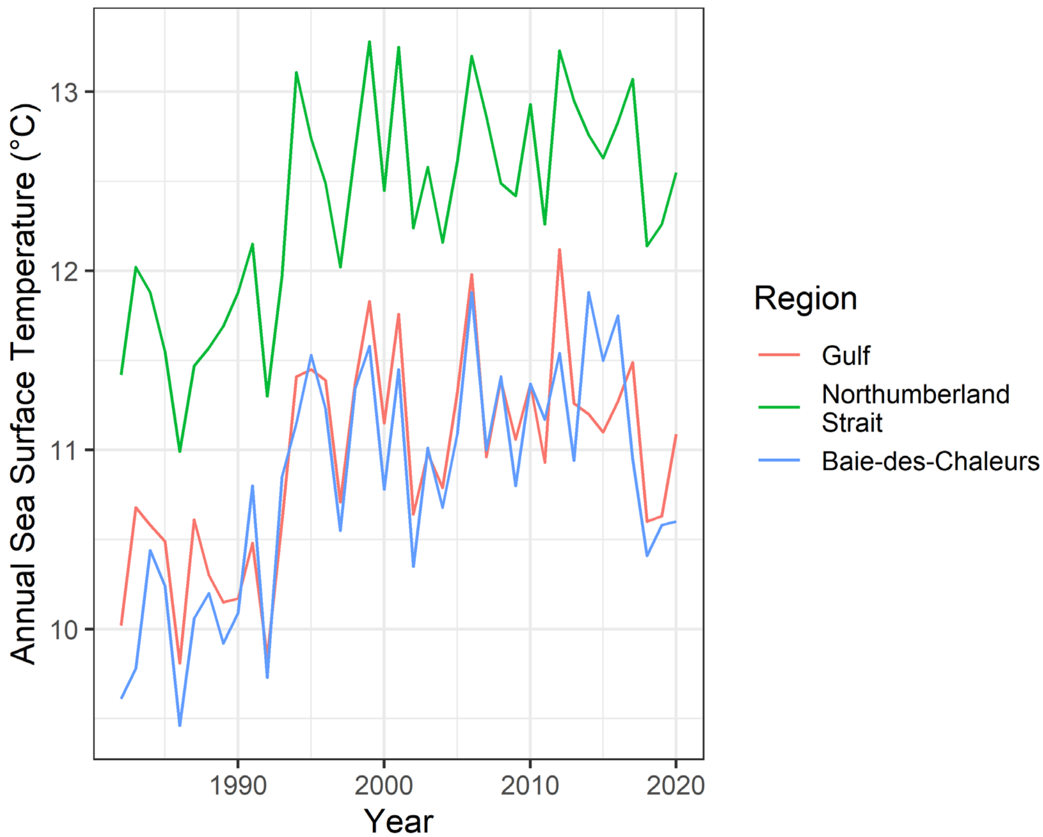

Figure 30: Annual average sea surface temperature in the Gulf of Saint-Lawrence, the Northumberland Strait and the Baie-des-Chaleurs regions. Data from the AZMP monitoring program (Galbraith et al. 2019).

Sources of Uncertainty

Uncertainty in SSB estimates have been reduced since the adoption of the new SCA population models for both spring and fall spawning stocks. Natural mortality estimation accounts for disappearing age classes through time that cannot be explained by fishery removals, and allows for recruitment estimation that better fits the data. Accurate natural mortality, recruitment, and SSB estimates are therefore crucial for projections accuracy, providing more realistic outcomes of management measures (Total Allowable Catch).

The estimation of time-varying natural mortality in the model generated some retrospective patterns in SSB, while seemingly less important for the recent years. Incorporating the spawning grounds acoustic survey data into the model, as suggested in the last assessment, seems to have lessened such patterns.

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

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

Catches of spring and fall spawning Herring in bait fisheries are presently accounted for in the assessments through natural mortality estimates, but the proportion of unreported catch, disease, or predation mortality cannot be disentangled. Catches in the bait fisheries are meant to be recorded in harvester logbooks but compliance with the requirement to complete and return logbooks to DFO is low. Catches of Herring in the bait fishery are expected to be much lower than landings in the commercial fishery, nonetheless this constitutes a source of uncertainty in the total fishing mortality. We expect that for the next assessment, the development of a mandatory electronic logbook will increase reporting of bait fishery.

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 allowing time-varying catchability.

The commercial CPUE calculations are subject to uncertainty. The estimates are mostly 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 and not trip-specific information. Trips with no catch are not documented prior to 2006 and therefore not incorporated in the effort data. A CPUE index for this time period should be calculated with the null tows for comparison with the traditional CPUE index. 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.

