Fisheries and Oceans Canada | Pêches et Océans Canada

Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2016/061

Gulf Region

Population modelling results for the assessment of Atlantic herring (*Clupea harengus*) stocks in the southern Gulf of St. Lawrence (NAFO Division 4T) to 2015

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September 2016

Canada

Foreword

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Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1919-5044

Correct citation for this publication:

Swain, D.P. 2016. Population modelling results for the assessment of Atlantic herring (*Clupea harengus*) stocks in the southern Gulf of St. Lawrence (NAFO Division 4T) to 2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/061. xi + 53 p.

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ABSTRACT

For assessment purposes, Atlantic herring in the southern Gulf of St. Lawrence are treated as two independent components, spring and fall spawners. Spring spawning herring were assessed using a virtual population analysis (VPA) which allowed for time-varying catchability (*q*) to the gillnet fishery. Model estimated spring spawner spawning stock biomass (SSB) has been in the critical zone of the Precautionary Approach (PA) framework since 2004. The median estimate of SSB at the start of 2016 (9,660 t) was less than 45% of the limit reference point (LRP = 22,000 t). The estimated instantaneous rate of fishing mortality (*F*) on aged 6 to 8 year old spring spawner herring declined below the reference level (F = 0.35) in 2010 and averaged 0.18 in 2013 to 2015. Based on projections with catch in 2016 and 2017 varying between 0 t and 2,500 t annually, the probability that SSB will be less than the LRP in 2018 varies between 90 and 95%, the probability that average *F* for ages 6 to 8 will exceed the reference level (0.35) in 2017 varies from 0 to 70%, and the probability of a 5% decline in SSB between 2016 and 2018 varies from 23 to 65%.

Fall spawning herring were assessed as separate populations in three spawning regions (North, Middle, South). The population model allowed for time-varying catchability (*q*) to the gillnet fishery, with different trends in *q* permitted between regions. Estimated SSB has been declining in all three regions in recent years, though it remains at a relatively high level in the North. Summed over all three regions, SSB at the start of 2016 is estimated to be about 165,000 t, just below the upper stock reference (USR) of 172,000 t, at a probability of 60%. Estimated *F* (ages 5 to 10) declined substantially in recent years in the North region but has remained higher in the Middle and South regions. Averaged over all regions, ages 5 to 10 *F* declined from about 0.4 in 2008 to 0.19 in 2012 with essentially zero chance of having exceeded the removal rate reference level of F = 0.32. The median projected value of SSB at the start of 2018 remained below the USR at all catch levels between 10,000 and 50,000 t, with the probability of being below the USR varying from 57% at 10,000 t to 87% at 50,000 t. The probability that ages 5 to10 fishing mortality rate will exceed F = 0.32 in 2017 is estimated to increase from 0% at catches of 10,000 t to 97% at 50,000 t.

Résultats de la modélisation de la population pour l'évaluation des stocks de hareng de l'Atlantique (*Clupea harengus*) dans le sud du golfe du Saint-Laurent (division 4T de l'OPANO) en 2015

RÉSUMÉ

Aux fins d'évaluation, les populations de hareng de l'Atlantique dans le sud du golfe du Saint-Laurent sont considérées comme étant formées de deux composantes indépendantes, c'est-à-dire les reproducteurs de printemps et d'automne. Les reproducteurs de printemps ont été évalués à l'aide d'une analyse de population virtuelle (APV), qui a permis d'examiner la capturabilité variable au fil du temps (*q*) dans le cadre de la pêche au filet maillant. Selon le modèle, la biomasse estimée du stock reproducteur (BSR) des reproducteurs de printemps se situe dans la zone critique du cadre de l'approche de précaution (AP) depuis 2004. L'estimation médiane de la BSR au début de 2016 (9 660 t) correspondait à moins de 45 % du point de référence limite (PRL) (PRL = 22 000 t). L'estimation du taux instantané de mortalité par pêche *(F)* des harengs reproducteurs de printemps âgés de 6 à 8 ans a diminué pour se situer en dessous des niveaux de référence (F = 0,35) en 2010, avec une moyenne de 0,18 de 2013 à 2015. D'après des projections des prises en 2016 et en 2017 variant de 0 t à 2 500 t par année, la probabilité que la BSR soit inférieure au PRL en 2018 varie entre 90 % et 95 %, la probabilité que la valeur moyenne de *F* pour les âges 6 à 8 dépasse le niveau de référence (0,35) en 2017 varie de 0 % à 70 %, et la probabilité d'un déclin de 5 % de la BSR entre 2016 et 2018 varie de 23 % à 65 %.

Les harengs reproducteurs d’automne ont été évalués en tant que populations distinctes dans trois régions de frai (Nord, Centre et Sud). Le modèle de population a permis d'examiner la capturabilité variable au fil du temps (*q*) dans le cadre de la pêche au filet maillant, avec différentes tendances dans *q* permises entre les régions. L'estimation de la BSR a affiché un déclin dans les trois régions au cours des dernières années, mais elle demeure à un niveau relativement élevé dans le Nord. Pour toutes les régions, la BSR au début de 2016 est estimée à environ 165 000 t, tout juste en dessous du point de référence supérieur (PRS) de 172 000 t, à une probabilité de 60 %. L'estimation de *F* (âges 5 à 10) a diminué de façon importante au cours des dernières années dans la région du Nord, mais elle est demeurée plus élevée dans les régions du Centre et du Sud. En moyenne, pour l'ensemble des régions, la valeur de *F* pour les âges 5 à 10 a diminué, passant d'environ 0,4 en 2008 à 0,19 en 2012, avec une probabilité quasi nulle de se situer au-dessus du taux d'exploitation de référence de F = 0,32. La valeur médiane projetée de la BSR au début de 2018 est demeurée en dessous du PRS pour tous les niveaux de prises entre 10 000 t et 50 000 t, avec une probabilité qu'elle se situe en dessous du PRS, variant entre 57 % à 10 000 t et 87 % à 50 000 t. La probabilité que les âges 5 à 10 dépassent le taux de mortalité par pêche F = 0,32 en 2017 devrait passer de 0 % à des niveaux de prises de 10 000 t à 97 % pour des niveaux de 50 000 t.

1. INTRODUCTION

Atlantic herring (*Clupea harengus*) in the southern Gulf of St. Lawrence (sGSL) consist of spring (SS) and fall (FS) spawner components. These two components are treated as separate stocks for assessment purposes. Both components are fished by two fleets; a gillnet or “fixed” gear fleet and a purse seine or “mobile” gear fleet. The two stocks are assessed using Virtual Population Analysis (VPA). Data inputs for these models include the fishery catch-at-age (summed over the two fleets), gillnet fishery catch-per-unit-effort (CPUE) abundance indices, and abundance indices from a research-vessel acoustic survey (McDermid et al. 2016).

During the peer review of the March 2014 assessment, issues were identified with the indices of abundance from the fall gillnet fishery and with the population models used to assess status of fall-spawning herring (LeBlanc et al. 2015). Consequently, a framework review of the assessment approach was held in March 2015. New and revised abundance indices for the fall-spawning component were reviewed and accepted at the meeting (Benoît et al. 2016) and a revised population model was accepted. This model incorporated the following changes:

- the fall spawners in three spawning regions (North, Middle and South spawning regions, Fig. 1) were treated as independent populations,
- time-varying fishery catchability was incorporated in the model, with independent random walks in catchability for each region, and
- additional indices were used in model fitting (Swain 2016).

This document describes the population modelling conducted for the assessment of NAFO Div. 4T (hereafter referred to as 4T) spring spawning and fall-spawning herring to the end of 2015. A new model is presented for spring spawners that addresses the poor fit to the fishery catch per unit effort commercial fishery indices and a strong retrospective pattern of the previous model. The assessment of fall spawning herring uses the population model accepted in April 2015 (DFO 2015), updated with the 2015 data. Data inputs and fishery performance for both the spring and fall spawning components are described by McDermid et al. (2016).

2. SPRING SPAWNER COMPONENT ASSESSMENT

In recent assessments of 4T spring spawning herring, resource status has been examined using a virtual population analysis (VPA) implemented using the ADAPT software (Gavaris 1999). This model was fit to two indices of abundance at age, fishery catch rates at ages 4 to 10 years (the CPUE index), and abundance indices at ages 4 to 8 years based on a fall acoustic survey. In the most recent assessment (LeBlanc et al. 2015), model fit to the CPUE index was poor, with a severe residual pattern. Furthermore, there was a strong “retrospective pattern” in estimates of spawning stock biomass (SSB) with estimates of SSB in a given year progressively declining as additional years of data were added to the analysis. These results suggest that the model failed to incorporate one or more non-stationary processes in the population dynamics of this stock or in the observation model relating indices of abundance to population abundance.

Three population models are compared in this assessment. Model 1 corresponds to the model used in the last assessment. Model 2 is like Model 1, except that the instantaneous rate of natural mortality (*M*) is allowed to vary over time. Model 3 is like Model 1, except that catchability to the fishery (q) is allowed to vary over time.

2.1 METHODS

All models incorporated ages 2 to 11+ (i.e., 11 years and older) and began in 1978. Abundance of the plus group (11+) was estimated using the F-ratio method (Gavaris 1999). In Model 1, *M* was assumed to be constant over time and ages and set at a value of 0.2. Model parameters included abundance at ages 5 to 11+ at the beginning of 2016, *q* at age to the fishery (i.e., the CPUE index, ages 4 to 10) and to the acoustic survey (ages 4 to 8), and the standard deviation (SD) of observation error at age for each of the indices. All parameters were estimated on the log scale.

Model 2 allowed for process error in *M*. *M* was allowed to differ between ages 2 to 5 and 6+. For each age group, *M* was modelled as a random walk:

(1) $M_{1978} = M_{init}$ and $M_t = M_{t-1}e^{Mdev_t}$ where t > 1978.

This model contains the following additional parameters: initial *M* in 1978 for each of the two age groups and the vector of *M* deviations (1979 to 2015) for each age group. Priors were included for the initial *M* of each age group, set at a mean of 0.2 and SD of 0.05. The *M* deviations were assumed to be normally distributed with a mean of 0 and a standard deviation of 0.05. The objective function included four penalty terms associated with the random walks in *M*: terms for the departures of the *M* deviations from 0 for each age group, and terms for the departures of initial *M* of each age group from its prior mean.

Model 3 allowed for process error in fully-recruited fishery *q*. Catchability to the fishery was estimated for 1990 to 2015 (the years with CPUE data) and was modelled as selectivity at age (S_a) times fully recruited *q*. Selectivity was modelled as a logistic function of age for ages 4 to 9, but was freely estimated for age 10 to allow for dome-shaped selectivity at age. In Models 1 and 2, catchability at age peaked at age 9 for the CPUE index. Fully-recruited *q* was freely estimated for 1990 and then allowed to vary over time following a random walk, like in equation 1 for *M*. The *q* deviations were assumed to be normally distributed with a mean of 0 and a standard deviation of 0.1. The objective function for model 3 included a term penalizing departures of the *q* deviations from 0. *M* was assumed to be constant at 0.2 for all years and ages.

All models were implemented in AD Model Builder (Fournier et al. 2011). Model estimates and their uncertainty were evaluated based on MCMC sampling, with every 40th of 200,000 samples saved. Results will differ slightly between this implementation and the ADAPT implementation even for Model 1 due to a number of differences in modelling procedures. For example, the ADAPT model was fit by minimizing the sum of squared residuals while the ADMB models were fit by minimizing the full likelihood function, including the estimates of observation error variance.

Because the youngest age in the abundance indices is age 4, it is not possible for these models to obtain direct estimates of abundance at ages 2 to 4 at the beginning of 2016, ages 2 to 3 at the beginning of 2015, and age 2 at the beginning of 2014. These were obtained using the estimated average recruitment rate in the most recent five years and the estimated SSB producing a particular cohort. For example, the abundance at age 4 at the start of 2016 was obtained based on the average recruitment rate to age 4 for the 2007 to 2011 cohorts and SSB in 2012. In previous assessments this was done outside of the model. In this assessment, this was incorporated within the models, thus accounting for uncertainty.

2.2 RESULTS

Based on Model 2, there were no changes in natural mortality of young herring (ages 2 to 5 years) but natural mortality increased for older herring in the early to mid-2000s (Fig. 2). The estimate of *M* for young herring remained near its prior mean of 0.2. For older herring, estimated

M increased from an average value of about 0.235 in the 1980s and 1990s to 0.46 in 2010 to 2015. Based on Model 3, catchability to the fishery and to the CPUE index averaged about 0.006 in the 1990s, increasing to a peak of 0.027 in 2007 and then declining to an average value of 0.018 in 2010 to 2015 (Fig. 3).

Residual patterns indicated a good fit of Model 1 to the age-disaggregated acoustic indices but a very poor fit to the CPUE indices (Fig. 4a). For the CPUE index, Model 1 residuals were relatively large and almost entirely negative in the 1990s (i.e., observed < predicted) and positive in the 2000s (i.e., observed > predicted). Model 2 provided no improvement in the severe residual pattern for the CPUE index, though the sum of squared residuals was slightly lower (Fig. 4b). In contrast, residual patterns for the CPUE index were greatly improved in Model 3 (Fig. 4c). For Model 3, there were no strong patterns in the residuals, and the sum of squared residuals for the CPUE index was half the value for Model 1. All models provided a similar fit to the acoustic index, though the sum of squared residuals was slightly smaller for Models 2 and 3.

Fits to the age-aggregated CPUE index were also much better for Model 3 than for Models 1 and 2 (Fig. 5). For Models 1 and 2, observed values were consistently (and considerably) lower than the predicted values in the mid to late 1990s and consistently greater than the predicted values in the mid to late 2000s. In contrast, the predicted CPUE index from Model 3 followed the temporal trends in the observed index well.

Because Model 2 provided negligible improvement over Model 1, retrospective analyses were conducted for Models 1 and 3 only (Fig. 6). Model 1 exhibited a relatively severe retrospective pattern in the estimated biomass of herring aged 5 to 10 years, with the biomass estimate for a particular year progressively declining as years of data were added to the model (Fig. 6a). In contrast, retrospective patterns in ages 5 to 10 biomass were slight for Model 3 (Fig. 6b).

The comparisons above indicate that Model 3 provides a substantial improvement over Models 1 and 2 in terms of both model fit and model reliability (i.e., retrospective patterns). Thus, Model 3 was chosen for the evaluation of stock status and provision of advice. The improved performance of this model reflected its ability to account for changes in catchability to the fishery. Catchability is defined as the proportion of the stock removed by a unit of fishing effort. There are a number of factors that could account for the changes in catchability estimated by this model. Estimated catchability increased as the stock declined below 60,000 t of spawner biomass (Fig. 7). Fishery catchability is often expected to increase as population size decreases (Paloheimo and Dickie 1964; Winters and Wheeler 1985; Swain and Sinclair 1994; Rose and Kulka 1999). Because the area occupied by a stock usually decreases as stock size decreases (MacCall 1990) and fish harvesters target fish aggregations (e.g. spawning aggregations), the proportion of the stock removed by a unit of fishing effort is expected to increase as a declining stock becomes increasingly concentrated in a smaller area. A nonlinear inverse relationship between catchability and population abundance (such as that in Figure 7) has been demonstrated for many pelagic fishes, including herring (see Winters and Wheeler 1985 and references therein). In a gillnet fishery, net saturation at high abundance may also contribute to increased catchability at low population size. Finally, catchability by fisheries is expected to increase over time due to technological improvements and improvements in fishing tactics.

Based on Model 3, recent estimates of spawning stock biomass (SSB) were lower than those estimated in the 2014 assessment (Fig. 8; Table 1). The estimates of SSB at the beginning of 2015 and 2016 were 9,076 t (95% confidence interval: 5,686 – 14,282) and 9,659 t (95% CI: 5,530 – 16,294), respectively. The estimate for 2016 is less than 45% of the Limit Reference Point (LRP = 22,000 t of SSB). The probabilities that SSB was above the LRP at the start of 2015 and 2016 were <0.02% and 0.2%, respectively.

Recruitment rates (the number of recruits divided by the SSB that produced them) were unusually high in the early 1980s (Fig. 9). This may reflect compensatory increases in recruitment success at low SSB and/or other ecosystem changes promoting good recruitment (e.g., reduced predation on larvae by other collapsed pelagic fishes as described in Swain and Sinclair 2000). Recruitment rates have been much lower since then, though periods of moderately high recruitment rates occurred in the late 1980s and early 1990s and between 2005 and 2009. Recruitment rates of the 2010 and 2011 cohorts were among the lowest observed. These recent low levels of recruitment success contrast the high recruitment rates in the early 1980s when SSB was also very low. This may reflect effects of climate change (Melvin et al. 2009) or other ecosystem changes.

Estimated abundances of 4-year-old herring at the start of 2014 and 2015 (the 2010 and 2011 year-classes) were the lowest on record (Fig. 10; Table 2). The age-4 abundance in 2016 is greater than these very low values. However, the value for 2016 depends on the assumption that recruitment rate for this cohort is the average of the rate for the preceding five cohorts. Recruitment rates vary widely among these five cohorts (Fig. 9). Thus, the uncertainty in age-4 abundance in 2016 is very high. The error bar for 2016 in Figure 10 does not take into account the uncertainty in the recruitment rate for this cohort as it depends on the assumption that its recruitment rate was the average of the five preceding cohorts. If the recruitment rate of the 2012 cohort was instead very low, like that of the 2010 and 2011 cohorts, age-4 abundance in 2016 would resemble the very low 2014 and 2015 values.

The most recent estimate of spawner (4+) abundance is for 2015, since the 2016 value depends on the recruitment rate assumed for the 2012 cohort. The maximum likelihood estimate (MLE) for 2015 is 53.5 million, and the MCMC median is 51.4 million herring (95% CI: 32.0 – 83.1), about 13% of the average spawner abundance in 1985 to 1995. Only the 1981, 1982 and 2006 values were lower than the MLE value for 2015 (Table 2).

Estimated exploitation rates were very high in 1980 and in most years from 2000 to 2007 (Fig. 11; *F* values in Table 3). The estimated exploitation rate declined below the reference level in 2010, reaching a low value of 0.07 in 2012. Exploitation rates in 2013 to 2015 averaged 0.15.

The spring-spawner population trajectory with respect to spawning stock biomass and fishing mortality levels is shown in Figure 12. The stock has been in the critical zone (SSB < LRP = 22,000 t) since 2004 but experienced fishing mortalities above the $F_{0.1}$ level until 2010. *F* has remained below $F_{0.1}$ since then.

2.3 PROJECTIONS

The population model was projected forward to the start of 2018 during the MCMC sampling of the joint posterior distribution of the parameters. This takes into account uncertainties in the parameter estimates. No model estimates are available for abundances at ages 2 to 4 in 2016. These were estimated in the projection using recruitment rates at ages 2 to 4 years and estimates of the SSB producing each cohort. Unlike in the model, recruitment rates for the projections were randomly selected from the five most recent estimates (the 2007 to 2011 cohorts). This random selection was repeated in each of the 200,000 MCMC iterations. This procedure was also used to obtain estimates of age-2 abundance at the start of 2017 and 2018. For each iteration, vectors of beginning of year weights at age in the population and weights at age in the fishery catch were randomly selected from the last five years. Projections were conducted at six levels of annual catch (0 to 2,500 t in increments of 500 t). Partial recruitment to the fishery was set at the average of the last 10 years.

Projections of SSB and ages 6 to 8 fully recruited *F* are shown in Figures 13 and 14, and the probabilities of meeting various objectives are given in Table 4 for each catch level. SSB was projected to increase slightly at annual catches of 0 and 500 t, remain roughly stable at a catch of 1,000 t, and decline at catches of 1,500 t or more. However, uncertainty was high. The probability of no decline in SSB between the beginning of 2016 and the beginning of 2018 decreased from 66% at 0 t of catch to 51% at 1,000 t of catch and 31% at 2,500 t of catch. The probability of a 5% increase in SSB decreased from 60% at 0 t of catch to 48% at 1,000 t of catch and 27% at 2,500 t of catch. The probability of a 5% decline in SSB increased from 23% at 0 t of catch to 47% at 1,000 t of catch and 65% at 2,500 t of catch. For all catch levels (including no catch), there was a high probability that SSB would remain below the LRP at the start of 2018 (90% at 0 t of catch, 93% at 1,000 t of catch, and 95% at 2,500 t of catch). There was no chance that the population would be at or above the Upper Stock Reference (USR) in 2018 even with no catch. The probability that age 6 to 8 fully recruited *F* would be greater than the removal rate reference level of F = 0.35 was small at 1000 t of catch (6%), increasing to 29% at 1,500 t of catch and 70% at 2,500 t of catch. Estimates of projected SSB and ages 6 to 8 *F* in 2017 and 2018, and their uncertainties are provided in Table 5.

2.4 DISCUSSION AND CONCLUSIONS

In recent assessments of the spring spawner component of herring in the sGSL, model fits to the CPUE indices were poor, with a severe residual pattern consisting of a block of large negative residuals in the 1990s and a block of large positive residuals in the 2000s (LeBlanc et al. 2015). This was reflected in a strong retrospective pattern, with recent SSB systematically overestimated. These results suggest that the model was failing to account for one or more non-stationary processes. Allowing natural mortality to vary over time did not reduce this problem. However, allowing catchability to the gillnet fishery to vary over time largely eliminated the problem. Estimated catchability increased sharply in the 2000s, reaching a peak in 2007 that was about 4.5 times the level in the 1990s. Since 2010, catchability declined to a level about 3 times the 1990s level. The increase in fishery catchability (q) in the 2000s appeared to be density dependent, which has been observed in other herring stocks (Winters and Wheeler 1985). This is expected to occur because the area occupied by a stock is expected to decrease as stock size decreases. Thus, fish harvesters targeting aggregations of fish (e.g. spawning aggregations) would be expected to remove a higher proportion of the stock with a unit of fishing effort. The estimated decline in q to an intermediate level since 2010 may reflect changes in management measures in the spring fishery that have been in effect since 2010. These measures, including closures of some spawning areas and regulations which prevented the targeting of herring aggregations overnight, would be expected to reduce catchability to the fishery.

Estimated SSB of spring spawners has been below the LRP since 2004, with the median estimate at the start of 2016 (9,659 t) less than 45% of the LRP. Considering the uncertainty accounted for by the model, the probability that the SSB was above the LRP at the start of 2016 is only 0.002 (0.2%). Recruitment rates were high in the early 1980s but have been much lower since. The most recent estimates of recruitment rate (for the 2010 and 2011 year-classes) are among the lowest observed. The abundances of these two year-classes at age 4 are the lowest on record. The median estimate of spawner (4+) abundance at the start of 2015 (the most recent full estimate) is about 13% of the average spawner abundance in 1985 to 1995. Exploitation rates (ages 6 to 8) were high (above the removal rate reference level of F = 0.35) from 1999 to 2008 but declined to a lower level in 2011 to 2015 (F < 0.2). Despite large uncertainty in the projections, the probability that SSB will remain below the LRP at the start of 2018 was high (0.9), even with no catch. The median probability that *F* (ages 6 to 8) will exceed 0.35 in 2017 is low (< 0.06) with catches of 1,000 t or less, increasing to 0.7 with catches of 2500 t. The median probability that SSB will decline by 5% or more by 2018 is about 23% with no catch, 50% at catches between 1,000 and 1,500 t, and 65% with catches of 2,500 t.

3. FALL SPAWNER COMPONENT ASSESSMENT

The assessment framework for the fall spawning stock of herring in the sGSL was reviewed in March 2015. Previous models for this stock displayed a severe residual pattern between observed gillnet fishery catch rates and model predictions (LeBlanc et al. 2015). These models also had strong retrospective patterns, with the biomass estimate for a particular year decreasing as additional years of data were added to the analysis. Size-at-age showed a declining trend since the mid-1980s and there was a concern that catchability of fish aged 4 and 5 years to the gillnet fishery was declining. Finally, management requested models which treated the fall-spawning stock as three independent populations corresponding to the North, Middle, and South spawning grounds (Fig. 1).

At the 2015 framework review, indices of relative selectivity by age, year and mesh size (2⅝and 2 ¾ inches) were developed to address the issue of changes in catchability to the gillnet fishery due to declines in size-at-age. Additional indices were also introduced: experimental net catch rates, acoustic indices for ages 2-3 and indices for ages 4-6 years based on catch rates in the annual Research Vessel (RV) bottom trawl survey (Benoît et al. 2016). Models were also developed which treated the stock as three independent regions (Swain 2016).

Three types of models were examined to address the residual and retrospective patterns:

- Model 1: a model similar to those used in earlier years but including the new indices,
- Model 2: a model which allowed natural mortality to vary over time, and
- Model 3: a model which allowed catchability to the gillnet fishery to vary over time.

Residual patterns remained severe for Models 1 and 2 but were greatly improved in Model 3. Model 3, with the stock assumed to comprise three independent populations spawning in the North, Middle or South regions, was chosen as the model to use to evaluate stock status and provide advice and was also used for this assessment (DFO 2015; Swain 2016).

3.1 METHODS

Model 3 is a virtual population analysis (VPA) implemented using AD Model Builder (Fournier et al. 2011). Ages 2 to 11+ (i.e., 11 years and older) were incorporated in the model. Abundance of the plus group (11+) was estimated using the F-ratio method (Gavaris 1999).

Data inputs were fishery catches at ages 2 to 11+ (in numbers), fishery catch-per-unit-effort (CPUE) in numbers at ages 4 to 10 years from 1986 to 2015, catch rates at age in experimental nets (ages 3 to 9 or 10, 2002 or 2003 to 2015, with indices missing in some years in some regions), abundance indices at ages 2 and 3 from the fall acoustic survey (1994 to 2014), and catch rates at ages 4 to 6 in the September RV survey. Separate fishery catches 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 RV survey indices were considered abundance indices for the sum of the three regions. Additional inputs included the proportion of gillnets with 2 ⅝inch mesh in each region in each year, and relative selectivity to the gillnet fishery by age, year and mesh size. Data inputs are described in detail by McDermid et al. (2016).

