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# UPDATED ASSESSMENT TO 2014 OF THE FALL SPAWNING COMPONENT OF ATLANTIC HERRING (*CLUPEA HARENGUS*) IN THE SOUTHERN GULF OF ST. LAWRENCE (NAFO DIV. 4T) AND ADVICE FOR THE 2015 FISHERY

## Context

The peer review meeting of the assessment of Atlantic herring (*Clupea harengus*) in the southern Gulf of St. Lawrence conducted in March 2014 identified issues with the indices of abundance from the gillnet fisheries and the assessment models for the fall spawning component (DFO 2014). Two assessment models were examined, differing in the assumptions about catchabilities in the gillnets for ages 4 and 5, presumably associated with observed declines in weight at age. The estimated absolute biomass values differed substantially between models although the trends in estimated abundance were largely the same. Neither model was considered appropriate as both were characterized by an important lack of fit to indices and retrospective patterns. As a result, catch advice for the fall spawner component of Atlantic herring was only provided for the 2014 fishery (DFO 2014). A framework review of the assessment approach for the fall spawning component was recommended to address the identified shortcomings and to review alternative model formulations. Updated catch advice for the fall spawner component of the 2015 fishery would be developed based on the recommendations from the framework review. Advice for the spring spawning component of Atlantic herring for the 2015 fishery was provided in DFO (2014) and remains valid.

This report results from the Science Response Process meeting held April 16, 2015 on the Atlantic Herring fall spawner stock assessment update for 2015. The timelines for the framework review and the need to provide updated advice for 2015 were very short. The updated assessment used the recommended approach from the assessment framework of April 13-15, 2015. The proceedings from the peer review process that document the recommended approaches from the framework review are in preparation.

## Background

The assessment of Atlantic herring (*Clupea harengus*) in the southern Gulf of St. Lawrence (sGSL; NAFO Div. 4T) (Fig. 1) is conducted on a two-year cycle. The next full assessment for this stock is scheduled for March 2016 for the provision of catch advice for the 2016 and 2017 fishing seasons.

Atlantic herring in the sGSL consist of spring and fall spawner components. Spring spawning occurs primarily in April-May, but may extend into June in some areas. Fall spawning occurs mainly from mid-August to October. Adults overwinter in deeper waters off the Laurentian Channel in 4T as well as the east coast of Cape Breton in NAFO Division 4Vn, which is included in the stock area for sGSL herring (Fig. 1).

Southern Gulf of St. Lawrence herring are harvested by a gillnet fleet on spawning grounds and a purse seine fleet (vessels >65’) in deeper water. The gillnet 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 purse seine fleet harvests a mixture of spring and fall spawner components during their fishery.

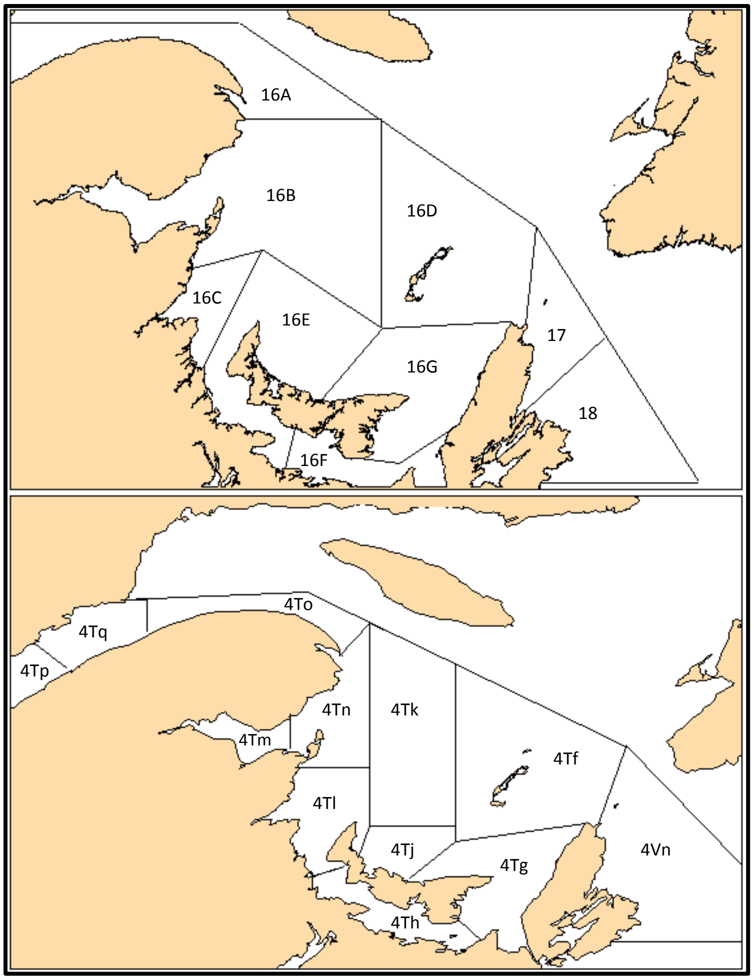


*Figure 1. Southern Gulf of St. Lawrence herring fishery management zones (upper) and Northwest Atlantic Fisheries Organization (NAFO) divisions 4T and 4Vn unit areas (lower).*

The last assessment from March 2014 provided advice for the fall spawner component for only the 2014 fishery year (DFO 2014). This was because two possible population models, which differed in their assumptions about catchability in the gillnets, were considered and these produced different interpretations of stock status and catch advice (Table 1). Furthermore, neither model was considered appropriate as both were characterized by an important lack of fit to indices and retrospective patterns.

*Table 1. Contrasts between model assumptions, stock status and catch options for the two population models reviewed in the previous peer review meeting for sGSL herring in March 2014 (DFO 2014; LeBlanc et al. 2015).*

| Characteristics | Model 1 | Model 2 |
|---|---|---|
| Assumption | Constant catchability at age in gillnets | Trend in catchabilities of ages 4 and 5 since 2004 |
| Trend in abundance | Decline from peak in 2009 | Decline from peak in 2009 |
| Estimated exploitation rate in 2013 (reference level $F_{0.1}$ = 25%) | 31% | 21% |
| 2014 Spawning stock biomass (t) | 98,000 | 182,800 |
| Precautionary approach status zone (upper stock reference $B_{USR}$ = 172,000 t) | Cautious zone | Healthy zone |
| Retrospective pattern | Yes | Yes |
| Catch advice at $F_{0.1}$ (t) | 22,100 | 38,017 |

A framework review of the assessment approach for the fall spawning component was recommended to address the identified shortcomings and to review alternative model formulations (DFO 2014). Updated catch advice for the fall spawner component for the 2015 fishery has been developed based on the conclusions and recommendations from the framework review of April 13-15, 2015.

## Description of the fishery to 2014

The total allowable catch (TAC) for the fall spawning component in 2014 was 35,280 t (Table 2). In the 2014 fall fishery, 84% of the total fall TAC was attained; seiners caught 48% of their allocation during both the spring and fall fishing seasons, while the inshore gillnet fleet caught 95% of their allocation (Table 2). The total estimated catch of the fall spawner component in the 2014 fisheries was 29,141 t, partitioned between 25,785 t by the gillnets and 3,356 t by the seiner fleet (Fig. 2; Table 3).

*Table 2. Total allowable catch (TAC; t) by fleet and overall for the fall fishing season and preliminary landings by fleet and overall for the fall fishing season of Atlantic herring for 2014. Catches are from ZIFF (zonal interchange file format database) and purchase slip files, from quota monitoring, and logbook data.*

| Fleet | TAC (t) | Share (%) | Landings (t) | % of TAC |
|---|---|---|---|---|
| Inshore (gillnets) | 27,252 | 77 | 25,916 | 95% |
| Seiners | 8,028 | 23 | 3,841[1] | 48% |
| Total | 35,280 | 100 | 29,757 | 84% |

[1] for seiners, the landings which were comprised mostly of fall spawners were realized in both the spring and fall fishing seasons

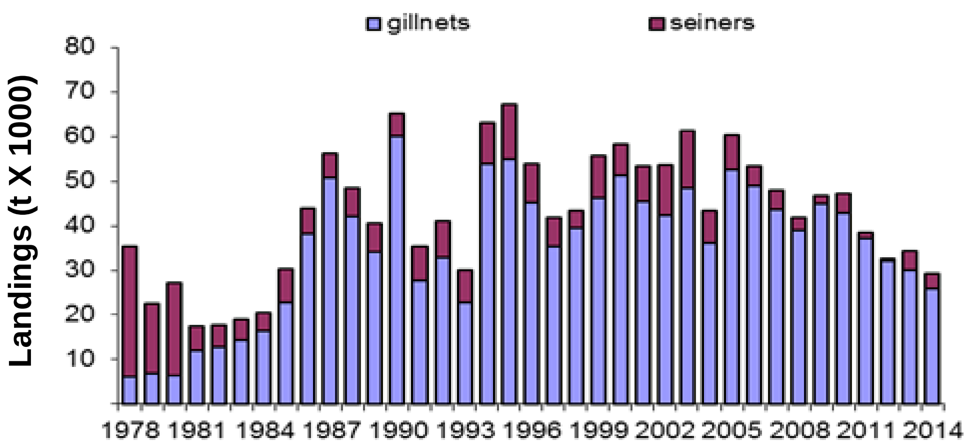


*Figure 2. Total landings (1000 t; excluding bait permit landings) by gear type of Atlantic herring fall spawner component from NAFO Div. 4T, 1978 to 2014.*

Most of the 2014 gillnet catches during the fall fishing season came from area 16B (Table 3). Less than 1% of the gillnet catches were spring spawners, occuring primarily outside the spawning areas and in the early part of the season. Spring spawner herring comprised 13% of the seiner catches in both the spring and fall fishing seasons (Table 3).

