Fisheries and Oceans Canada
Ecosystems and Oceans Science

Pêches et Océans Canada
Sciences des écosystèmes et des océans

NOAA FISHERIES
NATIONAL MARINE FISHERIES SERVICE

CERT

Comité d'évaluation des ressources transfrontalières

Document de référence 2015/03

Ne pas citer sans
autorisation des auteurs

TRAC

Transboundary Resources Assessment Committee

Reference Document 2015/03

Not to be cited without
permission of the authors

Assessment of Eastern Georges Bank Atlantic Cod for 2015

Y. Wang[1], L. O'Brien[2], I. Andrushchenko[1], and K.J. Clark[1]

[1]Fisheries and Oceans Canada
St. Andrews Biological Station
531 Brandy Cove Roadd
St. Andrews, New Brunswick E5B 3L9
Canada

[2]NOAA/NMFS
Northeast Fisheries Science Center
166 Water Street
Woods Hole, Massachusetts 02543
USA

Canada

TABLE OF CONTENTS

ABSTRACT

The combined 2014 Canada/USA Atlantic Cod catches were 574 mt with a quota of 700 mt. Catches in the National Marine Fisheries Service (NMFS) fall and spring surveys decreased from 2014, and catches from all three research surveys were among the lowest in the time series. Both fishery and survey catches showed truncated age structure in recent years.

The Virtual Population Analysis (VPA) “M 0.8” model from the 2013 benchmark assessment was used to provide catch advice in conjunction with a consequence analysis of the uncertainties in the VPA “M 0.8” and ASAP model results. In the VPA “M 0.8” model, natural mortality (M) was assumed to be 0.2 except M = 0.8 for ages 6+ since 1994, whereas in the ASAP model M = 0.2 for all ages and years.

While management measures have resulted in a decreased exploitation rate since 1995, total mortality has remained high and adult biomass has fluctuated at a low level. The adult population biomass at the beginning of 2015 was estimated at 10,048 mt, which was about 20% of the adult biomass in 1978. Fishing mortality was high prior to 1994 and was estimated to be 0.04 in 2014, the lowest on record. Recruitment at age 1 has been low in recent years. High natural mortality, lower weights at age in the population in recent years and poor recruitment have contributed to the lack of rebuilding.

In 2016, a 50% probability of not exceeding fishing reference point F = 0.11 corresponds to catches of 675 mt. However, given the extremely low spawning stock biomass (SSB), the Transboundary Resources Assessment Committee (TRAC) advises that management aim to rebuild Spawning Stock Biomass (SSB). Even with no fishing in 2016 there is a greater than 50% risk of a decrease in adult biomass from 2016 to 2017, and a catch of 475 mt would result in at least a 75% risk that 2017 adult biomass would decrease.

In 2017, a 50% probability of not exceeding F = 0.11 corresponds to a catch of 725 mt. A catch of 625 mt will result in a neutral (50%) risk that 2018 age 3+ biomass will be lower than 2017, whereas a catch of 225 mt has a lower (25%) risk.

Discovery that the risk analysis did not account for the differences in natural mortality rate between young ages and ages 6+ could have impacted catch advice since 2009. Considering the current status of the stock, the TRAC recommends that the risk calculations provided remain appropriate despite the unaccounted for age specific difference in the stochastic projections.

A consequence analysis to understand the risks associated with assumptions of the VPA “M 0.8” and ASAP “M 0.2” model was examined in the projection and risk analysis. The consequence analysis reflects the uncertainties in the assessment model assumptions. Despite model uncertainties, all assessment results indicate that low catches are needed to promote rebuilding.

RÉSUMÉ

En 2014, les prises de morues franches combinées du Canada et des États-Unis se sont chiffrées à 574 tm, sur un quota de 700 tm. Les prises des relevés d'automne et de printemps effectués par le National Marine Fisheries Service (NMFS) ont diminué par rapport à 2014, et les prises des trois relevés de recherche comptaient parmi les plus basses de la série chronologique. Au cours des dernières années, les prises de la pêche et des relevés ont montré une structure selon l'âge tronquée.

Le modèle d'analyse de population virtuelle (APV) « M = 0,8 » de l'évaluation de référence de 2013 a été utilisé pour faire des recommandations en matière de prises en plus d'une analyse des conséquences des incertitudes liées aux résultats du modèle d'APV « M = 0,8 » et du modèle du PESA. Dans le modèle d'APV « M = 0,8 », la mortalité naturelle (M) est estimée à 0,2, sauf pour les individus de 6 ans et plus, où M = 0,8 depuis 1994, tandis que dans le modèle du Programme d'évaluation selon la structure d'âge (PESA), la mortalité naturelle est estimée à 0,2 pour tous les âges et toutes les années.

Quoique les mesures de gestion aient eu pour effet de faire baisser le taux d'exploitation depuis 1995, la mortalité totale est demeurée élevée et la biomasse des adultes a fluctué tout en restant faible. La biomasse de la population adulte était estimée à 10 048 tm au début de 2015, ce qui correspondait à environ 20 % de la biomasse des adultes de 1978. La mortalité par pêche était élevée avant 1994 et elle a été estimée à 0,04 en 2014, soit le niveau le plus faible jamais enregistré. Le recrutement à l'âge 1 a été faible ces dernières années. Au cours des dernières années, la mortalité naturelle élevée, les plus faibles poids selon l'âge au sein de la population et le faible recrutement ont nui au rétablissement du stock.

En 2016, une probabilité de 50 % que le taux de mortalité par pêche ne dépasse pas le point de référence de la pêche où F = 0,11 suppose des prises de 675 tm. Toutefois, le Comité d'évaluation des ressources transfrontalières (CERT) recommande que les gestionnaires tentent de rétablir la biomasse du stock reproducteur (BSR) qui est extrêmement faible. Même sans pêche en 2016 suppose qu'il existe un risque de plus de 50 % d'une diminution de la biomasse des adultes de 2016 à 2017, et des prises de 475 tm se traduiraient au minimum par un risque de 75 % d'une diminution de la biomasse des adultes de 2017.

En 2017, une probabilité de 50 % que le taux de mortalité par pêche ne dépasse pas F = 0,11 suppose des prises de 725 tm. Des prises de 625 tm se traduiraient par une probabilité neutre (50 %) que la biomasse des adultes de 3 ans et plus de 2018 soit inférieure à 2017, tandis que des prises de 225 tm présenteraient un risque inférieur (25 %).

La découverte que l'analyse des risques ne tenait pas compte des différences des taux de mortalité naturelle entre les jeunes poissons et les âges de 6 ans et plus pourraient avoir eu une incidence sur les recommandations en matière de prises depuis 2009. En tenant compte de l'état actuel des stocks, le CERT croit que le calcul des risques fourni demeure approprié, malgré la différence spécifique à l'âge qui n'est pas prise en compte dans les projections stochastiques.

Dans la projection et l'analyse des risques, on a examiné les résultats d'une analyse des conséquences, afin de comprendre les risques associés aux hypothèses du modèle d'APV « M = 0,8 » et du modèle du PESA « M = 0,2 ». L'analyse des conséquences reflète les incertitudes liées aux hypothèses du modèle d'évaluation. Indépendamment de ces incertitudes liées au modèle, tous les résultats de l'évaluation militent en faveur de faibles prises pour faciliter le rétablissement du stock.

INTRODUCTION

The basis and background for the delineation of management units of cod on Georges Bank and the vicinity were reviewed and summarized at the 2009 Eastern Georges Bank cod benchmark assessment meeting (O'Brien and Worcester 2009). For the purpose of a sharing agreement and consistent management by Canada and the USA, agreement was reached that the transboundary management unit for Atlantic Cod would be limited to the eastern portion of Georges Bank (DFO Statistical Unit Areas 5Zej and 5Zem; USA Statistical Areas 551, 552, 561 and 562) (DFO 2002). The management area is shown in Figure 1.

The 2015 assessment for the management unit of cod on Eastern Georges Bank (Figure 1) was updated using the 2013 benchmark model formulations (Claytor and O'Brien 2013). The assessment used Canadian and USA fishery information updated to 2014, including commercial landings and discards, the Fisheries and Oceans Canada (DFO) survey updated to 2015, the National Marine Fisheries Services (NMFS) spring survey updated to 2015, and the NMFS fall survey updated to 2014.

FISHERY

COMMERCIAL FISHERY CATCHES

Combined Canada/USA catches averaged 17,198 mt between 1978 and 1993, peaked at 26,463 mt in 1982, and then declined to 1,683 mt in 1995. They fluctuated around 3,000 mt until 2004 and subsequently declined again. Catches in 2014 were 574 mt, including 30 mt of discards (Table 1; Figure 2). Catches included USA and Canadian discards in all years where discard estimates were available.

Canadian catches peaked at 17,898 mt in 1982 and declined to 1,140 mt in 1995 (Table 1; Figure 3). Since 1995, with lower cod quotas, the fishery has reduced targeting for cod through changes in fishing practices (Appendix A). From 1995-2013, Canadian catches fluctuated between 463 mt and 3,405 mt (Table 1). In 2014, total Canadian catch (extracted landings on May 15, 2014, was 430 mt), including discards, was 458 mt against a quota of 546 mt, taken primarily between June and December by otter trawl and longline (Figures 4 and 5). All 2014 landings were subject to dockside monitoring.

For the Canadian otter trawl fishery on Eastern Georges Bank, codend of 130 mm square mesh has been the standard mesh size since 1995. In 2014, a test project with alternative codend meshes of 125 mm square and 145 mm diamond was undertaken for the purpose of improving the catch rate of haddock and reducing cod bycatch relative to haddock catches. The test result was reported by Morin (2014).

For the Canadian groundfish fishery on Eastern Georges Bank, discard of cod are not permitted. From 1996 to 2014, the ratio of sums method, which uses the difference in ratio of cod to haddock from observed and unobserved trips, was applied to estimate discards of cod (Van Eeckhaute and Gavaris 2004; Hunt et al. 2005; Gavaris et al. 2006, 2007a; Clark et al. 2008). Cod discards from the 2014 Canadian groundfish fishery were estimated at 10 mt from the mobile gear and 3 mt from the fixed gear fishery (Table 1).

For the Canadian scallop fishery, landings until 1995 included those catches reported by the scallop fishery. Since 1996, the Canadian scallop fishery has not been permitted to land cod. The 3-month moving average observed discards rate has been applied to scallop effort to estimate discards of cod since 2005 (Gavaris et al. 2007b). In 2014, the estimated discards of cod by the Canadian scallop fishery were 15 mt (Table 1).