Catchability (q) to the fishery was modelled as logistic selectivity at age (S_a) multiplied by fully recruited q in year t:

(2) $q'_{atp} = (P_{1tp}\, Sr_{1,a,t} + (1 - P_{1tp})Sr_{2,a,t})S_a q_{tp}$

where a indexes age, t indexes year, and p indexes population or region, P_{1tp} is the proportion of gillnets with 2 ⅝ mesh in year t in population p, and Sr_{1at} and Sr_{2at} are the indices of relative selectivity of the 2⅝ and 2¾ inch meshes, respectively, at age a in year t. The matrices Sr_{1at}

and Sr_{2at} have been revised since the 2015 framework assessment (Benoît et al. 2016) but show similar trends to those used in 2015 (Fig. 15). The use of logistic selectivity at age (S_a) was considered adequate given the estimates of catchability at age reported by LeBlanc et al. (2015) for fall spawners. Fully recruited catchability was allowed to vary following a random walk:

(3) $q_{1986,p} = q_{1,p}$ and $q_{t,p} = q_{t-1,p}e^{Qdev_{t,p}}$ if t>1986

Random walks were independent between populations *p*. For each region, *q* in 1986 was a freely estimated parameter. The Qdevs were assumed to be normally distributed with a mean of 0 and a standard deviation of 0.1. The objective function included terms (one per population) penalizing departures of the Qdevs from 0:

(4) $0.5 \cdot (\sum_t Qdev_t^2)/\sigma^2$ where $\sigma = 0.1$

Sensitivity analyses indicated that the value of 0.1 assumed for σ was large enough to alleviate the residual patterns but small enough that the trends in *q* were not unduly influenced by noise in the data. As in previous assessments, natural mortality (*M*) was assumed to be constant over ages and years at an instantaneous rate of 0.2.

Unlike in previous analyses (Swain 2016), indices for age 3 herring were available for each region in the final year (2015). This permitted estimation of the abundances of all mature ages (4+) at the beginning of 2016. Thus, an estimate of SSB for each region in 2016 can be obtained without using an assumed recruitment rate to estimate age 4 abundance in 2016. However, the age 4 abundance estimates for 2016 are based on single observations (the age-3 experimental net index for each regions), and uncertainty may remain high for these estimates.

Uncertainty in model estimates was evaluated based on MCMC sampling, with every 40^{th} of 200,000 samples saved.

3.2 RESULTS

Similar to the results for this model in 2015, residual patterns for the CPUE indices were not severe (Fig. 16), indicating an adequate fit to these indices. There was a tendency to overestimate abundance at ages 8+ in the Middle region in the late1980s and early 1990s and to overestimate abundances at ages 4 and 5 in all regions in most years since 2010. However, there was no severe blocking of residuals, with negative residuals for nearly all age-year cells prior to 1995 and positive in most cells since 2005, as was observed in earlier models assuming constant catchability.

Residual patterns for the experimental net indices were similar to those for these indices in the 2015 assessment (Fig. 17). There was a block of positive residuals in 2003 to 2005 and negative residuals in 2008 and 2009 in the North region. As in 2015, a number of year effects were evident (e.g., 2004 in the North region, 2007 in the Middle region, and 2010 in the South region). Year effects were also evident in the RV and acoustic indices (Figs. 16 and 17).

Fits to the age-aggregated CPUE indices were reasonably good, with predicted values consistent with the general trends in the indices (Fig. 18). Fits were also acceptable for the age-aggregated experimental net indices (Fig. 19), though these indices were quite noisy and trends were minor for these short indices, except in the North region. The fit to the age-aggregated RV index was reasonable (Fig. 19) but predicted values for the acoustic juvenile (age 2-3) index tended to underestimate observed values early in the time series (Fig. 18).

Retrospective patterns resembled those for the 2015 model (Fig. 20). As years were added to the analysis prior to 2010, the estimate of SSB for a particular year tended to decrease. As the last three years were added to the analysis, the estimate for SSB tended to increase. The retrospective pattern was negligible for the Middle region and greatest for the North region, though not in a consistent direction.

Estimated changes in fully-recruited catchability to the gillnet fishery differed between regions (Fig. 21). Catchability was lowest and varied little over time in the North region. Catchability in the South region increased over time, primarily between 1995 and 2010. In this region, *q* since 2010 has been 3.5 times greater than *q* prior to 1995. Estimated catchability was greatest in the Middle region until the mid-2000s when it was surpassed by catchability in the South region. In the Middle region, fully-recruited *q* was at its lowest around 1990, and then increased to a level about twice as high by 2000, where it has since remained. Estimates of catchability at age are shown in Figure 22 for the fishery (i.e., the CPUE index) and Figure 23 for the experimental nets. Catchability to the experimental nets was highest in the Middle region and lowest in the North region. Catchability in the South was similar to the North at young ages and slightly greater than the North at older ages. The patterns in relative catchability between regions for the experimental nets resemble those for the gillnet fishery in 1986 (e.g., *q* relatively low in the South) and contrast those for the gillnet fishery in 2014 (e.g., *q* relatively high in the South).

As discussed in the spring spawner assessment, catchability to fisheries is expected to change over time for a number of reasons. Fishery catchability is expected to increase as population abundance declines because a unit of fishing effort removes a higher proportion of the population when it is aggregated in a small area at low abundance (e.g., Winters and Wheeler 1985). Improvements in fishing technology and tactics are also expected to lead to increases in catchability over time. There is a tendency for catchability to decline with population biomass among these three regions, but most of the variation in *q* within the Middle and South regions is independent of stock biomass (Fig. 24). This suggests that much of the increase in *q* in these two regions is related to technological improvements and improved fishing tactics. The similarities in patterns in *q*-at-age between the experimental nets and the CPUE index in 1986 but not in 2014 (Fig. 23) is consistent with this suggestion.

Estimated SSB in the North region was at a high level from the mid-1980s to the early 1990s, declined to a lower level from the mid-1990s to the late 2000s and then returned to a higher level (Fig. 25). Estimated SSB in this region declined substantially from 2012 to 2015, but the median estimate remains above the average level between 1995 and 2008. In the Middle region, estimated SSB increased gradually from 1980 to the late 2000s, but declined by about 60% between 2009 and 2016. SSB in the South region was at a relatively high level from about the mid-1980s to the late 2000s. However, estimated SSB has been in decline since 2009, with the median estimate at the start of 2016 at 40% of the 2009 value. However, uncertainty in the 2016 estimate is very high. Summed over the three regions, the median estimate of total SSB at the start of 2016 is 165,000 t based on MCMC sampling (160,500 t based on the maximum likelihood estimate). The estimated probabilities that total SSB was below the USR of 172,000 t at the beginning of 2015 and 2016 are 22% and 60%, respectively (Fig. 26).

Estimated abundance of fall-spawning herring 4 years of age and older has declined in all three populations in recent years (Fig. 27). To a large extent, this reflects drastic reductions in the recruitment of 4-year-old herring. In all three regions, estimated abundances of 4-year-old herring for the last three years (2014 to 2016) are among the lowest observed, comparable to the low levels estimated for the late 1970s. However, the estimates for the start of 2016 are highly uncertain, particularly for the North and South regions. The 2016 estimates are based on single observations (age 3 catch rates in the experimental nets in 2015).

The three most recent estimates of recruitment rate (recruit abundance divided by the SSB producing them) were among the lowest observed in the North and Middle regions (the 2010 to 2012 cohorts in Figure 28). The estimates for these three cohorts were also low in the South region, though the estimate for the 2012 cohort was extremely uncertain. Summed over all three regions, total recruitment rates for the 2010 to 2012 cohorts were among the lowest observed.

Estimated fishing mortality (ages 5 to 10) declined substantially in the late 2000s and early 2010s in the North region but has remained higher in the Middle and South regions (Fig. 29). In the North region, ages 5 to 10 *F* averaged 0.54 from 1995 to 2008, declining to 0.11 to 0.14 in 2014 and 2015. Estimated ages 5 to 10 *F* has averaged 0.35 since 2001 in the Middle region and 2005 in the South region. The weighted average ages 5 to 10 *F* over all three regions (weighted by regional abundance of 5 to 10 year olds) has generally declined since 2008, from about 0.40 to an average of 0.19 since 2012. Based on the population model, the probability that overall ages 5 to 10 *F* exceeded 0.32 (the reference level in the healthy zone above the USR) in 2015 is essentially 0 (0.02%).

3.3 PROJECTIONS

The population model was projected forward to the start of 2018 during the MCMC sampling of the joint posterior distribution of the parameters. This takes into account uncertainties in the parameter estimates. No model estimates are available for abundances at age 2 in 2015 and ages 2 and 3 in 2016. Abundances at age 2 in these years and in projection years 2017 and 2018 were estimated using recruitment rates and estimates of the SSB producing each cohort. Recruitment rates were randomly selected from the five most recent estimates (the 2008 to 2012 cohorts). This random selection was repeated in each of the 200,000 MCMC iterations. For each iteration, vectors of beginning of year weight at age in each region, weight at age in the fishery catch for each region and partial recruitment at age to the fishery in each region were randomly selected from the last five years. Projections were conducted at catch levels from 10,000 to 50,000 t in increments of 2,000 t.

Summed over all three regions, the median value of SSB at the start of 2018 was below the USR at all catch levels between 10,000 and 50,000 t (Fig. 30). The probability that SSB would be below the USR at the start of 2018 increased from 57% at a catch of 10,000 t, to 87% at a catch of 50,000 t. At a catch of 28,000 t (the catch in 2015) in 2016 and 2017, this probability would be 76.5%.

At catch levels from 10,000 to 28,000 t in 2016 and 2017, the median value of weighted average ages 5 to 10 *F* over all regions in 2017 was below 0.32 (Fig. 31). The median increased from 0.07 at a catch of 10,000 t to 0.79 at a catch of 50,000 t. At a catch of 28,000 t, the median was 0.30. The probability that *F* would be greater than 0.32 in 2017 was 0 at a catch of 10,000 t, increasing to 97% at a catch of 50,000 t. With a catch of 28,000 t in 2016 and 2017, this probability would be 42%.

Projection results are influenced by estimates of recent recruitment rates and estimated abundance at age 4 in 2016. In each region, this last estimate is based on a single observation, the experimental net index at age 3 in 2014. This estimate extends the number of cohorts with a recruitment rate estimate by one, changing the average recruitment rate of the most recent five cohorts. To examine the influence of this estimate, a second set of projections was conducted, omitting the estimates of abundance at ages 2 to 4 for the 2012 cohort. Abundance at early ages in this cohort were instead obtained using recruitment rates randomly selected from the most recent five estimates.

Results of this projection were somewhat more optimistic. Summed over all three regions, the median value of SSB at the start of 2018 was above the USR at all catch levels between 10,000 and 24,000 t (Fig. 32). The probability that SSB would be below the USR at the start of 2018 increased from 30% at a catch of 10,000 t to 71% at a catch of 50,000 t. At a catch of 28,000 t (the catch in 2015) in 2016 and 2017, this probability would be 52%.

In this second set of projections, the median value of weighted average ages 5 to 10 *F* over all regions in 2017 was below 0.32 at catch levels from 10,000 to 30,000 t in 2016 and 2017 (Fig. 33). The median increased from 0.06 at a catch of 10,000 t to 0.67 at a catch of 50,000 t. At 28,000 t, the median was 0.25. The probability that *F* would be greater than 0.32 in 2017 was 0 at a catch of 10,000 t, increasing to 99% at a catch of 50,000 t. With a catch of 28,000 t in 2016 and 2017, this probability would be 25%.

3.4 DISCUSSION AND CONCLUSIONS

Following the recommendations of the 2015 assessment framework review for the fall spawning stock of herring in the sGSL, this assessment used a model that treated the fall spawning stock as independent populations in three spawning regions and allowed catchability to the fishery to vary over time (DFO 2015; Swain 2016). When estimates from all three regions are included, there was a weak tendency for catchability to increase as population size decreased, as expected from theory (e.g., Winters and Wheeler 1985). However, the variation in estimated *q* within the Middle and South regions was largely independent of population size. This and comparisons between estimated catchabilities to the fishery and the experimental nets suggest that increasing catchability to the fishery over time on the South region is due to technological improvements and improved fishing tactics.

Estimated SSB of fall spawners was well above the USR in 2009 to 2013 but has declined since then. All three regions contributed to this overall decline. The median estimate of total SSB at the start of 2016 was just below the USR, though uncertainty in this estimate was high. The probabilities that total SSB was below the USR at the start of 2015 and 2016 were 22% and 60%, respectively. Estimated F of herring aged 5 to 10 years (calculated as a weighted average over regions, with weighting based on abundance) has declined since the late 2000s, with essentially no chance that it exceeded 0.32 (the reference level in the healthy zone) in 2015. The recent decline in biomass and abundance in the three regions is primarily due to very weak incoming recruitment (i.e., the 2010 and 2011 cohorts). The 2010 and 2011 cohorts are among the weakest on record in each of the three regions. The strength of the 2012 cohort is currently highly uncertain. With a catch of 28,000 t (the catch in 2015), the probability that total SSB (i.e., summed over regions) will be below the USR at the start of 2018 is 0.87 or 0.71 with the direct estimate for the 2012 cohort included or excluded from the projection, respectively. With this catch in 2016 and 2017, the probability that *F* for ages 5 to 10 would exceed F = 0.32 in 2017 is 0.42 or 0.25, including or excluding the direct estimate of the strength for the 2012 cohort, respectively.

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TABLES

Table 1. Maximum likelihood estimates (MLEs) of beginning of year spring spawning herring biomass (t) based on Model 3. Shading indicates values that are not directly estimated by the model. These values are calculated using the average of the five most recent estimates of recruitment rate (recruits/SSB). Note that MLEs may differ slightly from the MCMC medians reported in the text.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	6687	5110	35034	6975	7016	3328	2017	1245	7516	2309	65441
1979	14357	5281	3791	21214	5203	4698	2302	1523	750	6090	45570
1980	7929	9031	3312	2346	9148	3408	1857	1269	796	671	22806
1981	30958	5639	5129	1618	1401	3279	483	260	302	564	13037
1982	37609	29085	3066	3469	1170	687	2001	133	35	255	10816
1983	35992	36267	22714	1980	2720	941	355	1637	7	0.01	30355
1984	31629	35908	32710	15055	1278	2415	811	264	1328	3	53863
1985	15944	41718	33869	29349	11790	1012	2164	636	271	1052	80142
1986	11170	17641	44990	30010	24315	9913	700	1679	497	1034	113139
1987	19570	11444	16645	36576	23879	17686	7112	388	1213	1035	104535
1988	13882	16887	10666	13747	26886	16707	11201	3915	44	1674	84841
1989	26007	17882	15321	8228	10069	17756	10041	6441	2215	585	70656
1990	89884	28537	19439	11336	6368	6596	10128	5883	3820	1604	65176
1991	34305	70625	25595	14528	8044	4333	4458	5389	3365	3873	69586
1992	16711	28424	56286	19387	8840	4214	2597	2538	2845	4268	100974
1993	51803	17399	24789	42633	13915	5384	2568	1630	1337	4309	96565
1994	9628	58231	16552	20638	29383	7706	3070	1401	663	2786	82199
1995	11234	8184	58962	13874	13651	15996	4441	1510	727	2011	111172
1996	11629	14500	7415	48242	9717	7864	6584	1966	597	779	83164
1997	12893	12562	14733	6364	33066	6199	3694	3238	854	576	68723
1998	10516	11952	11998	11316	4473	21055	3905	1985	1506	773	57010
1999	14967	11206	11092	9393	7132	3610	11941	2611	1049	1054	47881
2000	8364	15118	10637	8640	6481	4102	2577	6267	1383	894	40980
2001	8938	7443	13957	7478	4784	2683	1934	1130	2555	724	35246
2002	2614	8541	6207	10297	4094	2228	1108	855	586	705	26080
2003	4461	2784	7416	4439	5935	2176	1092	460	442	501	22461
2004	2825	5079	2601	4953	2051	2830	1054	400	154	406	14449
2005	4335	2964	4907	1914	1916	791	724	214	81	122	10670
2006	4159	3903	2597	3562	1217	602	175	170	41	86	8451
2007	4812	4407	3532	2071	2172	654	375	85	51	77	9017
2008	5841	4293	3888	2619	1451	1120	113	140	32	23	9385
2009	3569	4769	4411	2857	1469	808	614	37	47	19	10262
2010	4844	3222	4005	3166	2064	770	603	431	5	15	11060
2011	2042	4402	2690	3333	2493	1445	436	453	274	12	11136
2012	569	2586	4063	2315	2563	1932	877	238	189	101	12278
2013	1002	708	2730	3696	2087	2065	1521	666	148	191	13103
2014	3010	1040	727	2358	2999	1566	1502	1058	429	252	10891
2015	3585	2859	974	556	1982	2402	1143	1088	791	522	9457
2016	2980	3051	2825	849	453	1502	1709	862	770	1122	10092

Table 2. Maximum likelihood estimates of beginning of year spring spawning herring abundance (number in thousands) based on Model 3. Shading indicates values that are calculated using the SSB that produced these cohorts and the average of the five most recent estimates of recruitment rate (recruits/SSB).

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	59170	35988	164577	30126	27365	11498	6794	3745	20517	6243	270864
1979	81125	34988	20762	90219	20976	16347	7656	4682	2225	16704	179571
1980	53117	53237	17974	10418	35062	13079	6410	4234	2254	1899	91331
1981	212214	33310	25833	7099	4722	10730	1690	847	953	1441	53316
1982	299199	173024	15682	13939	4061	1832	5736	398	92	649	42389
1983	270946	242652	116993	8718	10473	2936	1150	4264	20	0.02	144554
1984	333673	220473	179221	68793	4813	8148	2278	878	3411	9	267549
1985	133220	272594	175806	132060	46929	3310	6617	1788	676	2796	369982
1986	89066	108014	214604	130287	92960	33212	2088	5327	1435	2514	482427
1987	130069	69126	82394	154559	88655	60131	21923	1168	3880	2655	415366
1988	159156	105149	53699	59248	99044	55793	34206	10981	128	4574	317673
1989	213017	124132	80980	36900	37639	57404	30909	18455	5968	1629	269885
1990	514505	174019	95384	47775	24378	22197	31522	17629	10724	4556	254165
1991	241786	416445	135097	64866	31603	15621	14541	17044	10131	10624	299526
1992	161634	196309	326998	97286	38034	16537	9356	8406	9166	12769	518552
1993	557563	131558	156238	234018	66140	22097	9795	5825	4420	13763	512296
1994	67913	453693	105359	116928	150412	35276	12279	4988	2372	8954	436567
1995	134925	55556	365927	78952	70460	74340	18584	5629	2410	6679	622981
1996	115688	109186	43871	272155	49719	37347	28149	7991	2101	2633	443966
1997	110923	94370	86363	33572	169412	29286	16043	12866	3439	1908	352888
1998	109949	90436	75897	62687	22700	97805	16908	7976	5720	2759	292452
1999	141425	89749	72615	53423	35781	16352	51703	10354	4033	3840	248101
2000	67185	114110	69360	49139	32532	18703	10520	25318	5277	3270	214120
2001	84466	53809	88556	42658	24588	12241	8229	4359	9872	2702	193204
2002	28618	65312	39878	57952	20949	10313	4602	3337	2152	2553	141736
2003	53294	22757	48383	25360	30339	10148	4720	1819	1663	1787	124217
2004	29140	43445	17785	29155	10581	13120	4556	1644	597	1478	78916
2005	38899	23399	33375	11826	10099	3732	3012	871	310	431	63655
2006	43015	30209	17412	21737	6569	2836	747	676	152	338	50468
2007	44758	35004	23273	12615	11983	3342	1723	335	204	306	53782
2008	47340	33351	24632	15065	7321	5612	587	470	88	90	53866
2009	32432	35560	25443	16946	8456	4442	2772	122	255	75	58510
2010	46819	26134	27237	19670	11518	4054	2931	1939	20	66	67433
2011	30928	38228	20900	20453	14873	7386	2064	2004	1258	54	68990
2012	8439	24754	30540	16403	15332	10924	4539	1164	847	476	80225
2013	11313	6894	19763	24233	12817	11789	8186	3401	721	821	81732
2014	32853	9150	5375	15157	17962	8818	7750	5278	2017	1167	63524
2015	35060	26592	7318	3742	11722	13417	6104	5182	3816	2239	53539
2016	29140	28379	21219	5713	2679	8391	9131	4104	3714	4816	59766

Table 3. Maximum likelihood estimates of the instantaneous rate of fishing mortality (F) of spring spawning herring by age, based on Model 3. No estimates are available for the 2012 and 2013 year-classes. $F_{6\text{-}8}$ is the abundance-weighted average F for ages 6 to 8 years.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	$F_{6\text{-}8}$
1978	0.325	0.350	0.401	0.162	0.315	0.207	0.172	0.320	0.271	0.271	0.267
1979	0.221	0.466	0.490	0.745	0.272	0.736	0.392	0.531	2.099	2.099	0.461
1980	0.267	0.523	0.729	0.591	0.984	1.846	1.824	1.291	0.859	0.859	1.289
1981	0.004	0.553	0.417	0.359	0.747	0.426	1.246	2.016	1.105	1.105	0.595
1982	0.009	0.191	0.387	0.086	0.124	0.265	0.097	2.805	10.14	10.14	0.133
1983	0.006	0.103	0.331	0.394	0.051	0.054	0.070	0.023	0.612	0.612	0.053
1984	0.002	0.026	0.105	0.182	0.174	0.008	0.042	0.062	0.001	0.001	0.066
1985	0.010	0.039	0.100	0.151	0.146	0.260	0.017	0.020	0.123	0.123	0.137
1986	0.053	0.071	0.128	0.185	0.236	0.215	0.381	0.117	0.197	0.197	0.233
1987	0.013	0.053	0.130	0.245	0.263	0.364	0.491	2.014	0.157	0.157	0.328
1988	0.049	0.061	0.175	0.254	0.345	0.391	0.417	0.410	0.860	0.860	0.372
1989	0.002	0.063	0.328	0.215	0.328	0.399	0.361	0.343	0.311	0.311	0.369
1990	0.011	0.053	0.186	0.213	0.245	0.223	0.415	0.354	0.163	0.163	0.307
1991	0.008	0.042	0.128	0.334	0.448	0.313	0.348	0.420	0.286	0.286	0.390
1992	0.006	0.028	0.135	0.186	0.343	0.324	0.274	0.443	0.266	0.266	0.328
1993	0.006	0.022	0.090	0.242	0.429	0.388	0.475	0.699	0.508	0.508	0.424
1994	0.001	0.015	0.089	0.307	0.505	0.441	0.580	0.527	0.328	0.328	0.498
1995	0.012	0.036	0.096	0.262	0.435	0.771	0.644	0.785	1.039	1.039	0.612
1996	0.004	0.034	0.068	0.274	0.329	0.645	0.583	0.643	0.709	0.709	0.494
1997	0.004	0.018	0.120	0.191	0.349	0.349	0.499	0.611	0.462	0.462	0.361
1998	0.003	0.019	0.151	0.361	0.128	0.437	0.290	0.482	0.592	0.592	0.368
1999	0.015	0.058	0.191	0.296	0.449	0.241	0.514	0.474	0.679	0.679	0.449
2000	0.022	0.054	0.286	0.492	0.777	0.621	0.681	0.742	0.952	0.952	0.714
2001	0.057	0.100	0.224	0.511	0.669	0.778	0.703	0.506	1.395	1.395	0.705
2002	0.029	0.100	0.253	0.447	0.525	0.582	0.728	0.497	0.768	0.768	0.567
2003	0.004	0.047	0.307	0.674	0.638	0.601	0.854	0.913	0.648	0.648	0.652
2004	0.019	0.064	0.208	0.860	0.842	1.271	1.455	1.469	1.372	1.372	1.140
2005	0.053	0.096	0.229	0.388	1.070	1.408	1.294	1.544	0.584	0.584	1.185
2006	0.006	0.061	0.122	0.396	0.476	0.298	0.601	0.996	0.271	0.271	0.435
2007	0.094	0.151	0.235	0.344	0.559	1.540	1.098	1.135	1.531	1.531	0.805
2008	0.086	0.071	0.174	0.377	0.300	0.505	1.372	0.414	0.671	0.671	0.432
2009	0.016	0.067	0.057	0.186	0.535	0.216	0.157	1.627	1.414	1.414	0.378
2010	0.003	0.024	0.086	0.080	0.244	0.475	0.180	0.233	0.257	0.257	0.285
2011	0.023	0.025	0.042	0.088	0.109	0.287	0.372	0.661	0.814	0.814	0.185
2012	0.002	0.025	0.031	0.047	0.063	0.089	0.089	0.279	0.276	0.276	0.076
2013	0.012	0.049	0.065	0.099	0.174	0.219	0.239	0.323	0.079	0.079	0.207
2014	na	0.023	0.162	0.057	0.092	0.168	0.203	0.124	0.152	0.152	0.136
2015	na	na	0.048	0.134	0.134	0.185	0.197	0.133	0.029	0.029	0.168

Table 4. Probabilities of various population states at the beginning of 2018 based on projections of Model 3 at different levels of annual catch. States related to change in SSB refer to the change between the start of 2016 and 2018.

	Catch option in 2016 and 2017					
Criterion	0 t	500 t	1,000 t	1,500 t	2,000 t	2,500 t
SSB < LRP	0.90	0.91	0.93	0.94	0.95	0.95
SSB < USR	1.00	1.00	1.00	1.00	1.00	1.00
$F_{6\text{-}8} > 0.35$	0.00	0.0004	0.057	0.29	0.53	0.70
No decline in SSB	0.66	0.56	0.51	0.44	0.38	0.31
5% increase in SSB	0.60	0.53	0.48	0.41	0.34	0.27
5% decline in SSB	0.23	0.41	0.47	0.52	0.58	0.65

Table 5. Posterior distribution summaries of estimates of beginning of year spring spawner SSB (t) at the start of 2017 and 2018 and ages 6 to 8 F during 2016 and 2017 based on projections of Model 3 at various levels of annual catch. Estimates of percentiles are based on 200,000 MCMC samples with every 40th sample saved.