*Table 3. Total allowable catch (t) by fleet and area and corresponding preliminary landings (t) of fall spawners by fleet and area in 2014. Catches are from ZIFF and purchase slip files, from quota monitoring, and logbook data. Attribution of fall spawners is from sampling.*

| Fleet and area | Season | TAC (t) | Preliminary catch (t) in 2014 |
|---|---|---|---|
| Inshore (gillnets) | | | |
| Isle Verte 16A | Jul 1 - Dec 31 | 43 | 5 |
| Baie des Chaleurs 16B | Jul 1 - Dec 31 | 12,656 | 13,335 |
| Escuminac 16C & West P.E.I. 16E | Jul 1 - Dec 31 | 5,176 | 5,107 |
| Magdalen 16D | Jul 1 - Dec 31 | 175 | 21 |
| Pictou 16F | Jul 1 - Dec 31 | 5,317 | 5,215 |
| Fisherman’s Bank 16G | Jul 1 - Dec 31 | 3,535 | 2,231 |
| 4Vn | Jul 1 - Dec 31 | 350 | - |
| Total inshore (spring and fall spawners) | Jul 1 - Dec 31 | 27,252 | 25,916 |
| Total inshore (fall spawners only) | Jul 1 - Dec 31 | - | 25,785 |
| Seiners (> 65 ft) | | | |
| Total seiners (spring and fall spawners) | Spring and fall | 8,028 | 3,841 |
| Total seiners (fall spawners only) | Spring and fall | 8,028 | 3,356 |
| Total all fleets (spring and fall spawners) | - | 35,280 | 29,757 |
| Total all fleets (fall spawners only) | - | - | 29,141 |

## Recommendations from the framework review of assessment methods

The framework review of the assessment methodology for the southern Gulf of St. Lawrence Atlantic herring fall spawner component was conducted during April 13-15, 2015. The recommended changes to the assessment approach (DFO 2014; LeBlanc et al. 2015) included:

- developing indices of abundance for three regions in the sGSL,
- incorporating new indices of abundance for the whole stock area (4T),
- incorporating effects of changes in size at age on selectivity of the fixed gear fishery (gillnets),
- modelling abundance using a population model that estimates abundance for three regions, and
- allowing for differences among the three regions in time varying catchabilities (q).

Changes in natural mortality (M) were examined. Allowing M to vary over time for two size groups of herring did not result in improved model fits to the indices of abundance and was not incorporated in the models.

Estimates of biomass specific to spawning beds derived using industry-led acoustic data collected during fishing trips could not be used as indices of abundance. This is because the survey design and sampling procedures could not provide biomass indices within a season that were representative indices of abundance among spawning beds within a year, nor within spawning beds among years.

### Indices and input data

Three fishing regions which jointly cover the entire sGSL fall spawning herring stock area and which are defined on the basis of traditional herring spawning beds and fishing areas were identified (refer to Fig. 1):

- North (Gaspe and Miscou; NAFO subareas 4Tmnopq),
- Middle (Escuminac-Richibucto and west Prince Edward Island; NAFO subarea 4Tl), and
- South (Fisherman`s Bank and Pictou; NAFO subareas 4Tfghj).

The boundaries of the regions were defined on the basis of the spatial coverage of the fisheries sampling available since 1978. Region specific inputs and indices include catches-at-age from the fishery (1978 to 2014), catches-at-age (ages 4 to 10) per unit of effort from the gillnet fishery (1986 to 2014), and catches-at-age (ages 3 to 10) per unit effort from multi-panel experimental gillnets (2002 to 2013). Inputs common to the entire sGSL area include indices of fall spawner juvenile (ages 2 and 3) abundances from the research acoustic survey (1994 to 2014) and age-specific fall spawner abundance indices (ages 4 to 6) from the multi-species bottom-trawl survey (1994 to 2011). Additional region specific information includes relative selectivity estimates at age (4 to 10 years) for 1986 to 2014, derived using the estimated annual proportions of gillnets in the fishery in each region which are $2^{5}/_{8}$ inches vs $2^{3}/_{4}$ inches (from post-season telephone surveys) and trends in mean length at age for the sGSL.

# Analysis and Response

## Indicators of stock status

### Age-disaggregated catch per unit effort (CPUE) from commercial gillnets

The gillnet CPUE indices are defined as catches in numbers per standard net-haul. The catch data were taken from the registered landings by region and week. Weekly effort per region was calculated as the number of trips, from the registered landings database, multiplied by the estimated number of standard net hauls per trip. The latter was calculated as the product of average number of nets per trip and average number of hauls per trip, from the annual post-fishery telephone survey of active herring fishers and additionally, since 2005, from available dockside monitoring data (LeBlanc et al. 2015). Separate multiplicative models were applied to CPUE data from each region to derive annual indices of abundance (kg per standard net haul), aggregated over all ages, adjusted for week of the fishery. Age-disaggregated indices (in numbers per haul) were derived from the aggregated CPUE values accounting for the weight at age and the catch at age estimates by region. Examination of internal consistency (ability of the CPUE indices to track cohorts) indicated that the age-disaggregated indices were informative for ages 4 to 10 years, at the region-specific level and for the sGSL overall.

Estimated region-specific values of the CPUE values are presented in Figures 3 and 4. There has been a recent decrease in catch rates of the younger ages of herring (ages 4 and 5) and increased catch rates of older herring (ages 7 year and older) in all regions. However, the declines in catch rates of the younger herring have been more pronounced in the south region (Figs. 3 and 4).

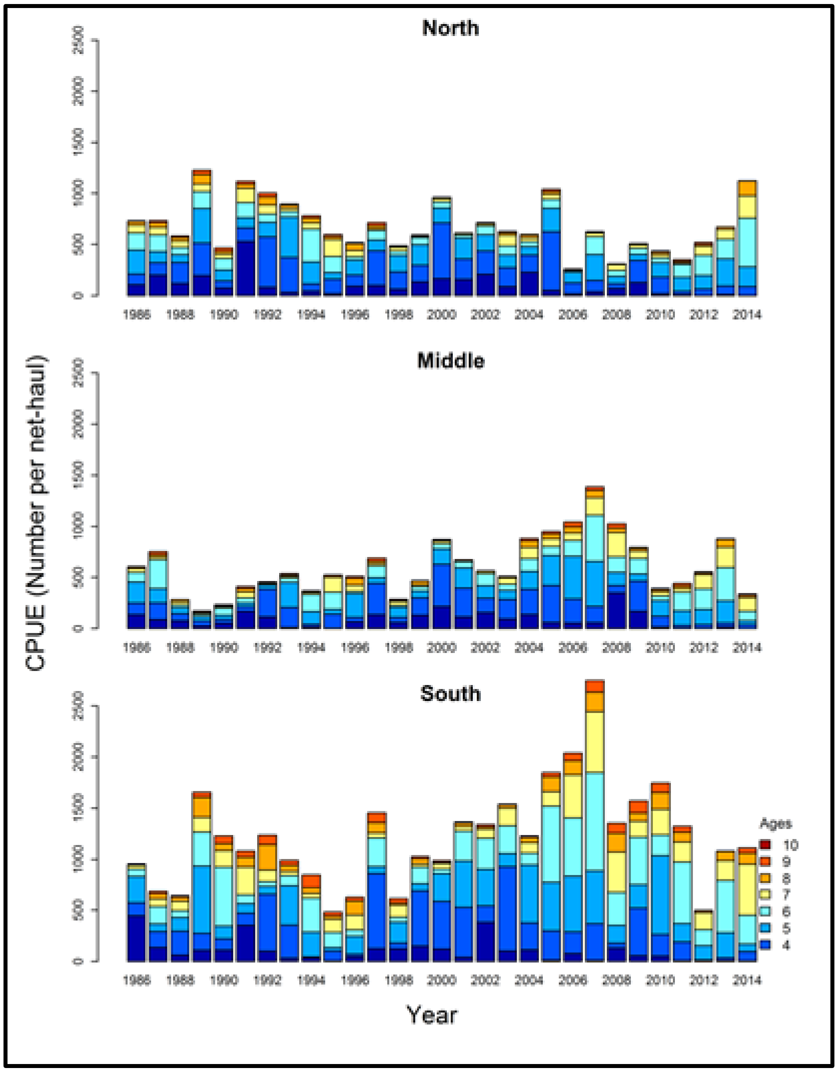


*Figure 3. Stacked bar plots of gillnet catch-per-unit-effort indices (number per net haul) for ages 4 to 10 years from the North (upper panel), Middle (middle panel) and South (lower panel) regions for 1986 to 2014.*