USA catches increased from 5,502 mt in 1978 to 10,550 mt in 1984 and subsequently fluctuated around 6,000 mt between 1985 and 1993 (Table 1; Figure 3). Since December 1994, under the more restricted fishery management measures (Appendix A), USA catches during 1994-2013 ranged between 39 mt and 1,204 mt. Total USA catch (landings and discards combined) was 116 mt for calendar year 2014 (Table 1; Figure 3). The majority of USA landings are usually taken by the second calendar quarter with the least amount landed during the third quarter (Figure 5). Otter trawl gear accounted for 96% and gillnet gear about 4% of the landings during 2014.

Discards by USA groundfish fleets occur because of trip limits and minimum size restrictions. In July 2013, there was a reduction in the minimum size for the USA fishery from 22 inches to 19 inches. A ratio of discarded cod to total kept of all species (d:k) was estimated on a trip basis (Wigley et al. 2008). Total discards (mt) were estimated from the product of d:k and total commercial landings from the Eastern Georges Bank area. In the 2012 SAW55 cod benchmark meeting (NEFSC 2013), ‘Delphi’ determined mortality rates (otter trawl: 75%) were applied to the final estimates of USA discards (Table 1). The estimated discards of cod in the groundfish fishery were 2 mt in 2014 (Table 1; Figure 3).

SIZE AND AGE COMPOSITION

The size and age compositions of the 2014 Canadian groundfish fishery landings were derived from the pooled port and at-sea samples from all principal gears and seasons (Table 2; Figure 6). Landings by length peaked at 49 cm (19 in) for bottom trawlers and 64 cm (25 in) for longliners. Gillnetters caught fewer cod but these fish were larger, peaking at 73 cm (29 in) (Figure 7). The combined landings for all gears peaked at 49-61 cm (19-24 in) (Figure 8).

The size composition by length of cod discards from the 2014 Canadian scallop fishery was derived from at-sea sampling, and peaked at 34 cm (13 in) (Figure 7). The discards by length from the groundfish fishery were assumed to have the same size composition as the groundfish landings. The Canadian combined cod discards by length in 2014 from the groundfish and scallop fisheries peaked at 34 to 49 cm (13 to 19 in) (Figure 8).

Otoliths taken from port samples were used for age determinations. Comparisons have indicated generally good agreement between DFO and NMFS age readers. (http://www.nefsc.noaa.gov/fbp/QA-QC/).

Catch at age composition was obtained by applying quarterly fishery age-length keys to the size composition. The age-length key from the 2014 DFO survey was used to augment the first quarter key.

The size and age compositions of the 2014 USA fishery landings on Eastern Georges Bank were estimated using port samples of length frequencies and age structures collected from all principal gears and seasons by market category (Wang et al. 2014). The age composition of the 2014 USA landings was estimated by market category by applying age-length keys to the size composition pooled by calendar quarter, semi-annually, or annually depending on the number of available length samples. The USA sampling protocol is one sample per 100 mt of landings (i.e., where 1 length sample = 100 fish and 1 age sample = 20-25 fish). The 2014 age-length keys were supplemented with age samples from statistical areas 522 and 525 for the catch at age calculations. Landings by length in 2014 peaked at 53-59 cm (21-23 in) (Figure 9).

The size and age composition of discarded fish were estimated using at-sea observer samples of length frequency and commercial and NMFS survey age keys from the same area and season. Discards in 2014 peaked at 47 cm (19 in) (Figure 9).

The 2014 total catch composition of combined landings and discards for Canada and the USA is shown in Figure 10. Canadian catches by length peaked at 49-61 cm (19-24 in); and USA catches by length peaked at 53-59 cm (21-23 in).

The 2014 combined Canada/USA landings and discards fishery age composition, by number, was the highest for the 2010 year class at age 4 (43%), followed by the 2011 year class at age 3 (35%) and the 2009 year class at age 5 (12%) (Table 3; Figure 11). By weight, the 2010 year class dominated the 2014 fishery (47%) followed by the 2011 (31%) and 2008 year classes (9%) (Figure 11). The contribution of age 7 and older fish continued to be small in recent years, 0.2% by number and 1% by weight in 2014 (Table 3; Figure 12).

Fishery weights at age showed a declining trend starting in the early 1990s (Table 4; Figure 13). Compared to 2013, the weights at age in 2014 improved for ages 3, 7 and 8, but still at lower levels.

ABUNDANCE INDICES

RESEARCH SURVEYS

Surveys of Georges Bank have been conducted by DFO each year (February/March) since 1986 and by NMFS each spring (April) since 1968 and each fall (October) since 1963. All surveys use a stratified random design (Figures 14 and 15). Most of the DFO surveys have been conducted by the CCGS *Alfred Needler* using a Western IIA trawl. A sister ship, the CCGS *Wilfred Templeman*, conducted the survey in 1993, 2004, 2007, and 2008. No conversion factors are available for the *Templeman*, however, this vessel is considered to be similar in fishing strength to the *Needler*. For the NMFS surveys, two vessels have been employed and there was a change in the trawl door in 1985. Vessel and door type conversion factors derived experimentally from comparative fishing have been applied to the survey results to make the series consistent (Forrester et al. 1997). Additionally, two different trawl nets have been used on the NMFS spring survey, a modified Yankee 41 from 1973-81 and a Yankee 36 in other years, but no net conversion factors were available for cod. A new net and vessel (NOAA ship *Henry B. Bigelow*), with revised station protocols have been used to conduct the NMFS spring and fall surveys since 2009. Length calibration factors (Brooks et al. 2010) were applied to the NMFS spring and fall survey results since 2009 (Wang et al. 2014).

The spatial distribution of ages 3 and older cod caught during the 2014 NMFS fall, 2015 DFO and 2015 NMFS spring stratified random surveys (Wang et al. 2014; Figures 14 and 15) were similar to observations from those surveys over the previous decade, with most fish concentrated on the northeastern part of Georges Bank (Figures 16-18).

The catch in numbers from the 2015 DFO survey was somewhat higher than 2014, but still amongst the lowest in the time series (1986-2015) (Table 5). The 2011 year class at age 4 was 44% by number, followed by the 2013 year class at age 2 (27% by number) and the 2010 year class at age 5 (25% by number). There was no catch of the 2014 year class at age 1 and no catch of fish older than 7 (Table 5; Figure 19).

The 2015 NMFS spring survey catch decreased from 2014. Similar to the DFO survey, 2015 was among the lowest in the time series (Table 6). The 2010 year class at age 5 was dominant (40% by number), followed by the 2011 year class at age 4 (27% in number) and 2013 year class at age 2 (20% in number). There were no catch of fish older than 6 (Table 6; Figure 19).

The catch from the 2014 NMFS fall survey decreased from 2013, below the average of the time series. There was one big tow, which contributed 48% to the total catch. The 2010 year class at age 4 was 32% by number, followed by the 2011 year class at age 3 (21% by number). The 2013 year class at age 1 accounted for 21% by number (Table 7; Figure 19).

The coefficient of variation (CV) of stratified mean catch number per tow for the three surveys is shown in Tables 8-10 and Figure 20. Median CV values indicated the most variable catch being the ages 1 and 8 for the DFO survey, ages 7 and 8 for the NMFS spring survey, and ages 1 and 5 for the NMFS fall survey. The CVs were similar between the DFO and NMFS spring survey values and smaller compared to the NMFS fall survey values. The catch from all three surveys became more variable after mid-1990s, which might be caused by patchy distribution of cod at low abundance.

The survey abundance at age shows poor recruitment since the 1990 year class in all three surveys and representation of older ages in recent years were poor (Tables 5-7; Figure 19).

For the survey swept area biomass, both the 2014 NMFS fall survey and 2015 NMFS spring survey biomass decreased from last year; the 3 surveys were among the lowest in the time series (Table 11; Figure 21).

The number weighted average weights at age derived from the DFO survey and NMFS spring survey were used to represent the population weight at age for the beginning of the year. All the weights at age display a declining trend since the early-1990s (Table 12; Figure 22).

Fulton’s condition factor (K), an indicator that uses observed weight and length to measure fish condition, was calculated using the data from all three surveys. It showed notable downward trends in recent years from the DFO survey samples and NMFS spring survey samples (Figure 23), although the NMFS spring survey does show an increasing trend since 2011. There were limited catches from the NMFS fall survey (Table 7). The trend from those samples was not clear (Figure 23).

The total mortality (Z) was calculated by two age groups (ages 4 and 5 and ages 6 to 8) using DFO survey and NMFS spring survey abundance indices, separately. It showed that Z of ages 4 and 5 has been lower than the older age group (Figure 24). Z has been high throughout the assessment time period for both age groups (Figure 24) and increasing in recent years, although relative F (fishery catch at age per survey abundance indices) declined significantly since the mid-1990s (Figure 25).

ESTIMATION AND DIAGNOSTICS

CALIBRATION OF VIRTUAL POPULATION ANAYSIS (VPA)

At the benchmark assessment review in 2013 there was no consensus on a benchmark model, however, the TRAC did agree to provide catch advice based on a virtual population analysis (VPA) “M 0.8” model, in conjunction with a consequence analysis that compares the VPA and ASAP model (presented below) projection results (Claytor and O’Brien 2013). The VPA used fishery catch statistics and size and age composition of the catch from 1978 to 2014 (including discards). The adaptive framework, ADAPT (Gavaris 1988), was used for calibrating the VPA with trends in abundance from three research bottom trawl survey series: DFO, NMFS spring and NMFS fall. Computational formulae used in ADAPT are described in Rivard and Gavaris (2003a).

In this model, natural mortality (M) was assumed equal to 0.2, except for ages 6+ from 1994 onwards where M was fixed at 0.8. The data used in the model were:

$C_{a,t}$ = catch at age for ages a = 1 to 10+ and time t = 1978-2014, where t represents the year during which the catch was taken.

$I_{1,a,t}$ = DFO survey for ages a = 1 to 8 and time t = 1986.17, 1987.17… 2014.17, 2015.00.

$I_{2,a,t}$ = NMFS spring survey (Yankee 41) for ages a = 1 to 8 and time t = 1978.28, 1979.28, 1980.28, 1981.28.

$I_{3,,a,t}$ = NMFS spring survey (Yankee 36) for ages a = 1 to 8 and time t = 1982.28, 1983.28… 2014.28, 2015.00.

$I_{4,a,t}$ = NMFS fall survey for ages a = 1 to 5 and time t = 1978.69, 1979.69… 2013.69, 2014.69.

The population was calculated to the beginning of 2015; therefore the DFO and NMFS spring survey indices for 2015 were designated as occurring at the beginning of the year (i.e., 2015.00). The benchmark formulations assumed that observation errors for the catch at age data were negligible. Observation errors for the abundance indices at age were assumed to be independent and identically-distributed after taking natural logarithms of the values. Zero observations for abundance indices were treated as missing data, as the logarithm of zero is not defined. Fishing mortality on age 9 for 1978-2013 was assumed to be equal to the population weighted average fishing mortality on ages 7 and 8. The population abundance at age 9 in 2014 was estimated, as there were no age 9 cod caught in the fishery in 2014. The benchmark VPA formulation did not provide specific guidance on how to address this situation, so this represents a change from previous years.