Percentiles of posterior distribution	Catch option in 2016 and 2017					
	0 t	500 t	1,000 t	1,500 t	2,000 t	2,500 t
2017 SSB						
97.5	24,606	24,154	23,703	23,252	22,802	22,353
75.0	14,443	13,986	13,528	13,076	12,618	12,171
50.0	10,177	9,722	9,267	8,813	8,360	7,913
25.0	7,504	7,047	6,593	6,137	5,681	5,230
2.5	4,647	4,194	3,740	3,285	2,845	2,398
2018 SSB						
97.5	29,683	28,802	27,922	17,044	26,166	25,290
75.0	16,325	15,460	14,597	13,731	12,870	12,019
50.0	10,668	9,819	8,977	8,128	7,284	6,440
25.0	7,348	6,506	5,663	4,813	3,982	3,156
2.5	4,421	3,566	2,735	1,918	1,157	1
2016 $F_{6\text{-}8}$						
97.5	-	0.134	0.337	0.686	1.358	2.446
75.0	-	0.081	0.185	0.323	0.512	0.793
50.0	-	0.063	0.139	0.231	0.345	0.492
25.0	-	0.049	0.106	0.172	0.248	0.339
2.5	-	0.030	0.063	0.100	0-.139	0.182
2017 $F_{6\text{-}8}$						
97.5	-	0.143	0.448	1.395	3.839	8.141
75.0	-	0.079	0.198	0.392	0.751	1.491
50.0	-	0.056	0.130	0.231	0.377	0.560
25.0	-	0.039	0.086	0.144	0.216	0.308
2.5	-	0.022	0.046	0.073	0.104	0.139

Table 6a. Maximum likelihood estimates of beginning of year biomass (t) of fall-spawning herring in the North region of the southern Gulf of St. Lawrence. Shading indicates cohorts that cannot yet be estimated by the model.

	Age (years)									
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	15556	9491	6235	7593	1982	2063	6156	650	249	7442	32368
1979	25421	11342	9123	2374	2257	731	1008	1197	254	1409	18354
1980	13376	29932	8017	6746	739	835	260	469	264	307	17638
1981	48087	22588	31138	7137	5524	428	210	85	235	153	44910
1982	27213	42676	28277	29139	6411	5009	304	93	55	281	69571
1983	16017	43096	40399	24468	21735	4905	4250	119	19	119	96015
1984	16648	26263	57138	38888	21412	16514	3965	3500	60	70	141546
1985	22048	24611	31682	55839	32972	17520	12989	3078	2896	19	156994
1986	19382	37235	30880	29982	46745	26033	12966	8762	1289	2067	158724
1987	17638	32805	50080	27670	25763	33833	16609	8080	5704	2097	169835
1988	13218	19608	38904	43963	20571	18265	21774	9562	4454	4813	162307
1989	46410	19415	22995	31897	33072	15255	12238	14936	6318	5118	141829
1990	33535	70137	25180	21360	22741	22329	9619	8270	9886	6995	126380
1991	8624	36436	83772	20949	14797	13518	11990	4984	4242	9806	164059
1992	13805	10532	39069	70206	15649	10958	8434	7033	3138	8855	163343
1993	6218	20323	11546	37450	51490	10393	7228	4726	3465	4983	131281
1994	15470	9166	27793	11950	28637	37488	7522	5149	2758	4864	126161
1995	14455	20453	12100	26421	8310	16599	18614	3692	2087	3191	91014
1996	13155	18445	26170	11417	14848	3447	5750	6087	1157	1416	70293
1997	21261	17523	22522	24011	6986	7139	1446	2231	2176	913	67425
1998	14867	31071	20146	21084	13546	3600	3510	703	815	1234	64638
1999	11234	20666	41604	17892	13611	6227	1523	1200	339	412	82809
2000	10608	17538	26213	39854	10176	4700	2513	552	533	273	84814
2001	10085	14969	23505	23666	23040	5003	2278	1078	244	359	79175
2002	30699	16604	19569	20103	14900	12998	3106	1360	716	399	73151
2003	22674	41996	21537	15681	11912	8497	8264	1836	897	569	69193
2004	13837	28804	49532	16909	7302	5600	3530	2325	328	223	85749
2005	8026	16278	31709	42989	11022	3966	3391	1828	1072	120	96098
2006	23776	11065	19230	30019	26224	4528	1318	1700	745	372	84136
2007	47048	31314	13275	18205	19811	13567	2287	623	565	380	68713
2008	26626	41485	38751	10565	11089	8379	6022	637	273	389	76105
2009	48351	42295	75321	36573	9862	9019	5509	1530	163	136	138114
2010	23877	51127	36173	52079	21968	5081	4149	2667	875	105	123096
2011	36366	25190	53253	34197	39312	13164	2345	2124	1172	344	145912
2012	5548	34270	24717	52963	30895	28339	6262	1307	1037	387	145908
2013	4891	5399	39961	27031	48615	23899	18897	2897	582	312	162194
2014	3773	4782	6002	42803	25837	38732	16714	14090	1967	722	146866
2015	na	3323	4950	6381	41322	21102	28374	11895	9646	2180	125850
2016	na	na	3873	5514	5692	33492	14881	20487	8256	10445	102638

Table 6b. Maximum likelihood estimates of beginning of year biomass (t) of fall spawning herring in the Middle region of the southern Gulf of St. Lawrence. Shading indicates cohorts that cannot yet be estimated by the model.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	762	2668	2353	2273	695	1249	2303	729	154	5268	15023
1979	3308	1502	1927	1129	1615	432	956	947	530	2872	10406
1980	1739	4966	1699	1536	616	405	110	223	168	161	4918
1981	2124	3443	5385	1407	811	375	266	15	70	185	8514
1982	3978	7792	4318	3689	815	341	169	15	0.2	76	9423
1983	1766	8054	5158	2912	2801	643	254	91	9	45	11915
1984	1122	3444	7690	2835	1539	905	248	102	6	3	13328
1985	1944	7257	4711	7889	2114	1202	501	106	55	1	16578
1986	3958	7050	4127	3571	6778	1719	939	256	17	30	17436
1987	853	7160	6096	3889	2467	5099	1010	612	110	9	19292
1988	1487	3062	7546	6395	3680	2065	4093	834	394	8	25014
1989	9112	6703	2327	5314	5416	2649	1688	3210	467	349	21418
1990	7834	20732	5530	1983	4278	4315	1947	1253	2465	568	22339
1991	1363	13795	23600	4589	1348	3464	2838	1481	982	2393	40695
1992	7056	3345	14263	18714	3619	773	2324	1698	806	2108	44304
1993	1973	9255	3479	12101	14115	2660	542	1792	1333	2153	38175
1994	4969	1130	8988	2637	9155	10268	1926	297	1437	2591	37299
1995	2099	4843	3063	10390	2049	6419	6444	1471	149	2957	32942
1996	4263	3571	10337	2762	8258	1178	2613	2838	942	1064	29991
1997	9879	9268	5442	8084	1883	4106	730	1368	1394	1072	24079
1998	8547	10573	10753	4045	4701	1182	2481	409	891	1523	25984
1999	6401	7470	18413	8520	2570	1685	562	1273	141	688	33852
2000	4250	4441	15749	14896	4769	1113	656	131	353	190	37857
2001	5378	10906	10403	11832	8792	2351	362	190	0.1	288	34219
2002	7990	11272	13596	8954	7570	5628	1291	151	104	166	37461
2003	5043	18842	14615	10111	6370	4919	3139	768	85	126	40133
2004	5652	13381	22043	11981	6308	4170	3339	1650	412	92	49995
2005	2573	4995	10981	17728	8277	3813	2316	1679	638	117	45549
2006	8145	4184	8994	9954	11274	3922	2219	1051	718	249	38381
2007	13589	20734	6937	7604	7802	6747	2165	1220	351	228	33053
2008	6912	10877	16770	3865	5166	3741	2737	814	594	149	33836
2009	7346	14274	17617	18280	4587	4810	3306	1078	396	189	50263
2010	2921	9093	13110	14744	12307	2587	2070	1550	514	283	47165
2011	9235	3211	10274	11793	11034	7330	1088	797	708	227	43250
2012	1816	9784	3362	9526	9908	6928	2984	295	154	135	33290
2013	1609	2053	12001	3741	7949	6825	3545	852	51	12	34977
2014	1870	1765	2329	12520	3370	5747	3898	1713	212	0.03	29789
2015	na	2050	2001	2394	11480	2497	3819	1557	1122	0.12	24870
2016	na	na	2345	2121	2059	8284	1185	1755	651	765	19164

Table 6c. Maximum likelihood estimates of beginning of year biomass (t) of fall spawning herring in the South region of the southern Gulf of St. Lawrence. Shading indicates cohorts that cannot yet be estimated by the model.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	3886	8966	4819	3217	1147	1780	1866	282	442	3419	16971
1979	14473	5518	9917	4577	2471	986	1287	866	83	1392	21580
1980	8666	11599	5850	9447	3749	1807	773	926	625	558	23736
1981	10575	11771	9156	3725	4016	1121	315	218	99	25	18677
1982	16076	15734	12726	7686	3318	3769	797	180	107	61	28646
1983	8545	26511	18742	11088	5936	1832	2257	357	29	97	40339
1984	15540	14446	34554	15948	8428	4241	1313	1494	144	35	66155
1985	16966	26277	18288	30807	13309	6353	3130	930	1177	106	74099
1986	15434	28211	34072	16292	24475	10134	4641	1975	596	847	93032
1987	7397	19690	37621	28222	13443	18313	7835	3429	1484	1178	111523
1988	5292	11981	20627	36027	23335	10562	12080	4819	1492	1063	110005
1989	16752	7784	14105	17027	29015	18093	7888	8380	3019	1570	99098
1990	16249	26590	10120	12595	15481	23654	14587	6250	6237	3439	92363
1991	4611	20875	33370	8743	9782	12053	9413	9324	3712	5525	91921
1992	7388	6615	23044	30071	7267	7790	9625	6433	7114	6534	97880
1993	3470	15484	6898	21914	24148	5567	6358	7514	4101	10395	86895
1994	17934	4323	17614	6448	18625	19410	4561	5317	6181	11061	89217
1995	3471	11519	5496	17072	5217	12536	11495	3414	3411	8701	67341
1996	15247	5467	14050	5869	14630	4484	8077	7051	2077	6523	62761
1997	20105	21566	7383	20015	4621	9658	2416	3655	2885	3165	53797
1998	14881	20861	26947	6970	13227	3684	5969	1653	2109	3075	63635
1999	9061	21297	26716	25138	5354	7866	2171	2661	888	1605	72400
2000	25156	13027	27389	30167	14795	3226	3322	792	941	733	81365
2001	17141	33936	16438	26879	20072	8295	1948	1760	434	731	76557
2002	19725	26689	44639	17194	19461	12118	3427	824	821	454	98939
2003	10562	24142	32418	43623	13545	11995	6227	1582	349	473	110213
2004	8336	13154	28099	29659	28140	9342	6055	2189	491	308	104283
2005	5615	15959	16365	28264	24962	18417	6566	3676	961	229	99440
2006	17684	7757	19943	17523	23964	17697	8703	4286	1537	455	94106
2007	15955	26206	9067	16321	13629	15982	10113	3692	2290	744	71838
2008	26317	11904	22936	8281	9842	6984	6198	4455	1889	1529	62115
2009	17353	19879	27361	36337	10297	12353	6303	4501	2824	1334	101311
2010	5967	15680	27003	18456	23362	5454	4389	3024	2408	1561	85657
2011	18905	5463	16183	24122	14111	13630	2828	1292	886	1660	74713
2012	3466	17207	5391	16951	20790	10515	6398	563	154	510	61272
2013	6207	3210	18019	5297	15514	15958	6023	2164	91	66	63132
2014	8887	5691	3553	16397	4574	11636	9098	3222	735	15	49230
2015	na	8156	5959	3231	14924	3428	7981	4330	1752	231	41835
2016	na	na	8535	5846	2564	11392	1967	4351	2829	1200	38684

Table 6d. Maximum likelihood estimates of beginning of year biomass (t) of fall spawning herring in the southern Gulf of St. Lawrence. Shading indicates cohorts that cannot yet be estimated by the model.

	Age (years)									
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	20204	21125	13406	13083	3823	5092	10324	1661	844	16128	64362
1979	43202	18361	20967	8079	6343	2149	3251	3010	867	5673	50341
1980	23781	46498	15567	17730	5104	3047	1143	1618	1057	1026	46292
1981	60786	37803	45679	12269	10351	1925	791	318	404	364	72101
1982	47267	66202	45322	40514	10544	9120	1271	288	162	418	107639
1983	26328	77661	64300	38469	30473	7380	6761	568	57	261	148268
1984	33309	44153	99382	57671	31379	21660	5525	5096	209	108	221029
1985	40958	58145	54681	94534	48395	25074	16620	4114	4128	126	247670
1986	38774	72496	69078	49846	77998	37886	18545	10993	1902	2945	269193
1987	25888	59656	93797	59781	41673	57245	25454	12121	7297	3284	300651
1988	19998	34650	67077	86385	47586	30892	37947	15216	6340	5884	297327
1989	72274	33902	39427	54238	67503	35996	21814	26526	9804	7037	262346
1990	57618	117459	40830	35939	42500	50298	26153	15773	18588	11001	241083
1991	14597	71106	140742	34281	25927	29035	24241	15789	8936	17724	296675
1992	28249	20492	76377	118991	26535	19522	20384	15164	11058	17497	305527
1993	11660	45062	21922	71465	89753	18620	14128	14033	8898	17531	256351
1994	38374	14618	54395	21036	56416	67166	14008	10763	10377	18517	252677
1995	20024	36816	20658	53884	15576	35554	36553	8576	5647	14849	191297
1996	32666	27483	50557	20047	37735	9109	16441	15976	4177	9003	163045
1997	51245	48357	35347	52109	13491	20903	4591	7255	6455	5150	145301
1998	38295	62505	57846	32099	31474	8466	11960	2766	3815	5833	154258
1999	26696	49433	86732	51550	21536	15779	4256	5134	1369	2706	189061
2000	40014	35006	69351	84917	29741	9039	6490	1475	1827	1196	204036
2001	32604	59812	50347	62377	51905	15649	4589	3028	678	1378	189951
2002	58414	54565	77805	46251	41931	30744	7823	2336	1641	1020	209551
2003	38279	84980	68571	69415	31827	25411	17630	4186	1331	1168	219540
2004	27824	55339	99674	58549	41751	19112	12924	6163	1231	623	240027
2005	16215	37231	59055	88981	44260	26196	12273	7184	2671	466	241086
2006	49606	23006	48167	57495	61462	26147	12240	7037	3000	1076	216623
2007	76592	78254	29279	42130	41242	36295	14565	5535	3205	1353	173604
2008	59855	64266	78457	22712	26098	19105	14958	5906	2755	2067	172056
2009	73050	76449	120300	91190	24746	26182	15119	7110	3383	1659	289687
2010	32765	75900	76286	85278	57638	13122	10608	7241	3796	1949	255917
2011	64507	33864	79710	70112	64456	34124	6261	4213	2766	2232	263874
2012	10830	61261	33470	79439	61593	45782	15645	2165	1345	1032	240470
2013	12707	10662	69981	36070	72079	46682	28465	5912	723	390	260303
2014	14530	12238	11884	71719	33781	56115	29710	19025	2914	737	225885
2015	na	13529	12910	12006	67727	27027	40174	17781	12520	2411	192556
2016	na	na	14752	13480	10315	53168	18033	26593	11735	12411	160487

Table 7a. Maximum likelihood estimates of abundance (number in thousands) of fall spawning herring in the North region of the southern Gulf of St. Lawrence. Shading indicates cohorts that cannot yet be estimated by the model.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	72572	55308	28765	31005	6742	7369	18237	2042	846	18551	113557
1979	248738	59346	41431	9111	8068	2480	3065	3350	693	3903	72100
1980	185673	198304	40439	25160	2463	2754	808	1319	698	755	74398
1981	295718	149900	144198	27615	17428	1201	586	216	577	352	192175
1982	404469	242063	118886	106172	20021	13726	756	231	124	618	260535
1983	223551	330235	188632	89050	70083	14071	10822	302	42	263	373264
1984	208304	183020	270066	145839	69424	49110	10574	8481	152	140	553786
1985	348914	170204	148513	210267	108990	51364	35847	7824	6766	40	569611
1986	257463	285367	137542	116748	153621	75962	34979	22944	3130	4715	549641
1987	176312	210547	231187	101426	84008	100671	45226	20687	14342	4946	602493
1988	188727	142873	162806	165375	68932	55633	61350	25414	11232	11830	562573
1989	638641	150995	114609	117788	110132	46458	35060	40743	16146	12652	493588
1990	336427	522127	122400	80917	74677	67065	27089	22436	25593	16829	437006
1991	112729	275366	421327	84797	51666	41832	34589	13786	11590	24686	684273
1992	258911	92294	220692	302705	59232	36373	25316	20141	8728	23363	696549
1993	110243	211938	75025	170561	202750	36859	22935	13789	10111	13763	545794
1994	238263	89978	169488	57145	116527	137218	25034	15364	7930	13324	542029
1995	208911	195073	73420	127167	35435	62731	64322	11550	5919	8709	389253
1996	179081	171042	158011	53939	65600	13705	20087	19778	3342	3689	338150
1997	400847	146295	137614	108496	28024	27694	5059	7096	6483	2422	322887
1998	255924	327858	115763	99759	55634	13375	12863	2266	2478	3513	305650
1999	219794	209486	267049	84275	57576	23578	5412	4093	1054	1216	444252
2000	184646	179329	164839	191034	42477	18326	8811	1892	1727	812	429919
2001	189712	150459	142181	111576	97012	19067	8165	3618	754	1073	383446
2002	444340	154244	116761	91717	60837	49066	10890	4406	2253	1115	337045
2003	320531	363725	124862	69730	48497	31430	28687	5984	2705	1663	313557
2004	191118	262429	293489	83085	30306	21772	12563	7756	1017	650	450637
2005	133152	156410	212570	211177	49199	15707	12473	6349	3569	382	511426
2006	383733	108291	125217	161244	115592	18694	4973	5862	2503	1201	435287
2007	569312	313451	86881	94121	91086	56945	9148	2245	1919	1233	343578
2008	399609	464767	243074	62256	60814	40854	23885	2619	916	1274	435692
2009	597370	325921	372858	177383	38925	32255	19317	5876	569	478	647661
2010	311136	488924	262164	279542	108473	22071	16811	10284	3279	362	702985
2011	486371	254731	398661	206307	195737	61974	9819	8384	4496	1204	886581
2012	71600	397144	207880	323003	161065	133921	28144	5242	4046	1399	864700
2013	64077	58584	324803	169773	255840	115384	85612	12510	2199	1176	967297
2014	49521	51986	47560	262353	129218	181150	74546	60006	7961	2485	765279
2015	na	40513	40956	38318	208351	95768	124864	50087	41887	8324	608555
2016	na	na	32039	33110	28698	151995	65487	86267	35850	39883	473328

Table 7b. Maximum likelihood estimates of abundance (number in thousands) of fall spawning herring in the Middle region of the southern Gulf of St. Lawrence. Shading indicates cohorts that cannot yet be estimated by the model.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	11901	14212	11515	9872	2542	4784	7050	2031	523	12761	51079
1979	36328	9726	10747	4598	5737	1401	2950	2577	1478	8170	37658
1980	24575	29743	7833	5506	1935	1224	307	507	384	381	18078
1981	39261	19999	23046	5290	2345	1018	716	34	139	399	32986
1982	66009	32140	15455	13233	2616	893	420	40	0.4	156	32813
1983	26630	54040	26260	11152	9407	1949	606	239	32	99	49745
1984	33036	21615	39212	12188	5593	2864	685	241	14	10	60807
1985	45616	27030	17612	30164	7307	3612	1368	262	125	2	60452
1986	40120	37347	22120	14207	23460	5073	2451	641	39	67	68057
1987	15952	32848	30535	16668	10434	16994	3146	1616	345	22	79760
1988	36767	13059	26621	24155	12058	7162	11157	2312	1082	24	84571
1989	153736	30102	9955	19010	17237	7648	4841	8063	1100	891	68744
1990	102306	125869	24631	7454	14273	12963	5636	3578	6260	1351	76145
1991	23193	83761	102854	18432	4852	10326	8226	4120	2585	5904	157299
1992	94363	18989	68563	78821	13632	2777	6879	4879	2233	5225	183007
1993	21736	77258	15536	52633	56048	10003	1793	5358	3796	5785	150952
1994	70475	17796	63253	12404	37134	38414	6914	933	4012	6776	169839
1995	41776	57700	14570	51020	8917	24186	23099	4639	442	7769	134641
1996	77727	34203	47241	11736	32766	4250	8881	9405	2575	2705	119559
1997	138473	63635	27982	35266	7598	15885	2449	4347	4411	2749	100687
1998	114699	113372	51843	18557	19024	4443	9300	1304	2716	4366	111551
1999	82391	93908	92746	37580	10821	6296	1928	4545	412	1973	156302
2000	98158	67456	76885	67181	19203	4303	2283	426	1191	530	172003
2001	109685	80365	55217	52992	36043	8754	1287	632	0.3	930	155855
2002	161735	89802	65451	40232	31184	20858	4550	492	331	499	163597
2003	112083	132417	72986	44989	25385	18670	10688	2550	249	352	175869
2004	73267	91766	108303	54662	26197	15801	11923	5400	1336	255	223875
2005	46418	59986	75118	83636	35644	15033	8366	5712	2055	334	225898
2006	182063	37865	47920	51568	48936	15870	8249	3606	2342	793	179284
2007	156447	149060	30976	37527	34734	27609	8398	4410	1217	737	145609
2008	118058	128088	121706	24066	27599	19612	13710	3462	2241	512	212907
2009	98181	96658	103582	88668	17382	18553	11274	3671	1462	675	245267
2010	39794	80384	79046	77423	59501	11201	8534	6021	1890	1056	244672
2011	133981	32581	65806	63337	53060	33454	4744	3125	2717	816	227059
2012	25082	109694	26675	53511	49970	32513	13453	1247	585	493	178447
2013	22483	20536	89803	21706	42064	33100	16186	3786	207	44	206897
2014	26351	18408	16807	72992	16756	28099	17658	7479	897	0.1	160688
2015	na	21574	15071	13760	57513	11466	17358	6586	4699	0.4	126454
2016	na	na	17663	12190	10317	38033	5383	7427	2725	2894	96632

Table 7c. Maximum likelihood estimates of abundance (number in thousands) of fall spawning herring in the South region of the southern Gulf of St. Lawrence. Shading indicates cohorts that cannot yet be estimated by the model.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	52189	88501	34284	15658	5462	6865	6599	976	1481	9058	80384
1979	116150	41561	55915	21692	9956	3525	4180	2597	250	4194	102308
1980	101420	95053	33710	41063	15077	6491	2455	2720	1687	1507	104709
1981	125089	82556	53020	16114	13842	3615	920	657	247	59	88473
1982	240733	101400	57832	28404	10291	10129	2095	448	297	141	109637
1983	119472	197096	82700	41004	19961	5525	6180	980	74	251	156675
1984	233891	97811	160821	60809	28966	13338	3598	3918	373	78	271900
1985	269554	191494	79721	118133	44770	19585	8860	2313	2864	249	276495
1986	131629	220692	156702	62163	82785	30903	13135	5247	1436	2223	354594
1987	92943	107356	179516	109762	45709	56905	22277	9279	3856	2752	430056
1988	74774	76087	86900	136911	78305	31886	33901	12640	3760	2572	386876
1989	236078	61174	61925	67180	97004	55384	21790	21749	7609	3668	336308
1990	181250	193284	50055	49476	53128	71906	41553	16214	15602	8400	306335
1991	59779	148395	157457	34881	34443	36551	26757	25164	9393	13312	337958
1992	165316	48943	121485	124441	27050	26991	28841	18395	19371	16759	383334
1993	56387	135349	40002	97950	94593	20506	20936	21813	11576	26829	334205
1994	183848	46166	110815	32478	77282	73924	15902	16775	17330	29991	374497
1995	66485	150522	37786	87432	24887	49430	41628	10636	10275	23531	285604
1996	224224	54414	122780	30402	63202	17582	28281	23182	6129	17699	309256
1997	277503	183554	44541	95163	20263	37467	8542	11813	8750	8593	235131
1998	259888	227140	149150	32259	54513	13685	21105	5277	6476	8606	291070
1999	167918	212778	185964	113627	22332	30218	7542	8898	2670	4681	375931
2000	421373	137459	173362	142432	61058	12472	11857	2586	2976	2079	408820
2001	301775	344778	110733	131257	86484	32139	7116	5994	1400	2323	377445
2002	288204	246321	276610	86460	83093	47719	12489	2856	2734	1427	513388
2003	160930	235100	199143	205034	59938	48583	23370	5646	1174	1532	544419
2004	159288	131577	188785	153081	124475	39882	23409	8156	1739	1052	540579
2005	93203	130009	105867	144084	112163	77196	26322	13549	3443	766	483391
2006	301722	76308	106440	86293	106833	73466	34725	16111	5583	1558	431010
2007	177335	246812	62105	84360	63295	68868	41294	14563	8586	2738	345810
2008	271839	145189	201565	50575	60728	39556	34169	20011	7482	5782	419867
2009	198157	222563	118607	160641	39806	43784	21562	14562	10223	5092	414277
2010	65245	162237	181848	94942	112911	23298	17442	11541	8674	5542	456198
2011	205628	53418	132770	146169	69374	63319	11558	5027	3395	6046	437658
2012	38379	168354	43735	108421	112878	50058	29224	2308	584	1955	349163
2013	68026	31422	137837	35749	87494	80384	27712	9732	377	250	379534
2014	97475	55679	25713	111187	26445	60235	43655	14233	3234	60	284761
2015	na	79805	45586	20448	85855	18079	39265	19719	7723	961	237637
2016	na	na	65284	36997	14752	60090	9677	19815	12473	4990	224079

