SOUTHERN GULF OF ST. LAWRENCE (NAFO DIVISION 4TVN) FALL SPAWNING ATLANTIC HERRING (*CLUPEA HARENGUS*) STOCK ASSESSMENT TO 2023

CONTEXT

The Fisheries and Harbour Management sector of Fisheries and Oceans (DFO) has requested a stock status for the southern Gulf of St. Lawrence (sGSL) (Northwest Atlantic Fisheries Organization (NAFO) 4TVn) Atlantic Herring (*Clupea harengus*) fall spawning component. This stock is prescribed under section 6 of the Fisheries Act. The last scientific assessment for this stock was completed in March 2022 to provide advice for the 2022 and 2023 fisheries (DFO 2022). This stock follows a two-year assessment and management cycle. This Science Advisory Report is from the regional peer review of March 19-20, 2024 on the Southern Gulf of St. Lawrence, NAFO Division 4TVn, Atlantic Herring (*Clupea harengus*) Stock Assessment to 2023. Additional publications from this meeting will be posted on the DFO Science Advisory Schedule as they become available.

SCIENCE ADVICE

Status

- The Spawning Stock Biomass (SSB) of the southern Gulf of St. Lawrence (NAFO division 4TVn) fall spawning Atlantic Herring has been in the Cautious Zone of the Precautionary Approach (PA) Framework since 2017.
- As of 2022 and 2023, SSB of fall spawning Atlantic Herring has (100% probability) remained in the Cautious Zone.

Trends

- Fall spawning Atlantic Herring has experienced declining SSB over the past decade, with declines continuing steadily over the past few years, except for 2023 where a slight increase in SSB was observed.
- Recruitment of fall spawning Atlantic Herring has been declining since 2006 to reach the lowest level of the time series in 2019. Recruitment has since increased and there was evidence of a notable recruitment event in 2022.
- Starting in 2010, natural mortality estimates for older ages of fall spawning Atlantic Herring sharply increased up to mid-2010s, then slightly decreased and remained at high levels.

Ecosystem and Climate Change Considerations

- Higher water temperatures, poor food quality and high predator abundance likely have negative implications for Atlantic Herring size-at-age, fecundity and overall abundance.

Stock Advice

- Under current conditions of high natural mortality, declines in weight-at-age, and low recruitment, the probabilities that SSB of fall spawning Atlantic Herring will increase by 2025 range from 48 to 53% across all considered catch options (2 to 18 kilotonnes). At all catch options, there is no chance that the SSB will decline into the Critical Zone by 2029.
- In light of recent stock trends and environmental conditions, caution should be taken when interpreting SSB projections for fall spawning Atlantic Herring as they suggest unrealistically optimistic trends. Therefore, stock advice should focus on 2023 SSB estimates rather than projections and a framework review should be conducted for this stock.

BASIS FOR ASSESSMENT

Assessment Details

Year Assessment Approach was Approved

2021 (Turcotte et al. 2021)

Assessment Type

Full Assessment

Most Recent Assessment Date

1. Last Full Assessment: 2021 (DFO 2022; Rolland et al. 2022)
2. Last Interim Year Update: n/a

Assessment Approach

1. Broad category: Single stock assessment model
2. Specific category: Spatially disaggregated statistical catch-at-age

Stock Structure Assumption

The southern Gulf of St. Lawrence (sGSL) fall spawning component of Atlantic Herring (hereafter; fall Herring) is genetically distinct from the spring spawning component (Lamichhaney et al. 2017), and thus is assessed as its own stock. The fall spawning stock is assessed using a regionally-disaggregated statistical catch-at-age model with time-varying catchability and natural mortality, where the model estimates biomass and other parameters in the North (Gaspé and Miscou; 4Tmnopq), Middle (Escuminac-Richibucto and west Prince Edward Island; 4Tkl) and South (east Prince Edward Island and Pictou; 4Tfghj) regions of the sGSL. The choice of three regions was determined by geographic proximity of spawning beds and is the finest level of disaggregation that can presently be supported by the available data. However, the advice presented for catch options are provided at the scale of the entire sGSL.

Reference Points

- Limit Reference Point (LRP): The LRP (64,900 tonnes (t)) is derived from $B_{recover}$, which is the lowest biomass from which the stock has been observed to readily recover, calculated as the average of the SSB estimates from 1978-1981 for the sGSL (Chouinard et al. 2005).

- Upper Stock Reference (USR): The USR is equivalent to 60% of the maximum August 1st SSB observed for the time series and is estimated to be 409,245 t for the sGSL (Turcotte et al. 2021).
- Removal Reference (RR): $F_{0.1}$ in the Healthy Zone of the Precautionary Approach Framework, which corresponds with a fully-recruited fishing mortality value of 0.32 (Chouinard et al. 2005).

Data

- Commercial landings extracted from dock monitoring reports, purchase slips and ZIFF (Zonal Interchange File Format) files (1978 – 2023)
- Dockside Monitoring Program to inform fishing effort calculation of CPUE (1978 – 2023)
- Telephone Survey to inform fishing effort calculation of CPUE (1986 – 2023)
- DFO Port Sampling to inform catch-at-age (1978 – 2023)
- Fishery-Independent Acoustic Survey (1994 – 2023)
- Industry Acoustic Survey of spawning grounds (2015 – 2023)
- Experimental Net Program (2001 – 2023)
- Multispecies Bottom-Trawl Survey (1994 – 2023)
- Ecosystem Information (2001 – 2021)

Commercial landings are provided by the Statistics Branch of Fisheries and Oceans Canada and the Dockside Monitoring Program. Port sampling is conducted to collect a sample of landed fish in order to understand the biological composition. The yearly telephone survey is also conducted to understand changes in biomass from a fisher’s perspective and to inform the Catch Per Unit Effort (CPUE) index.