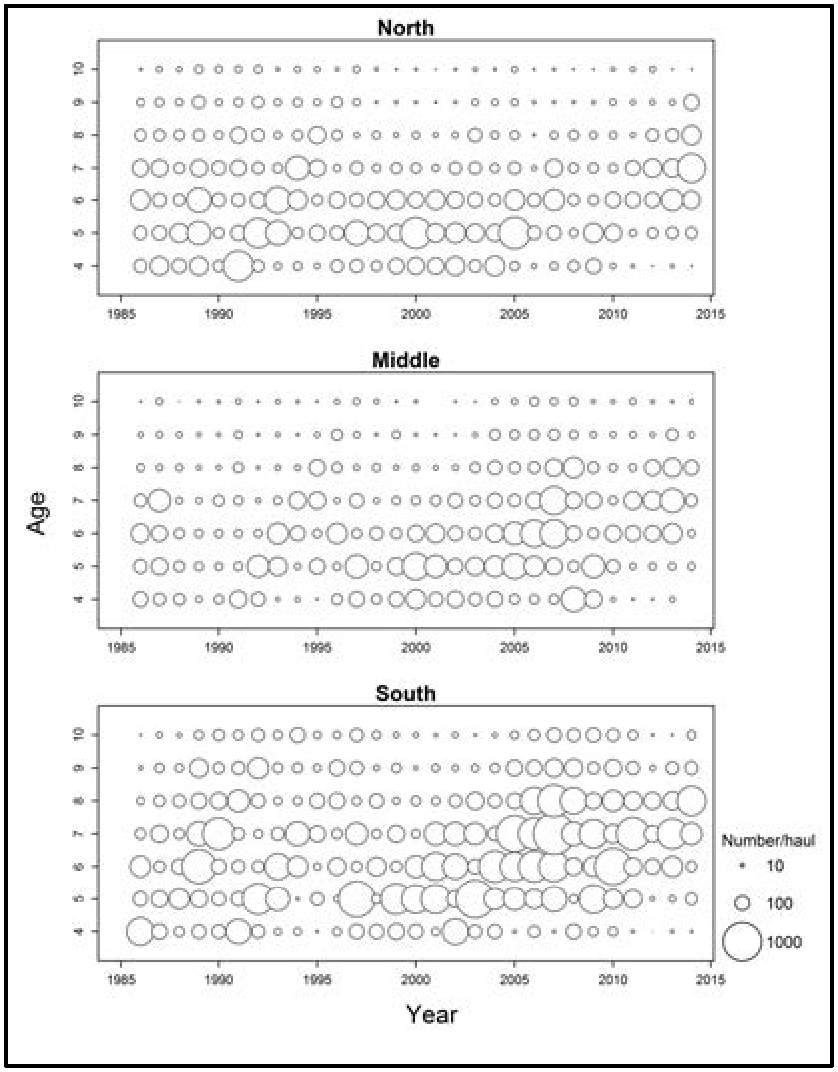


*Figure 4. Bubble plots of gillnet catch-per-unit-effort indices (number per net haul) at age (ages 4-10), by region, North (upper panel), Middle (middle panel) and South (lower panel), 1986 to 2014.*

### Multiple panel gillnets indices of abundance for three regions

Multiple panel experimental gillnets were fished annually during the fall commercial fishery season in 2002 to 2013. Each experimental gillnet was comprised of five panels, each with a different mesh size, from a set of seven possible mesh sizes, ranging from 2 inches to $2^3/_4$ inches in $^1/_8$ inch increments. All gillnets had panels with mesh sizes of $2^1/_2$ inches, $2^5/_8$ inches and $2^3/_4$ inches, plus two smaller mesh sizes that varied from fisherman to fisherman. Originally, the experimental nets were provided to one or two fishermen per region to collect data on herring size to verify acoustic target strength during spawning bed specific acoustic surveys. Standardized age-disaggregated catch rates were derived using the experimental net catch data and a mesh selectivity model which accounts for length-dependent changes in catchability among meshes. Estimates were produced by region for 2002 to 2013. There were no data for the North region in 2007 and 2013 and for the Middle region in 2002. The data from the Middle region in 2010 were excluded from the analysis because the catches were not considered representative for that area and that year. The indices generally track cohorts reasonably well, despite the small sample sizes, for the three regions and for ages 3 to 10 years. The indices suggest that there was an increase in herring abundance in the North, no strong trend in the Middle region, and an overall decline in the South region, particularly at younger ages (Fig. 5).

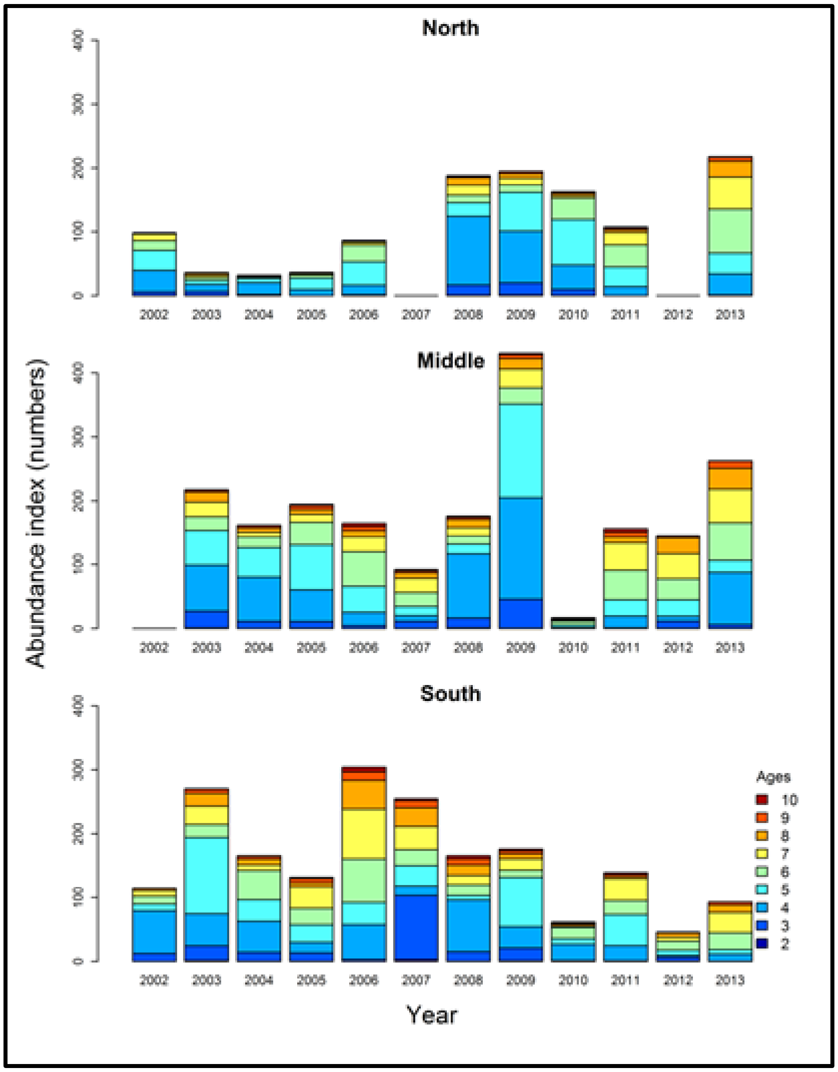


*Figure 5. Stacked bar plots of experimental net indices of abundance (numbers) at age (2 to 10 years) from the North (upper panel), Middle (middle panel) and South (lower panel) regions, 2002 to 2013. No data are available from the North region in 2007 and 2012 and from the Middle region in 2002.*

### Acoustic survey index for ages 2 and 3

Since 1991, an annual fishery-independent acoustic survey in the southern Gulf has been conducted in September and October. Although the standard annual survey area occurs in the Chaleurs-Miscou area, the acoustic index is considered to be representative of the abundance of herring at the sGSL stock level. In some years the survey has also covered waters north of P.E.I. though the observations made there are not included in the standardized index. The survey design is random parallel transects within strata, with two vessels: an acoustic vessel to quantify the biomass of fish schools and a fishing vessel to sample aggregations of fish with a pelagic trawl (LeBlanc et al. 2015). The internal consistency of index was considered appropriate for ages 2 and 3.