Table 7d. Maximum likelihood estimates of total abundance (number in thousands) of fall spawning herring in the southern Gulf of St. Lawrence. Shading indicates cohorts that cannot yet be estimated by the model.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	4+
1978	136662	158021	74564	56536	14747	19018	31886	5049	2850	40370	245020
1979	401216	110633	108093	35401	23760	7405	10195	8525	2421	16267	212067
1980	311668	323100	81982	71728	19475	10470	3570	4546	2769	2643	197184
1981	460068	252455	220264	49018	33616	5834	2222	907	963	810	313634
1982	711211	375603	192172	147809	32928	24748	3271	719	422	914	402984
1983	369653	581371	297592	141206	99451	21544	17608	1521	148	613	579685
1984	475231	302446	470099	218836	103983	65312	14856	12640	539	228	886493
1985	664084	388728	245846	358564	161067	74561	46075	10400	9755	291	906558
1986	429212	543406	316364	193118	259866	111938	50565	28832	4605	7004	972293
1987	285207	350751	441238	227856	140151	174570	70649	31582	18543	7719	1112309
1988	300267	232019	276327	326441	159296	94681	106408	40367	16074	14426	1034020
1989	1028455	242271	186489	203978	224374	109490	61691	70554	24855	17210	898640
1990	619983	841280	197086	137847	142078	151934	74278	42228	47454	26581	819486
1991	195701	507522	681638	138109	90961	88709	69572	43070	23569	43902	1179530
1992	518590	160226	410740	505967	99914	66141	61036	43414	30331	45347	1262889
1993	188366	424545	130563	321144	353391	67368	45664	40960	25483	46377	1030950
1994	492586	153940	343556	102027	230942	249557	47850	33072	29271	50091	1086366
1995	317172	403295	125776	265618	69240	136346	129049	26825	16636	40009	809498
1996	481032	259659	328032	96077	161567	35537	57249	52365	12046	24092	766965
1997	816823	393484	210137	238925	55885	81045	16050	23256	19644	13764	658705
1998	630511	668370	316756	150574	129170	31503	43268	8846	11669	16485	708271
1999	470103	516172	545759	235482	90728	60092	14882	17536	4136	7871	976486
2000	704177	384244	415086	400647	122738	35101	22951	4904	5894	3422	1010743
2001	601172	575602	308131	295825	219539	59960	16568	10243	2154	4326	916746
2002	894279	490367	458822	218409	175114	117643	27930	7754	5318	3040	1014029
2003	593544	731242	396991	319753	133819	98682	62745	14179	4128	3547	1033845
2004	423673	485772	590577	290827	180978	77454	47895	21312	4091	1957	1215091
2005	272773	346405	393555	438897	197006	107936	47161	25610	9068	1482	1220714
2006	867518	222464	279577	299105	271361	108031	47947	25579	10429	3553	1045580
2007	903094	709323	179962	216008	189116	153423	58841	21218	11721	4709	834996
2008	789506	738044	566345	136897	149141	100022	71764	26091	10638	7569	1068467
2009	893708	645142	595047	426692	96114	94592	52153	24109	12254	6245	1307205
2010	416175	731545	523058	451907	280885	56569	42787	27845	13843	6960	1403854
2011	825980	340730	597237	415813	318171	158747	26121	16536	10609	8065	1551298
2012	135061	675192	278289	484935	323913	216492	70822	8797	5215	3847	1392310
2013	154586	110541	552443	227228	385399	228867	129509	26029	2783	1470	1553728
2014	173347	126072	90080	446532	172419	269485	135858	81718	12093	2545	1210729
2015	na	141892	101613	72527	351719	125312	181488	76392	54310	9285	972645
2016	na	na	114986	82298	53767	250117	80547	113509	51048	47767	794039

Table 8a. Maximum likelihood estimates of the instantaneous rate of fishing mortality of fall-spawning herring in the North region of the southern Gulf of St. Lawrence. $F_{5\text{-}10}$ is the abundance-weighted average F for ages 5 to 10 years. No estimates are available for the shaded cell.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	$F_{5\text{-}10}$
1978	0.0012	0.089	0.950	1.146	0.800	0.677	1.494	0.881	1.403	1.403	1.150
1979	0.0266	0.184	0.299	1.108	0.875	0.921	0.643	1.369	1.606	1.606	1.013
1980	0.0140	0.119	0.181	0.167	0.518	1.348	1.117	0.626	1.217	1.217	0.355
1981	0.0002	0.032	0.106	0.122	0.039	0.263	0.730	0.354	0.209	0.209	0.104
1982	0.0028	0.049	0.089	0.215	0.153	0.038	0.719	1.497	0.836	0.836	0.195
1983	0.0000	0.001	0.057	0.049	0.156	0.086	0.044	0.482	0.581	0.581	0.093
1984	0.0020	0.009	0.050	0.091	0.101	0.115	0.101	0.026	1.788	1.788	0.097
1985	0.0010	0.013	0.041	0.114	0.161	0.184	0.246	0.716	0.167	0.167	0.158
1986	0.0012	0.011	0.105	0.129	0.223	0.319	0.325	0.270	0.261	0.261	0.225
1987	0.0103	0.057	0.135	0.186	0.212	0.295	0.376	0.411	0.289	0.289	0.262
1988	0.0231	0.020	0.124	0.207	0.195	0.262	0.209	0.254	0.400	0.400	0.221
1989	0.0014	0.010	0.148	0.256	0.296	0.339	0.246	0.265	0.337	0.337	0.282
1990	0.0003	0.015	0.167	0.249	0.380	0.462	0.475	0.460	0.341	0.341	0.374
1991	0.0000	0.021	0.131	0.159	0.151	0.302	0.341	0.257	0.240	0.240	0.218
1992	0.0002	0.007	0.058	0.201	0.274	0.261	0.408	0.489	0.647	0.647	0.248
1993	0.0031	0.024	0.072	0.181	0.190	0.187	0.201	0.353	0.383	0.383	0.196
1994	0.0000	0.003	0.087	0.278	0.419	0.558	0.574	0.754	0.692	0.692	0.481
1995	0.0000	0.011	0.108	0.462	0.750	0.939	0.979	1.040	1.178	1.178	0.736
1996	0.0022	0.017	0.176	0.455	0.662	0.797	0.841	0.915	0.866	0.866	0.662
1997	0.0010	0.034	0.122	0.468	0.540	0.567	0.603	0.852	0.730	0.730	0.522
1998	0.0002	0.005	0.117	0.350	0.658	0.705	0.945	0.565	1.395	1.395	0.525
1999	0.0035	0.040	0.135	0.485	0.945	0.784	0.851	0.663	0.828	0.828	0.693
2000	0.0048	0.032	0.190	0.478	0.601	0.608	0.690	0.720	0.662	0.662	0.517
2001	0.0070	0.054	0.238	0.407	0.482	0.360	0.417	0.274	0.294	0.294	0.431
2002	0.0002	0.011	0.315	0.437	0.460	0.337	0.399	0.288	0.506	0.506	0.417
2003	0.0000	0.015	0.207	0.633	0.601	0.717	1.108	1.572	1.705	1.705	0.757
2004	0.0004	0.011	0.129	0.324	0.457	0.357	0.482	0.576	1.274	1.274	0.386
2005	0.0067	0.022	0.076	0.403	0.768	0.950	0.555	0.731	0.991	0.991	0.512
2006	0.0023	0.020	0.085	0.371	0.508	0.515	0.595	0.917	0.900	0.900	0.449
2007	0.0029	0.054	0.133	0.237	0.602	0.669	1.051	0.697	0.706	0.706	0.500
2008	0.0038	0.020	0.115	0.270	0.434	0.549	1.202	1.326	1.323	1.323	0.518
2009	0.0003	0.018	0.088	0.292	0.367	0.452	0.430	0.383	0.861	0.861	0.334
2010	0.0000	0.004	0.040	0.156	0.360	0.610	0.496	0.627	0.907	0.907	0.259
2011	0.0027	0.003	0.010	0.048	0.180	0.589	0.428	0.529	1.205	1.205	0.196
2012	0.0006	0.001	0.002	0.033	0.134	0.247	0.611	0.669	1.333	1.333	0.139
2013	0.0091	0.008	0.014	0.073	0.145	0.237	0.155	0.252	0.106	0.106	0.146
2014	0.0008	0.038	0.016	0.030	0.100	0.172	0.198	0.159	0.027	0.027	0.107
2015	na	0.035	0.013	0.089	0.115	0.180	0.170	0.134	0.030	0.030	0.132

Table 8b. Maximum likelihood estimates of the instantaneous rate of fishing mortality of fall-spawning herring in the Middle region of the southern Gulf of St. Lawrence. $F_{5\text{-}10}$ is the abundance-weighted average F for ages 5 to 10 years. No estimates are available for the shaded cell.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	$F_{5\text{-}10}$
1978	0.0019	0.0795	0.718	0.343	0.396	0.283	0.806	0.118	0.286	0.286	0.441
1979	0.0000	0.0164	0.469	0.666	1.344	1.317	1.560	1.704	3.032	3.032	1.392
1980	0.0061	0.0551	0.193	0.654	0.442	0.337	2.010	1.095	0.451	0.451	0.630
1981	0.0001	0.0578	0.355	0.504	0.765	0.684	2.691	4.247	1.039	1.039	0.773
1982	0.0001	0.0021	0.126	0.141	0.094	0.188	0.363	0.010	0.252	0.252	0.142
1983	0.0086	0.1208	0.568	0.490	0.989	0.846	0.720	2.636	2.426	2.426	0.751
1984	0.0007	0.0049	0.062	0.312	0.237	0.539	0.759	0.460	2.334	2.334	0.340
1985	0.0000	0.0004	0.015	0.051	0.165	0.188	0.558	1.712	0.442	0.442	0.110
1986	0.0000	0.0014	0.083	0.109	0.122	0.278	0.217	0.419	1.371	1.371	0.146
1987	0.0001	0.0102	0.034	0.124	0.176	0.221	0.108	0.201	2.538	2.538	0.187
1988	0.0000	0.0714	0.137	0.137	0.255	0.192	0.125	0.543	0.016	0.016	0.180
1989	0.0000	0.0006	0.089	0.087	0.085	0.105	0.102	0.053	0.188	0.188	0.087
1990	0.0000	0.0019	0.090	0.229	0.124	0.255	0.113	0.125	0.054	0.054	0.163
1991	0.0000	0.0002	0.066	0.102	0.358	0.206	0.322	0.413	0.285	0.285	0.223
1992	0.0000	0.0007	0.064	0.141	0.110	0.237	0.050	0.051	0.054	0.054	0.128
1993	0.0000	0.0000	0.025	0.149	0.178	0.169	0.454	0.089	0.146	0.146	0.165
1994	0.0000	0.0000	0.015	0.130	0.229	0.309	0.199	0.546	0.128	0.128	0.244
1995	0.0000	0.0000	0.016	0.243	0.541	0.802	0.699	0.389	0.911	0.911	0.489
1996	0.0000	0.0008	0.092	0.235	0.524	0.351	0.514	0.557	0.453	0.453	0.465
1997	0.0000	0.0049	0.211	0.417	0.337	0.335	0.430	0.270	0.295	0.295	0.374
1998	0.0000	0.0008	0.122	0.339	0.906	0.635	0.516	0.952	1.078	1.078	0.638
1999	0.0000	0.0000	0.122	0.471	0.722	0.814	1.309	1.140	1.303	1.303	0.632
2000	0.0000	0.0002	0.172	0.423	0.586	1.007	1.085	7.002	0.416	0.416	0.528
2001	0.0000	0.0053	0.117	0.330	0.347	0.454	0.761	0.447	0.423	0.423	0.353
2002	0.0000	0.0073	0.175	0.260	0.313	0.469	0.379	0.482	0.657	0.657	0.330
2003	0.0000	0.0010	0.089	0.341	0.274	0.248	0.483	0.447	0.659	0.659	0.326
2004	0.0000	0.0002	0.058	0.228	0.355	0.436	0.536	0.766	1.361	1.361	0.355
2005	0.0037	0.0246	0.176	0.336	0.609	0.400	0.642	0.691	0.902	0.902	0.445
2006	0.0000	0.0008	0.044	0.195	0.372	0.436	0.426	0.887	1.248	1.248	0.343
2007	0.0000	0.0027	0.052	0.107	0.372	0.500	0.686	0.477	1.139	1.139	0.351
2008	0.0000	0.0124	0.117	0.125	0.197	0.354	1.118	0.662	1.206	1.206	0.394
2009	0.0000	0.0012	0.091	0.199	0.239	0.577	0.427	0.464	0.505	0.505	0.282
2010	0.0000	0.0001	0.022	0.178	0.376	0.659	0.805	0.596	1.084	1.084	0.340
2011	0.0000	0.0000	0.007	0.037	0.290	0.711	1.136	1.476	1.770	1.770	0.351
2012	0.0000	0.0001	0.006	0.041	0.212	0.498	1.068	1.598	2.996	2.996	0.311
2013	0.0000	0.0004	0.007	0.059	0.203	0.428	0.572	1.240	7.600	7.600	0.338
2014	0.0000	0.0000	0.000	0.038	0.179	0.282	0.786	0.265	7.413	7.413	0.252
2015	na	0.0000	0.012	0.088	0.214	0.556	0.649	0.683	0.285	0.285	0.332

Table 8c. Maximum likelihood estimates of the instantaneous rate of fishing mortality of fall-spawning herring in the South region of the southern Gulf of St. Lawrence. $F_{5\text{-}10}$ is the abundance-weighted average F for ages 5 to 10 years. No estimates are available for the shaded cell.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	$F_{5\text{-}10}$
1978	0.0277	0.2592	0.258	0.253	0.238	0.296	0.732	1.161	0.721	0.721	0.387
1979	0.0005	0.0094	0.109	0.164	0.228	0.162	0.230	0.231	0.882	0.882	0.194
1980	0.0058	0.3838	0.538	0.887	1.228	1.754	1.119	2.199	3.788	3.788	1.172
1981	0.0100	0.1559	0.424	0.248	0.112	0.346	0.519	0.592	0.577	0.577	0.221
1982	0.0000	0.0039	0.144	0.153	0.422	0.294	0.559	1.604	0.359	0.359	0.264
1983	0.0001	0.0034	0.107	0.148	0.203	0.229	0.256	0.768	1.222	1.222	0.187
1984	0.0000	0.0045	0.108	0.106	0.191	0.209	0.242	0.113	0.393	0.393	0.146
1985	0.0000	0.0005	0.049	0.156	0.171	0.199	0.324	0.277	0.137	0.137	0.172
1986	0.0038	0.0065	0.156	0.107	0.175	0.127	0.147	0.108	0.085	0.085	0.142
1987	0.0001	0.0114	0.071	0.138	0.160	0.318	0.367	0.703	0.744	0.744	0.234
1988	0.0007	0.0060	0.057	0.145	0.146	0.181	0.244	0.308	0.346	0.346	0.170
1989	0.0000	0.0006	0.024	0.035	0.099	0.087	0.096	0.132	0.094	0.094	0.083
1990	0.0000	0.0050	0.161	0.162	0.174	0.789	0.302	0.346	0.389	0.389	0.396
1991	0.0000	0.0001	0.035	0.054	0.044	0.037	0.175	0.062	0.104	0.104	0.071
1992	0.0000	0.0017	0.015	0.074	0.077	0.054	0.079	0.263	0.098	0.098	0.089
1993	0.0000	0.0000	0.008	0.037	0.047	0.054	0.022	0.030	0.047	0.047	0.040
1994	0.0000	0.0003	0.037	0.066	0.247	0.374	0.202	0.290	0.499	0.499	0.281
1995	0.0004	0.0037	0.017	0.125	0.147	0.358	0.385	0.351	0.447	0.447	0.253
1996	0.0001	0.0002	0.055	0.206	0.323	0.522	0.673	0.774	0.820	0.820	0.461
1997	0.0003	0.0076	0.123	0.357	0.192	0.374	0.282	0.401	0.501	0.501	0.348
1998	0.0000	0.0000	0.072	0.168	0.390	0.396	0.664	0.481	0.970	0.970	0.412
1999	0.0002	0.0049	0.067	0.421	0.383	0.736	0.871	0.895	1.063	1.063	0.518
2000	0.0006	0.0162	0.078	0.299	0.442	0.361	0.482	0.413	0.578	0.578	0.354
2001	0.0030	0.0203	0.047	0.257	0.395	0.745	0.713	0.585	0.759	0.759	0.384
2002	0.0037	0.0126	0.099	0.166	0.337	0.514	0.594	0.689	0.799	0.799	0.333
2003	0.0014	0.0194	0.063	0.299	0.207	0.530	0.853	0.978	0.745	0.745	0.366
2004	0.0031	0.0174	0.070	0.111	0.278	0.216	0.347	0.662	1.093	1.093	0.215
2005	0.0000	0.0000	0.004	0.099	0.223	0.599	0.291	0.687	0.794	0.794	0.279
2006	0.0009	0.0060	0.032	0.110	0.239	0.376	0.669	0.429	0.759	0.759	0.300
2007	0.0000	0.0025	0.005	0.129	0.270	0.501	0.524	0.466	0.472	0.472	0.338
2008	0.0000	0.0022	0.027	0.039	0.127	0.407	0.653	0.472	0.757	0.757	0.297
2009	0.0000	0.0020	0.023	0.153	0.336	0.720	0.425	0.318	0.816	0.816	0.315
2010	0.0000	0.0004	0.018	0.114	0.378	0.501	1.044	1.023	0.655	0.655	0.375
2011	0.0000	0.0000	0.003	0.058	0.126	0.573	1.411	1.952	1.375	1.375	0.282
2012	0.0000	0.0000	0.002	0.014	0.139	0.391	0.900	1.612	2.119	2.119	0.225
2013	0.0003	0.0005	0.015	0.101	0.173	0.411	0.466	0.902	2.148	2.148	0.308
2014	0.0000	0.0000	0.029	0.059	0.180	0.228	0.595	0.411	1.032	1.032	0.232
2015	na	0.0008	0.009	0.127	0.157	0.425	0.484	0.258	0.354	0.354	0.265

Table 8d. Maximum likelihood estimates of the instantaneous rate of fishing mortality of fall spawning herring of the southern Gulf of St. Lawrence, based on abundance-weighted averages of the estimates for the North, Middle and South regions. $F_{5\text{-}10}$ is the abundance-weighted average F for ages 5 to 10 years. No estimates are available for the shaded cell.

	Age (years)										
Year	2	3	4	5	6	7	8	9	10	11+	$F_{5\text{-}10}$
1978	0.0114	0.1834	0.596	0.759	0.522	0.441	1.185	0.628	0.844	0.897	0.787
1979	0.0166	0.1034	0.217	0.472	0.717	0.635	0.739	1.124	2.402	2.135	0.700
1980	0.0107	0.1908	0.329	0.617	1.060	1.481	1.195	1.619	2.677	2.572	0.883
1981	0.0029	0.0745	0.209	0.205	0.120	0.388	1.275	0.671	0.423	0.644	0.218
1982	0.0016	0.0331	0.108	0.197	0.232	0.148	0.571	1.482	0.499	0.663	0.207
1983	0.0007	0.0130	0.116	0.112	0.244	0.191	0.141	1.005	1.300	1.142	0.172
1984	0.0009	0.0072	0.071	0.108	0.134	0.153	0.165	0.061	0.838	1.331	0.123
1985	0.0006	0.0060	0.041	0.122	0.164	0.188	0.270	0.643	0.162	0.143	0.159
1986	0.0019	0.0083	0.129	0.121	0.198	0.264	0.274	0.244	0.216	0.216	0.195
1987	0.0064	0.0387	0.102	0.158	0.193	0.295	0.361	0.486	0.425	0.457	0.246
1988	0.0147	0.0186	0.104	0.175	0.175	0.229	0.211	0.287	0.362	0.390	0.198
1989	0.0009	0.0064	0.104	0.167	0.195	0.196	0.182	0.200	0.256	0.278	0.188
1990	0.0002	0.0104	0.156	0.217	0.277	0.599	0.351	0.388	0.319	0.342	0.366
1991	0.0000	0.0116	0.099	0.125	0.121	0.182	0.275	0.158	0.191	0.205	0.165
1992	0.0001	0.0047	0.046	0.160	0.198	0.176	0.212	0.344	0.252	0.375	0.184
1993	0.0018	0.0117	0.047	0.132	0.150	0.144	0.128	0.147	0.195	0.159	0.143
1994	0.0000	0.0021	0.058	0.193	0.331	0.465	0.396	0.513	0.500	0.500	0.379
1995	0.0001	0.0066	0.070	0.309	0.506	0.704	0.737	0.654	0.719	0.696	0.525
1996	0.0009	0.0116	0.119	0.349	0.502	0.607	0.707	0.789	0.754	0.786	0.547
1997	0.0006	0.0170	0.134	0.416	0.386	0.432	0.406	0.514	0.530	0.500	0.425
1998	0.0001	0.0027	0.097	0.309	0.582	0.561	0.716	0.572	1.085	1.089	0.501
1999	0.0017	0.0181	0.110	0.452	0.780	0.763	0.920	0.904	1.027	1.087	0.607
2000	0.0016	0.0208	0.140	0.405	0.519	0.569	0.622	1.105	0.569	0.572	0.454
2001	0.0037	0.0269	0.148	0.327	0.425	0.580	0.571	0.466	0.596	0.571	0.398
2002	0.0013	0.0112	0.165	0.297	0.375	0.432	0.483	0.448	0.666	0.668	0.366
2003	0.0004	0.0137	0.113	0.378	0.363	0.536	0.906	1.133	1.369	1.186	0.475
2004	0.0014	0.0105	0.097	0.194	0.319	0.300	0.429	0.657	1.225	1.188	0.284
2005	0.0039	0.0144	0.076	0.290	0.429	0.622	0.423	0.699	0.896	0.869	0.394
2006	0.0013	0.0121	0.058	0.265	0.378	0.409	0.620	0.606	0.902	0.916	0.368
2007	0.0018	0.0254	0.075	0.172	0.449	0.563	0.629	0.493	0.580	0.638	0.404
2008	0.0019	0.0154	0.084	0.159	0.265	0.454	0.925	0.583	0.901	0.883	0.400
2009	0.0002	0.0098	0.076	0.220	0.331	0.601	0.428	0.356	0.781	0.786	0.316
2010	0.0000	0.0028	0.030	0.151	0.371	0.575	0.781	0.785	0.773	0.733	0.310
2011	0.0016	0.0024	0.008	0.050	0.186	0.609	0.991	1.140	1.404	1.389	0.250
2012	0.0003	0.0006	0.003	0.030	0.148	0.318	0.817	1.048	1.607	1.946	0.186
2013	0.0039	0.0047	0.013	0.076	0.158	0.326	0.274	0.639	0.939	0.678	0.207
2014	0.0002	0.0159	0.017	0.039	0.120	0.196	0.402	0.213	0.844	0.051	0.155
2015	na	0.0104	0.011	0.099	0.142	0.250	0.284	0.214	0.098	0.064	0.187

Table 9. Results of projections for fall spawning herring in the southern Gulf of St. Lawrence at various catch levels in 2016 and 2017. The same catch is assumed for 2016 and 2017. SSB and $F_{5\text{-}10}$ are median estimates based on MCMC sampling. SSB is beginning-of-year spawning stock biomass, $F_{5\text{-}10}$ is the average instantaneous rate of fishing mortality for ages 5 to 10 years, and USR is the upper stock reference (172,000 t of SSB).