Several fisheries independent surveys are also conducted each year. The DFO-led acoustic survey in the Baie-des-Chaleurs and the multi-species bottom trawl survey across the sGSL estimate relative age aggregated biomass and proportions at age indices for ages 2-3 (acoustic survey) and ages 4-6 (multi-species survey). The spawning grounds acoustic survey pairs acoustic data at the spawning grounds with experimental net program to estimate biomass throughout the sGSL over five weeks. The experimental nets also allow calculation of mesh selectivity. A subsample of fish are processed in the lab at the Gulf Fisheries Centre and are used for spawning stock assignment to understand the proportion of fall Herring observed in each data source (see Rolland et al. 2022).

ASSESSMENT

NORTH

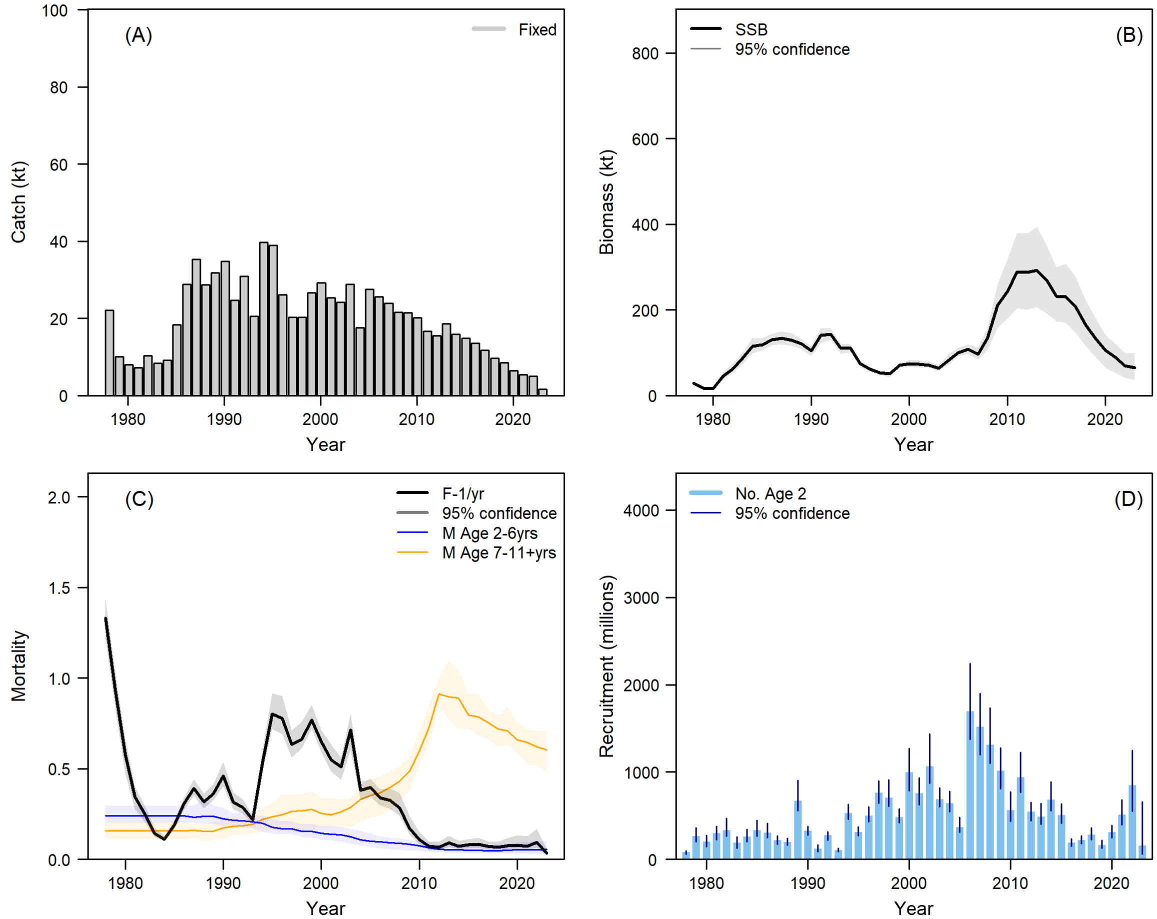

Figure 1. (A) Catch in kilotonnes (kt) for fixed gear, (B) Spawning Stock Biomass (SSB; kt), (C) Fishing Mortality (F; black), Natural Mortality (M) for ages 2-6 (blue) and ages 7-11 + (yellow), (D) Recruitment (number-at-age 2) of fall spawning Atlantic Herring in the North region of the Gulf of Saint Lawrence.