The fall spawner age-disaggregated juvenile (ages 2 and 3) indices of abundance from the acoustic survey suggest that the abundance of two year olds was relatively high in 2014, an increase from one of the lowest values estimated in 2013. In contrast, the abundance of three year-olds in 2014 was below average, though greater than in 2013 (Fig. 6).

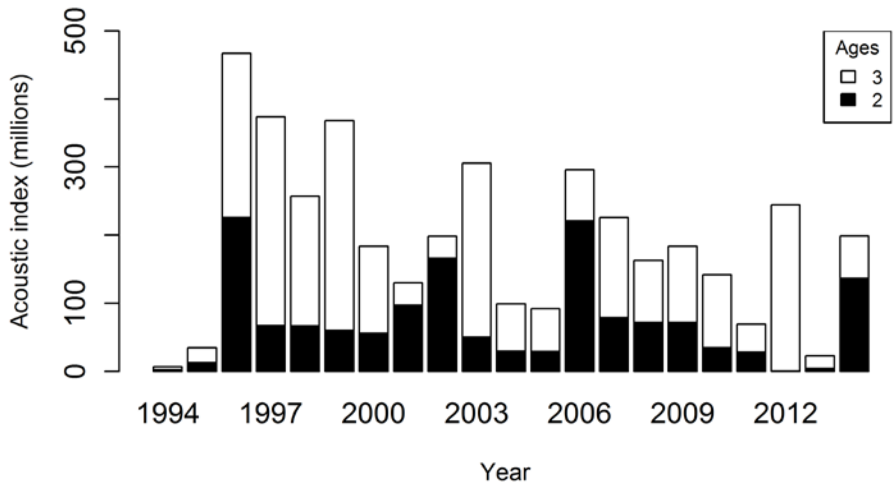


*Figure 6. Fall spawner acoustic survey juvenile index (in millions of fish, for ages 2 and 3), 1994 to 2014.*

## Multi-species bottom-trawl survey index for ages 4 to 6

An annual multi-species bottom trawl survey, conducted each September since 1971, provides information on the abundance and distribution of 4T herring throughout the sGSL. Sampling of herring catches since 1994 has allowed the development of an age-disaggregated index by spawner group. Data were available from 1994 to 2011. These data were not used in the previous assessment because the index did not track cohort abundance (LeBlanc et al. 2015) but the analysis of these data with an alternate model provided an index of abundance for ages 4 to 6 that showed some internal consistency in tracking cohorts. The indices suggest an increasing trend in four year old herring from the mid-1990s to 2011, and generally higher abundance of six year old herring in the 2000s compared to the 1990s (Fig. 7).

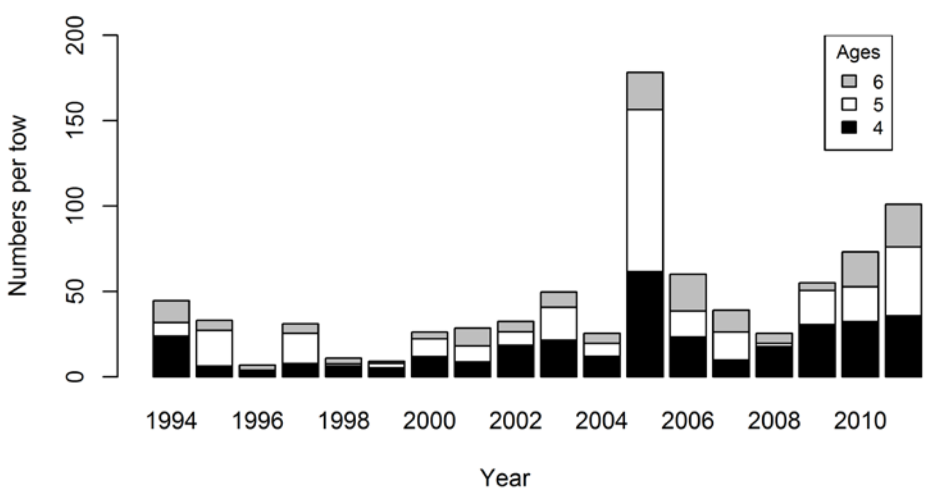


*Figure 7. Multispecies bottom trawl survey abundance index (number of fish per standardized tow) for herring ages 4 to 6 years, 1994 to 2011.*

## Inputs for modelling abundance

### Changes in selectivity of the gillnet fisheries

There are two factors that are likely to have affected the catchability of herring to the gillnet fishery over time; changes in size at age and changes in the mesh-size used by harvesters.

Lengths-at-age in the fishery have been declining steadily since 1978 for all ages, with an average decrease to 2014 of around 20% (Fig. 8). The mean length of herring at age 8 years in 2014 is approximately the same as the mean length of herring at age 4 years in the late 1980s (Fig. 8).

The fall gillnet fisheries have used varying proportions of gillnets of mesh sizes $2^5/_8$ inches and $2^3/_4$ inches. The minimum mesh size of gillnets has been set at $2^5/_8$ inches since 1993. Beginning in 1992, many fishers started using bigger mesh sizes ($2^3/_4$ inches) but by 2002, the proportion of $2^5/_8$ inches mesh gillnets in the fall fishery reverted to pre-1992 numbers (Fig. 9). There were regional differences in proportions, particularly during 1990 to 2008, but since 2008 the proportions of $2^5/_8$ inches mesh have been high, between 0.94 and 0.99, in all regions.

The data from the multi- panel experimental gillnets were used to model relative selectivity at length of herring in $2^5/_8$ inches and $2^3/_4$ inches mesh nets. These selectivity at size curves were combined with annual length at age distributions based on mobile fishery catches, which were considered to be less selective for size at age than gillnets, to derive selectivity at age coefficients for $2^5/_8$ inches and $2^3/_4$ inches meshes. These were then combined with the relative proportions of $2^5/_8$ inches and $2^3/_4$ inches mesh nets in each region (Fig. 9) to derive relative selectivities at age for the gillnet fisheries in each region (Fig. 10). Over the time period 1986 to 2014, relative selectivities have continuously declined for younger ages (4 to 6 years), declined most recently for age 7 years, and increased to the mid-2000s and declined since 2010 for the older age groups (Fig. 10).

These estimates were used to account for changes in size at age and variations in the proportions of mesh size. The selectivities in the fishery were used in the modelling of abundance and in the estimation of the catchability coefficient at age for each region.