Annual Catch (by 1,000 t)	SSB in 2018 (by 1000 t)	Probability of SSB < USR	Average $F_{5\text{-}10}$ in 2017	Probability of $F_{5\text{-}10}$ > 0.32
10	163.232	0.57	0.072	0.00
12	159.957	0.59	0.090	0.00
14	156.682	0.62	0.110	0.00
16	153.408	0.64	0.131	0.00
18	150.122	0.67	0.154	0.00
20	146.946	0.69	0.179	0.01
22	143.762	0.71	0.207	0.04
24	140.602	0.73	0.237	0.11
26	137.462	0.75	0.270	0.26
28	134.347	0.77	0.304	0.42
30	131.606	0.78	0.341	0.60
32	128.774	0.79	0.381	0.73
34	125.988	0.80	0.421	0.81
36	123.241	0.81	0.464	0.87
38	120.759	0.82	0.509	0.90
40	118.207	0.83	0.553	0.92
42	115.876	0.84	0.599	0.94
44	113.499	0.85	0.645	0.95
46	111.184	0.86	0.692	0.96
48	108.770	0.87	0.740	0.97
50	106.689	0.87	0.789	0.97

FIGURES

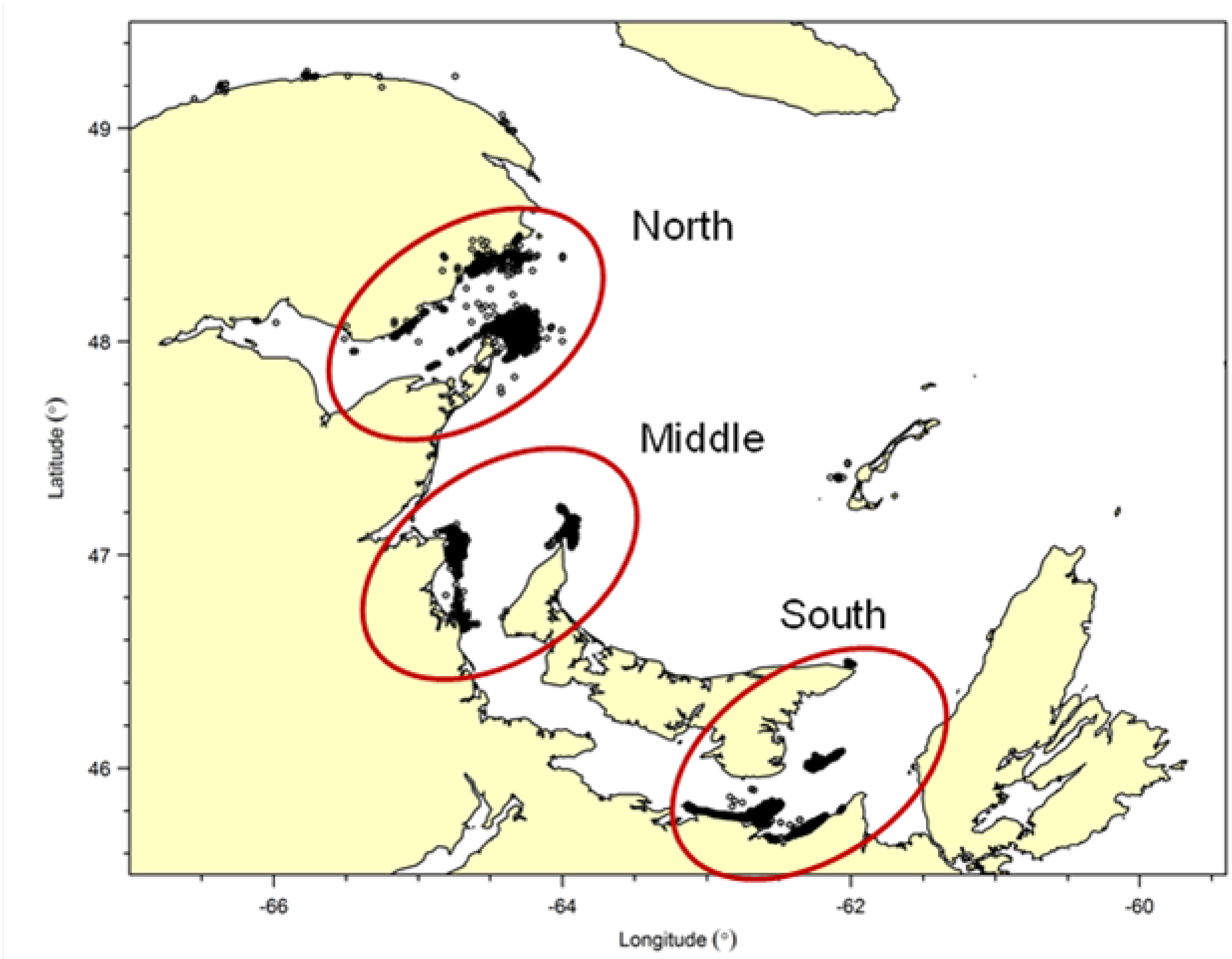

Figure 1. Fall herring spawning grounds in the southern Gulf of St. Lawrence and their grouping into three regions for assessment and management purposes.

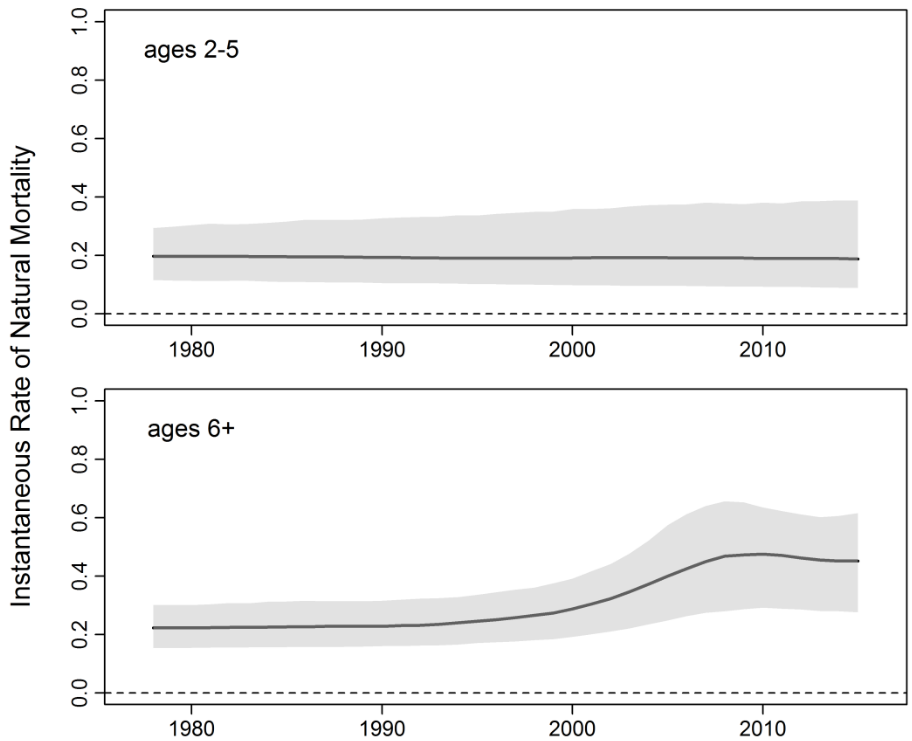

Figure 2. Estimated rate of natural mortality from Model 2 of two age groups of spring spawning herring in the southern Gulf of St. Lawrence. Lines show the median estimates and shading their 95% confidence interval based on MCMC sampling.

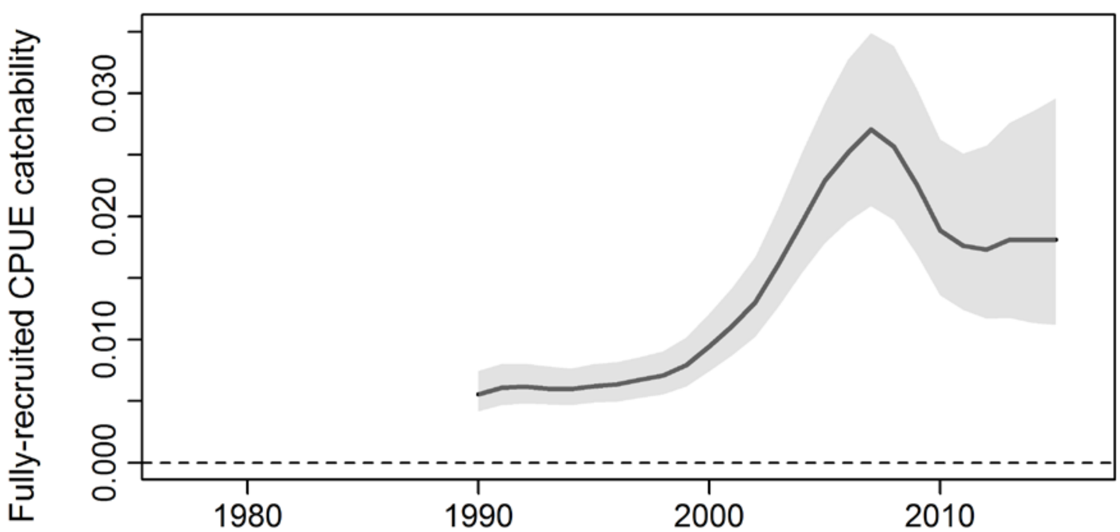

Figure 3. Estimated fully-recruited catchability to the CPUE index based on Model 3 for spring spawning herring in the southern Gulf of St. Lawrence. Lines show the median estimates and shading their 95% confidence interval based on MCMC sampling.

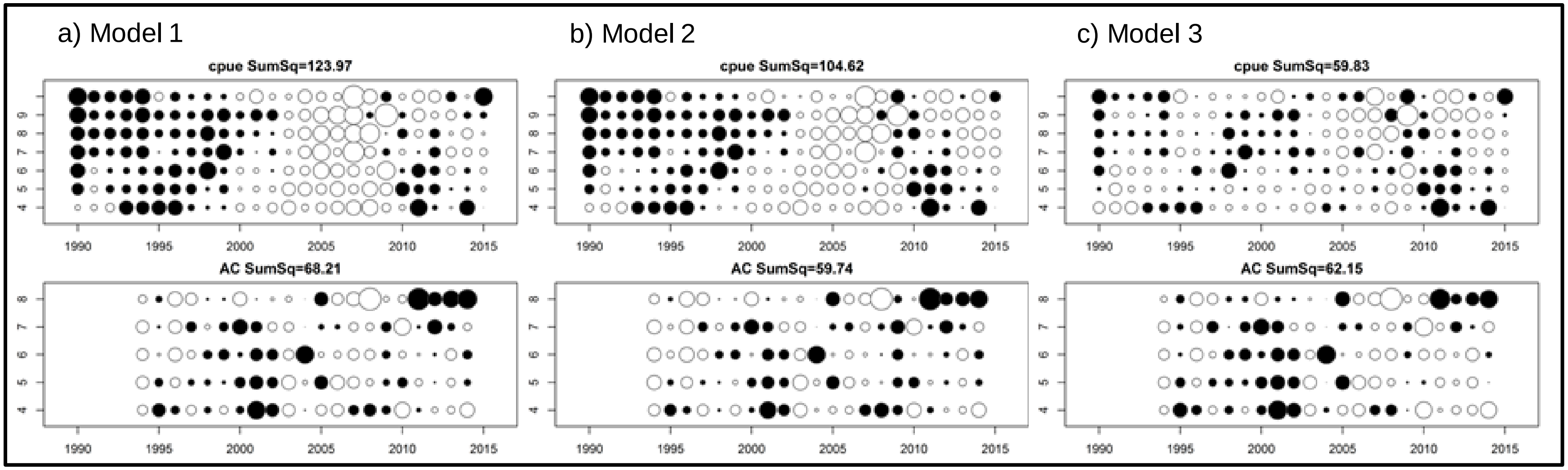

Figure 4. Residuals (observed – predicted indices) for population models f(a – Model 1; b – Model 2; c- Model 3) of the spring spawning herring stock of the southern Gulf of St. Lawrence. For each model, the upper panel shows residuals for the CPUE index and the bottom panel shows residuals for the acoustic index. Rows are for ages and columns years. Circle radius is proportional to the absolute value of residuals. Black circles indicate negative residuals (i.e., observed < predicted).

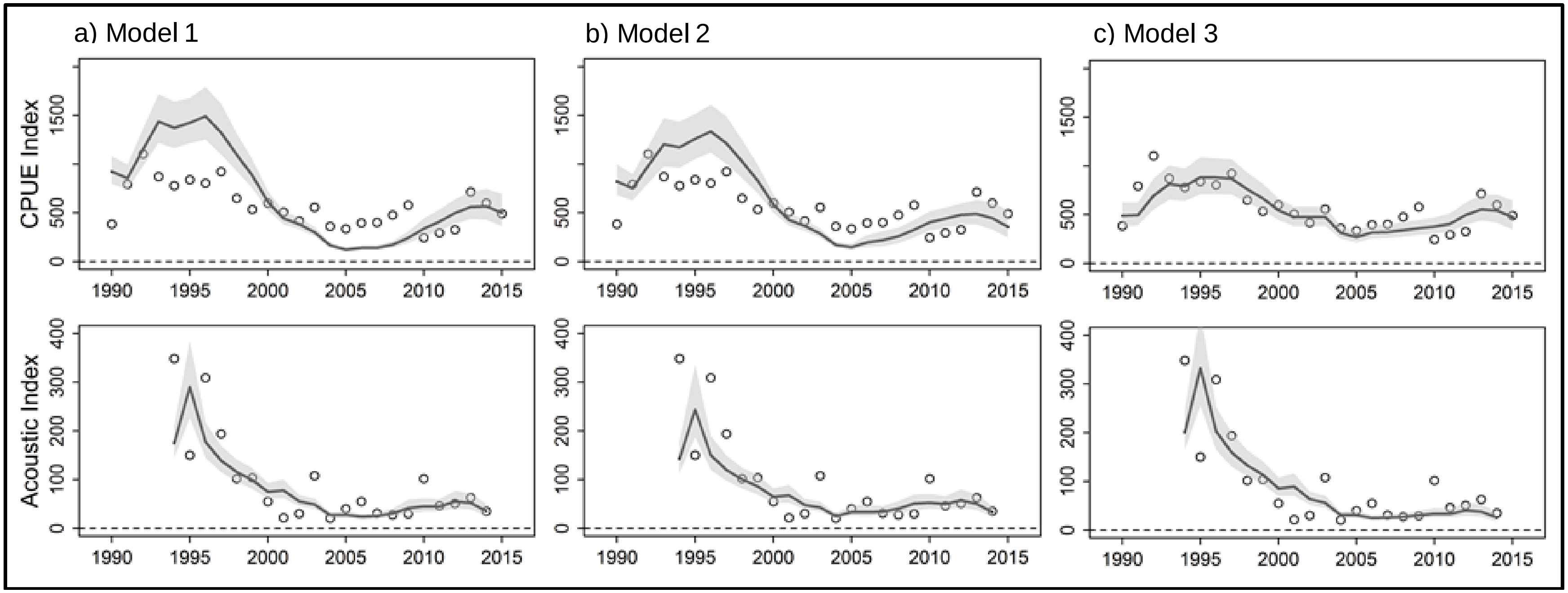

Figure 5. Observed (circles) and predicted (lines and shading) age-aggregated CPUE (upper panels) and acoustic (lower panels) indices for three models (a – Model 1; b – Model 2; c – Model 3) of spring spawning herring of the southern Gulf of St. Lawrence. The lines show the median predicted indices and the shading the 95% confidence intervals of the predictions based on MCMC sampling.

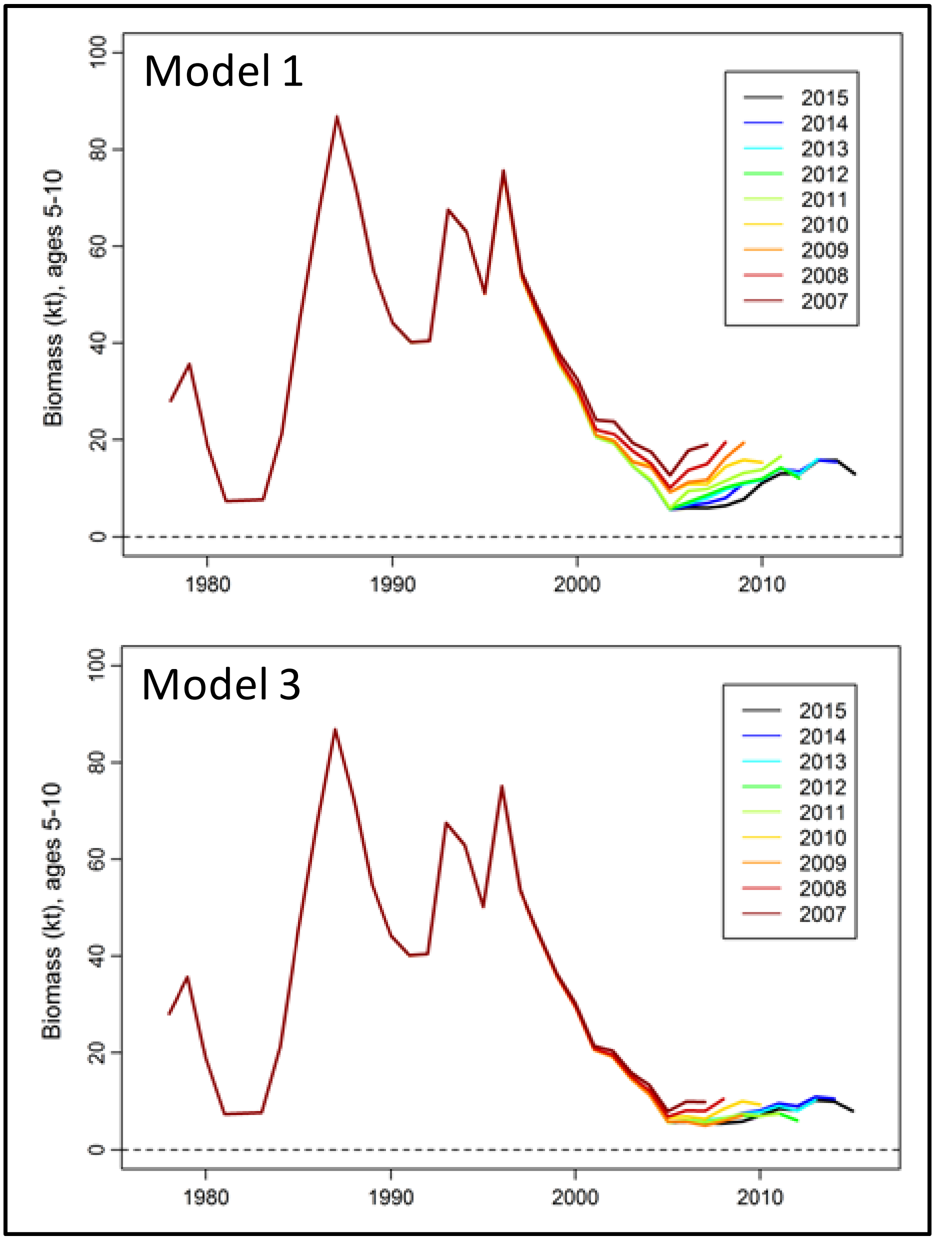

Figure 6. Retrospective patterns in estimated biomass of ages 5 to 10 for spring spawning herring of the southern Gulf of St. Lawrence, based on Model 1 (upper panel) and Model 3 (lower panel).

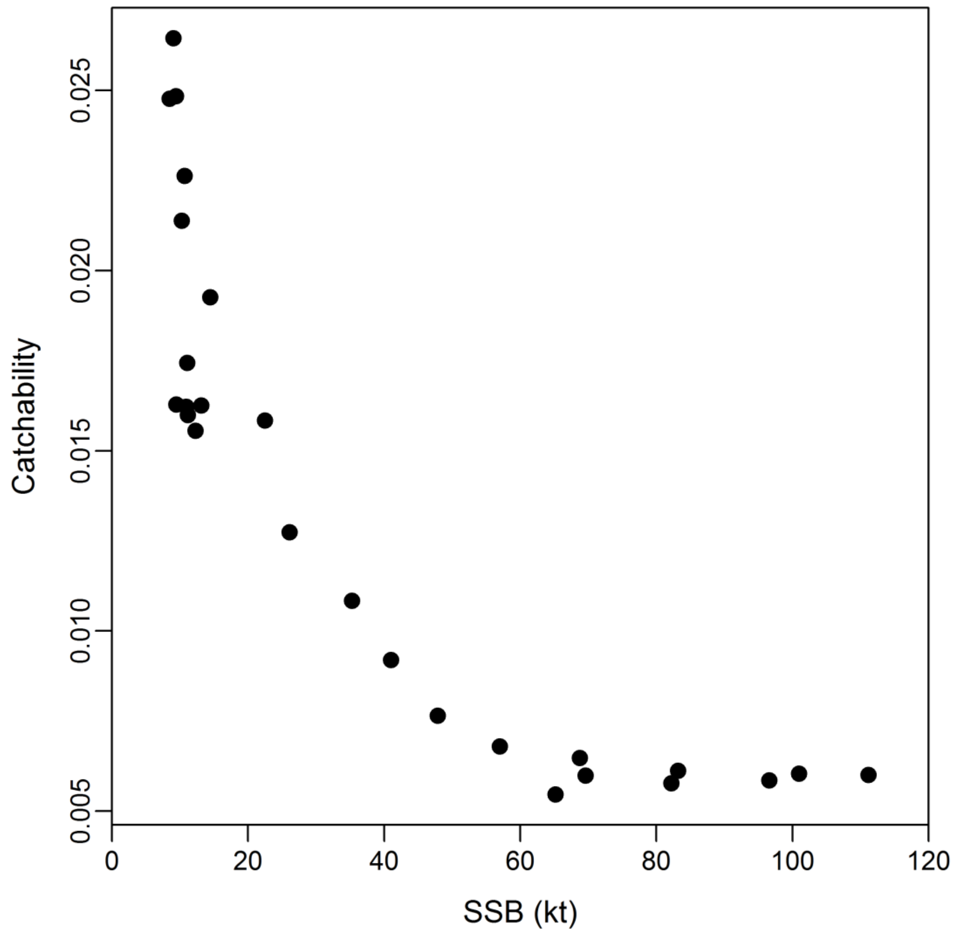

Figure 7. Fully-recruited catchability of Atlantic herring to the spring spawner gillnet fishery in relation to estimated spring spawner SSB.

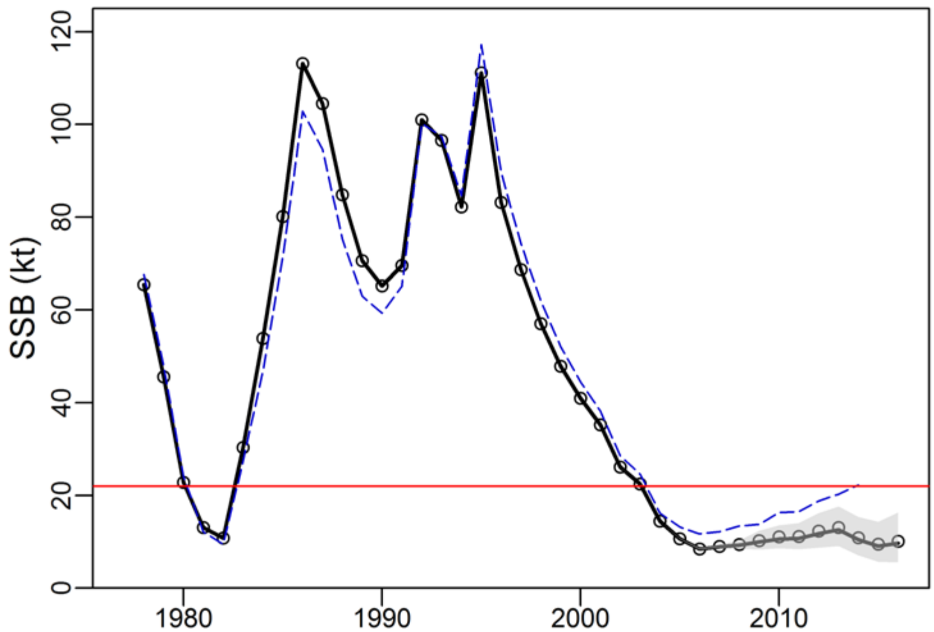

Figure 8. Estimated spawning stock biomass (SSB) of the spring spawning component of Atlantic herring in the southern Gulf of St. Lawrence. Circles show the maximum likelihood estimates (MLEs). The solid line is the median MCMC estimate and shading its 95% confidence interval. The red horizontal line is the Limit Reference Point (22,000 t of SSB). The blue dashed line shows the estimates from the 2014 assessment.

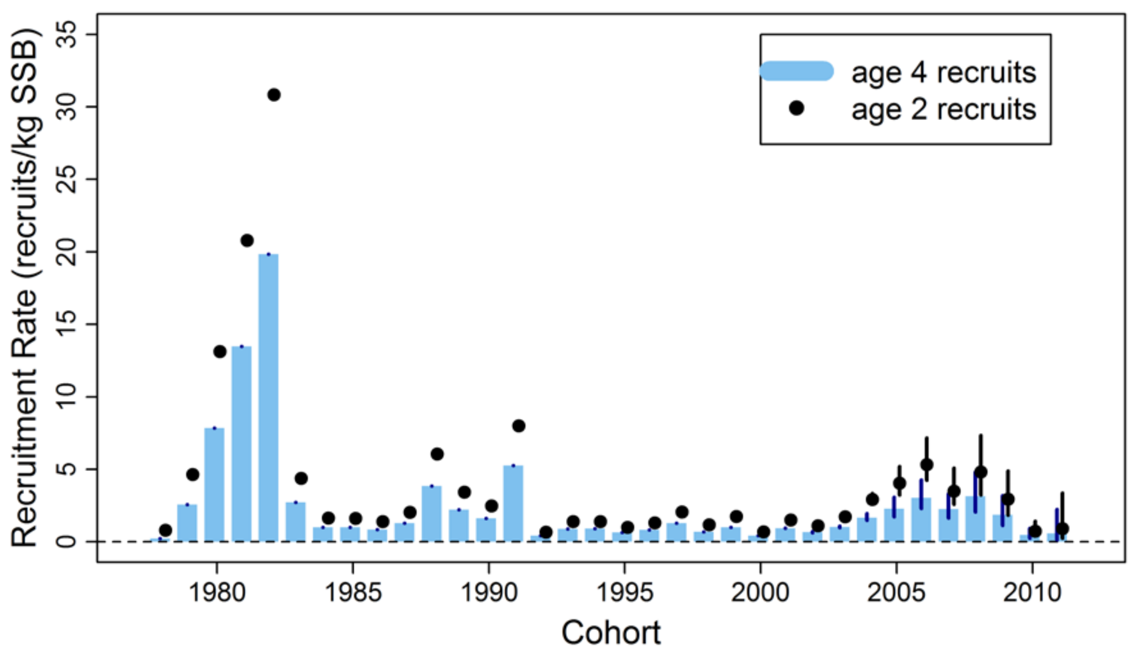

Figure 9. Recruitment rates for age 2 (circles) and age 4 (bars) recruits for the 1978 to 2011 cohorts of spring spawning Atlantic herring in the southern Gulf of St. Lawrence. Vertical lines indicate 95% confidence intervals.