MIDDLE

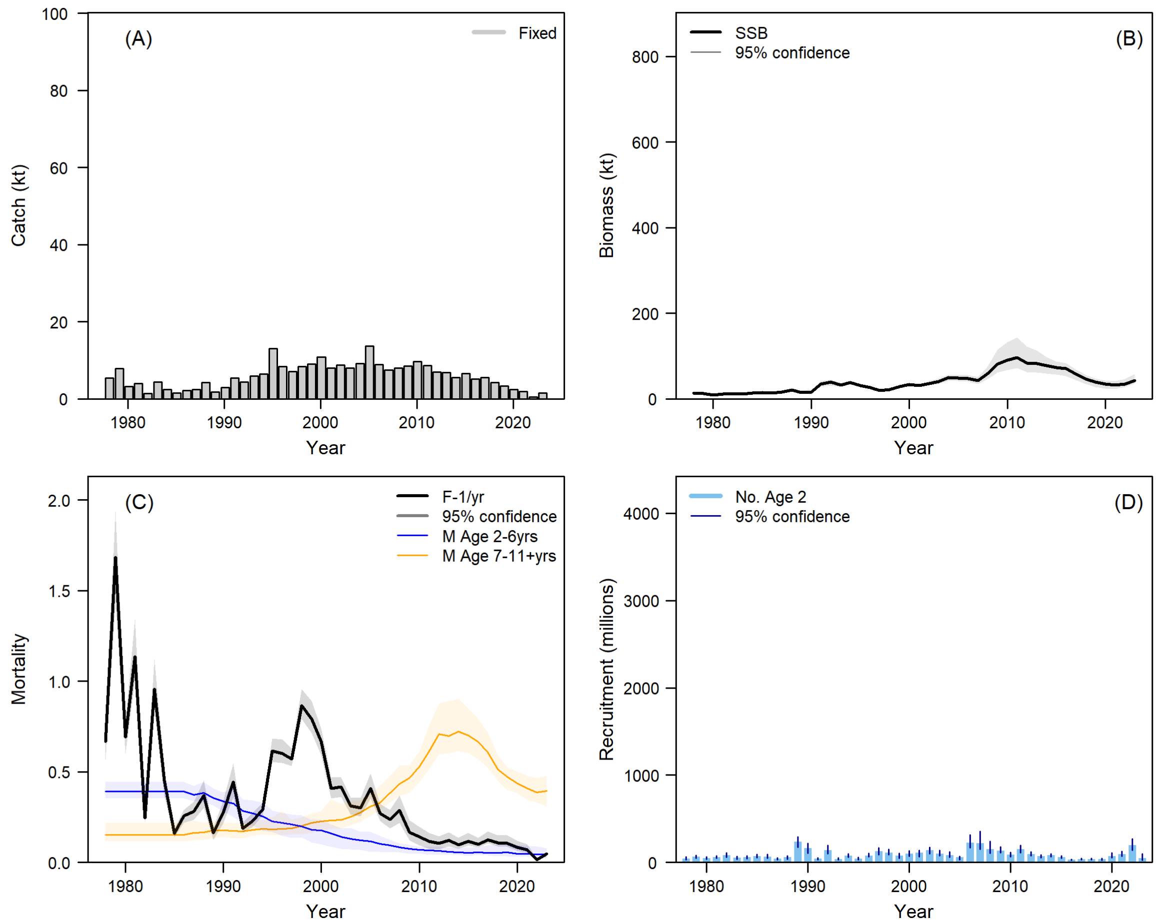

Figure 2. (A) Catch in kilotonnes (kt) for fixed gear, (B) Spawning Stock Biomass (SSB; kt), (C) Fishing Mortality (F; black) and Natural Mortality (M) for ages 2-6 (blue) and ages 7-11 + (yellow), (D) Recruitment (number-at-age 2) of fall spawning Atlantic Herring in the Middle region of the Gulf of Saint Lawrence.