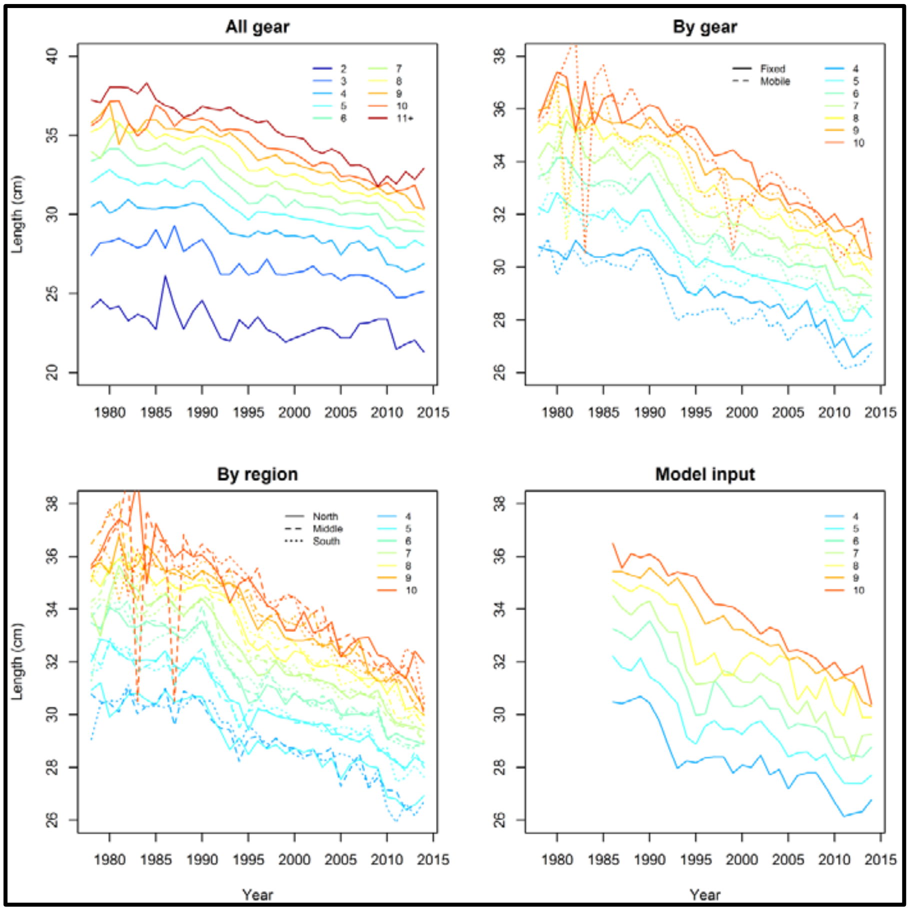


*Figure 8. Trends in mean length-at-age (in late summer and early fall) of fall spawning herring in the fisheries by mobile and fixed gear (gillnet) fisheries combined (top left), by gear (top right) and by region for gillnets only (bottom left). The bottom right panel shows the values from the mobile gear fishery which are considered more representative of length at age of the population.*

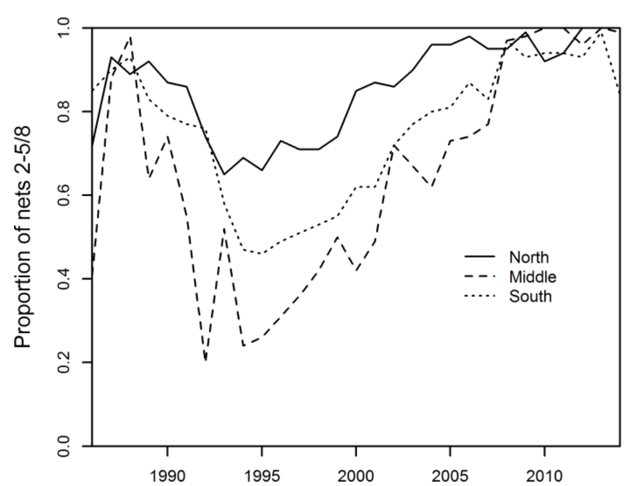


*Figure 9. The proportions of gillnets in the fall fishery that were $2^5/_8$ inches mesh size (minimum size since 1993), for three regions in the sGSL, 1986 to 2014. It is assumed that the other nets used in the fishery were $2^3/_4$ inches mesh.*

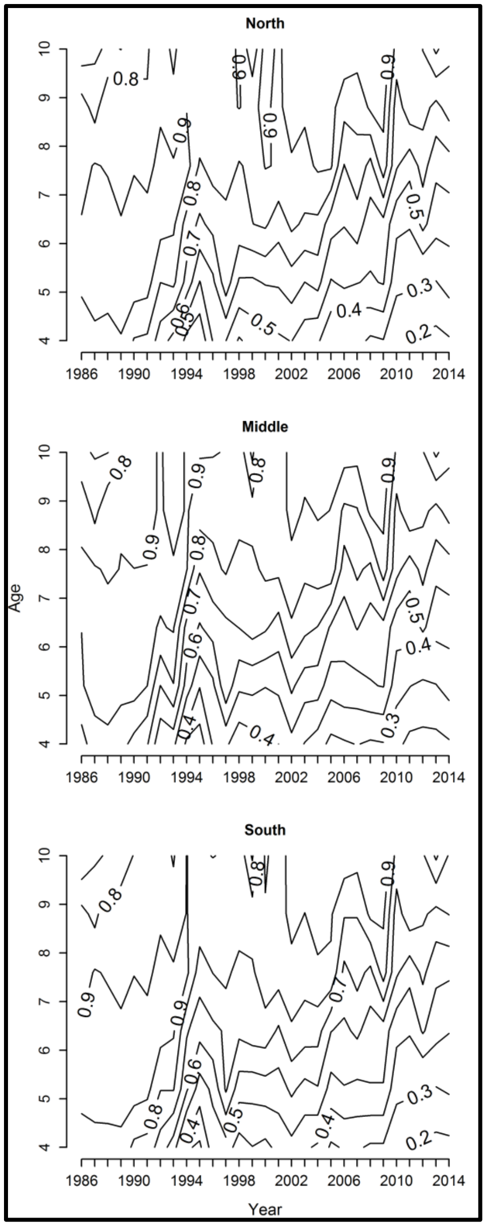


*Figure 10. Contour plots of relative selectivities as a function of age and year in the fall herring gillnet fishery by region, 1986 to 2014. These values were derived from the annual proportion of nets by mesh size by region and the selectivity ogives of the mesh sizes at age.*

## Catches at age by region

Catches at age from the fishery were compiled by region and year. Catches from the gillnets were attributed to the region of capture. Catches by herring seiners were attributed to the region which is most proximate to the location of capture. Catches made in NAFO 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.

Catches-at-age and weight-at-age matrices for 4T herring fall spawner components 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. The individual weights-at-age for the whole area were assumed to apply to each of the three regions, given little evidence for regional differences.

Region-specific catches-at-age used in the initial model fitting for both gears combined, are presented in Figure 11. The catches of younger ages (less than 6 years) have recently decreased in the fisheries consistent with the estimated changes in selectivity by the gillnet fleet.

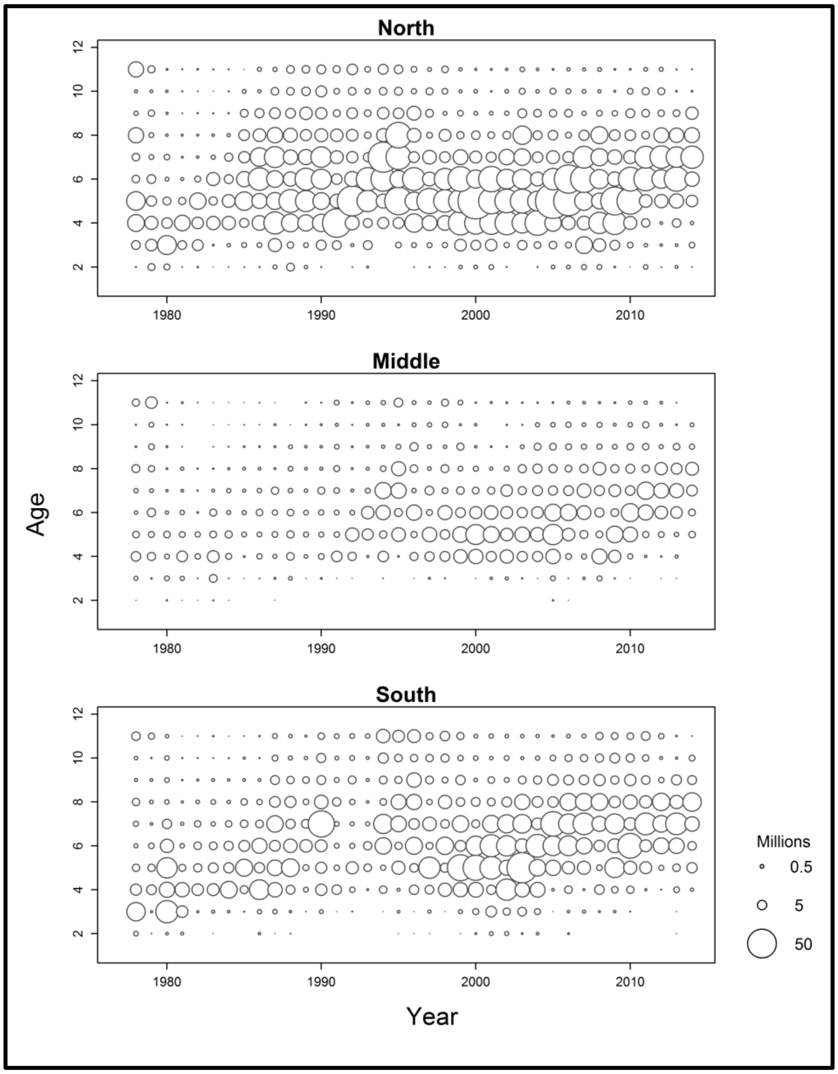


*Figure 11. Bubble plots of fishery catch-at-age (number) by region for both mobile and fixed gear combined, 1978 to 2014. The area of the bubble is proportional to the number of fish in the catch at age. Note that the catches indicated at age 11 actually represent catches for ages 11 years and older.*

## Estimates of spawning stock biomass

### Model description and results

A Virtual Population Analysis (VPA) was used to model abundance at age. Fall spawners from three regions, North, Middle and South, were treated as three separate populations, though the biological basis for this separation has yet to be confirmed (e.g., via genetic analysis). Region specific fishery catches at age, CPUE indices from the gillnet fishery, and indices from the experimental nets were used in fitting the model. The acoustic and bottom trawl survey indices were considered as abundance indices for the sGSL stock, i.e. the sum of the three populations. The relative annual selectivities at age for each region were included as an input. The model included an estimation of independent trends over time in fishery catchability (*q*) for each region.