Reference points, especially the USR and the F0.1 removal reference in the Healthy Zone, will be re-visited for future assessments. This work will occur in the development of the rebuilding plans of both stocks. For this assessment, USRs were scaled to be similar to what was used in previous assessments. As neither stocks are headed for the USRs in the short or long-term, the uncertainty around the appropriateness of the USRs and F0.1 is not expected to have a big impact on the assessment and risk analysis of catch options.

CONCLUSIONS AND ADVICE

For spring spawning Herring, the assessment to the end of 2019 fishing year indicated that the stock had been in the Critical Zone since 2002 and that even in the absence of any removals of spring spawners, there was a high probability that the stock would remain in the Critical Zone (DFO 2020). For fall spawners, it was virtually certain (100%) that the spawning stock biomass would be in the Cautious Zone in 2020 and unlikely (0-33%) the stock would increase by 2022 (DFO 2020). This assessment confirmed the status of previous years and the expectations of abundance in 2020 and 2021 of both spring and fall spawners.

Spring Spawner Component (SS)

The spring spawner component trajectory with respect to spawning stock biomass and fishing mortality levels is shown in Figure 31. Fishing mortality exceeded the removal reference level in 28 of the 44 years of the time series The stock has been in the Critical Zone (SSB < LRP) since 2002 but experienced fishing mortalities above the provisional harvest decision rule of the Precautionary Approach Framework since 1999. For the short term projections and all catch options (0 to 1,250 t), it was unlikely (0-33%) that SSB would exceed the LRP to reach the Cautious Zone by 2024 (under 20%). The prognosis for this stock is that even in the absence of fisheries removals, the stock will remain in the Critical Zone into 2027. 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 2006).

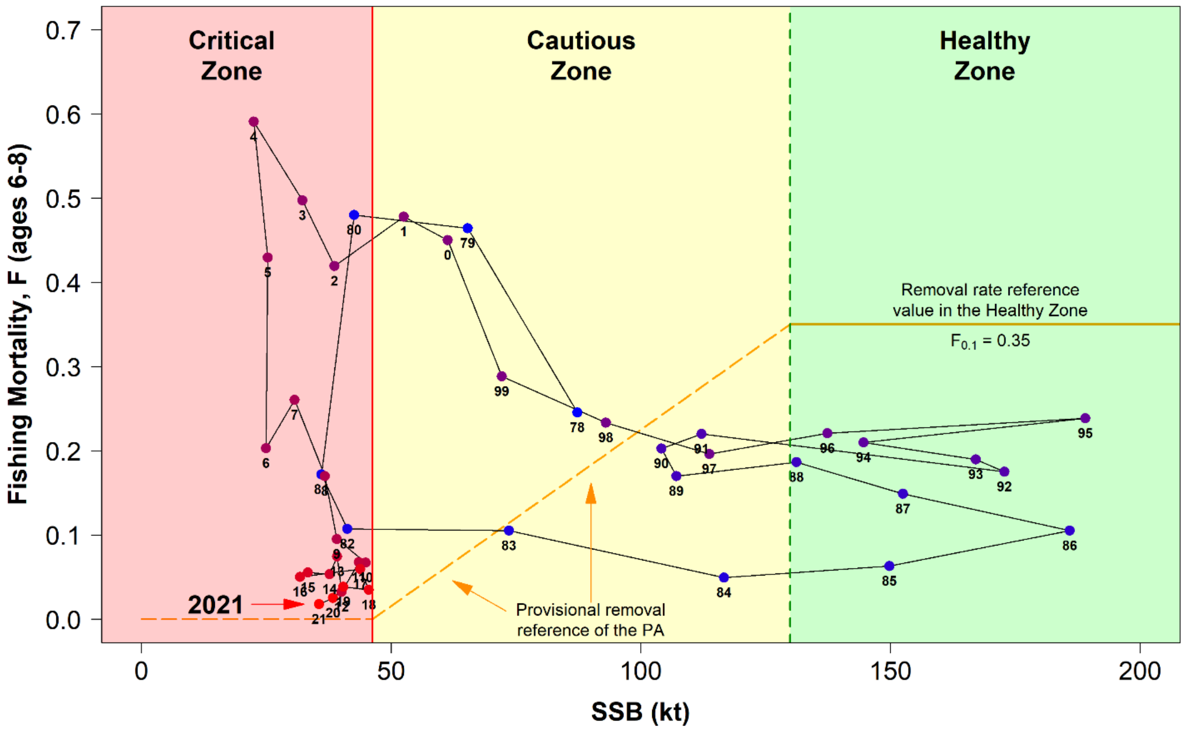

Figure 31. The southern Gulf of St. Lawrence spring spawning Herring component trajectory in relation to SSB (kt = thousand t) and abundance weighted fishing mortality rates for ages 6 to 8 years. The red vertical line is the LRP and the green dashed vertical line is the Upper Stock Reference (USR). The orange solid horizontal line is the removal rate reference value ($F_{0.1}$ = 0.35) in the Healthy Zone and orange dashed line is the provisional harvest decision rule of the Precautionary Approach Framework in the Cautious and Critical Zones. Point labels are years (83 = 1983, 0 = 2000). Colour coding is from blue in 1978 to red in 2021.