Estimation was based on minimization of the objective function:

$$\sum_{s,a,t}\left(lnI_{s,a,t}-\left(\hat{\kappa}_{s,a}+v_{a,t}\right)\right)^2$$

where s indexes survey. The estimated model parameters were:

$v_{a,t}$ = $lnN_{a,t}$ = *ln* population abundance for ages a = 2 to 9 at beginning of 2015; age 9 in 2014.

$K_{1,a}$ = *ln* DFO survey catchability for ages a = 1 to 8 at time t = 1986-2015

$K_{2,a}$ = *ln* NMFS spring survey (Yankee 41) catchability for ages a = 1 to 8 at time t = 1978-1981.

$K_{3,a}$ = *ln* NMFS spring survey (Yankee 36) catchability for ages a = 1 to 8 at time t = 1982-2015.

$K_{4,a}$ = *ln* NMFS fall survey catchability for ages a = 1 to 5 at time t = 1978-2014.

Statistical properties of the estimators were determined using conditional non-parametric bootstrapping of model residuals (Efron and Tibshirani 1993; Rivard and Gavaris 2003a).

For the beginning of 2015, the population abundance estimate of the 2013 year classes at age 2 exhibited the largest relative bias of 14% and relative error of 56%. The relative bias for other ages ranged between 1% and 8% and the relative error ranged between 45% and 31% (Table 13). The population abundance of the 2005 year class at age 9 in 2014 was estimated as 0.09 million, with relative bias of 1% and relative error of 24%. Survey catchability (q) at age progressively increased until age 4 for DFO survey and NMFS spring survey (Figure 26). Survey catchability at age for the NMFS fall survey was very low (Figure 26).

The overall fit of model estimated biomass to the DFO, NMFS spring and NMFS fall surveys was generally consistent with the survey trends after 1994 (Figure 27). There were residual patterns that suggested obvious year effects (Figure 28). Average fishing mortality (F4-9) by time blocks for 1978-1993, 1994-2009 and the recent 5 years 2010-2014 was 0.48, 0.27 and 0.08, respectively. The temporal trend of fishing mortality was consistent with fishery management effort trend. The fishery partial recruitment (PR) started to show a dome-shape in the most recent 5-year period (Figure 29). In contrast, there was relatively flat fishery PR pattern for the earlier two time periods, except for the age 10+ group (Figure 29).

Retrospective analysis was used to detect any bias of consistently overestimating or underestimating fishing mortality, biomass, or recruitment relative to the terminal year estimates. At the 2013 benchmark meeting, the VPA “M 0.8” model with catch data through 2011 did not show any retrospective pattern (Claytor and O’Brien 2013), suggesting that the model assumptions on natural mortality were appropriate and that the fishery catch at age was consistent with the survey indices. However, in the 2013 assessment, with catch data through 2012 (Wang and O'Brien 2013a), the 2003 year class was estimated to be substantially smaller than the estimate from the 2013 benchmark model formulation with one less year of data. In the 2013 assessment, the 2003 year class was estimated at 4.1 million at age 1 compared to the benchmark estimate of 13.5 million, with one less year of data (Figure 30). The estimate was 4.4 million in the 2015 (Table 15) and 2014 assessments, close to the 2013 assessment (Wang et al. 2014). In the retrospective analysis, the 2015 assessment results were very close with the 2014 and 2013 assessment. The average Mohn's rho was calculated for the seven retrospective relative differences in assessment years 2009-2015. The values for Mohn's rho were 0.5 for SSB, -0.34 for F, and -0.24 for age-1 recruitment (Table 14).

Possible reasons for the appearance of a retrospective bias after adding one more year of data were explored in the 2013 and 2014 assessments (Wang and O'Brien 2013a; Wang et al. 2014). One reason could be error in the fishery catch which caused low catch of the 2003 year class at age 9 in 2012 or, consequently, error which caused high catch of the 2003 year class at the younger ages (3-6). Another possible reason might be the actual natural mortality experienced by the 2003 year class between ages 8 and 9 was higher than the assumed M = 0.8 (Z>>1 from surveys using catch curve analysis). Using the assumed natural mortality would artificially reduce the abundance of the entire 2003 cohort in the backward calculation (even if the 0.8 is a good approximation of M among ages 6 and 7).

In the 2013 and 2014 assessment, sensitivity runs were conducted to explore the uncertainties in estimation of the 2003 year class (Wang and O'Brien 2013a; Wang et al. 2014). The sensitivity analyses suggested that the low estimate of the 2003 year class may be an outlier, which then caused a retrospective bias in the 2013 and 2014 assessment. The "M 0.8" model got very similar population abundance estimates of other year classes in the terminal year or recruitments in other years when the effect of the 2003 year class was removed from the objective function by removing the 2003 year class abundance indices. Also the bias in the estimate of the 2003 year class had little impact on projection in the 2013 and 2014 assessment (Wang and O'Brien 2013a; Wang et al. 2014).

Fixing the retrospective bias could be done using the "est 2003yc" model (Figure 31). In this sensitivity run, the 2003 year class at age 9 was estimated in the model for the terminal year of 2013, 2014 and 2015, respectively. The average Mohn's rho was calculated for the seven retrospective relative differences in years 2009-2015. The values for Mohn's rho were 0.08 for SSB, 0.04 for F, and -0.23 for age-1 recruitment (Table 14).

Applying the Mohn's rho adjustment was thought not to be appropriate and was not conducted in this assessment. Residuals of the 2003 year class from the three surveys were predominantly positive, which means that the 2003 year class was underestimated in the 2013, 2014 and 2015 assessment from the "M 0.8" model (Figure 32). Mohn's rho adjustment would further underestimate the biomass. The sensitivity analysis in the 2013 and 2014 assessment illustrated the terminal year population abundance estimate and projection from the VPA "M 0.8" model is robust to the uncertainties in the estimate of the 2003 year class.

STATE OF RESOURCE

The estimates presented below were from the 2015 VPA "M 0.8" model (Tables 15-17).

Adult population biomass (ages 3+) declined substantially from about 52,000 mt in 1990 to below 16,000 mt in 1995, the lowest observed at that time (Table 14; Figure 33). Biomass has subsequently fluctuated between 5,900 mt and 18,800 mt. The estimate of age 3+ biomass was 10,048 mt (80% confidence interval: 8,272-12,579 mt) at the beginning of 2015 (Table 14). The increase of age 3+ biomass during 2005-2009 was largely due to the recruitment and growth of the 2003 year class and, since 2011, was largely due to the recruitment and growth of the 2010 year class (Figure 34). High natural mortality, lower weights at age in the population in recent years and generally poor recruitment have contributed to the lack of sustained rebuilding. Survey biomass indices have been lower since the mid-1990s (Figure 21). The estimated adult population biomass at the beginning of 2015 from the VPA was about one-fifth of the 1978 biomass (Figure 33).

Recruitment at age 1 has been low in recent years (Table 19; Figure 33). Since 2000, the 2003 year class at 4.4 million fish at age 1 (13.5 million fish at age 1 from the 2012 assessment) had been the highest recruitment estimated. The current estimate of the 2010 year class at age 1 is 4.3 million, which is close the 2003 year class based on the 2015 assessment. Both the 2003 and 2010 year classes are around half of the average (about 11 million age 1 fish) during 1978-1990 when the productivity was considered to be higher (Table 15; Figure 33). Recruitment for the 2002, 2004, 2008 and 2012 year classes are the lowest on record. The current biomass is well below 30,000 mt, above which there is expected to be a better chance for higher recruitment (Figure 35).

Fishing mortality (population number weighted average of ages 4-9) was high prior to 1994 (Table 16; Figure 36). F declined in 1995 to F = 0.11 due to restrictive management measures. F in 2014 was estimated to be 0.04 (80% confidence interval: 0.035-0.058). The assessment showed that F has been declining since 2007 and has been at or below F = 0.11 since 2011.

PRODUCTIVITY

Recruitment, natural mortality, age structure, fish growth and spatial distribution typically reflect changes in the productive potential. While management measures have resulted in a decreased exploitation rate since 1995 (Figure 25), total mortality has remained high and adult biomass has fluctuated at a low level. The current biomass is well below 30,000 mt; when biomass is above this threshold there is a better chance for higher recruitment (Figure 35). Average weight at length, used to reflect condition, has been stable in the past, but has started to decline in recent years. Size at age in the 2014 fishery remains low for most age groups (Table 4; Figure 13). The research survey spatial distribution patterns of adult (age 3+) cod have not changed over the past decade (Figures 16-18). High natural mortality of age 6+, low weights at age in the population in recent years and poor recruitment have contributed to the lack of rebuilding.

HARVEST STRATEGY

The Transboundary Management Guidance Committee (TMGC) has adopted a strategy to maintain a low to neutral risk of exceeding the fishing mortality reference. At the 2013 benchmark meeting, it was agreed that the current F_{ref} = 0.18 (TMGC meeting in December 2002) is not consistent with the VPA “M 0.8” model, and a lower value for F_{ref} would be more appropriate (Claytor and O’Brien 2013). At the 2014 TRAC meeting, it was agreed that F = 0.11 was an appropriate fishing reference point for the VPA “M 0.8” model based on the analyses presented (O’Brien and Worcester 2014). This value was derived from an age-disaggregated Sissenwine-Shepherd production model using M = 0.8 (Wang and O’Brien 2013b). TRAC recommends basing catch advice on F = 0.11. When stock conditions are poor fishing mortality rates should be further reduced to promote rebuilding.

OUTLOOK

This outlook is provided in terms of consequences with respect to the harvest reference points for alternative catch quotas in 2016 and 2017 (Gavaris and Sinclair 1998; Rivard and Gavaris 2003b).

Uncertainty about current biomass generates uncertainty in forecast results, which is expressed here as the probability of exceeding F = 0.11 in 2016 and 2017, as well as the change in adult biomass from 2016 to 2017 and from 2017 to 2018. The risk calculations assist in evaluating the consequences of alternative catch quotas by providing a general measure of the uncertainties. However, risk calculations are dependent on the data, and model assumptions and do not include uncertainty due to variations in weight at age, PR to the fishery, natural mortality, systematic errors in data reporting or the possibility that the model may not reflect stock dynamics closely enough.

For projections, the average of the most recent three years of fishery and survey weights at age is used for fishery and beginning year population biomass for 2015-2017. The 2015-2017 PR is based on the most recent five years of estimated PR (Table 18). The 2010-2014 average recruitment at age 1 is used for 2015-2018 projections. The uncertainties for this estimate are not reflected in the projection.