Changes in *q* over time in the North region were relatively small (Fig. 12). In the South, *q* began to increase in the mid-1990s, with a steeper and continued increase since the mid-2000s. The overall increase in the South was over five-fold. In the Middle region, *q* was relatively low in the early 1990s and high since the late 1990s. Prior to 2007, fishery *q* was highest in the Middle region. The trends in *q* for the South region are consistent with ongoing changes in fishing practices reported by local harvesters, while the relative stability in *q* for the North region is consistent with a reported general maintenance of traditional fishing practices.

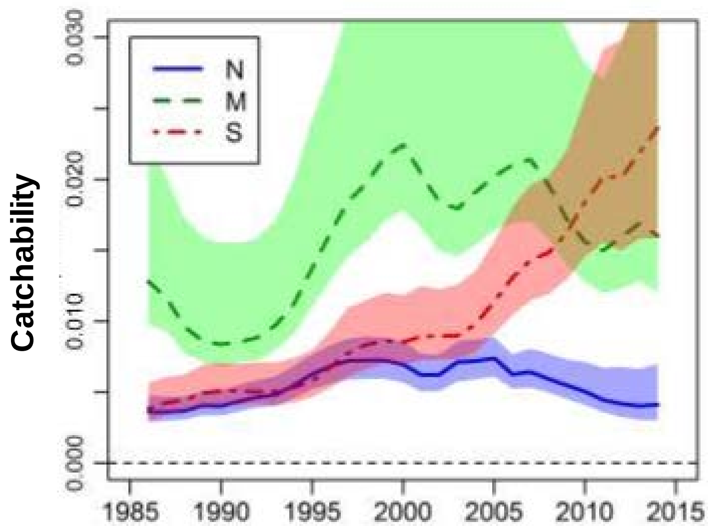


*Figure 12. Estimated trends in fully recruited catchability (*q*) to the gillnet fishery by region for the model, 1986 to 2014. Lines show the Maximum Likelihood Estimate value and the shadings represent the 95% confidence bands based on Monte Carlo Markov Chain (MCMC) sampling. Regions are indicated as: N = North, M = Middle, S = South.*

Estimated annual spawning stock biomass (SSB) up to January 2015 for each region and overall for the sGSL are shown in Figure 13. Predicted age-2 abundance in 2013 was based on the estimated SSB in 2011 and the estimated recruitment rates (number of age-2 recruits divided by the SSB that produced them) for the previous five years cohorts, 2006 to 2010. These values were projected forward to age 4 in 2015, taking into account the uncertainty in estimated SSB and the uncertainty and variability in recent recruitment rates.

Overall sGSL SSB as of January 1, 2015 is estimated to be 182,000 t (95% confidence interval of 109,000 to 295,000). There was a 53% probability that the SSB was above the $B_{USR}$ value (172,000 t) at the start of 2015 (Fig. 13). The estimated SSB on January 1, 2014 was about 173,000 t, a value which is slightly lower than the estimated SSB from the Model 2 (182,000 t) in the previous assessment (DFO 2014; LeBlanc et al. 2015).

Estimated SSB trends differ by region (Fig. 13). Estimated SSB in the North has remained high since 2009 but with large uncertainties in the more recent years. SSB trends in the Middle and particularly in the South show a declining abundance since 2009 (Fig. 13). The estimated SSB in the North is the dominant proportion of the sGSL estimated SSB.

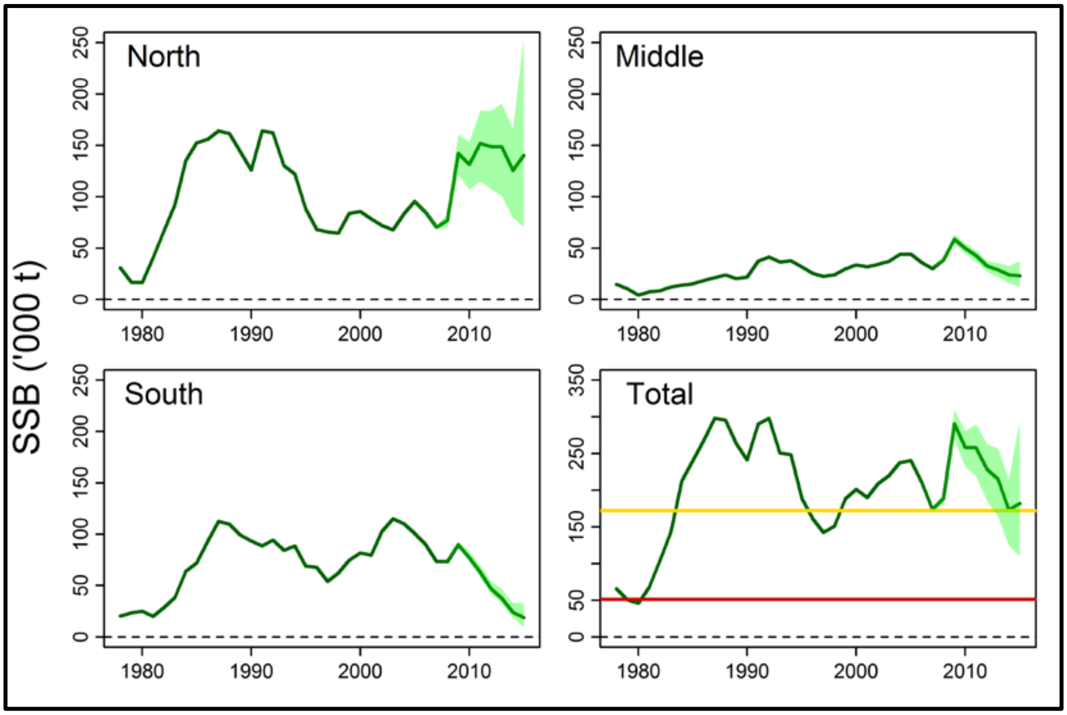


*Figure 13. Estimated spawning stock biomass (SSB; thousands of tonnes) by region and for the entire sGSL (Total; bottom right panel). The yellow upper line for the Total estimate is the Upper Stock Reference point ($B_{USR}$ = 172,000 t) and the bottom red line in the same panel is the Limit Reference Point ($B_{LIM}$ = 51,000 t). Shading shows the 95% confidence bands.*

The estimated abundance of the 2010 year-class is the weakest on record for the sGSL (Fig. 14). This year-class was also estimated to be the weakest on record in the North and South but for the Middle region, the 2008 year-class and some year-classes in the 1980s and late 1970s were weaker (Fig. 14).

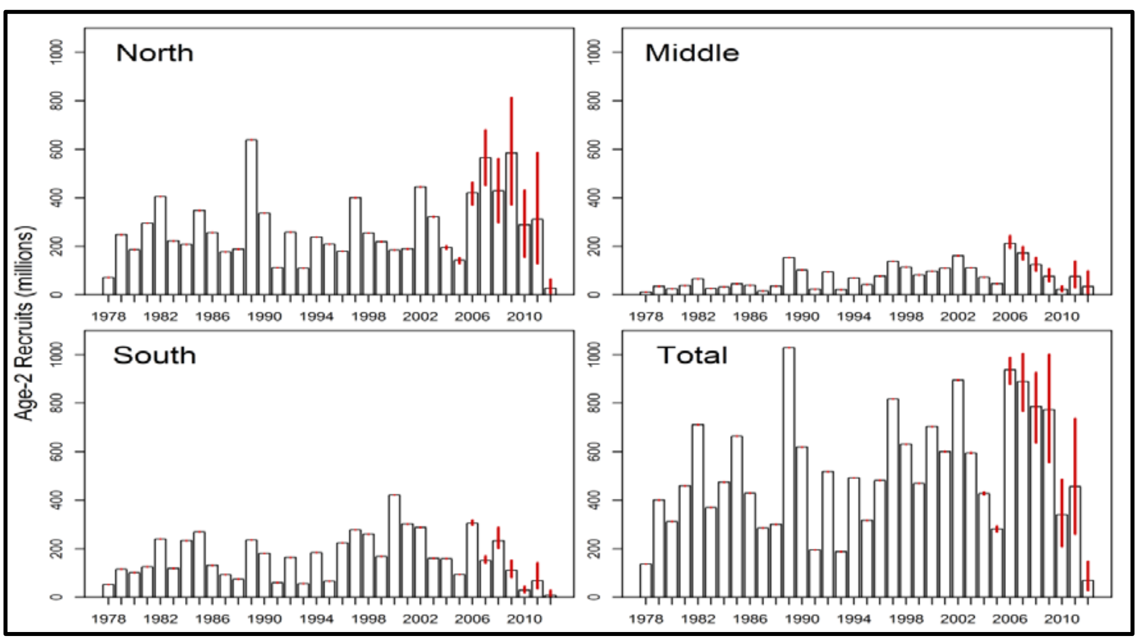


*Figure 14. Estimated annual abundance (number) of age-2 recruits by region and for the sGSL overall (bottom right panel). The vertical red lines are the 95% confidence interval ranges. The last estimate in 2012 represents the abundance of the 2010 year-class.*