Fall Spawner Component (FS)

The fall spawner component trajectory with respect to SSB/USR and fishing mortality ($F/F_{0.1}$) levels 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 Precautionary Approach removal reference from 1978 to 1983, in 1987, 1990, from 1994 to 2007 and since 2020. As a consequence of low productivity, reduced weight-at-age, and high natural mortality, exploitation of this stock should assert caution until high recruitment is observed for consecutive years. Until high recruitment events occur, the decline in SSB is more likely to continue. As the stock is deep in the Cautious Zone, the Precautionary Approach framework states that actions should promote stock rebuilding towards the Healthy zone. For the first time since 2007, the stock has moved above the provisional removal reference ($F/F_{0.1}$) of the PA, indicating a state of overfishing that could prevent any growth over the short and long term. Projections have showed that reducing fishing mortality would slightly reduce the probabilities of a decline for the 2022 and 2023 seasons. The annual catch levels offering the greatest probabilities of increasing SSB in the short and long term are 0, 2,000 and 4,000 t.

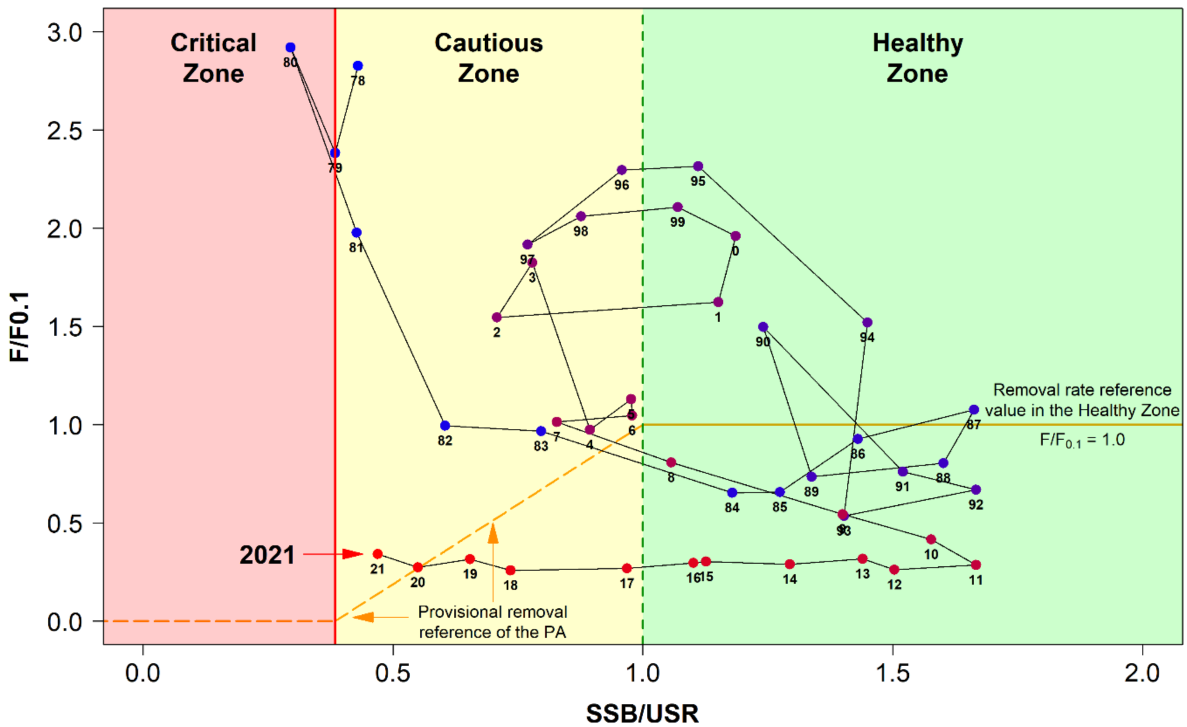

Figure 32. Southern Gulf of St. Lawrence fall spawning Herring component trajectory in relation to SSB/USB and fishing mortality rates for ages 5 to 10 years from the SCA population model. The red vertical line is the LRP and the green vertical line is the USR. The orange solid horizontal line is the removal rate reference value ($F/F_{0.1}$ = 1.0) in the Healthy Zone and orange dashed line is the provisional removal reference of the Precautionary Approach Framework. Point labels are years (83 = 1983, 0 = 2000). Colour coding is from blue in 1978 to red in 2021.

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This Science Advisory Report is from the March 22-23, 2022 regional science peer review meeting on the 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 2022 and 2023 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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