2016 PROJECTION AND RISK ANALYSIS

Assuming a 2015 catch equal to the 650 mt total quota, both deterministic (Table 19) and stochastic (Table 20; Figure 37) projections based on F reference point 0.11 are provided. In 2016, a 50% risk of not exceeding F = 0.11 corresponds to catches of 675 mt. Catches of 600 mt correspond to a lower (25%) risk (Table 20; Figure 37). Even with no fishing in 2016, there is a greater than 50% risk of a decrease in adult biomass from 2016 to 2017. A catch of 475 mt would result in at least a 75% risk that 2017 adult biomass would decrease (Figure 37).

2017 PROJECTION AND RISK ANALYSIS

Assuming a 2015 catch equal to the 650 mt total quota and 2016 fishing mortality equal to 0.11, the deterministic projection for 2017 is shown in Table 19. In 2017, a 50% risk of not exceeding F = 0.11 corresponds to catches of 725 mt. Catches of 640 mt correspond to a lower (25%) risk (Table 20; Figure 38). A catch of 625 mt will result in a neutral risk (50%) risk that 2018 age 3+ biomass will be lower than 2017. A catch of 225 mt has a lower (25%) risk (Figure 38).

A sensitivity risk analysis was conducted with an assumed 2016 catch equal to 600 mt, which has a 25% risk of exceeding F = 0.11. In 2017, a 50% risk of not exceeding F = 0.11 corresponds to catches of 750 mt, and catches of 650 mt corresponds to a lower (25%) risk (Table 20; Figure 39). A catch of 575 mt will result in a neutral (50%) risk that 2018 age 3+ biomass will be lower than 2017. A catch of 175 mt has a lower (25%) risk (Figure 39).

ERRORS DISCOVERED IN THE STOCHASTIC PROJECTION

For the stochastic projection in the software of ADAPT (Gavaris 1988), the exploitation rate on fully-recruited age groups calculated from the consequence of alternative catch quota options is compared with the exploitation rate reference point (U_{ref}), instead of fishing mortality comparison with fishing mortality reference point (F_{ref}). Uref is a function of natural mortality and F_{ref}. If the natural mortality is constant across ages there is no difference when an exploitation rate reference (U_{ref}) or fishing mortality reference point (F_{ref}) is used. However, if the natural mortality varies with ages the U_{ref} would be different across ages even if F_{ref} is the same for all the ages.

During the TRAC, it was discovered that the age-specific difference in natural mortality (M = 0.2, except M = 0.8 for ages 6+) was not accounted for in calculations of Uref in the stochastic projections for the VPA “M = 0.8” model. The stochastic projection was undertaken using U_{ref} = 7%, a value calculated from ages 6+ natural mortality (M = 0.8) and F_{ref} = 0.11 (Table 20a), while U_{ref} = 10% if calculated from natural mortality of younger fish (M = 0.2) and F_{ref} = 0.11. This difference was not noticed in the past assessments due to the flat fishery PR, but given differences in the PR between younger and older fish this year (Figure 29), the mis-accounting of the two Uref values has become more apparent.

Considering the current ADAPT software does not incorporate the age-variant U_{ref} in the stochastic projection, it was agreed that this year's assessment should not attempt re-analysis. A sensitivity run with the U_{ref} = 10%, a value derived from natural mortality of younger fish (M = 0.2) and F_{ref} = 0.11, was conducted. It should be noted that although U_{ref} = 10% is appropriate for the younger fish, it would be overfishing for the older fish if there is a flat PR. In 2016, a 50% risk of not exceeding F = 0.11 corresponds to catches of 875 mt. Catches of 775 mt correspond to a lower (25%) risk (Figure 40). In 2017, a 50% risk of not exceeding F = 0.11 corresponds to catches of 950 mt. Catches of 825 mt correspond to a lower (25%) risk (Figure 40).

Although the specific implications of this could not be evaluated at TRAC, it was noted that the deterministic projection (with the correct calculation that accounted for the age differences in M) produced a 2016 catch of 842 mt. Generally, deterministic projection and the 50% risk of not exceeding F_{ref} in the stochastic projection result in very similar estimates of catch. On this basis, the TRAC agreed that a revised stochastic risk analysis would likely result in an increase in the calculated catch on the order of 100-200 mt (Tables 19 and 20). Given this uncertainty, and due to the current status of the stock, the TRAC recommends that the risk calculations provided remain appropriate despite the unaccounted for age-specific difference in the stochastic projections.

CONSEQUENCE ANALYSIS (RISKS ASSOCIATED WITH 2016-2017 PROJECTED CATCH)

A consequence analysis to understand the risks associated with assumptions of the VPA "M 0.8" and ASAP "M 0.2" models (Appendix B) was examined. This consequence analysis shows (Table 21):

1. the projected catch (ages 1+) at F_{ref} = 0.18 and F=0.11 and percent change in biomass, as if each model represented the "true state" of the resource; and
2. the consequences to fishing mortality and expected biomass (ages 3+) when 'true state' catch levels are removed under the assumptions of the other "alternate state" model.

In 2016, a catch of 675 mt at F = 0.11 would result in a decrease in the 2017 biomass of 6% in the VPA "true state" and an increase of 21% in the ASAP "alternate state". A catch of 223 mt at F_{ref} = 0.18 would result in a 42% increase in the 2017 biomass based on the ASAP "true state", but a decrease of 2.8% based on the VPA "alternate state".

In 2017, a catch of 725 mt at F = 0.11 would result in a decrease in the 2017 biomass of 0.6% in the VPA "true state" and an increase of 31% in the ASAP "alternate state". A catch of 304 mt at F_{ref} = 0.18 would result in a 40% increase in the 2017 biomass based on the ASAP "true state", but a decrease of 2.7% based on the VPA "alternate state".

SPECIAL CONSIDERATIONS

Table 22 summarizes the performance of the management system. It reports the TRAC advice, TMGC quota decision, actual catch, and realized stock conditions for this stock.

Fishing mortality and trajectory of age 3+ biomass from the assessment following the catch year are compared to results from this assessment. These comparisons were kindly provided in 2011 by Tom Nies (staff member of the New England Fishery Management Council, NEFMC) and updated for this assessment. The inconsistency of TRAC advice in the past, with the realized stock conditions from the recent assessment, was mainly due to assessment model changes following the 2009 benchmark assessment. Further, the retrospective bias in the assessment also accounted for part of this inconsistency.

The consequence analysis reflects the uncertainties in the assessment model assumptions. Considering the current poor stock conditions, despite these uncertainties, all assessment results indicate that low catches are needed to promote rebuilding.

Discovery that the calculation being made in the risk analysis for the VPA results did not account for the differences in natural mortality rate between young ages and ages 6+ could have impacted catch advice since 2009. The TRAC compared deterministic and stochastic projections results for assessments since 2009 and found that the differences were minimal (-11- 7%) until 2015 (20%) (Table 23).

ACKNOWLEDGEMENTS

We thank J.R. Martin for providing the Canadian discards data, B. Hatt of DFO and N. Shepherd of NMFS for providing ageing information for the DFO and NMFS surveys and Canadian and USA fisheries, G. Donaldson and D. Frotten of DFO and at-sea observers from Javitech Ltd. for providing samples from the Canadian fishery.

REFERENCES

Benoît, H.P. 2006. Standardizing the Suthern Gulf of St. Lawrence Bottom Trawl Survey Time Series: Results of the 2004-2005 Comparative Fishing Experiments and other Recommendations for the Analysis of the Survey Data. DFO Can. Sci. Advis. Sec.Res. Doc. 2006/008.

Brooks, E., T. Miller, C. Legault, L. O’Brien, K. Clark, S. Gavaris, and L. Van Eeckhaute. 2010. Determining Length-based Calibration Factors for Cod, Haddock and Yellowtail Flounder. TRAC Ref. Doc. 2010/08.

Clark, K., L. O’Brien, Y. Wang, S. Gavaris, and B. Hatt. 2008. Assessment of Eastern Georges Bank Atlantic Cod for 2008. TRAC Ref. Doc. 2008/01: 74p.

Claytor, R., and L. O’Brien. 2013. Transboundary Resources Assessment Committee (TRAC) Eastern Georges Bank Cod Benchmark Assessment and TRAC Benchmark Criteria Discussion: Report of Meeting held 9-11 April 2013.. TRAC Proceed. 2013/01.

DFO. 2002. Development of a Sharing Allocation Proposal for Transboundary Resources of Cod, Haddock and Yellowtail Flounder on Georges Bank. DFO Maritime Provinces, Regional Fisheries Management Report 2002/01: 59p.

Efron, B., and R.J. Tibshirani. 1993. An Introduction to the Bootstrap. Chapman & Hall. New York. 436p.

Forrester, J.R.S., C.J. Byrne, M.J. Fogarty, M.P. Sissenwine, and E.W. Bowman. 1997. Background Papers on USA Vessel, Trawl, and Door Conversion Studies. SAW/SARC 24 Working Paper Gen 6. Northeast Fisheries Science Center, Woods Hole, MA.

Gavaris, S. 1988. An Adaptive Framework for the Estimation of Population Ssize. Can. Atl. Fish. Sci. Advis. Committ. Res. Doc. 88/29: 12p.

Gavaris S., and A. Sinclair. 1998. From Fisheries Assessment Uncertainty to Risk Analysis for Immediate Management Actions; 903-916 pp. *In*: F. Funk, T.G. Quin II, J. Heifetz, J.N. Ianelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan, and C.I. Zhang. [editors]. Fishery Stock Assessment Models. Alaska Sea Grant College Program Report No. AK-SG-98-01. University of Alaska, Fairbanks.

Gavaris, S., L. O'Brien, B. Hatt, and K. Clark. 2006. Assessment of Eastern Georges Bank Cod for 2006. TRAC Ref. Doc. 2006/05: 48p.

Gavaris, S., L. Van Eeckhaute, and K. Clark. 2007a. Discards of Cod from the 2006 Canadian Groundfish Fishery on Eastern Georges Bank. TRAC Ref. Doc. 2007/02: 19p.

Gavaris, S., G. Robert, and L. Van Eeckhaute. 2007b. Discards of Atlantic Cod, Haddock and Yellowtail Flounder from the 2005 and 2006 Canadian Scallop Fishery on Georges Bank. TRAC Ref. Doc. 2007/03: 10p.

Hunt, J.J., L. O'Brien, and B. Hatt. 2005. Population Status of Eastern Georges bank Cod (Unit Areas 5Zj,m) for 1978-2006. TRAC Ref. Doc. 2005/01: 48p.