## Projections and catch advice for the 2015 fishery

Projections of abundance to January 1, 2016 were done by region and summed to obtain estimates of abundance for the sGSL overall. Stochastic projections based on Monte Carlo Markov Chain (MCMC) methodology were used in order to incorporate the uncertainty in population model estimates and fishery characteristics. Catch options from 10,000 t to 50,000 t by increments of 2,000 t were considered.

For each region and MCMC sample, predicted age-2 recruitment in 2013 to 2015 was obtained by randomly selecting recruitment rates from the most recent five available estimates (the 2006 – 2010 year-classes). Natural mortality (M) was fixed at 0.2.

Because of the declining trends in weights at age, catch weights at age for each population were randomly selected from only the four most recent years (2011 to 2014). A vector of partial recruitment to the fishery was selected for each region, based on the estimates from the recent five years (2008 to 2012). Maturities at age were the same values as assumed in previous assessments.

To assess catch options, catch was partitioned among the three regions based on the realized catch proportions of the last 5 years. For each iteration, catch proportions were selected at random from one of these years.

Projected SSB at the start of the year in 2016 is very uncertain due to the large uncertainties in the future levels of recruitment. Recruitment rates sampled from most recent five years of estimates show wide variability in the values used within and among regions (Fig. 15). There is a declining trend in recent estimates of recruitment rate. If this trend persists, then the projections are overly optimistic. Alternatively, the single index of recruitment at age 2 for 2014 (from the acoustic survey) is very high (Fig. 6), although highly uncertain. If the 2012 year-class is indeed very strong, then the projections may be overly pessimistic.

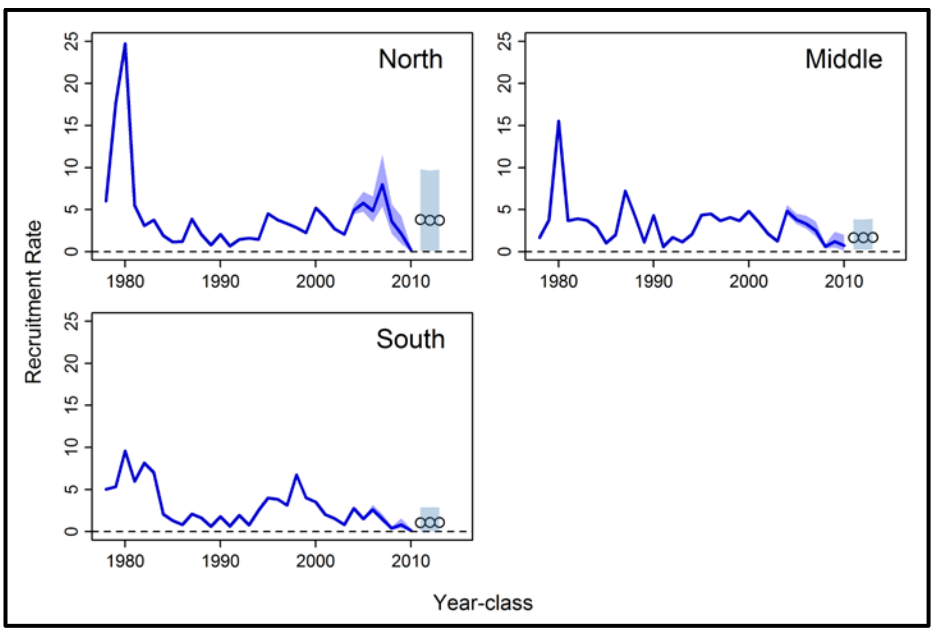


*Figure 15. Estimated recruitment rates at age-2 by region (with associated 95% confidence interval bands). Circles show the predicted mean recruitment rates and shading the central 95% interval of the rates used for the projections of SSB at the start of the year in 2016 for the sGSL overall.*

Based on these projections, the probabilities of exceeding the fully recruited harvest reference level based on $F_{0.1}$ (F = 0.32) for ages 5 to 10 years for different catch options in the 2015 fishery are shown in Figure 16 (left panel) and in Table 4. The probabilities of the SSB in January 1, 2016 being less than the Upper Stock Reference level ($B_{USR}$ = 172,000 t) are shown in the right panel of Figure 16 and in Table 4. A catch option of approximately 30,000 t for the fall spawner component for the sGSL overall will result in a 50% chance of exceeding the harvest reference level. At this catch option, there is about a 40% chance that the SSB at the start of the year in 2016 will be less than $B_{USR}$ (Fig. 16; Table 4). There is a near zero probability that the SSB at the start of the year in 2016 will be below the limit reference point ($B_{lim}$ = 52,000 t) for any of the catch options examined.

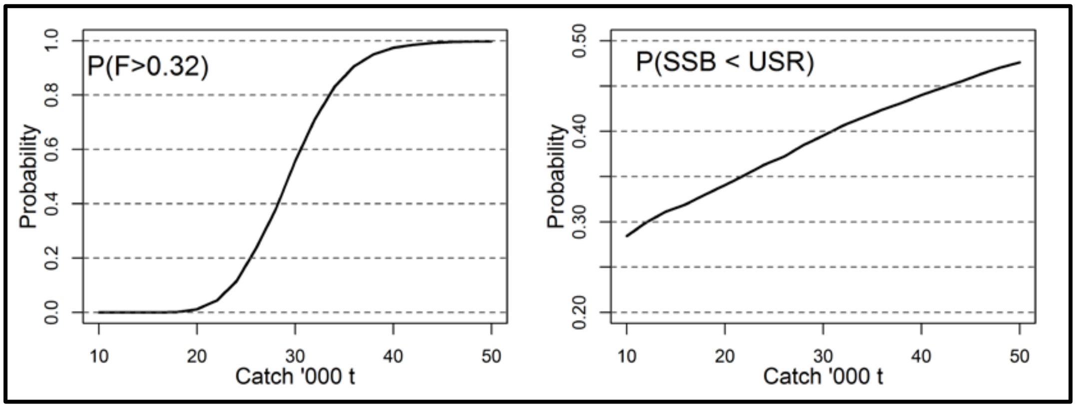


*Figure 16. Probabilities of the fishing mortality rate in 2015 exceeding the harvest reference level (F > 0.32; left panel) and probabilities that the sGSL fall spawner component SSB at the start of 2016 will be less than the Upper Stock Reference ($B_{USR}$) (right panel) for 2015 fishery catch options of 10,000 t to 50,000 t in steps of 2,000 t.*

*Table 4. Probabilities of the fishing mortality rate in 2015 exceeding the harvest reference level (F > 0.32) and probabilities that the sGSL fall spawner component SSB at the start of 2016 will be less than the Upper Stock Reference ($B_{USR}$) for 2015 fishery catch options of 10,000 t to 50,000 t, in increments of 2,000 t.*

| Catch (X 1,000 t) | Probability F > 0.32 | Probability SSB < $B_{USR}$ |
|---|---|---|
| 10 | 0.000 | 0.284 |
| 12 | 0.000 | 0.300 |
| 14 | 0.000 | 0.311 |
| 16 | 0.000 | 0.319 |
| 18 | 0.002 | 0.330 |
| 20 | 0.012 | 0.341 |
| 22 | 0.044 | 0.352 |
| 24 | 0.114 | 0.363 |
| 26 | 0.235 | 0.372 |
| 28 | 0.379 | 0.385 |
| 30 | 0.557 | 0.395 |
| 32 | 0.711 | 0.406 |
| 34 | 0.830 | 0.415 |
| 36 | 0.907 | 0.424 |
| 38 | 0.951 | 0.431 |
| 40 | 0.975 | 0.440 |
| 42 | 0.985 | 0.448 |
| 44 | 0.992 | 0.455 |
| 46 | 0.996 | 0.463 |
| 48 | 0.998 | 0.470 |
| 50 | 0.999 | 0.476 |

## Uncertainties

The recommendations from the framework review were to model abundance for three regions, based on available data, and to incorporate information on changes in size at age of herring and variations in the mesh sizes used in the fixed gear gillnet fishery. Additional fishery-independent indices of abundance were incorporated in the model. The estimated catchabilities of the gillnet fishery show differences among regions, and over time, particularly in the South where catchability in the gillnets is estimated to have greatly increased since 2004. This pattern indicates that current attempts to estimate effective effort for this fishery (accounting for regional and annual variations in mesh size, selectivities of the different meshes, number of fishing trips, average number of nets per trip, and average number of hauls per trip) are inadequate and fail to capture changes in fishing fleet efficiency over time.