SOUTH

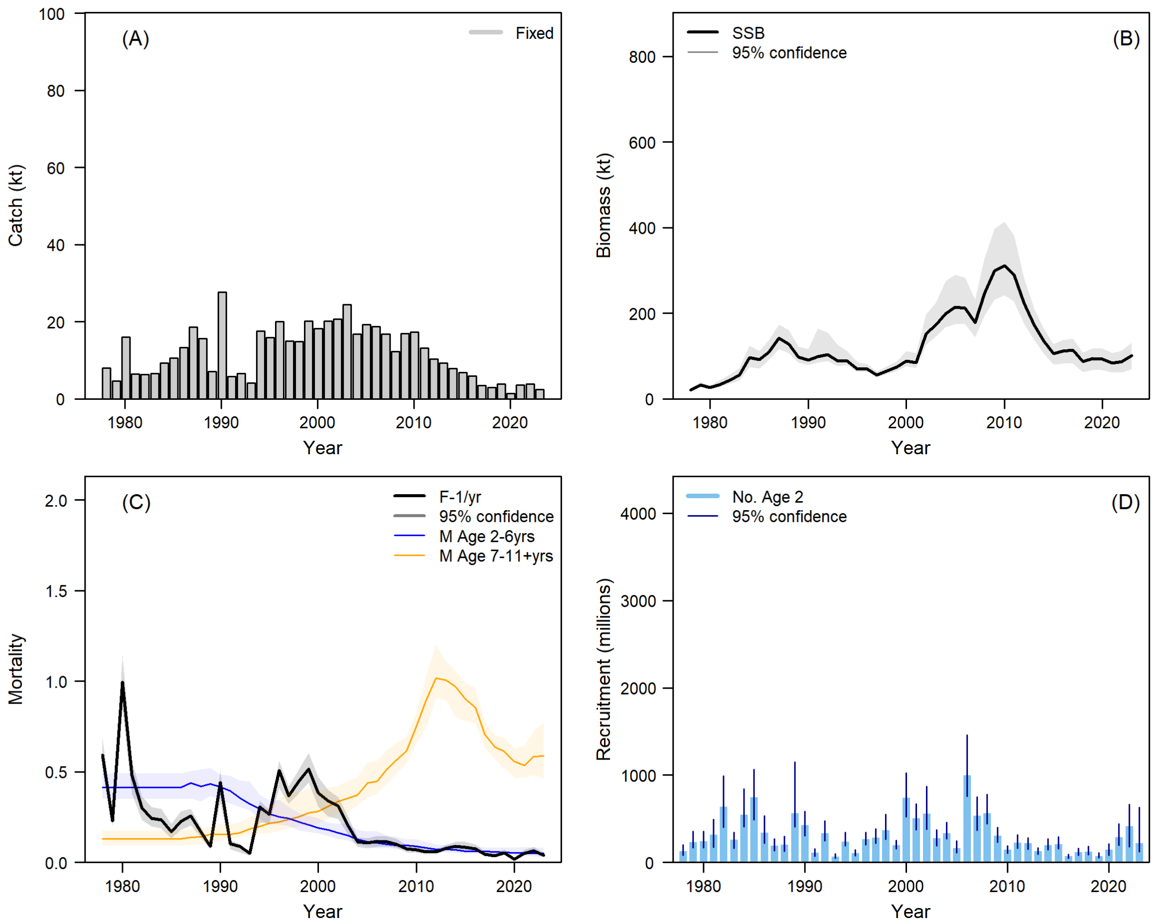

Figure 3. (A) Catch in kilotonnes (kt) for fixed gear, (B) Spawning Stock Biomass (SSB; kt), (C) Fishing Mortality (F; black) Natural Mortality (M) for ages 2-6 (blue) and ages 7-11 + (yellow), (D) Recruitment (number-at-age 2) of fall spawning Atlantic Herring in the South region of the Gulf of Saint Lawrence.