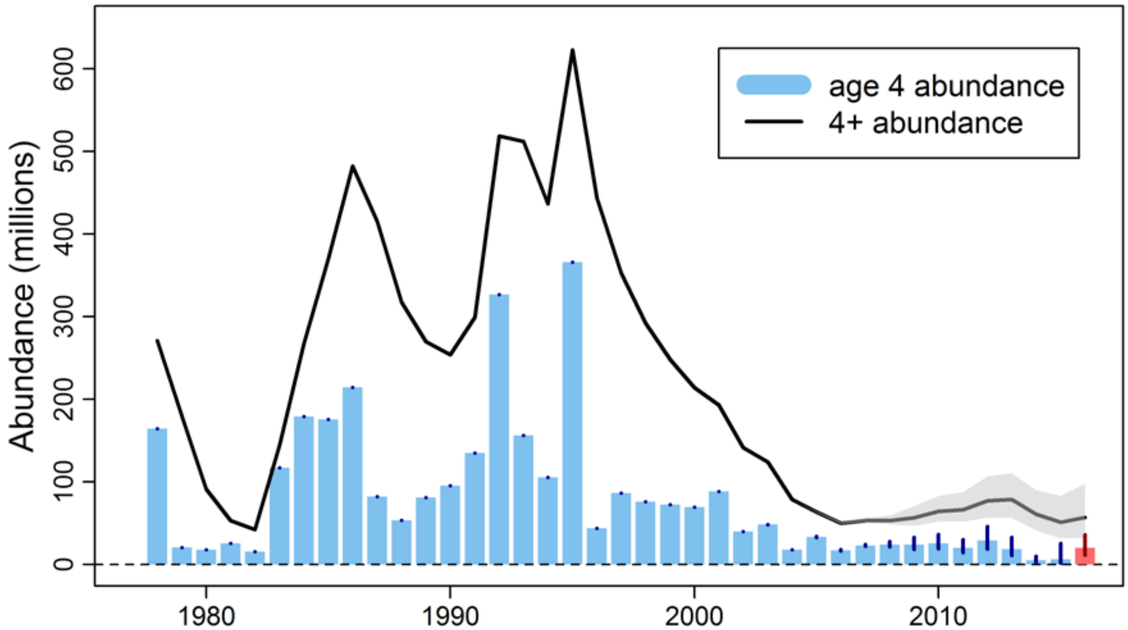

Figure 10. Estimated beginning-of-year abundance of 4 year old herring (blue bars) and herring 4 years and older (line) of the spring spawning component in the southern Gulf of St. Lawrence. Bars and the line show the median MCMC estimate and vertical lines or shading its 95% confidence interval. Age-4 abundance in 2015 (the red bar) was estimated assuming the recruitment rate for this cohort was the average of the rates for the preceding five cohorts.

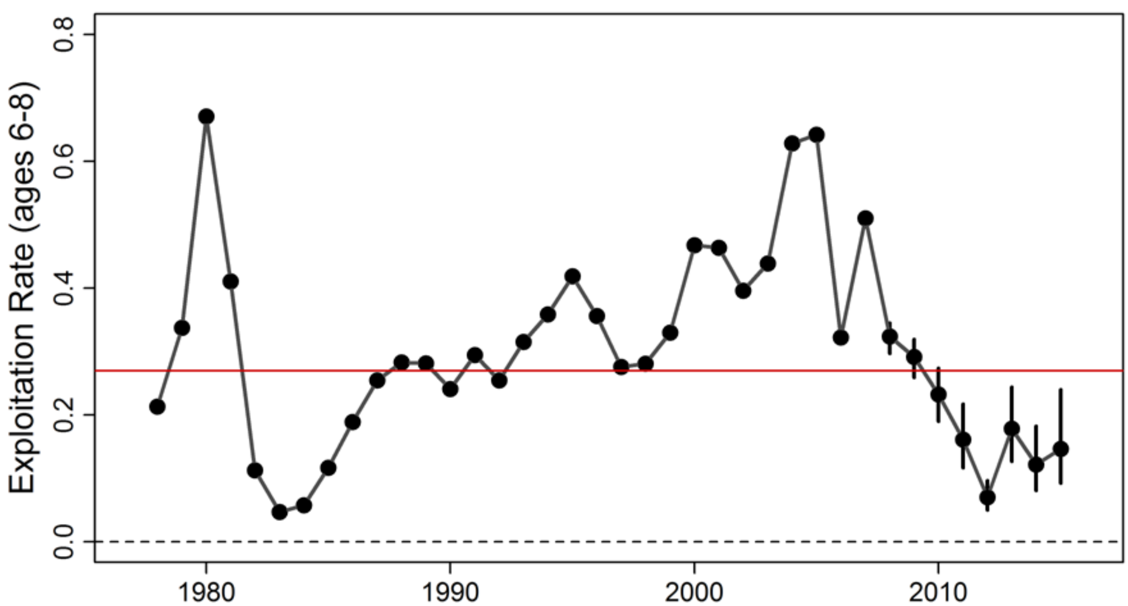

Figure 11. Estimated exploitation rate of spring-spawning herring aged 6 to 8 years in the southern Gulf of St. Lawrence. Circles are the median estimates based on MCMC sampling and vertical lines their 95% confidence intervals. The red horizontal line shows the reference level exploitation corresponding to $F_{0.1}$.

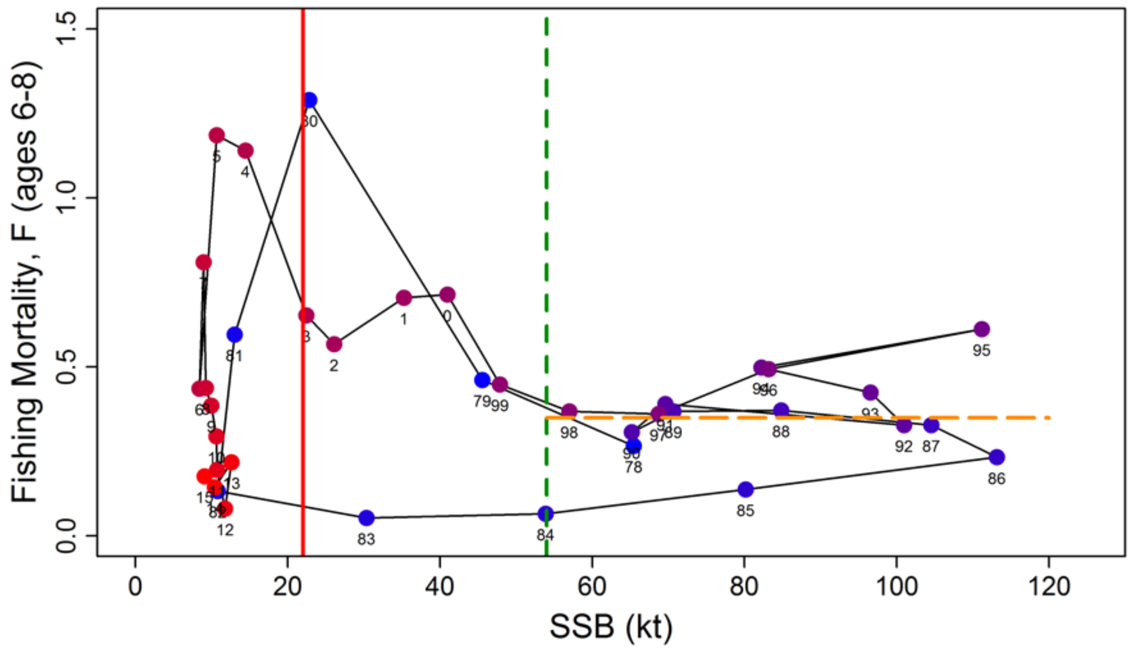

Figure 12. The southern Gulf of St. Lawrence spring spawning herring population trajectory in relation to estimated spawning stock biomass (SSB) and estimated fishing mortality rates for ages 6 to 8 years. The solid red vertical line is the LRP (SSB = 22,000 t), the green dashed vertical line is the Upper Stock Reference (USR; SSB = 54,000 t), and the dashed horizontal line is the removal rate reference at $F_{0.1}$ in the healthy zone (SSB > USR). Point labels are years (83 = 1983, 0 = 2000).

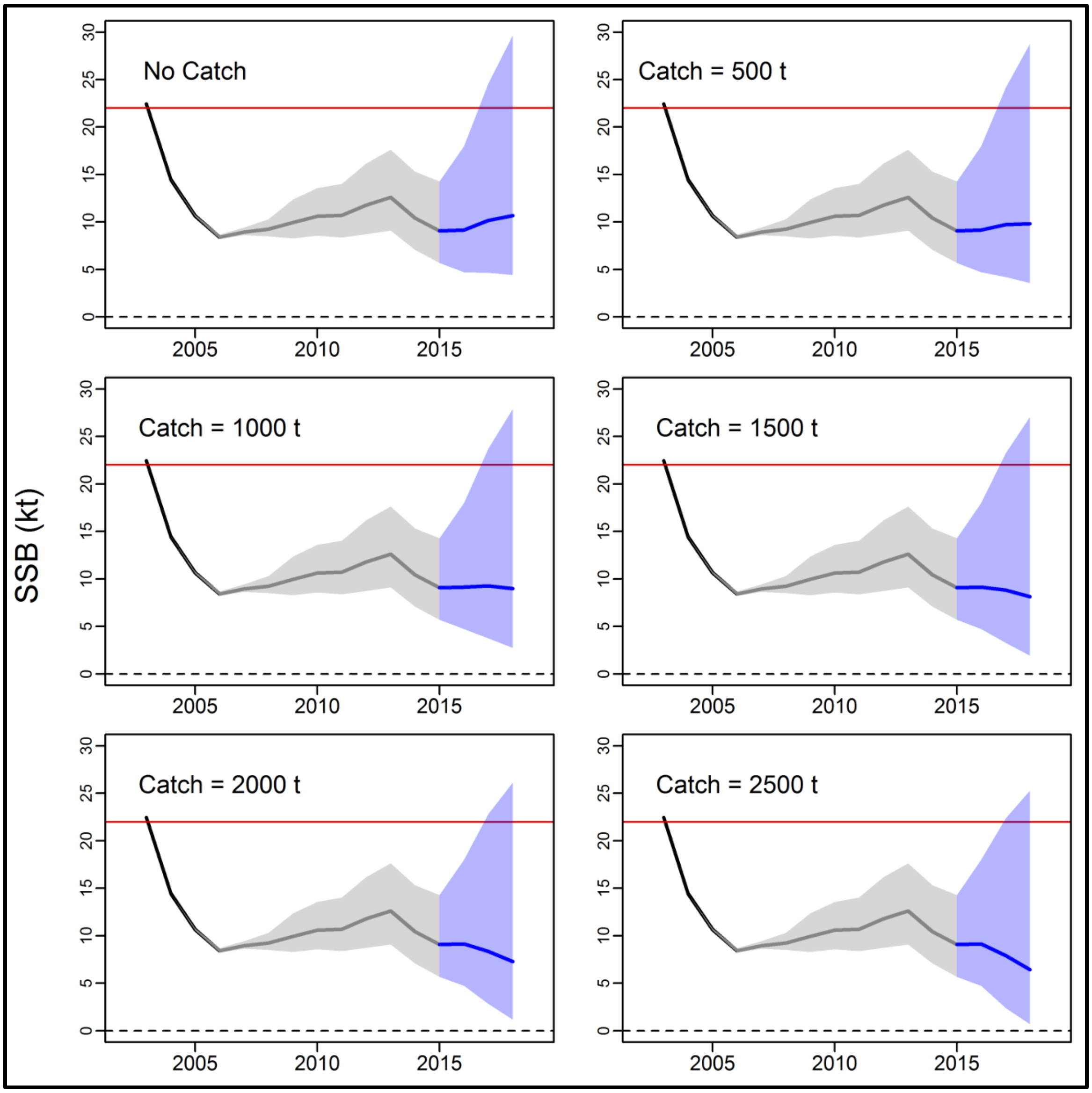

Figure 13. Projected spawning stock biomass (SSB in kt) of spring spawning Atlantic herring from the southern Gulf of St. Lawrence at various catch levels in 2016 and 2017. Lines show the median estimates of the beginning-of-year SSB and shading the 95% confidence intervals of these estimates (based on MCMC sampling). Black and grey indicate the historical period and blue the projection period. The red horizontal line is the LRP.

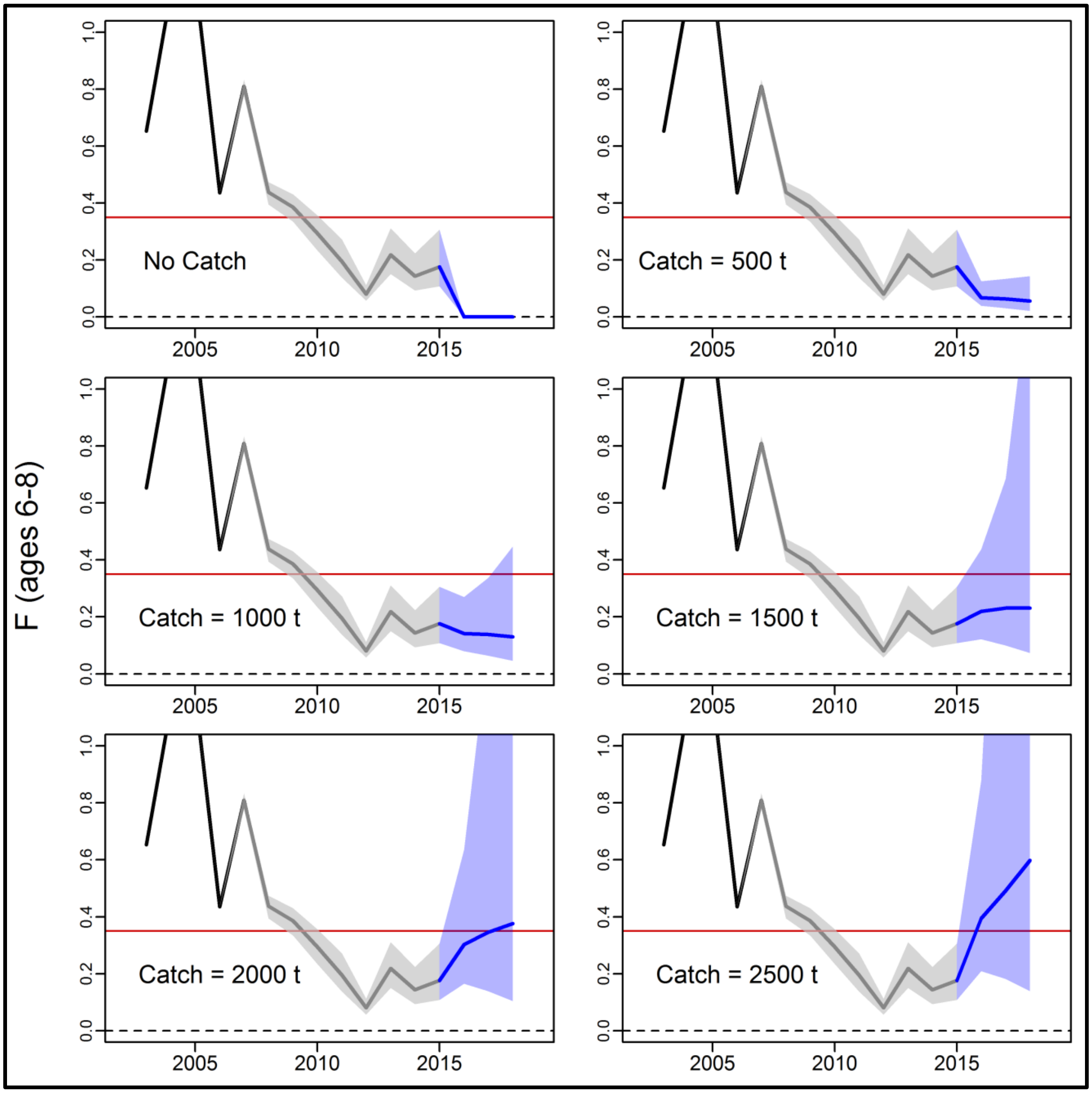

Figure 14. Projected ages 6 to 8 fishing mortality rate (F) of spring spawning Atlantic herring from the southern Gulf of St. Lawrence at various catch levels in 2016 and 2017. Lines show the median estimates and shading their 95% confidence intervals (based on MCMC sampling). Black and grey indicate the historical period and blue the projection period. The red horizontal line is the removal rate reference level F = 0.35.

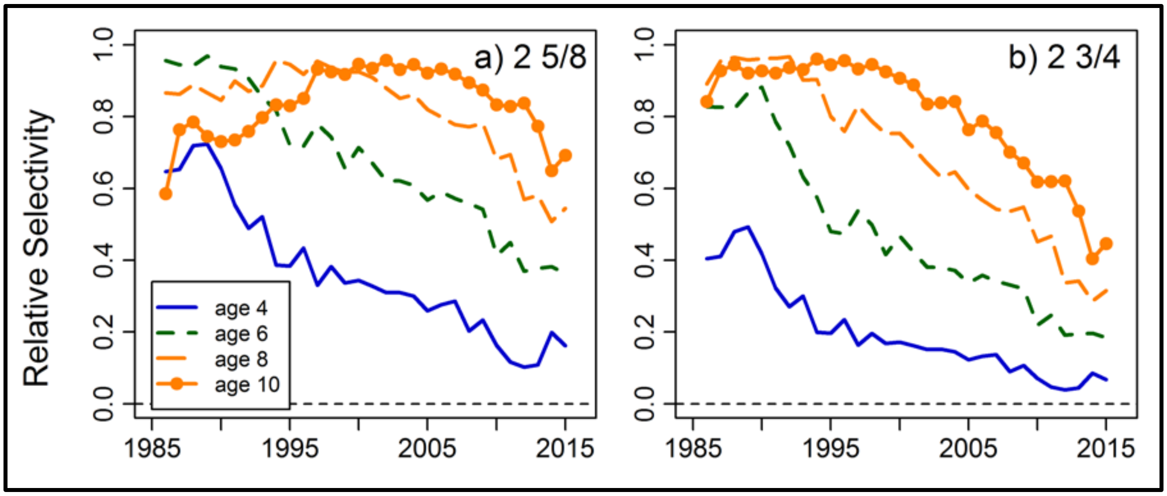

Figure 15. Changes in relative selectivity of fall spawning herring aged 4, 6, 8 and 10 years to gillnets with mesh sizes of 2 ⅝inches (a) or 2 ¾ inches (b) over the 1986 to 2015 period in the southern Gulf of St. Lawrence.

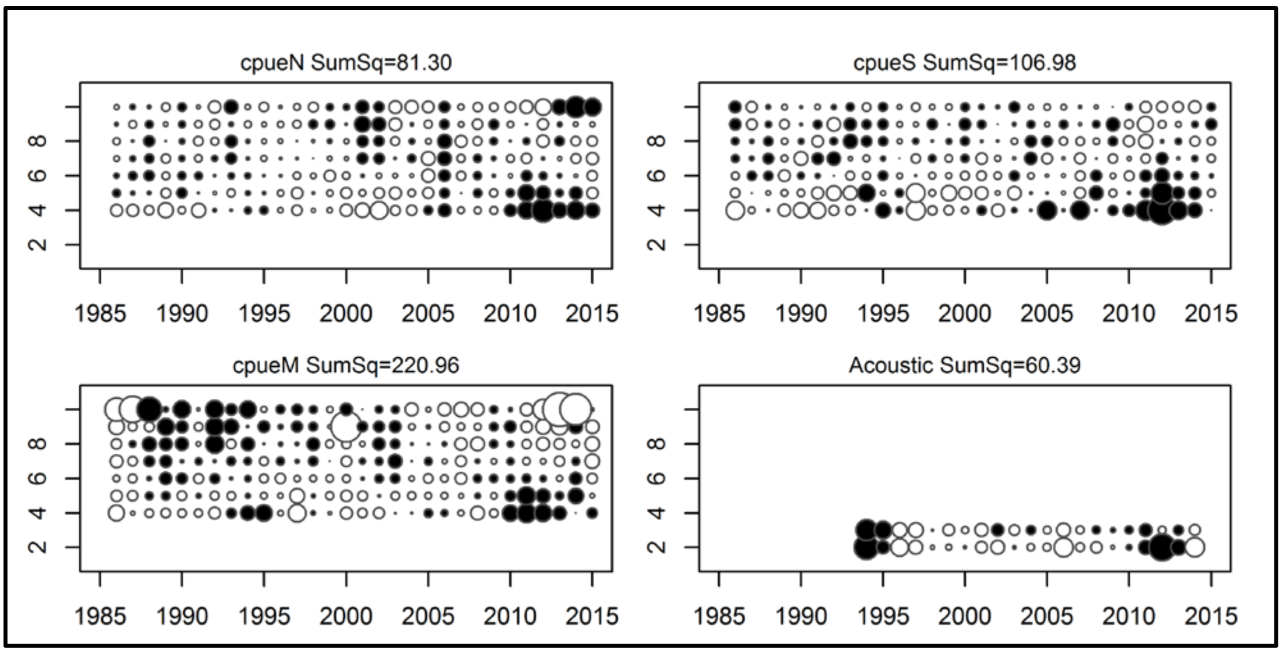

Figure 16. Commercial gillnet CPUE index residuals (observed – predicted indices) by region (cpueN = North; cpueM = Middle; cpueS = South) and residuals between predicted and observed indices from the acoustic survey (Acoustic, all regions combined) for fall spawning herring from the southern Gulf of St. Lawrence. Rows are for ages and columns are years. The circle radius is proportional to the absolute value of residuals. Black circles indicate negative residuals (i.e., observed < predicted).

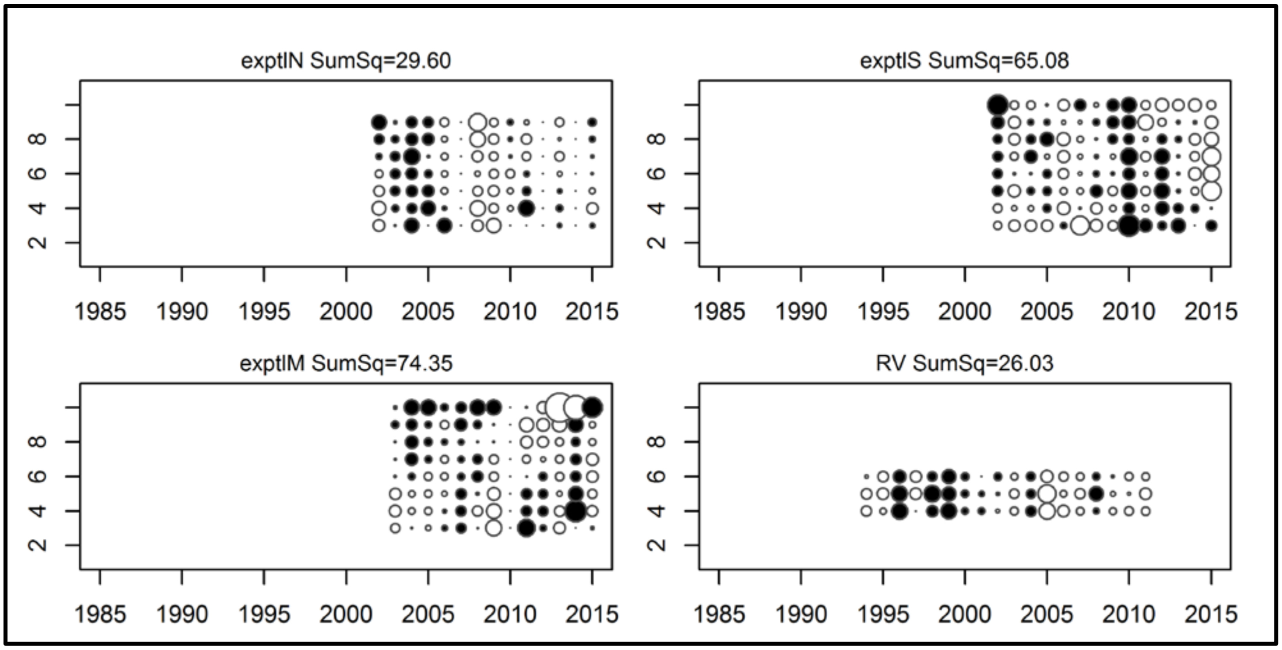

Figure 17. Experimental gillnet index residuals (observed – predicted indices) by region (exptlN = North; exptlM = Middle; exptlS = South), and residuals between predicted and observed indices from the RV survey (RV, all regions combined) for fall spawning herring from the southern Gulf of St. Lawrence. Rows are for ages and columns are years. The circle radius is proportional to the absolute value of residuals. Black circles indicate negative residuals (i.e., observed < predicted).

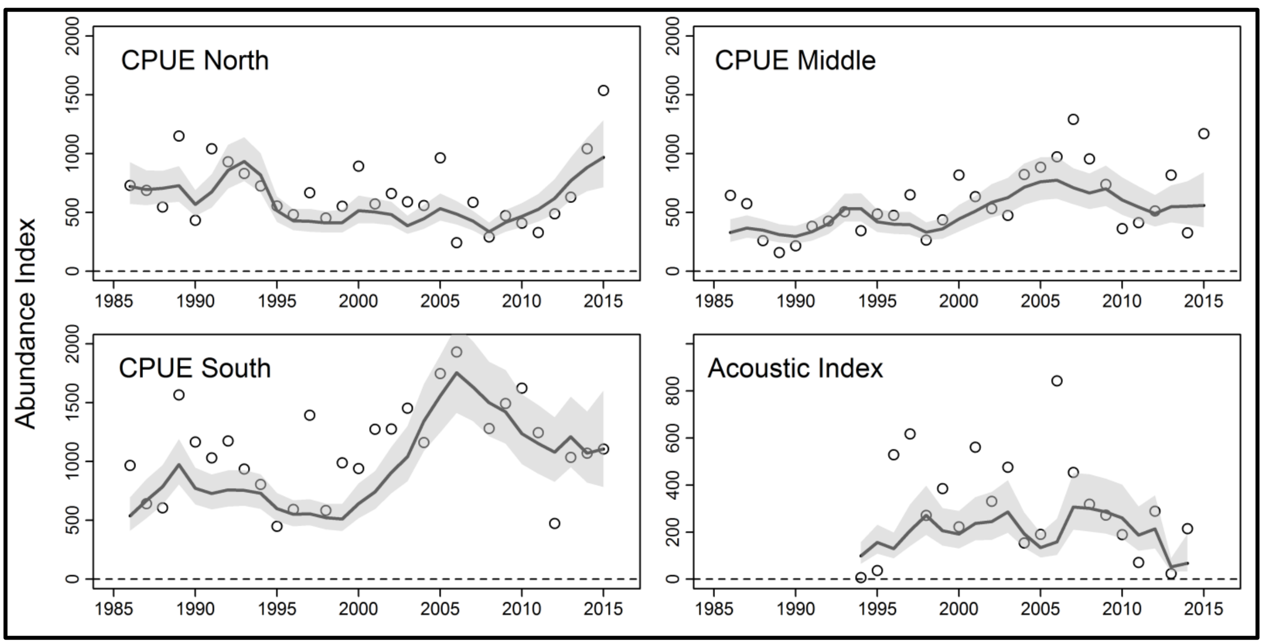

Figure 18. Observed (circles) and predicted (lines and shading) age-aggregated commercial gillnet CPUE indices by region (CPUE North, CPUE Middle, CPUE South) and acoustic indices (Acoustic, all regions combined) for fall spawning herring from the southern Gulf of St. Lawrence. The lines show the median predicted indices and the shading the 95% confidence intervals of the predictions based on MCMC sampling.