As previously indicated (DFO 2014), fishery dependent indices, such as the commercial gillnet CPUE indices, may not be proportional to abundance due to hyperstability. The fleets target spawning aggregations and catch rates can be maintained at high levels even as abundance declines. With improved technology, including acoustics and fleet communications, catch rates calculated on the basis of realized landings and nominal effort would be subject to such a bias.

The new modelling approach considers populations of fall spawning herring in three regions. The dynamics are modelled independently among regions and assuming closed populations, i.e. SSB in each region produces recruitment and future SSB to that region. This is a strong assumption that can have consequences on region specific estimates of abundance and dynamics. Spawning bed locations for fall herring have been annually predictable and there is empirical evidence from tagging that herring show spawning bed fidelity to locations where they previously spawned. Elemental analyses of otolith structures show distinct differences between spring spawners and fall spawners in the sGSL but not between regions for fall spawners. There is ongoing research using genetics to determine if there are population level differences between regions for fall spawners.

Although the recent industry-led acoustic surveys of spawning beds for five fall spawning areas are not considered to produce representative indices of abundance, modifications to the sampling design and data collection protocols could in the future produce such indices. Efforts in this direction should be pursued as the model currently relies heavily on fishery-dependent indices to estimate abundance in each region.

There were improvements in retrospective patterns using the recommended model compared to the previous models but the retrospective patterns previously observed around 2005 and 2009 persisted (LeBlanc et al. 2015). An alternate model formulation based on Statistical Catch at Age (SCA) was explored during the framework review but there was insufficient time to complete the analyses and review. Preliminary results using the same input data indicated that the retrospective pattern for those years was due to estimation errors in the catch at age. Further work on this modelling approach is recommended and it should be examined further in the next full assessment for the sGSL herring (March 2016).

# Conclusions

The updated assessment of spawning stock biomass (SSB) for the fall spawner component of Atlantic herring from the sGSL to the start of the year 2015 was conducted based on recommendations from a framework review of assessment methods for this stock. The framework review was conducted April 13-15, 2015 and the proceedings report documenting the review and the recommendations is presently being drafted.

SSB was estimated separately for three regions (North, Middle, South) and these were then summed to produce the SSB for the overall sGSL. Abundance indices for the three regions were derived using the commercial catch and effort information from the fixed gear gillnet fisheries and from experimental multi-mesh panel gillnet catches. Variations in size at age, selectivities in gillnets of the two most important mesh sizes, and variations in the annual proportions of the mesh sizes used in the fishery were inputs to the model. Overall sGSL fishery-independent indices which are presently not available by region were also used in the model. The model also allowed for temporal changes in catchability within each region.

SSB at the start of the year in 2015 was estimated to be 182,000 t (95% confidence interval 109,000 to 295,000 t). There was a 53% probability that the SSB was in the healthy zone of the Precautionary Approach framework ($B_{USR}$ of 172,000 t) at the start of 2015.

Projected SSB at the start of the year in 2016 is very uncertain due to the large uncertainties in the predicted levels of recruitment. A catch option of approximately 30,000 t for the fall spawner component for the sGSL overall in 2015 will result in a 50% chance of exceeding the $F_{0.1}$ reference level. At this catch option, there is less than 40% chance that the SSB at the start of the year in 2016 will be less than $B_{USR}$. There is a near zero probability that the SSB at the start of the year in 2016 will be below $B_{lim}$ (52,000 t) for any of the catch options examined.

## Contributors

This updated assessment of the fall spawner component biomass at the start of 2015 and catch advice for the 2015 fishery on the fall spawner component was completed on April 16, 2015, immediately following the framework review of the assessment methods for this stock which took place April 13-15, 2015. The final version of the projections and catch advice were reviewed during a conference call on April 23, 2015. Participants at the framework review, with some additional participants from DFO Fisheries Management, the fishing industry, and provincial government representatives, were present during the meeting and conference call reviews of the updated assessment and catch advice. The names of the participants for the updated assessment review are provided in Appendix 1.

## Approved by

Doug Bliss
Science Director, Gulf Region
May 11, 2015

## Sources of information

This Science Response Report results from the Science Response Process of April 16, 2015 of the Atlantic Herring fall spawner stock assessment update for 2015. Publications from the assessment framework for the Atlantic herring stock of the southern Gulf of St. Lawrence (NAFO Div. 4T) of April 13-15, 2015 which support this science response report will be posted on the DFO Science Advisory Schedule as they become available.

DFO. 2014. Assessment of Atlantic herring in the southern Gulf of St. Lawrence (NAFO Div. 4T) to 2013. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/040.

LeBlanc, C.H., Mallet, A., Surette, T., and Swain, D. 2015. Assessment of the NAFO Division 4T southern Gulf of St. Lawrence herring stocks in 2013. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/025. vi + 133 p.

# Appendix

*Appendix 1. List of participants to the Science Response update review of the assessment of fall spawner component of Atlantic herring from the southern Gulf of St. Lawrence to 2014 and updated advice for the 2015 fishery, April 16, 2015.*

| Name | Affiliation |
|---|---|
| Albert, Gabriel | New Brunswick Department of Agriculture, Aquaculture and Fisheries |
| Allain, Robert | MSC certification consultant |
| Allen, Carl | Maritime Fishernen's Union |
| Benchabane, Samir | Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec |
| Benoit, Hugues | DFO Science Gulf Region |
| Bergeron, Mathieu | DFO Fisheries Management, Quebec Region |
| Bliss, Doug | DFO Science Gulf Region |
| Cadigan, Noel | Memorial University, St. John's, Newfoundland and Labrador |
| Castonguay, Martin | DFO Science Quebec Region |
| Chaput, Gérald | DFO Science Gulf Region |
| Clay, Allen | FEMTO Electronics |
| Cloutier, O'Neil | Regroupement des pêcheurs professionnels du sud de la Gaspésie |
| Cox, Sean | Simon Fraser University, Burnaby, British Columbia |
| Duguay, Gilles | Regroupement des pêcheurs professionnels du sud de la Gaspésie |
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| Ferguson, Annie | New Brunswick Department of Agriculture, Aquaculture and Fisheries |
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| LeBlanc, Claude | DFO Science Gulf Region |
| Leclair, Kenneth | Prince Edward Island Fishermen's Association |
| MacEwen, Dave | Prince Edward Island Department of Fisheries and Aquaculture |
| Mallet, Allain | DFO Science Gulf Region |
| Mallet, Pierre | DFO Fisheries Management Gulf Region |
| Mattews, Brian | Prince Edward Island Fishermen's Association |
| McDermid, Jenni | DFO Science Gulf Region |
| Melvin, Gary | DFO Science Maritimes Region |
| Mowbray, Fran | DFO Science Newfoundland and Labrador Region |
| Plourde, Stéphane | DFO Science Quebec Region |
| Ramsay, Laura | Prince Edward Island Fishermen's Association |
| Richard, Michel | Maritime Fishermen's Union |
| Ruest, Richard | DFO Fisheries Management Gulf Region |
| Singh, Rabindra | DFO Science Maritimes Region |
| Surette, Tobie | DFO Science Gulf Region |
| Swain, Doug | DFO Science Gulf Region |
| White, Chuck | Prince Edward Island Fishermen's Association |

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*Aussi disponible en français :*

*MPO. 2015. Mise à jour jusqu'en 2014 de l'évaluation de la composante des reproducteurs d'automne du hareng de l'Atlantique (Clupea harengus) dans le sud du golfe du Saint-Laurent (division 4t de l'OPANO) et recommandations pour la pêche de 2015. Secr. can. de consult. sci. du MPO, Rép. des Sci. 2015/033.*