Morin, R. 2014. Testing the Effect of Alternative Codend Mesh Sizes on the Size and Age Composition of Haddock in the Trawl Fishery on Eastern Georges Bank. Groundfish Enterprise Allocation Council Report.

NEFSC. 2013. 55th Northeast Regional Stock Assessment Workshop (55th SAW) Assessment Report. B. Georges Bank Atlantic Cod (*Gadus morhua*) Stock Assessment for 2012. Northeast Fish. Sci. Cent. Ref. Doc. 13-11: 845p.

O'Brien, L., and T. Worcester. 2009. Transboundary Resources Assessment Committee Eastern Georges Bank cod benchmark assessment. TRAC Proceed. 2009/02: 47p.

O'Brien, L., and T. Worcester. 2014. Proceedings of the Transboundary Resources Assessment Committee for Eastern Georges Bank Cod and Haddock, and Georges Bank Yellowtail Flounder: Report of Meeting held 23-26 June 2014. TRAC Proceed. 2014/02.

Rivard, D., and S. Gavaris. 2003a. St. Andrews (S. Gavaris) Version of ADAPT: Estimation of Population Abundance. NAFO Sci. Coun. Studies 36: 201-249.

Rivard, D., and S. Gavaris. 2003b. Projections and Risk Analysis with ADAPT. NAFO Sci. Coun. Studies 36: 251-271.

Van Eeckhaute, L., and S. Gavaris. 2004. Determination of Discards of Georges Bank Cod from Species Composition Comparison. TRAC Ref. Doc. 2004/04: 27p.

Wang, Y., and L. O'Brien. 2013a. Assessment of Eastern Georges Bank Cod for 2013. TRAC Ref. Doc. 2013/02: 99p.

Wang, Y., and L. O'Brien. 2013b. 2013 Benchmark Assessment of Eastern Georges Bank Atlantic Cod. TRAC Ref. Doc. 2013/07: 62p.

Wang, Y., L. O'Brien, H. Stone, and E. Gross. 2014. Assessment of Eastern Georges Bank Cod for 2014. TRAC Ref. Doc. 2014/02: 201p.

Wigley, S.E., M.C. Palmer, J. Blaylock, P.J. Rago. 2008. A Brief Description of the Discard Eastimation of the National Bycatch Report. NEFSC Ref. Doc. 08-02: 35p.

TABLES

Table 1. Catches (mt) of cod from Eastern Georges Bank, 1978 to 2014. A dash (-) indicates that discards were likely to be zero because there were no quota limitations.

Year	Canada				USA			Total (mt)
	Landings (mt)	Discards Scallop (mt)	Discards Groundfish (mt)	Total (mt)	Landings (mt)	Discards (mt)	Total (mt)	
1978	8,777	98	-	8,875	5,502	-	5,502	14,377
1979	5,979	103	-	6,082	6,408	-	6,408	12,490
1980	8,066	83	-	8,149	6,418	-	6,418	14,567
1981	8,508	98	-	8,606	8,092	-	8,092	16,698
1982	17,827	71	-	17,898	8,565	-	8,565	26,463
1983	12,131	65	-	12,196	8,572	-	8,572	20,769
1984	5,761	68	-	5,829	10,558	-	10,558	16,387
1985	10,442	103	-	10,545	6,641	-	6,641	17,186
1986	8,504	51	-	8,555	5,696	-	5,696	14,251
1987	11,844	76	-	11,920	4,793	-	4,793	16,713
1988	12,741	83	-	12,824	7,645	-	7,645	20,470
1989	7,895	76	-	7,971	6,182	84	6,267	14,238
1990	14,364	70	-	14,434	6,414	69	6,483	20,917
1991	13,467	65	-	13,532	6,353	112	6,464	19,997
1992	11,667	71	-	11,738	5,080	177	5,257	16,995
1993	8,526	63	-	8,589	4,019	57	4,077	12,665
1994	5,277	63	-	5,340	998	5	1,003	6,343
1995	1,102	38	-	1,140	543	0.2	544	1,683
1996	1,924	56	0	1,980	676	1	677	2,657
1997	2,919	58	428	3,405	549	6	555	3,960
1998	1,907	92	273	2,272	679	7	686	2,959
1999	1,818	85	253	2,156	1,195	9	1,204	3,360
2000	1,572	69	0	1,641	772	16	788	2,429
2001	2,143	143	0	2,286	1,488	146	1,634	3,920
2002	1,278	94	0	1,372	1,688	9	1,697	3,069
2003	1,317	200	0	1,528	1,851	85	1,935	3,463
2004	1,112	145	0	1,257	1,006	57	1,063	2,321
2005	630	84	144	859	171	199	370	1,228
2006	1,096	112	237	1,445	131	94	226	1,671
2007	1,108	114	0	1,222	234	279	513	1,735
2008	1,390	36	103	1,529	224	20	244	1,774
2009	1,003	69	137	1,209	433	147	580	1,789
2010	748	44	48	840	357	97	454	1,294
2011	702	29	13	743	267	20	287	1,030
2012	395	42	31	468	96	52	148	616
2013	385	18	21	424	24	16	40	464
2014	430	15	13	458	114	2	116	574
Minimum	385	15	13	424	24	<1	40	464
Maximum	17,827	200	428	17,898	10,558	279	10,558	26,463
Average	5,318	77	142	5,441	3,255	68	3,303	8,744

Table 2. Length and age samples from the USA and Canadian fisheries on Eastern Georges Bank. For Canadian fisheries, at-sea observer samples are included since 1990. The first quarter age samples are supplemented with USA fishery age samples from 5Zjm for 1978-1986 and DFO survey age samples for 1987-2014; the numbers are shown in brackets. The highlighted numbers include samples from western Georges Bank.

Year	**USA**		**Canada**	
	Lengths	**Ages**	**Lengths**	**Ages**
1978	2,294	384	7,684	1,364
1979	2,384	402	3,103	796(205)
1980	2,080	286	2,784	728(192)
1981	1,498	455	4,147	897
1982	4,466	778	4,705	1,126(268)
1983	3,906	903	3,822	754(150)
1984	3,891	1,130	1,889	1,243(858)
1985	2,076	597	7,031	1,309(351)
1986	2,145	643	5,890	991(103)
1987	1,865	524	9,133	1,429(193)
1988	3,229	797	11,350	2,437(510)
1989	1,572	347	8,726	1,561
1990	2,395	552	31,974	2,825(1,153)
1991	1,969	442	27,869	1,782
1992	2,048	489	29,082	2,215(359)
1993	2,215	569	31,588	2,146
1994	898	180	27,972	1,268
1995	2645	14	6,660	548
1996	4,895	1,163	26,069	828
1997	1,761	82	31,617	1,216
1998	1,301	338	26,180	1,643
1999	726	228	26,232	1,290(410)
2000	500	121	20,582	1,374
2001	1,434	397	19,055	1,505
2002	1,424	429	16,119	1,252
2003	1,367	416	19,757	1,070
2004	1,547	517	18,392	1,357
2005	297	65	23,937	1,483(697)
2006	446	151	44,708	1,460(648)
2007	589	183	141,607	1,647(456)
2008	972	295	64,387	1,709(495)
2009	1,286	326	48,335	1,725(246)
2010	1,446	333	30,594	1,455(433)
2011	1,203	213	40,936	1,655(536)
2012	598	746	49,447	1,115(216)
2013	2,951	842	75,275	1,334(319)
2014	547	85	50501	957(184)

Table 1. Annual catch at age numbers (thousands) for Eastern Georges Bank cod for 1978-2014.

Year	Age																	Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	
1978	1	8	108	3644	1167	394	163	127	22	23	6	2	1	0.10	0.34	0.39	0.23	5668
1979	1	15	890	735	1520	543	182	74	61	11	3	2	1	0.01	1	0	0	4037
1980	2	6	973	1650	301	968	354	97	26	46	16	4	1	0	0	0	0	4445
1981	3	35	860	1865	1337	279	475	181	96	59	21	2	1	0	0	0	0	5216
1982	0.01	15	3516	1971	1269	1087	196	399	155	49	14	22	6	3	4	1	0	8707
1983	10	22	783	2510	1297	562	398	118	182	102	25	28	12	1	3	1	0.07	6055
1984	0.13	17	231	805	1354	546	377	279	39	90	38	17	7	2	3	0	1	3806
1985	33	9	2861	1409	661	987	271	110	110	21	27	3	4	1	1	0.12	0	6508
1986	1	41	451	2266	588	343	456	68	48	29	4	8	1	0	0	0	0	4303
1987	2	22	4116	846	1148	163	132	174	41	24	8	3	1	0.06	0	0	0	6680
1988	1	23	289	4189	680	855	130	116	182	52	21	13	4	1	0.05	0.12	0	6556
1989	1	18	680	811	1983	228	373	56	40	59	15	7	5	0.13	0.36	0	0	4278
1990	1	16	726	3109	1038	1374	145	153	12	12	24	3	2	1	0	0.50	0	6617
1991	0.44	63	991	1008	1927	904	746	105	69	21	11	8	4	2	0.40	1	0	5862
1992	0	68	2581	1379	460	889	314	315	45	34	3	5	2	1	0	0	0	6096
1993	0	10	501	1894	909	299	359	133	97	25	17	3	0.08	0.20	0	0	0	4246
1994	1	6	182	483	788	270	45	61	30	21	2	1	0	0.14	0.01	0.01	0	1889
1995	3	1	57	237	94	105	18	7	4	4	0.12	0.08	0.01	0	0	0	0	531
1996	0.12	5	40	234	398	79	60	13	4	3	0.28	0.14	0	0	0	0	0	837
1997	1	10	148	205	358	358	84	37	13	4	1	1	0.05	0	0	0	0	1219
1998	0.10	5	101	314	161	158	134	23	13	4	1	0.25	1	0.04	0	0	0	917
1999	0.13	9	79	483	337	109	61	57	14	2	1	0.08	0	0.01	0	0	0	1152
2000	1	3	64	111	380	151	37	22	12	3	0.25	0.29	0.01	0	0.08	0	0	785
2001	1	3	107	511	211	398	105	32	17	7	1	0.26	0.07	0	0	0	0	1394
2002	1	1	10	125	447	108	156	30	9	6	2	1	0.39	0	0.04	0	0	896
2003	13	0	35	148	243	405	81	89	19	4	1	0.27	0	0	0	0	0	1040
2004	0	23	12	140	151	147	139	35	30	7	1	1	0.24	0	0.01	0	0.02	686
2005	0	4	71	45	201	50	34	35	10	5	1	0.02	0.15	0.15	0	0	0	457
2006	0	3	19	226	78	195	48	18	18	2	2	0.32	0.12	0	0	0	0	608
2007	0	2	53	62	422	34	85	12	7	7	0.44	0.14	0	0	0	0	0	683
2008	0	1	45	141	61	249	15	33	4	2	1	0.10	0	0.01	0	0	0	552
2009	1	7	44	200	139	46	137	9	10	1	1	0.05	0	0	0	0	0	595
2010	0.02	3	44	94	210	74	15	35	3	2	0.31	0.04	0	0	0	0	0	479
2011	0	9	44	76	93	115	26	12	7	0.23	0.23	0.01	0	0	0	0	0	382
2012	0	2	68	106	49	29	25	6	1	0.78	0.02	0	0	0	0	0	0	287
2013	0.48	1	27	112	52	11	7	2	0.44	0.03	0.08	0	0	0	0	0	0	212
2014	0	5	16	82	103	28	4	0.26	0.11	0	0	0	0	0	0	0	0	238

Table 2. Average fishery weights at age (kg) of cod from Eastern Georges Bank. A dash (-) indicates no data.