TOTAL

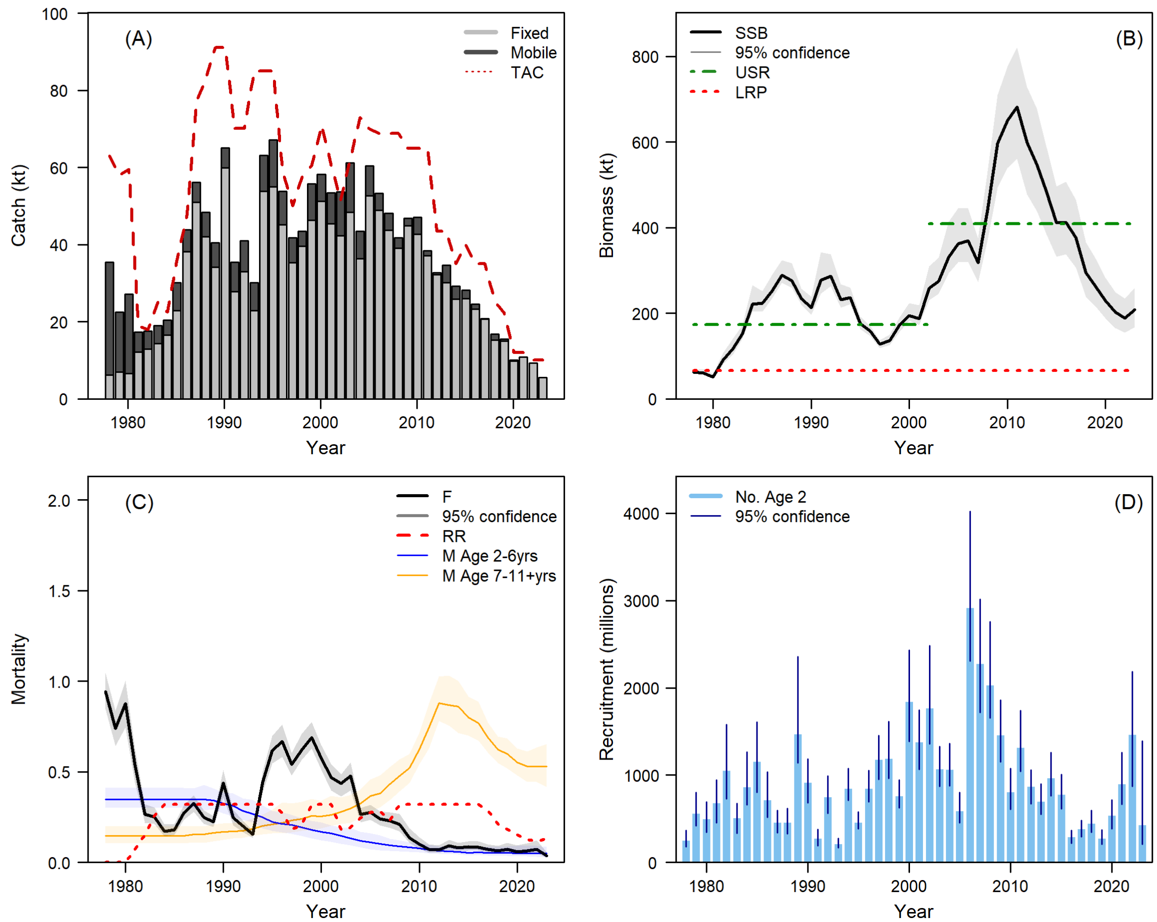

Figure 4. (A) Catch in kilotonnes (kt) for fixed gear and mobile gear vs Total Allowable Catch (TAC; kt), (B) Spawning Stock Biomass (SSB; kt) in relation to the Limit Reference Point (LRP; dotted red) and Upper Stock Reference (USR; dotted green), (C) Fishing Mortality (F; black) the Removal Reference (RR; dotted red) and Natural Mortality (M) for ages 2-6 (blue) and ages 7-11 + (yellow), (D) Recruitment (number-at-age 2) across the southern Gulf of Saint Lawrence.

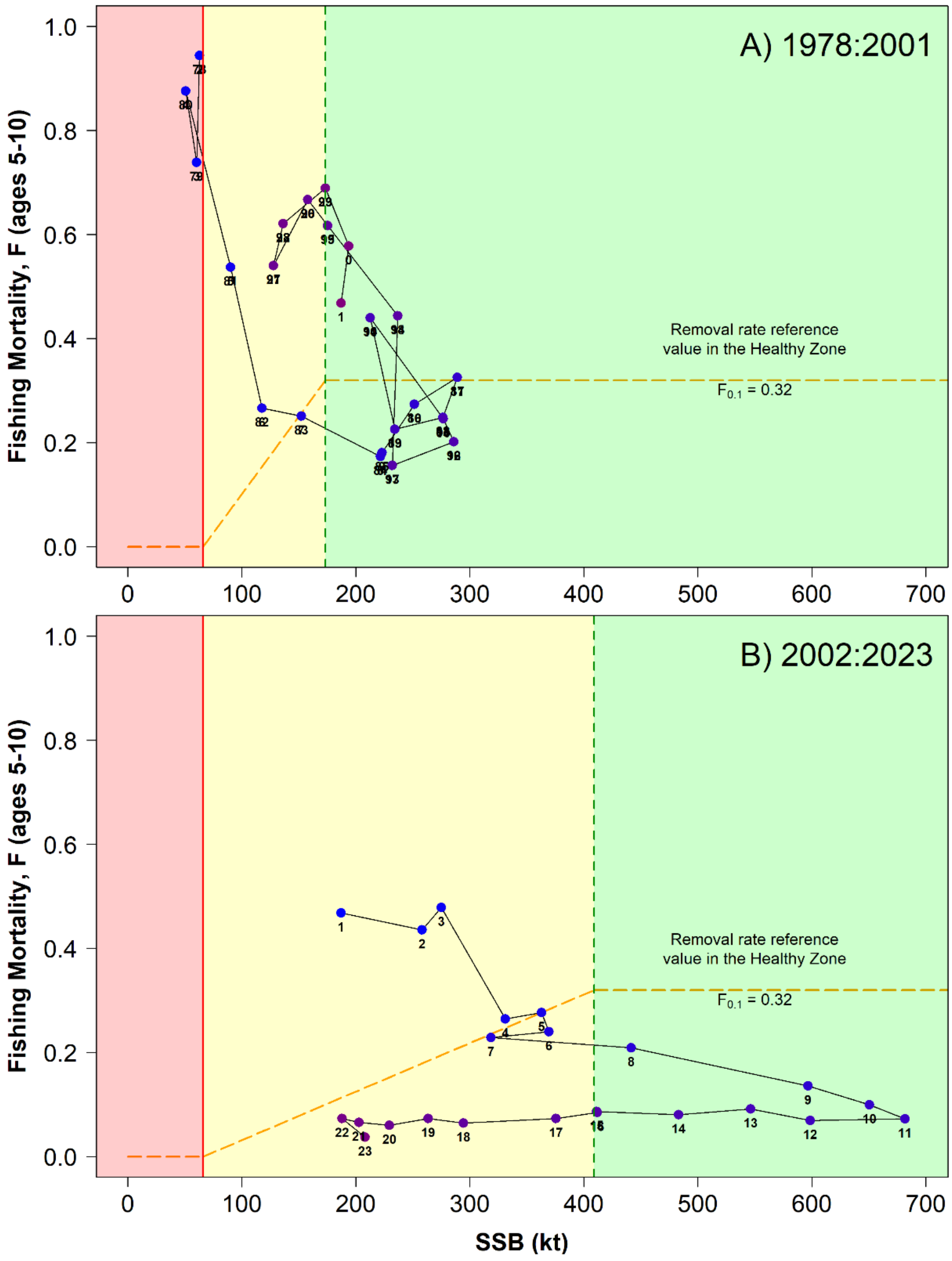

Figure 5. The southern Gulf of St. Lawrence Atlantic Herring fall spawner component trajectory in relation to spawning stock biomass (kt = kilotonnes) and abundance weighted fishing mortality rates for ages 6 to 8 years for A) 1978:2001 (top) and B) 2002:2023 (bottom). The red vertical lines are the Limit Reference Point (LRP) and the green dashed vertical lines are the Upper Stock Reference (USR). The orange solid horizontal lines are the removal rate reference value ($F_{0.1}$ = 0.32) 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).