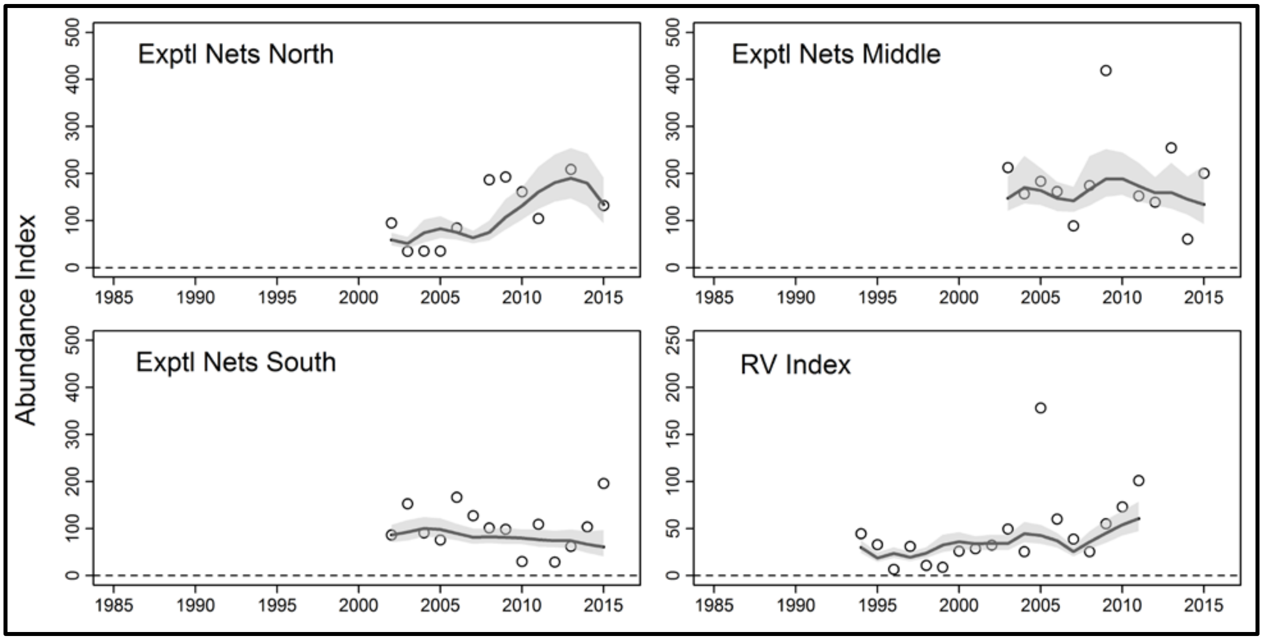

Figure 19. Observed (circles) and predicted (lines and shading) age-aggregated experimental gillnet indices by region (North, Middle, South) and RV indices (RV, all regions combined) for fall spawning herring from the southern Gulf of St. Lawrence. The lines show the median predicted indices and the shading the 95% confidence intervals of the predictions based on MCMC sampling.

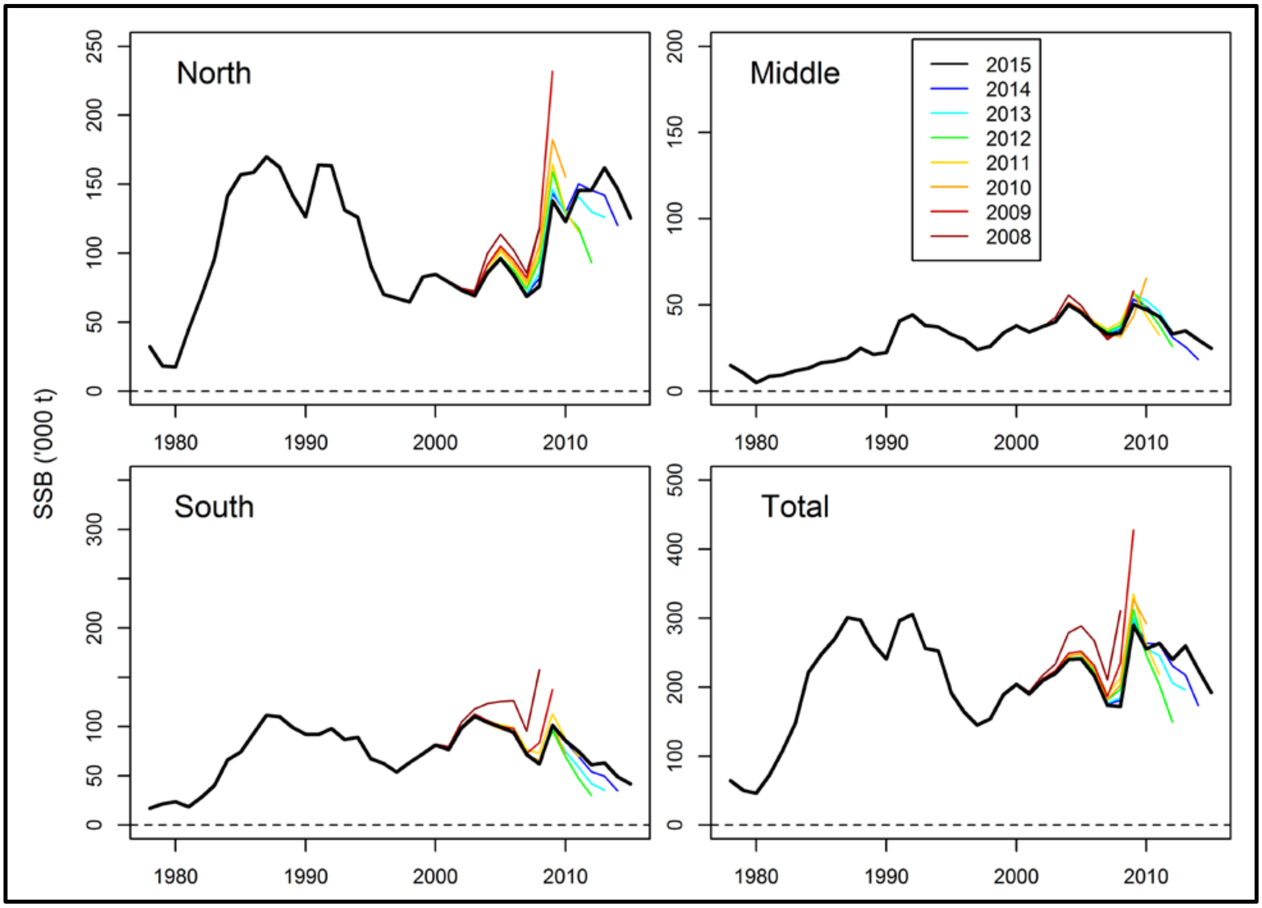

Figure 20. Retrospective patterns in spawning stock biomass (SSB) of fall-spawning herring within the three regions (North, Middle, South) and overall for the southern Gulf of St. Lawrence.

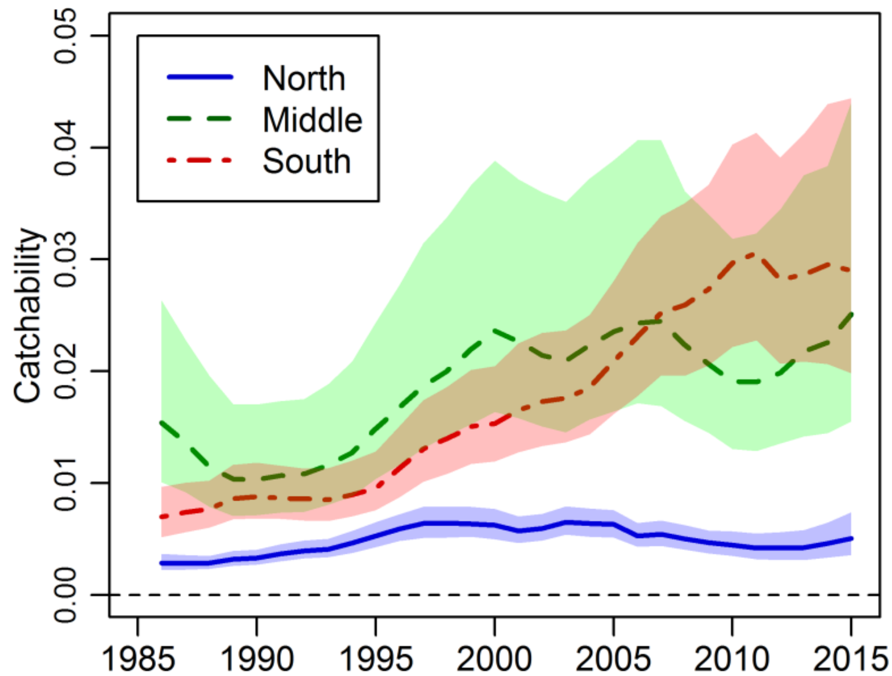

Figure 21. Estimated fully-recruited catchability of fall spawning herring for the commercial gillnet CPUE index by region in the southern Gulf of St. Lawrence. Lines show the median estimates and shading their 95% confidence intervals based on MCMC sampling.

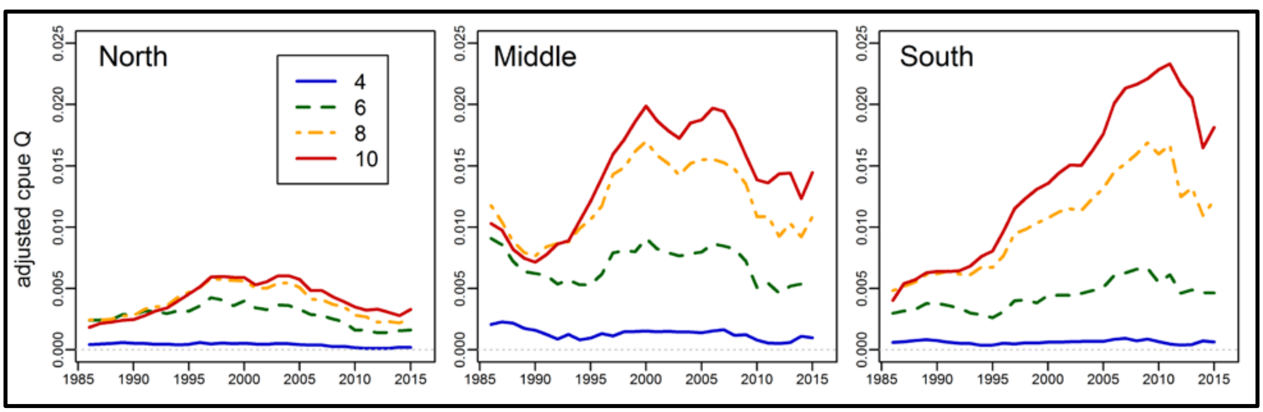

Figure 22. Estimated catchability (q) at age ($q_a{}'$ in equation 2) to the gillnet fishery in three regions (North, Middle and South) for fall spawning herring of the southern Gulf of St. Lawrence. $q_a{}'$ takes into account changes in mesh size and length at age, as well as non-stationarity in fully recruited q.

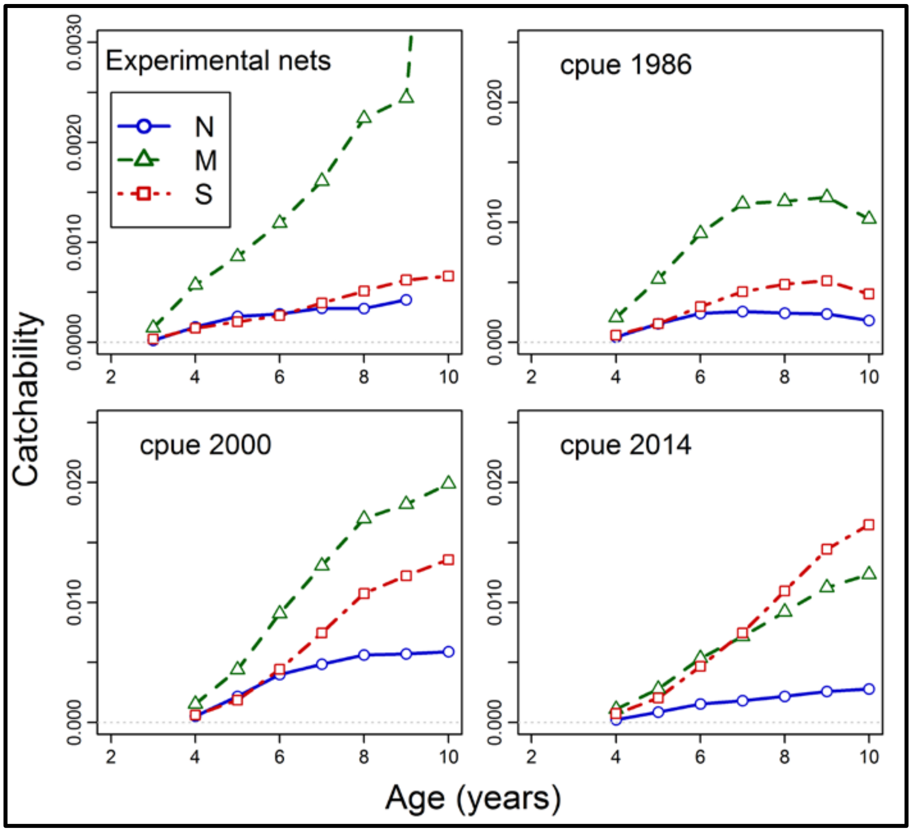

Figure 23. Catchability (q) at age to the experimental gillnets by region (upper left panel) compared to q-at-age in the commercial gillnet fishery in selected years (1986, 2000, and 2014) for fall spawning herring of the southern Gulf of St. Lawrence.

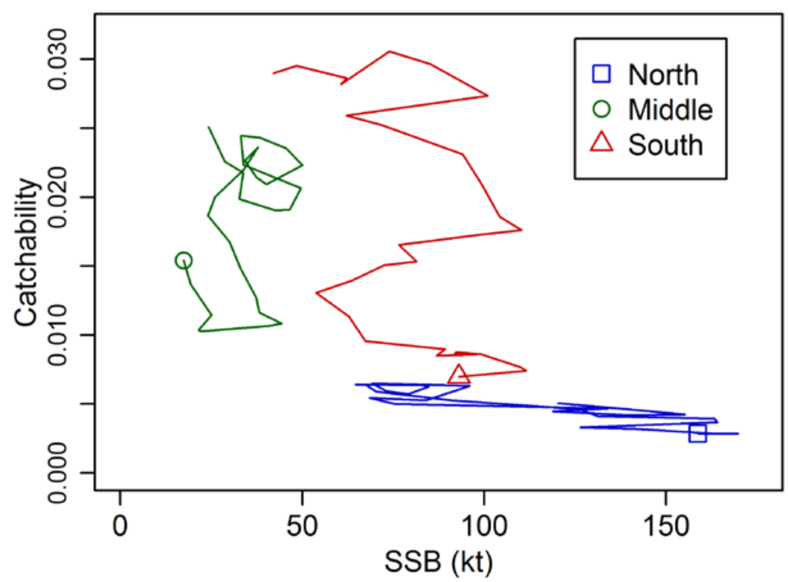

Figure 24. Fully-recruited catchability (q) in relation to spawning stock biomass (SSB) of fall spawning herring for the three regions of the southern Gulf of St. Lawrence. For each region, the marker denotes the first year in the 1986 to 2015 time series.

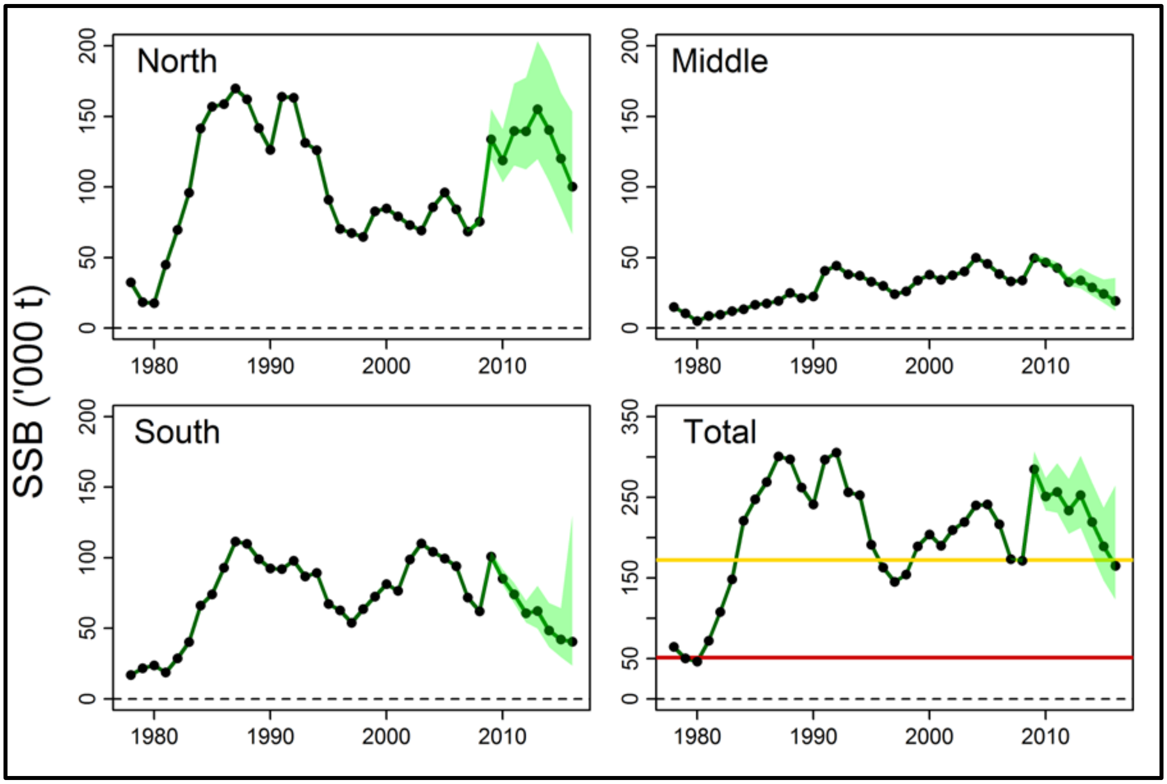

Figure 25. Estimated spawning stock biomass (SSB) of fall-spawning herring by region and summed over regions for the southern Gulf of St. Lawrence. The line and circles show the median estimates and the shading their 95% confidence intervals. The gold horizontal line is the upper stock reference level (USR) and the red horizontal line is the limit reference point (LRP).

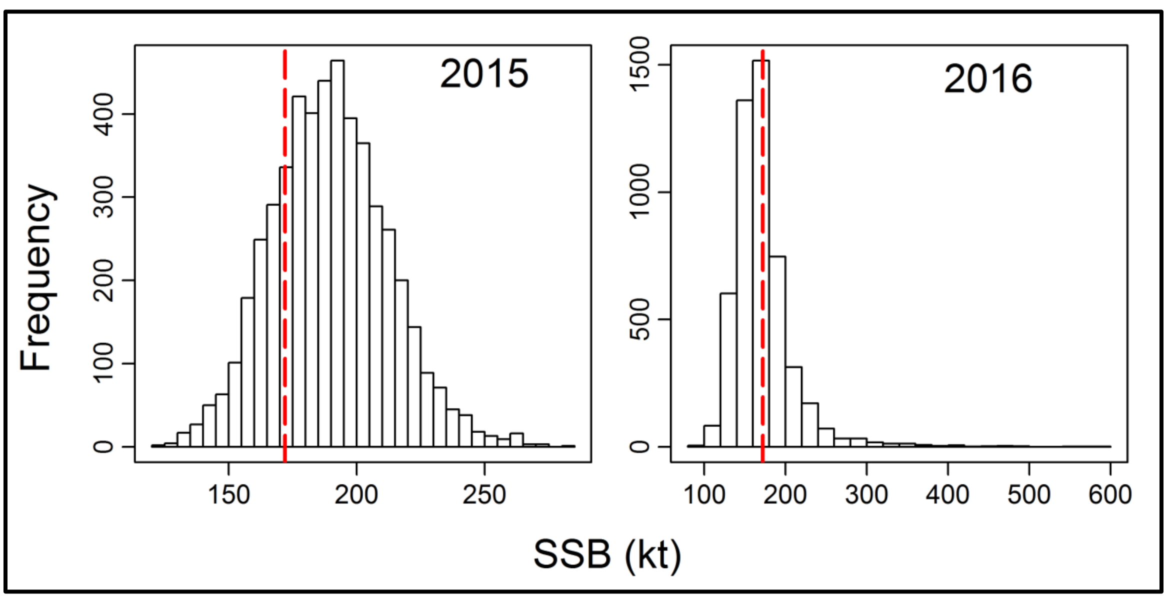

Figure 26. Posterior distributions of estimated total SSB of fall-spawning herring of the southern Gulf of St. Lawrence at the start of 2015 and 2016 based on MCMC sampling.

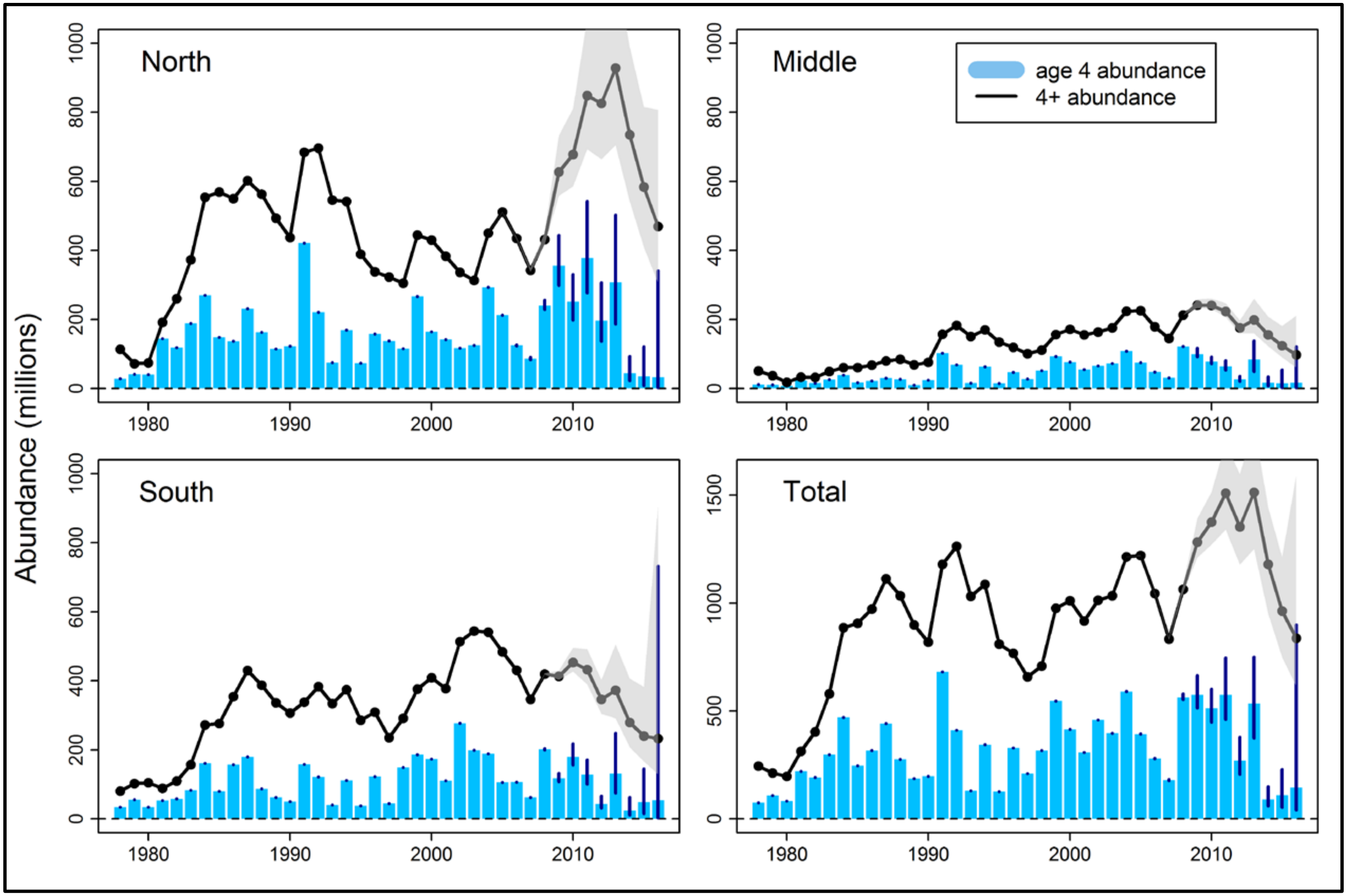

Figure 27. Estimated abundance (millions) of fall spawning herring at ages 4 (histograms) and 4+ (circle symbols and lines) in the three regions and summed over regions for the southern Gulf of St. Lawrence. Line and circles (age 4+) and bars (age 4) show the median estimates and shading or vertical lines show the 95% confidence intervals.