Year	Age									
	1	2	3	4	5	6	7	8	9	10
1978	0.44	1.26	2.07	2.72	3.72	5.41	5.61	8.28	7.50	11.32
1979	0.73	1.45	1.52	3.28	4.45	6.59	9.41	9.62	9.86	14.18
1980	0.38	1.24	2.21	3.07	4.96	6.29	7.22	11.46	10.41	12.54
1981	0.52	1.28	1.99	3.06	4.54	6.50	8.02	9.25	11.62	15.19
1982	0.56	1.30	2.13	3.61	5.01	6.76	8.51	9.86	11.86	13.98
1983	0.90	1.49	2.21	3.10	4.60	6.10	7.81	10.15	11.47	13.20
1984	0.68	1.60	2.31	3.42	4.76	6.09	8.30	9.35	11.16	12.03
1985	0.54	1.32	1.81	3.19	4.55	5.95	7.91	9.60	10.75	12.52
1986	0.54	1.36	2.43	3.30	4.83	6.70	8.08	9.20	11.38	11.46
1987	0.58	1.46	2.38	3.93	5.38	7.23	8.76	9.46	11.27	12.01
1988	0.62	1.17	2.19	3.07	4.91	6.10	8.27	9.89	11.14	12.49
1989	0.62	1.27	1.96	3.35	4.89	6.02	6.79	9.80	10.70	12.77
1990	0.69	1.55	2.38	3.22	4.59	6.04	7.80	9.81	11.19	12.82
1991	0.75	1.52	2.42	3.14	4.24	5.53	7.45	9.46	9.18	13.28
1992	0.86	1.41	2.28	3.32	4.24	5.66	6.80	8.66	11.22	14.85
1993	0.60	1.40	2.11	2.84	4.29	5.40	6.76	8.29	9.14	11.13
1994	0.60	1.33	2.14	3.44	4.39	6.42	7.19	8.15	7.97	11.40
1995	0.32	1.32	2.12	3.35	4.94	6.38	10.10	10.01	10.44	15.35
1996	0.51	1.42	2.17	3.05	4.70	5.83	6.42	8.96	10.35	10.38
1997	0.67	1.42	2.07	2.93	3.86	5.36	7.26	8.31	11.48	9.88
1998	0.70	1.34	2.15	2.98	3.97	5.33	6.59	7.82	10.23	12.88
1999	0.54	1.30	1.97	3.10	3.91	5.48	6.27	7.54	9.38	13.52
2000	0.61	1.32	1.96	2.90	4.02	4.70	5.72	6.77	8.35	14.05
2001	0.21	0.93	1.84	2.74	3.58	4.87	5.22	7.27	8.65	11.07
2002	0.33	1.20	1.96	2.84	4.01	4.88	6.41	8.23	7.98	10.11
2003	-	1.24	2.12	2.71	3.53	4.24	5.47	6.84	7.63	8.13
2004	0.24	1.23	1.84	2.77	3.46	4.56	5.24	7.24	8.54	8.64
2005	0.40	0.83	1.56	2.35	3.49	4.50	4.85	6.74	7.88	9.26
2006	0.27	0.64	1.73	2.30	3.29	4.28	6.10	5.78	6.89	7.18
2007	0.46	1.04	1.61	2.32	2.99	3.91	6.09	6.84	6.90	9.35
2008	0.30	1.27	2.22	2.79	3.65	5.03	5.82	7.92	7.97	8.73
2009	0.66	1.13	1.92	3.03	3.70	4.51	5.74	6.73	10.00	10.26
2010	0.474	1.309	2.046	2.531	3.381	3.433	5.099	6.078	8.809	10.87
2011	0.308	1.074	1.721	2.556	3.514	4.278	4.227	6.065	9.852	9.368
2012	0.289	0.934	1.666	2.628	3.687	4.1	4.643	5.7	5.329	5.23
2013	0.329	1.006	1.85	2.77	3.73	4.86	5.37	5.87	7.89	7.17
2014	0.284	0.983	2.10	2.60	3.48	4.49	6.24	8.26	-	-
Minimum	0.21	0.64	1.52	2.30	2.99	3.43	4.23	5.70	5.33	5.23
Maximum	0.90	1.60	2.43	3.93	5.38	7.23	10.10	11.46	11.86	15.35
Average[1]	0.34	1.07	1.88	2.69	3.58	4.28	5.22	6.45	8.38	8.58

[1] for 2010-2014

Table 5. Indices of swept area abundance (thousands) for Eastern Georges Bank cod from the DFO survey, 1986-2015.

Year	Age																	Total
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16+**	
1986	0	770	3538	3204	331	692	445	219	35	66	0	10	0	0	0	0	0	9311
1987	0	48	1791	642	753	162	89	181	89	13	13	0	13	16	0	0	0	3812
1988	0	148	450	5337	565	838	95	79	179	18	12	4	0	16	0	0	0	7741
1989	0	350	2169	764	1706	258	332	42	85	112	5	32	8	5	0	0	0	5868
1990	20	106	795	3471	1953	4402	535	1094	144	157	289	65	52	37	0	0	5	13125
1991	0	1198	1019	1408	1639	882	1195	148	249	38	45	30	12	5	8	0	0	7876
1992	0	48	2049	1221	409	643	451	300	93	38	0	3	3	18	0	0	0	5276
1993	0	31	355	1723	622	370	754	274	268	51	31	0	20	6	0	0	0	4504
1994	0	13	629	691	1289	477	182	363	84	119	12	0	0	0	8	5	0	3871
1995	0	32	187	1240	757	520	186	44	67	28	18	8	6	0	0	0	0	3093
1996	0	90	203	1744	4337	1432	1034	445	107	149	39	4	0	0	5	0	0	9590
1997	0	30	376	568	1325	1262	216	50	35	23	17	0	3	0	0	0	0	3905
1998	0	6	582	831	322	317	238	56	29	7	8	3	4	0	0	0	0	2402
1999	0	3	156	1298	1090	449	317	190	10	28	5	9	0	3	0	0	0	3561
2000	0	0	423	1294	4967	2157	1031	510	317	20	23	12	0	0	0	0	0	10754
2001	0	3	37	802	519	1391	645	334	224	225	36	24	7	0	0	0	0	4248
2002	0	0	118	477	2097	694	1283	458	188	63	76	7	0	0	0	0	0	5462
2003	0	0	8	200	510	867	194	219	69	12	0	0	0	0	0	0	0	2078
2004	0	427	40	246	381	422	353	59	108	25	5	0	3	0	0	0	0	2069
2005	0	25	1025	1398	7149	1766	816	743	60	87	8	4	0	0	0	0	0	13082
2006	0	0	41	1500	673	1779	757	217	216	83	34	10	15	0	0	0	0	5325
2007	0	18	130	549	2606	379	653	119	81	53	0	4	0	0	0	0	0	4591
2008	0	12	147	1027	755	2978	194	392	41	4	20	0	0	0	0	0	0	5569
2009	0	11	51	2487	2261	519	2955	0	82	0	0	0	18	0	0	0	0	8384
2010	0	5	92	956	4105	1781	703	1828	65	84	5	0	0	0	0	0	0	9623
2011	0	193	271	766	952	1324	256	67	112	14	8	2	0	0	0	0	0	3965
2012	0	9	149	327	315	195	158	7	18	4	0	0	0	0	0	0	0	1182
2013	0	0	431	3754	2173	285	81	52	10	0	0	0	0	0	0	0	0	6786
2014	0	76	9	360	538	169	35	0	27	0	0	0	0	0	0	0	0	1213
2015	0	0	476	152	598	439	97	7	0	0	0	0	0	0	0	0	0	1770

Table 6. Indices of swept area abundance (thousands) for Eastern Georges Bank cod from the NMFS spring survey, 1970-2015. Conversion factors to account for vessel and trawl door changes were applied. From 1973-1981, a Yankee 41 net was used rather than the Yankee 36 net.