Historical and Recent Stock Trajectory and Trends

Abundance and biomass indices

The fishery-independent acoustic survey provides a useful abundance index of recruiting fall Herring (ages 2 and 3) for the sGSL, but not for adults as it is restricted spatially during a time when adult fall Herring are spawning in several locations across the sGSL. This biomass index of age 2 and 3 year olds was following a downward trend, being lower in 2023 (4,304 t) compared to 2021 (7,396 t) and 2022 (13,418 t). This abundance index has been at notably low levels since 2015 (average 5,998 t, 95% CI: 3,585 – 8,411 t) compared to historic values observed from 1994-2014 (31,800 t, 95% CI: 22,400 – 41,100 t).

In 2023, fish of ages 6-8 composed the majority of the catches in the North and Middle regions. The south region catches were mainly composed of fish of ages 7-9. In 2023, overall abundance of these age categories was lower than cohorts born before 2015.

The fisheries independent multi-species bottom trawl survey 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 since 2015.

Spawning Stock Biomass

Trends in estimated SSB were relatively similar between regions, increasing from lowest values in 1980 to high values from the mid-1980s to the early 1990s, then declining to a moderate level in the mid-90s before increasing to reach the maximum of the time series between 2008 and 2013 (Figures 1-3B). SSB has since been declining rapidly but saw a slight increase in 2023 (Figure 4B). SSB in the North region (Figure 1B) has been declining more rapidly compared to the Middle (Figure 2B) and South (Figure 3B) regions. Overall the median estimate of total August 1st SSB in 2022 and 2023 were 188 kt (95% CI: 155 – 235 kt) and 208 kt (95% CI:167–259 kt), respectively. In 2023 there was a 0% probability SSB was either below the LRP or above the USR (Figure 5B).

Removal Rate

Fishing mortality for ages 5-10 was at its highest level in all regions around 1980 (approximately 55-80% annual mortality) before declining to low levels between 1982-1993 (around 20% annual mortality; Figures 1-4C). Subsequently, fishing mortality increased to approximately 45% annual mortality for a decade before declining rapidly and has been around 10% annual mortality rate since 2010 across regions (Figures 1-4C; Figure 5).

Natural Mortality

Natural mortality (M) trends are similar within age groups across the three regions. For ages 2-6, estimated M was stable early in the time series at a level near 0.2 (North region) or 0.4 (Middle, South regions) before declining near 1990, reaching very low levels in recent years (around 0.05 in all regions), which are unreasonable from a biological perspective. For the older age group (ages 7-11+), estimates from all regions were stable at around 0.15 until 1986 before rapidly increasing to reach extreme values in the mid-2010s of 0.9 (North region), 0.7 (Middle region) and 1.0 (South region). Values then declined to reach 0.6, 0.4 and 0.6 in 2023 for the North, Middle and South regions, respectively (Figures 1-4C). Estimated values remained at a relatively stable high level in recent years in all regions (between 33% and 45% annual mortality in 2023), suggesting relatively high natural mortality likely resulting from predation.

Recruitment

The most recent estimates of recruitment (number of age 2 fish) indicate that recruitment has been low since 2017 (average of 461 million fish; 95% CI: 305 - 617), with the exception of 2022 (1,462 million fish, Figure 4D). In 2023 recruitment was estimated at a median values of 210 million individuals in the North region (Figure 1D), 97 million in the Middle region (Figure 2D) and 193 million in the South region (Figure 3D).

History of Commercial Landings and TAC

A Total Allowable Catch (TAC) for the combined harvest of both components (spring and fall spawners) in 4T and 4Vn has been in place since 1972. Since 1991, TAC has been allocated by spawning component. The total landings have generally been less than the TAC for the whole time-series (Figure 4A). The TAC values for fall Herring were 10 kilotonnes in 2022 and 2023 (Table 1).

In the sGSL, Atlantic 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. Over the 1981 to 2023, the majority of fall Herring were landed by the fixed-gear fleet. Local stocks are generally targeted by the fixed gear fishery which takes place on the spawning grounds.

There were approximately 9.33 and 5.52 kilotonnes of total landings (Table 1) of fall Herring during 2022 and 2023, respectively, in majority from the fall Herring fishery.

Table 1. Landings and Total Allowable Catch (TAC) in kilotonnes (kt) of southern Gulf of St. Lawrence Atlantic Herring fall spawner component by recent years (2019-2023), fishing season (spring and fall) and gear (fixed and mobile). The percentage (%) of catch in the fixed gear fishery is also provided.

Year	TAC (kt)	Spring fishery landings (kt)			Fall fishery landings (kt)			Total landings	Fixed gear (%)
		Fixed	*Mobile*	*Total*	*Fixed*	*Mobile*	*Total*		
2019	22.25	0.056	0	0.056	14.84	0.64	15.49	15.54	96%
2020	12	0.076	0	0.076	9.66	0.36	10.02	10.09	96%
2021	12	0.025	0	0.025	10.80	0	10.80	10.83	100%
2022	10	0	0	0	9.31	0.015	9.33	9.33	99%
2023	10	0	0	0	5.52	0	5.52	5.52	100%

Projections

The population model was projected forward for two years to the start of the 2026 fishing season (August 1st) and six years forward to 2029. Projections were conducted at annual catch options between 0 and 18 kt (Table 2).These projections incorporated uncertainty in parameter estimates as they are strongly influenced by slight variations in recruitment (Figures 1-4D). Under a 0 catch scenario, predicted August 1st SSB in 2025 was 411 kt (95% CI: 278 – 634 kt). For 2024, predicted August 1st SSB was 409 kt (95% CI: 288 – 557 kt).