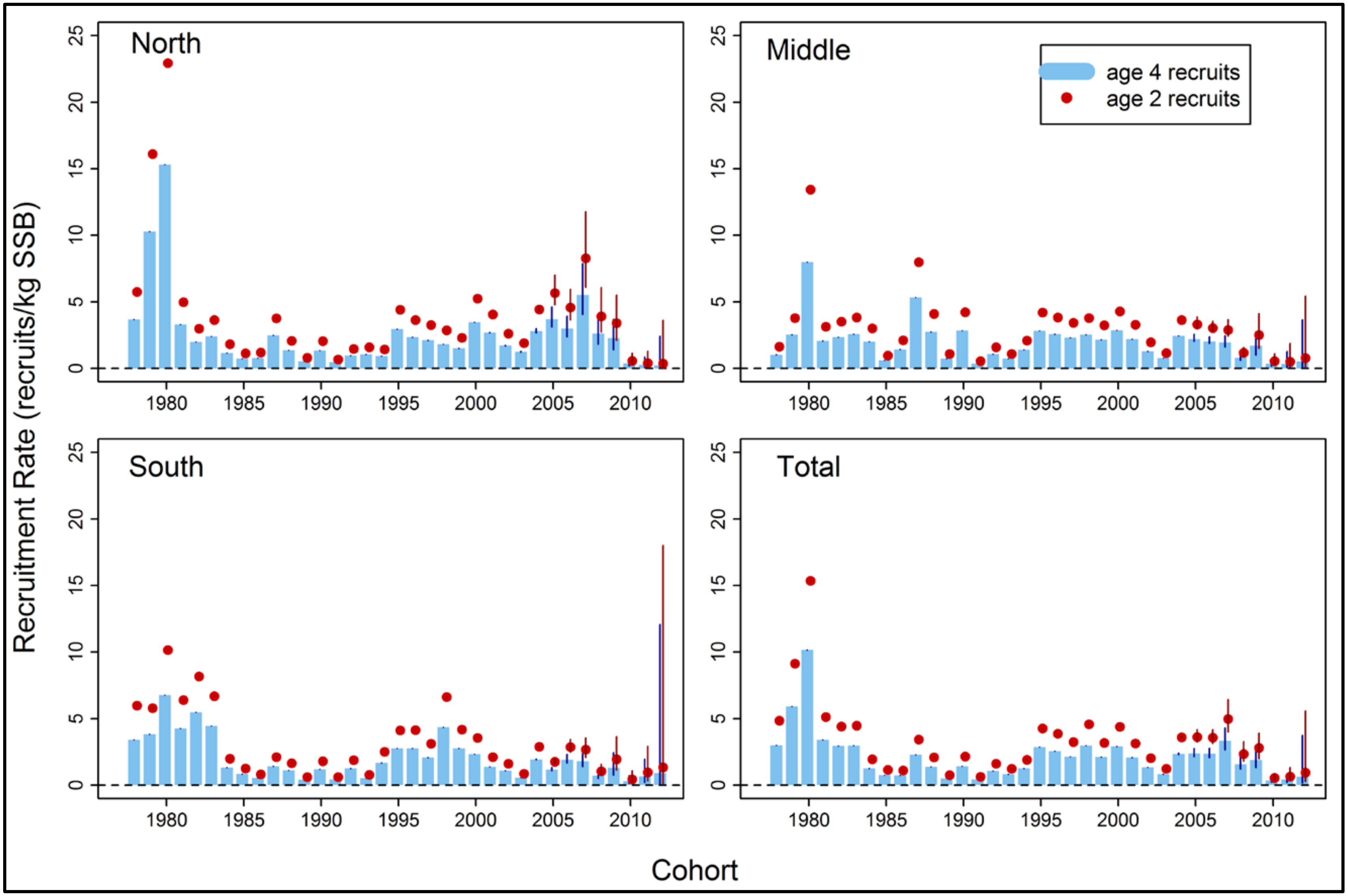

Figure 28. Estimated recruitment rate (recruits per kg of SSB) at age 2 (circles) and at age 4 (bars) of fall spawning herring in the three regions (North, Middle, South) and summed over regions (Total) for the southern Gulf of St. Lawrence. Line and circles (age 4+) and bars (age 4) show the median estimates and shading or vertical lines show the 95% confidence intervals.

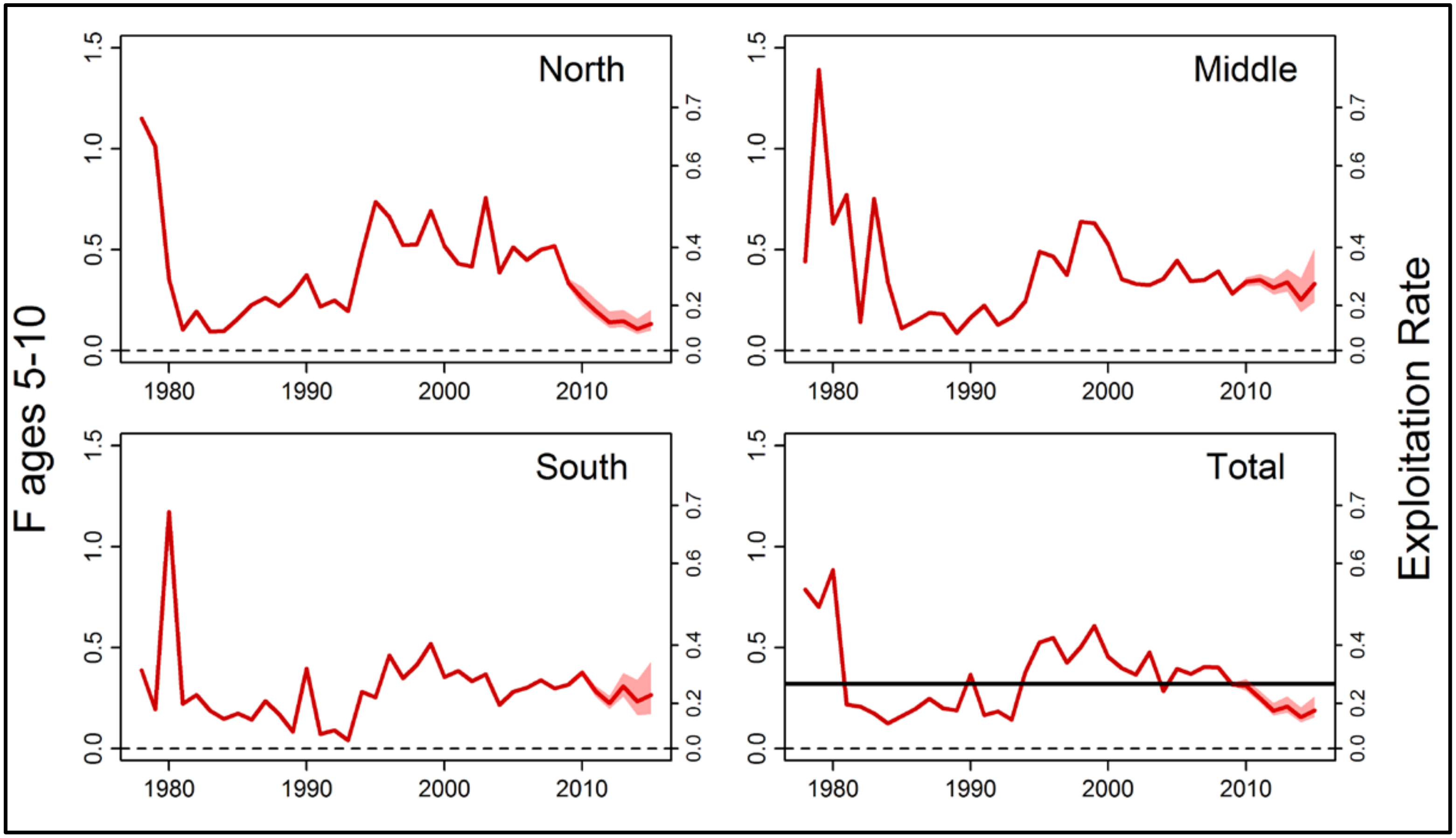

Figure 29. Estimated ages 5 to 10 fishing mortality rate (instantaneous rate F, left axes; annual exploitation rate right axes) of fall-spawning herring in the three regions (North, Middle, South) and averaged over regions (weighted by regional abundance at ages 5-10 years) of the southern Gulf of St. Lawrence. Lines show the median estimates and shading their 95% confidence intervals. The horizontal line shows the reference removal rate (F level) in the healthy zone.

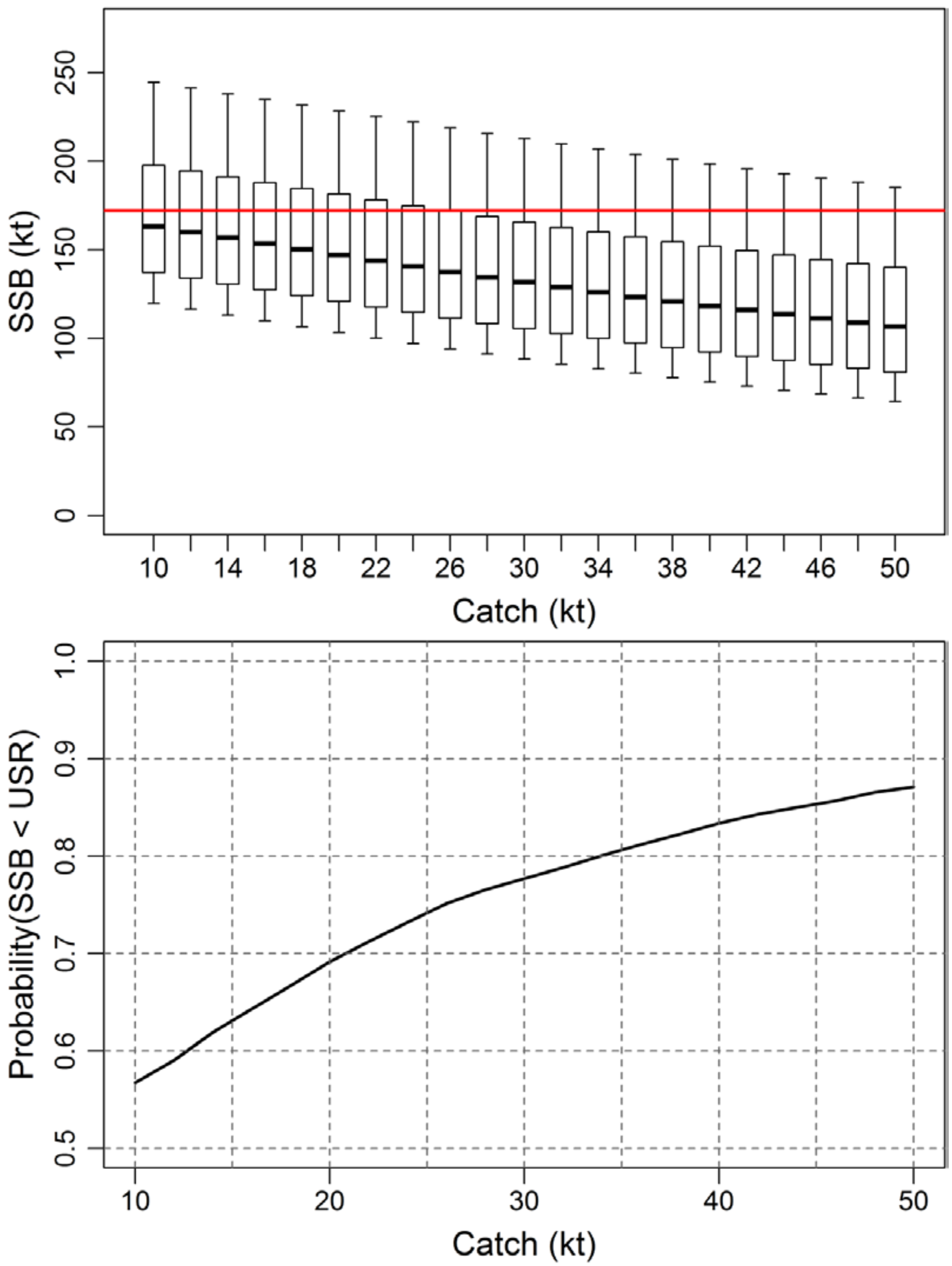

Figure 30. Beginning of year 2018 SSB (kt) of fall spawning Atlantic herring in the southern Gulf of St. Lawrence (upper panel) and probabilities that total SSB at the start of 2018 will be below the USR (lower panel) at various levels of catch in 2016 and 2017. The results of projections include the estimates of age 4 abundance in 2016. In the upper panel, the heavy horizontal line is the median estimate, the box extends from the 25^{th} to 75^{th} percentiles of the estimates and the error bars show the 80% confidence intervals (10^{th} to 90^{th} percentiles).

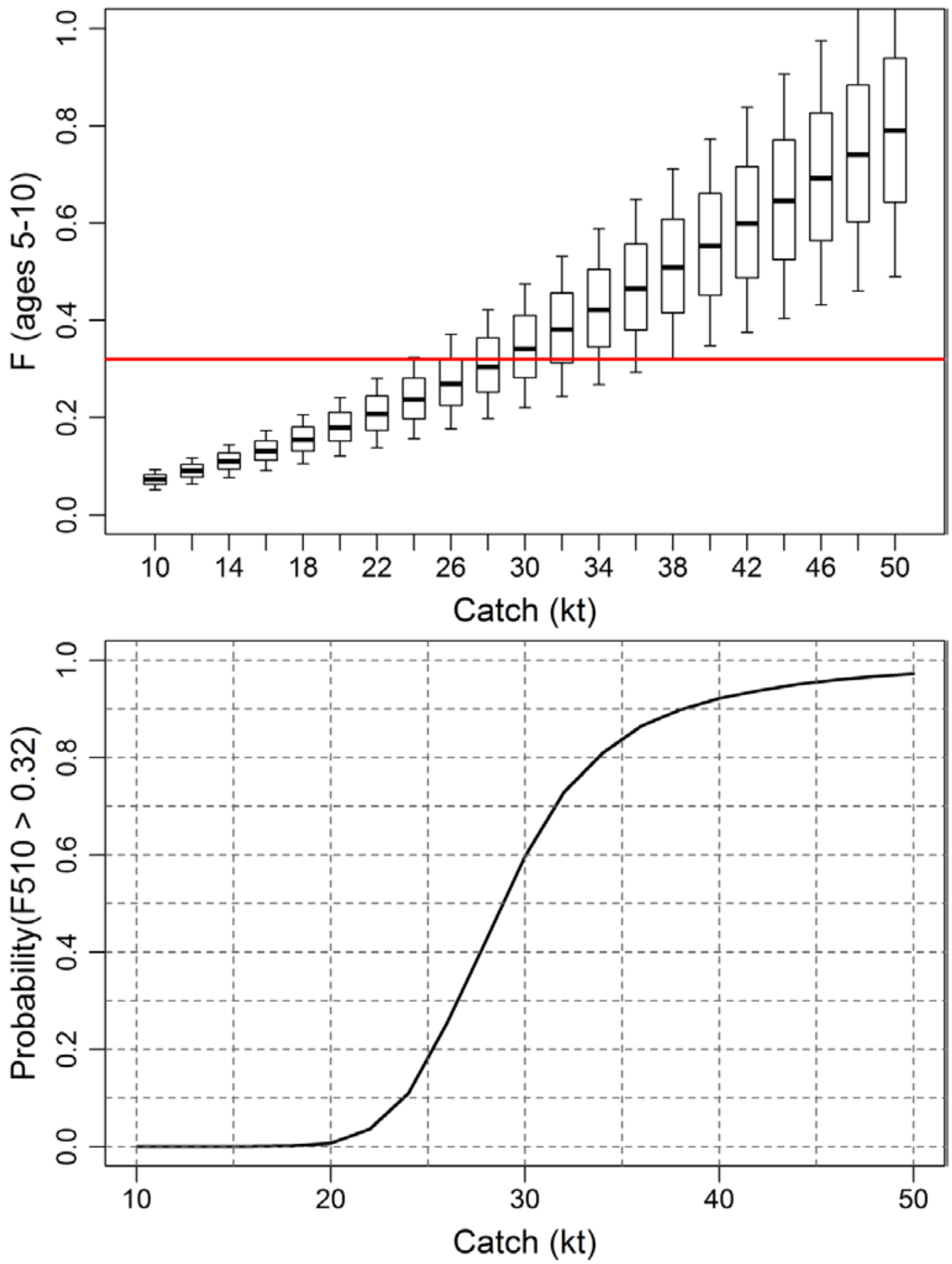

Figure 31. Estimated fishing mortality rates for ages 5 to 10 ($F_{5\text{-}10}$) (upper panel) and probabilities that average $F_{5\text{-}10}$ in 2017 will be greater than the reference removal rate of F = 0.32 (lower panel) at various levels of catch in 2016 and 2017 of fall spawning Atlantic herring from the southern Gulf of St. Lawrence. The results of projections include the estimates of age 4 abundance in 2016. In the upper panel, the heavy horizontal line is the median estimate, the box extends from the 25th to 75th percentiles of the estimates and the error bars show the 80% confidence intervals (10th to 90th percentiles).

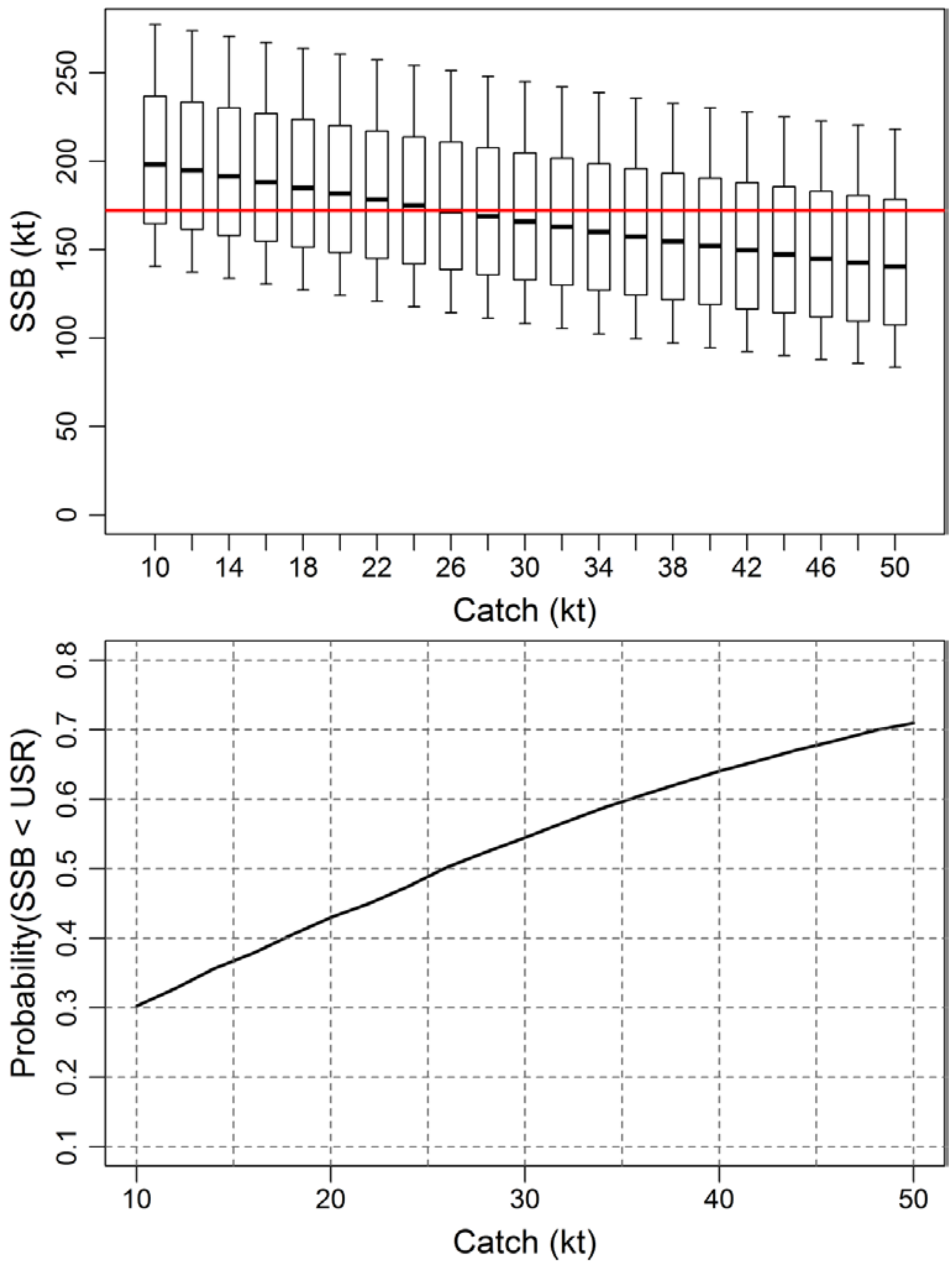

Figure 32. Beginning of year 2018 SSB (kt) of fall spawning Atlantic herring in the southern Gulf of St. Lawrence (upper panel) and probabilities that total SSB at the start of 2018 will be below the USR (lower panel) at various levels of catch in 2016 and 2017. The results of projections exclude the estimates of age 4 abundance in 2016. In the upper panel, the heavy horizontal line is the median estimate, the box extends from the 25^{th} to 75^{th} percentiles of the estimates and the error bars show the 80% confidence intervals (10^{th} to 90^{th} percentiles).

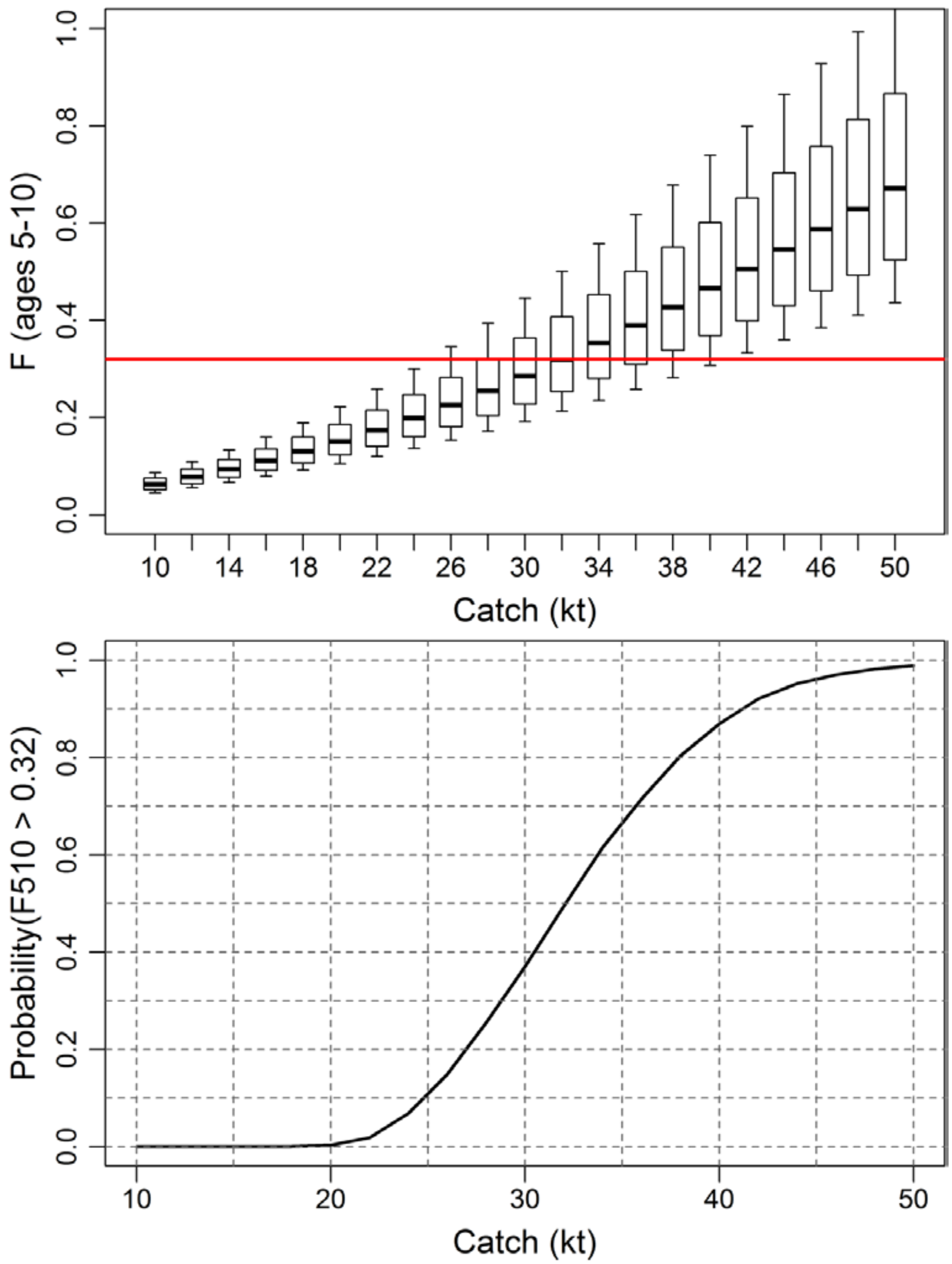

Figure 33. Estimated fishing mortality rates for ages 5 to 10 (F_{5-10}) (upper panel) and probabilities that average F_{5-10} in 2017 will be greater than the reference removal rate of F = 0.32 (lower panel) at various levels of catch in 2016 and 2017 of fall spawning Atlantic herring from the southern Gulf of St. Lawrence. The results of projections exclude the estimates of age 4 abundance in 2016. In the upper panel, the heavy horizontal line is the median estimate, the box extends from the 25th to 75th percentiles of the estimates and the error bars show the 80% confidence intervals (10th to 90th percentiles).