Year	Age																	Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	
1970	0	354	1115	302	610	73	263	48	0	71	24	0	48	0	0	0	0	2907
1971	0	185	716	503	119	326	124	257	227	40	40	79	0	0	0	0	0	2615
1972	56	1578	1856	2480	393	114	136	60	88	73	18	14	0	0	14	0	0	6879
1973	0	665	37880	5474	6109	567	467	413	0	163	231	0	0	0	95	0	0	52064
1974	0	461	5877	4030	759	2001	360	91	267	45	48	54	0	0	0	0	0	13991
1975	0	0	467	3061	4348	446	960	79	0	122	0	0	0	0	0	0	0	9483
1976	84	1733	1111	620	444	759	0	167	35	0	0	0	0	48	0	0	0	5001
1977	0	0	2358	736	354	307	334	22	35	0	0	0	0	0	0	0	0	4145
1978	373	187	0	2825	615	916	153	787	62	43	40	0	0	0	0	0	0	6001
1979	71	339	1332	122	1430	543	176	91	130	0	0	0	0	0	0	0	0	4234
1980	0	11	2251	2168	169	1984	410	78	48	31	0	47	0	0	0	0	0	7197
1981	283	1956	1311	2006	1093	43	453	197	59	0	0	0	0	0	0	0	0	7399
1982	44	455	6642	13614	12667	9406	0	3088	992	120	0	0	0	0	0	0	0	47027
1983	0	389	2017	3781	779	608	315	106	98	0	70	0	0	0	0	0	35	8197
1984	0	103	117	344	483	92	182	74	18	105	0	0	0	0	0	0	0	1518
1985	58	36	2032	633	1061	1518	328	217	213	83	116	34	23	0	0	0	0	6352
1986	97	619	339	1132	298	427	536	20	109	142	0	0	0	0	0	0	0	3719
1987	0	0	1194	247	568	0	152	148	30	54	0	0	0	0	0	0	0	2394
1988	138	320	243	2795	274	461	51	5	67	0	0	10	0	0	0	0	0	4364
1989	0	174	1238	338	1685	234	396	99	12	36	48	24	0	0	0	0	0	4284
1990	24	45	360	1687	586	634	152	164	19	0	0	24	0	0	0	0	0	3696
1991	217	725	620	514	903	460	382	44	17	0	24	53	0	0	0	0	0	3957
1992	0	81	666	349	103	261	152	159	27	52	0	0	0	0	0	0	0	1850
1993	0	0	462	1284	262	46	182	46	43	46	12	0	0	0	0	0	0	2382
1994	38	54	194	152	185	44	11	33	0	8	0	0	0	0	0	0	0	720
1995	384	70	294	927	495	932	191	253	0	68	0	0	0	0	0	0	0	3614
1996	0	139	300	990	1343	121	94	28	0	0	0	0	0	0	0	0	0	3016
1997	271	54	218	48	402	519	53	126	57	0	0	0	0	0	0	0	0	1747
1998	54	0	1040	1985	995	983	609	30	31	0	0	0	0	0	0	0	0	5729
1999	22	22	145	673	624	370	172	107	34	8	0	0	0	0	0	0	0	2176
2000	36	0	304	643	1348	492	138	52	20	0	0	0	0	0	0	0	0	3032
2001	0	0	64	889	96	350	109	0	12	10	0	0	0	0	0	0	0	1530
2002	36	0	121	470	1081	175	214	61	0	0	0	0	0	0	0	0	0	2158
2003	0	0	125	287	812	1154	135	78	9	0	0	0	0	0	0	0	0	2599
2004	0	549	10	838	2091	2105	1351	239	382	29	0	0	0	0	0	0	0	7595
2005	36	15	345	70	747	287	190	131	34	0	0	0	0	0	0	0	0	1855
2006	0	37	73	952	411	1007	340	151	79	0	0	0	0	0	0	0	0	3050
2007	0	0	369	308	2258	239	291	47	28	0	0	0	0	0	0	0	0	3540
2008	43	37	112	675	372	1385	51	66	0	0	0	0	0	0	0	0	0	2741
2009	0	61	86	875	408	219	377	24	12	15	0	0	0	0	0	0	0	2078
2010	0	25	126	367	667	168	44	147	0	12	0	0	0	0	0	0	0	1556
2011	0	88	164	164	266	144	56	9	24	0	0	0	0	0	0	0	0	914
2012	3	3	450	749	834	209	127	13	0	0	0	0	0	0	0	0	0	2389
2013	0	0	653	3864	1202	129	64	15	0	0	0	0	0	0	0	0	0	5926
2014	0	55	64	568	922	109	27	0	0	0	0	0	0	0	0	0	0	1746
2015	0	9	165	71	222	331	23	0	0	0	0	0	0	0	0	0	0	820

Table 7. Indices of swept area abundance (thousands) for Eastern Georges Bank cod from the NMFS fall survey, 1970-2014. Conversion factors to account for vessel and trawl door changes have been applied.

Year	Age																	Total
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	
1970	348	1416	836	208	412	11	0	0	5	25	0	0	0	0	0	0	0	3261
1971	203	1148	900	181	232	130	142	14	0	0	0	0	0	0	0	0	0	2951
1972	1110	3299	614	667	24	40	0	0	0	0	0	0	0	0	0	0	0	5753
1973	46	2435	2947	997	979	93	0	25	63	0	0	0	0	0	0	0	0	7584
1974	77	196	399	622	54	31	15	0	0	0	0	0	0	0	0	0	0	1394
1975	414	660	177	414	764	27	46	0	0	0	0	0	0	0	0	0	0	2501
1976	0	8260	362	144	0	91	0	48	0	0	0	0	0	0	0	0	0	8904
1977	51	0	3475	714	184	156	178	3	0	0	0	0	0	0	0	0	0	4760
1978	113	1519	58	3027	417	58	63	77	0	0	0	0	0	0	0	0	0	5330
1979	182	1704	1695	116	1522	243	48	20	11	18	0	0	0	0	0	0	0	5557
1980	315	782	409	649	22	184	14	17	20	0	0	0	0	0	0	0	0	2412
1981	360	2352	1208	933	269	15	29	0	0	0	53	0	0	0	0	0	0	5220
1982	0	549	718	54	59	0	0	27	0	0	0	0	0	0	0	0	0	1406
1983	948	73	267	567	24	8	8	0	23	0	0	0	0	0	0	0	0	1917
1984	29	1805	120	690	1025	23	32	0	0	9	0	0	0	0	0	0	0	3734
1985	1245	209	993	161	18	5	9	0	0	0	4	0	0	0	0	0	0	2645
1986	119	3018	56	198	0	0	6	0	0	0	0	0	0	0	0	0	0	3396
1987	156	129	845	121	100	0	0	0	0	0	0	0	7	0	0	0	0	1357
1988	95	561	177	1182	163	206	0	30	41	10	0	0	0	0	0	0	0	2464
1989	318	570	1335	222	607	78	24	0	0	0	0	0	0	0	0	0	0	3154
1990	198	403	442	831	120	204	20	0	15	0	0	0	0	0	0	0	0	2232
1991	0	158	60	71	10	24	0	0	0	0	0	0	0	0	0	0	0	322
1992	0	205	726	154	0	37	12	0	0	0	0	0	0	0	0	0	0	1134
1993	0	81	104	158	19	0	0	0	0	0	0	0	0	0	0	0	0	362
1994	10	78	282	220	143	13	26	0	0	0	0	0	0	0	0	0	0	771
1995	223	28	122	304	66	29	7	0	0	0	0	0	0	0	0	0	0	779
1996	10	291	76	293	211	53	28	0	0	0	0	0	0	0	0	0	0	961
1997	0	161	394	181	58	84	29	0	0	0	0	0	0	0	0	0	0	907
1998	0	171	684	480	65	109	0	0	29	0	0	0	0	0	0	0	0	1538
1999	0	15	14	249	124	32	0	0	0	0	0	0	0	0	0	0	0	434
2000	30	55	204	68	89	46	0	0	0	0	0	0	0	0	0	0	0	493
2001	25	74	106	257	38	75	12	12	0	0	0	0	0	0	0	0	0	598
2002	122	110	635	712	2499	170	211	17	0	0	0	0	0	0	0	0	0	4476
2003	76	0	24	100	70	17	0	6	0	0	0	0	0	0	0	0	0	293
2004	108	422	68	840	385	545	436	103	30	0	30	0	0	0	0	0	0	2969
2005	21	29	508	114	251	43	0	10	0	0	0	0	0	0	0	0	0	976
2006	0	146	123	530	37	263	16	16	16	16	0	0	0	0	0	0	0	1162
2007	60	22	136	7	69	0	7	0	0	0	0	0	0	0	0	0	0	302
2008	0	74	170	55	15	98	15	15	0	0	0	0	0	0	0	0	0	442
2009	54	37	194	280	39	18	11	0	0	0	0	0	0	0	0	0	0	633
2010	434	27	79	74	121	20	0	0	0	0	0	0	0	0	0	0	0	755
2011	58	323	362	248	177	110	32	0	0	0	0	0	0	0	0	0	0	1309
2012	0	14	188	90	13	20	0	0	0	0	0	0	0	0	0	0	0	324
2013	162	51	565	554	226	0	0	0	0	0	0	0	0	0	0	0	0	1559
2014	98	144	47	145	223	28	14	0	0	0	0	0	0	0	0	0	0	697

Table 8. Coefficients of variation (CV) of mean catch number per tow (num/tow) for DFO survey.

Year	**Age**								**cv of mean num/tow**	**Mean num/tow**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**		
1987	0.75	0.43	0.52	0.50	0.36	0.33	0.36	0.28	0.42	9.2
1988	0.38	0.26	0.38	0.37	0.33	0.28	0.28	0.29	0.33	18.6
1989	0.34	0.23	0.21	0.19	0.25	0.27	0.33	0.27	0.16	14.1
1990	0.41	0.20	0.19	0.18	0.25	0.29	0.33	0.34	0.18	31.6
1991	0.54	0.20	0.19	0.20	0.21	0.23	0.34	0.35	0.16	19.0
1992	0.37	0.21	0.20	0.19	0.23	0.33	0.36	0.39	0.16	19.0
1993	0.57	0.21	0.23	0.25	0.28	0.25	0.24	0.22	0.21	10.8
1994	1.00	0.25	0.22	0.30	0.49	0.71	0.66	0.61	0.32	9.3
1995	0.60	0.34	0.39	0.38	0.31	0.35	0.46	0.55	0.34	7.4
1996	0.53	0.28	0.21	0.25	0.29	0.40	0.33	0.54	0.24	23.1
1997	0.72	0.28	0.26	0.27	0.26	0.28	0.30	0.41	0.25	9.4
1998	0.70	0.33	0.20	0.19	0.21	0.25	0.29	0.32	0.19	5.8
1999	1.00	0.21	0.21	0.24	0.32	0.46	0.59	0.84	0.24	8.6
2000	0.00	0.61	0.72	0.64	0.52	0.45	0.44	0.48	0.55	25.9
2001	1.00	0.34	0.32	0.33	0.35	0.39	0.47	0.47	0.37	10.2
2002	0.00	0.53	0.27	0.26	0.33	0.39	0.47	0.55	0.31	13.2
2003	0.00	0.85	0.19	0.15	0.15	0.16	0.23	0.27	0.15	5.0
2004	0.48	0.52	0.17	0.17	0.24	0.27	0.32	0.35	0.20	5.0
2005	0.57	0.53	0.75	0.73	0.56	0.55	0.47	0.44	0.66	31.5
2006	0.00	0.48	0.27	0.28	0.30	0.32	0.32	0.32	0.27	12.8
2007	0.85	0.22	0.24	0.20	0.22	0.32	0.43	0.41	0.21	11.1
2008	0.75	0.36	0.25	0.25	0.28	0.29	0.32	0.34	0.27	13.4
2009	1.00	0.42	0.48	0.62	0.67	0.76	0.00	0.81	0.58	20.2
2010	1.00	0.56	0.40	0.53	0.67	0.69	0.72	0.73	0.59	23.2
2011	0.43	0.34	0.22	0.26	0.27	0.30	0.29	0.27	0.22	9.5
2012	0.74	0.21	0.19	0.22	0.25	0.23	0.56	0.56	0.18	2.8
2013		0.58	0.41	0.53	0.64	0.70	0.70	0.76	0.43	16.3
2014	0.58	0.54	0.21	0.24	0.30	0.36	0.00	0.60	0.22	2.9
2015	0.00	0.47	0.28	0.38	0.40	0.46	1.00	0.00	0.33	4.3
Median	0.60	0.34	0.24	0.26	0.30	0.33	0.36	0.41	0.25	11.1

Table 9. Coefficients of variation (CV) of mean catch number per tow (num/tow) for NMFS spring survey. During 1973-1981 a Yankee 41 net was used rather than the standard Yankee 36 net.