SSB may increase slightly (5%) from 2024 to 2025 at all catch levels (probabilities 47 - 53%; Table 2) and will unlikely increase from 2025 to 2026 at all catch levels (probabilities 28-34%; Table 2).

The probabilities of SSB being in the Critical Zone (under the LRP) by 2025 and 2026 were null for all catch options (Table 2). In light of recent stock trends and environmental conditions, caution should be taken when interpreting projections as they suggest unrealistically optimistic trends (see sources of uncertainty).

Table 2. Risk analysis table of annual catch options (between 2 and 18 kilotonnes (kt) for 2025 to 2029, with predicted resulting SSB in kilotonnes (kt) in 2025, 2026 and 2029, resulting probabilities (%) of SSB being greater than the LRP, resulting probabilities of increases in SSB by 5%, and resulting abundance weighted fishing mortality rate (F6-8) for the fall spawner component of Atlantic Herring from the southern Gulf of St. Lawrence.

	Year	Catch options (kilotonnes)								
		2	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*
SSB (kt)	2025	407	406	406	405	403	402	399	399	397
	2026	389	387	385	384	381	379	378	375	373
SSB < LRP	2025	0	0	0	0	0	0	0	0	0
	2026	0	0	0	0	0	0	0	0	0
	2029	0	0	0	0	0	0	0	0	0
Increase in SSB (%)	2025	53	52	52	51	50	49	49	47	48
	2026	34	33	33	32	31	30	30	29	28
Median F5-10	2024	0.01	0.01	0.02	0.03	0.03	0.04	0.05	0.05	0.06
	2025	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.05	0.05

Ecosystem and Climate Change Considerations

Fall Herring are a critical component of the ecosystem and the abundance, recruitment, mortality and overall success of the stock are impacted by a wide range of biological and physical ecosystem factors. Recruitment of fall Herring has been relatively low for the past decade with the exception of 2022 and has been shown to be impacted by the amount of zooplankton, abundance of warm water zooplankton and phenology of zooplankton and weight-at-age of adults (Burbank et al. 2023a). Higher amounts of zooplankton and higher weight-at-age along with earlier development of zooplankton has been shown to positively impact recruitment. The composition of zooplankton is critical, with higher proportion of lipid rich zooplankton positively impacting recruitment. As the sGSL ecosystem is changing, the synchronicity of zooplankton composition, abundance and quality with the timing of the release of Herring larvae and recruitment are difficult to predict.

Atlantic Herring is an important prey for numerous predators in the sGSL (Benoît & Rail 2016), serving an essential role in the ecosystem by facilitating transfer of energy from lower trophic levels (e.g. zooplankton), to higher trophic levels. Given the role of Atlantic Herring as prey in the sGSL, it is expected they experience substantial natural mortality from predation. Over the past two decades, increases in the abundance of several predators (e.g. seabirds and grey seals) in the sGSL have coincided with increases in natural mortality of older Atlantic Herring (ages 7-11+), however this seems to have stabilized in the past few years. High natural mortality in older ages can be problematic for recruitment as older individuals produce disproportionately more eggs. With high mortality in older age groups from natural causes and/or fishing, negative implications for reproductive output may be expected. Additionally, warmer water temperatures increases energetic demands which can limit growth, resulting in smaller size-at-age Atlantic Herring with lower egg production (Burbank et al. 2023b) and may have negative implications for reproductive output and the capacity to rebuild. This is exacerbated for fall Herring as recent research has uncovered a reduced size-fecundity relationship compared to the 1970s, therefore fish of a given size are currently producing less eggs now compared to this period.

SOURCES OF UNCERTAINTY

The spatially disaggregated SCA model exhibits minor retrospective patterns, where the addition of each new year slightly increases previous estimates of SSB, resulting in a negative retrospective pattern as indicated by a negative Mohn's rho statistic. A negative value for the rho statistic means that the quantity being evaluated is consistently being underestimated (when compared with the estimate from the full time-series) and is typically less problematic than overestimation in terms of sustainability. Addressing issues in catch-at-age matrices, along with the addition of time varying natural mortality and catchability within the population model and the addition of the spawning grounds acoustic index in previous assessments have dampened the retrospective patterns. We followed Hurtado-Ferro et al., (2014) recommended threshold for Mohn's rho of -0.22 for short-lived species, and compared recent values to values obtained in the previous assessment (Rolland et al. 2022). Overall, the recent patterns observed are relatively minor and are well under the aforementioned threshold (-0.16 to -0.01), with only the North region slightly above the threshold (-0.24).

The modelling approach considers the population dynamics of fall 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 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 Herring, however additional genetic analyses of fish microbiome will be undertaken to see if each region exhibits substantially different microbiomes.

Additionally, the fishery-independent acoustic survey has been conducted at the same time each year and over the same number of weeks, despite changes in environmental conditions and potential changes in occupancy timing of Atlantic Herring. Inter-annual variability in occupancy is expected, however given that the survey spans more than three weeks and covers a large area it should be relatively robust to shifts in occupancy timing arising from shifting conditions. Such variability is common among annual surveys, and also applies to the multispecies bottom trawl survey conducted in September. Changes in the spatial distribution of Atlantic Herring over time are also not expected to have biased the biomass estimates from the acoustic survey because the transects extend well beyond the depths preferred by Atlantic Herring and the spatial coverage is broad enough to encompass several environments historically inhabited by Atlantic Herring.

There have been numerous observations on the water by harvesters in the fall of an increase in the amount of small Atlantic Herring, which is consistent with recruitment observations in the stock assessment.

Projections show a large confidence interval (high uncertainty) and a steep increase in SSB. Projections are driven largely by recruitment (i.e. number of fish at age 2). In the recent years, age 2 fish are mostly estimated by the fishery-independent acoustic survey in the model, given that there are no landings of age 2 fish which also limits our estimates of recruitment in the Middle and South regions. The model estimates of the abundance of age 2 fish in 2022 is uncertain as it is informed by few data sources. As more years of data are added, more information on the size of this cohort will be obtained from samples of age 4 fish from all data sources. Statistical catch-at-age models are very sensitive to sudden increases in fish abundance, which paired with low estimates of mortality-at-ages 2-6 can result in overoptimistic projections. Moreover, a review of the natural mortality estimation for the age group 2-6 will help project the dynamics of this cohort more adequately. Additionally, age 3 fish are heavier in 2022 and 2023, which also influences the projected biomass to increase. In 2024-2029 projections, the optimistic increase is responding to a stronger estimate of age 2 in 2022 (which will be age 4 in 2024, only one year into reproductive maturity), and not necessarily representative of the overall small abundance of recruits observed in the recent years (Figures 1-4D).

Even if these projections were to happen and SSB increases as early as 2024, this stronger cohort would be at age 4 in 2024, meaning only one year into reproductive maturity. Younger, smaller fish are known to produce less eggs that are of lower quality (Hixon et al. 2014), and extensively fishing (above the catch option presented) this cohort may not enable the population to sustain a higher SSB in the long-term as they would not be given multiple chances to reproduce as they grow. Including environmental variables to estimate recruitment or considering other methods of modelling projections would likely help reduce this uncertainty. In light of recent stock trends and environmental conditions caution should be taken when interpreting projections as they are unrealistically optimistic. Therefore, a focus should be put on applying 2023 observations rather than projections for stock advice.

Research Recommendations

Various research directions that would help advance understanding of Atlantic Herring population dynamics and improve the science available for species management are either currently ongoing or being considered. Research on the incorporation of ecosystem based predictions of recruitment could be used to drive projections, better informing population dynamics given the ecosystem conditions. Additionally testing of different model parameterizations and alternative stock assessment models should be considered to improve model performance and the reliability of projections. Therefore, it would seem appropriate to conduct an assessment framework review for this stock prior to the next stock assessment.

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Samuel Anderson	West Coast Newfoundland Seiner
Ethan Augustine	North Shore Mi'kmaq Tribal Council - Anqotum Resource Management
Trevor Barlow	Spring Herring C&E
Bill Barry	Barry Group Inc.
David Barry	Barry Group Inc.
Caeman Macdonald	Herring fisher from 16G
Stephanie Boudreau	DFO Gulf Science
Jacob Burbank	DFO Gulf Science
Lindsay Carroll	The Confederacy of Mainland Mi’kmaq
Ryan Chlebak	DFO National Capital Region
Jack Daly	Oceana Canada
Rachel DeJong	DFO Gulf Science
Gilles Duguay	Regroupement des pêcheurs professionnels du sud de la Gaspésie
Kim Emond	DFO Quebec Science
Louis Ferguson	The Maritimes Fishermen’s Union
Etienne Germain	Université du Québec à Rimouski

Name	Affiliation
David Giard	DFO Gulf Fisheries and Aquaculture Management
Benjamin Gregoire	DFO Quebec Fisheries and Aquaculture Management
Leila Kadivar	DFO National Capital Region
Nicolas Lagacé	Government of New Brunswick
Kenneth LeClair	Prince Edward Island Fishermen's Association (PEIFA)
Roberto Licandeo	University of British Colombia
Reagan MacDonald	Government of Prince Edward Island
Laurie Maynard	DFO Gulf Science
Jenni McDermid	DFO Gulf Science
Hannah Murphy	DFO Newfoundland and Labrador Science
Marc Ouellette	DFO Gulf Science
Maryline Patterson	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ)
Tyson Paul	Unama'ki Institute of Natural Resources
Mathieu Pellerin	DFO Quebec Fisheries and Aquaculture Management
Laura Ramsay	Prince Edward Island Fishermen's Association (PEIFA)
Dominique Robert	Université du Québec à Rimouski
Nicolas Rolland	DFO National Capital Region Science
Amélie Rondeau	DFO Gulf Science
Mélanie Roy	DFO Gulf Science
Emmanuel Saindt-Duguay	Mi'gmaq Wolastoqey Indigenous Fisheries Management Association
Roger Sark	Maliseet Nation Conservation Council
Katie Schleit	Oceans North
François-Étienne Sylvain	DFO Gulf Science
François Turcotte	DFO Gulf Science
Lysandre Landry	DFO Gulf Science

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Gulf Region
Fisheries and Oceans Canada
P.O. Box 5030, Moncton (NB) E1C 9B6

E-Mail: dfo.glfcsa-casglf.mpo@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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