Year	Age								CV of mean num/tow	Mean num/tow
	1	2	3	4	5	6	7	8		
1970	0.44	0.19	0.70	0.35	2.90	0.80	4.45	0.00	0.38	3.58
1971	0.58	0.30	0.28	0.40	0.42	0.45	0.53	0.58	0.26	3.02
1972	0.27	0.35	0.23	0.29	0.53	0.36	0.49	0.47	0.19	7.95
1973	0.30	0.70	0.60	0.53	0.48	0.45	0.38	0.00	0.64	60.20
1974	0.52	0.39	0.31	0.28	0.29	0.33	0.62	0.33	0.28	16.18
1975	0.00	0.15	0.21	0.17	0.16	0.14	0.67	0.00	0.17	10.96
1976	0.50	0.36	0.28	0.37	0.30	0.00	0.45	0.78	0.25	6.16
1977	0.00	0.14	0.26	0.32	0.34	0.32	0.63	0.43	0.15	4.79
1978	0.60	0.00	0.25	0.46	0.38	0.33	0.31	0.49	0.26	6.94
1979	0.30	0.35	0.25	0.20	0.25	0.32	0.52	0.38	0.21	4.90
1980	1.00	0.53	0.36	0.36	0.37	0.37	0.41	0.67	0.37	8.87
1981	0.40	0.35	0.27	0.23	0.37	0.19	0.27	0.67	0.22	11.18
1982	0.64	0.53	0.89	0.88	0.88	0.00	0.89	0.89	0.83	68.83
1983	0.26	0.06	0.12	0.12	0.30	0.51	0.96	0.81	0.13	9.48
1984	0.44	0.51	0.29	0.33	0.36	0.42	0.64	1.00	0.20	1.87
1985	0.84	0.43	0.51	0.37	0.30	0.25	0.33	0.35	0.35	11.46
1986	0.57	0.38	0.29	0.38	0.38	0.28	0.74	0.53	0.21	6.71
1987	0.00	0.34	0.34	0.41	0.00	0.41	0.35	0.74	0.23	4.32
1988	0.66	0.49	0.41	0.44	0.32	0.49	1.03	0.64	0.34	7.87
1989	0.34	0.51	0.41	0.33	0.28	0.33	0.39	1.08	0.32	9.78
1990	0.76	0.56	0.58	0.40	0.27	0.24	0.41	0.62	0.42	8.72
1991	0.32	0.26	0.21	0.19	0.18	0.23	0.28	0.73	0.15	9.04
1992	0.80	0.32	0.40	0.33	0.24	0.25	0.25	0.43	0.22	3.34
1993	0.00	0.68	0.45	0.37	0.67	0.38	0.48	0.36	0.41	4.30
1994	0.59	0.54	0.57	0.46	0.30	0.49	0.49	0.00	0.37	1.75
1995	0.40	0.52	0.34	0.49	0.55	0.52	0.55	0.00	0.36	6.52
1996	0.34	0.36	0.48	0.47	0.59	0.53	0.62	0.00	0.39	5.44
1997	1.04	0.69	0.40	0.36	0.28	0.59	0.33	0.38	0.28	3.15
1998	0.00	0.44	0.51	0.49	0.49	0.50	1.03	0.55	0.46	11.01
1999	0.78	0.31	0.26	0.19	0.24	0.38	0.43	0.49	0.21	3.92
2000	0.00	0.44	0.30	0.28	0.29	0.26	0.59	1.03	0.28	5.47
2001	0.00	0.37	0.44	0.54	0.50	0.65	0.00	1.03	0.44	2.76
2002	0.00	0.65	0.46	0.35	0.30	0.39	0.56	0.00	0.32	4.15
2003	0.00	0.23	0.38	0.48	0.57	0.44	0.65	0.62	0.48	5.94
2004	0.38	1.16	0.43	0.51	0.63	0.70	0.61	0.71	0.54	13.70
2005	1.03	0.50	0.56	0.20	0.23	0.22	0.31	1.03	0.24	3.35
2006	1.04	0.74	0.38	0.35	0.32	0.40	0.31	0.34	0.26	5.50
2007	0.00	0.37	0.32	0.32	0.25	0.26	0.31	0.80	0.29	6.39
2008	0.74	0.41	0.30	0.29	0.28	0.33	0.28	0.00	0.26	4.94
2009	0.32	0.53	0.61	0.28	0.24	0.18	0.31	0.35	0.36	3.42
2010	0.72	0.41	0.19	0.17	0.31	0.30	0.35	0.00	0.20	2.57
2011	0.38	0.40	0.29	0.36	0.37	0.41	0.49	0.77	0.29	2.11
2012	1.07	0.37	0.33	0.20	0.28	0.30	0.34	0.00	0.30	4.57
2013	0.00	0.52	0.67	0.58	0.42	0.70	1.00	0.00	0.62	11.18
2014	0.46	0.38	0.40	0.31	0.33	0.81	0.00	0.00	0.32	3.29
2015	0.60	0.28	0.30	0.24	0.23	0.38	0.00	0.00	0.20	1.61
Median	0.42	0.40	0.35	0.35	0.32	0.37	0.47	0.48	0.29	5.49

Table 10. Coefficients of variation (CV) of mean catch number per tow (num/tow) for NMFS fall survey.

Year	**Age**					**CV of mean num/tow**	**Mean num/tow**
	1	**2**	**3**	**4**	**5**		
1970	0.31	0.36	0.37	0.32	1.04	0.22	3.77
1971	0.70	0.13	0.58	0.25	0.79	0.37	3.41
1972	0.61	0.46	0.42	0.75	1.43	0.59	6.65
1973	0.47	0.33	0.52	0.59	0.68	0.33	9.16
1974	0.58	0.42	0.40	0.48	1.00	0.41	1.72
1975	0.51	0.41	0.57	0.49	1.00	0.41	2.89
1976	0.47	0.37	0.44	0.00	0.78	0.44	10.97
1977	0.00	0.22	0.17	0.19	0.39	0.19	6.97
1978	0.31	0.27	0.25	0.25	0.29	0.24	7.80
1979	0.43	0.36	0.28	0.23	0.27	0.32	8.13
1980	0.39	0.29	0.32	0.54	0.39	0.27	3.54
1981	0.27	0.35	0.33	0.33	0.85	0.26	7.64
1982	0.69	0.48	0.56	0.86	0.00	0.52	1.63
1983	0.50	0.45	0.63	1.35	1.35	0.29	2.22
1984	0.59	0.35	0.62	0.75	0.75	0.43	4.32
1985	0.46	0.93	0.99	0.83	1.04	0.53	4.77
1986	0.63	0.48	0.37	0.00	0.00	0.57	6.13
1987	0.77	0.47	0.56	0.56	0.00	0.47	2.45
1988	0.73	0.39	0.39	0.45	0.50	0.36	4.44
1989	0.38	0.46	0.49	0.46	0.51	0.42	7.20
1990	0.75	0.78	0.68	0.73	0.77	0.58	5.10
1991	0.66	0.64	0.60	0.52	0.74	0.55	0.91
1992	0.45	0.42	0.49	0.00	1.03	0.41	2.05
1993	0.74	0.45	0.59	0.78	0.00	0.48	0.83
1994	0.55	0.46	0.93	0.96	0.85	0.68	1.44
1995	1.08	0.47	0.54	0.77	0.66	0.47	1.41
1996	0.57	0.64	0.50	0.48	0.44	0.47	1.85
1997	0.74	0.80	1.04	0.88	1.08	0.88	1.64
1998	0.63	0.39	0.31	0.38	0.15	0.35	2.90
1999	1.03	0.90	0.78	0.70	0.40	0.74	0.78
2000	0.66	0.69	0.47	0.41	0.39	0.41	0.89
2001	1.10	0.52	0.56	0.95	0.98	0.45	1.08
2002	0.70	0.39	0.50	0.66	0.78	0.54	8.07
2003	0.00	0.50	0.43	0.51	0.70	0.36	0.67
2004	0.47	0.47	0.48	0.66	0.84	0.59	5.36
2005	1.00	0.44	0.59	0.46	0.54	0.44	1.76
2006	0.60	0.69	0.62	0.74	0.90	0.66	2.23
2007	0.64	0.43	1.00	0.36	0.00	0.33	0.54
2008	0.60	0.41	0.39	1.00	0.32	0.27	0.80
2009	0.44	0.41	0.39	0.39	0.55	0.45	1.23
2010	0.41	0.60	0.43	0.34	0.75	0.77	2.81
2011	0.49	0.56	0.60	0.68	0.89	0.52	3.27
2012	0.62	0.51	0.39	0.44	0.89	0.46	0.70
2013	0.85	0.67	0.72	0.58	0.00	0.58	3.47
2014	0.37	0.23	0.21	0.49	1.24	0.53	1.77
Median	0.59	0.45	0.50	0.51	0.74	0.45	2.81

Table 11. Swept area biomass (mt) for Eastern Georges Bank cod from the NMFS Fall, NMFS Spring and DFO surveys. Conversion factors to account for vessel and trawl door changes have been applied, including the biomass conversion factor of 1.58 used for the vessel Henry B. Bigelow since 2009. The DFO survey began in 1986, indicated by a dash (-) in that column prior to 1986. The dash (-) in the data cell for 2015 fall NMFS survey indicates that this survey had not yet occurred.

Year	Swept Area Biomass (mt)		
	NMFS Fall	NMFS Spring	DFO
1970	5,054	7,801	-
1971	5,287	10,435	-
1972	3,947	13,779	-
1973	11,697	82,311	-
1974	2,741	27,269	-
1975	5,246	23,503	-
1976	5,082	10,354	-
1977	9,509	9,335	-
1978	12,213	22,731	-
1979	13,050	12,831	-
1980	4,494	20,520	-
1981	7,256	18,568	-
1982	2,216	172,300	-
1983	2,449	20,376	-
1984	7,018	4,808	-
1985	2,390	23,190	-
1986	2,174	12,532	18,633
1987	2,634	7,615	8,824
1988	6,764	9,294	19,452
1989	5,145	12,104	14,547
1990	5,121	10,828	56,665
1991	435	9,391	25,068
1992	1,734	6,113	14,581
1993	606	6,598	16,545
1994	1,734	1,294	13,140
1995	1,220	10,113	8,118
1996	1,790	6,613	32,173
1997	1,875	4,051	11,004
1998	2,970	12,267	5,006
1999	1,044	5,308	9,178
2000	895	7,374	32,298
2001	1,159	3,721	18,037
2002	11,525	4,432	20,333
2003	608	6,405	6,218
2004	8,347	21,080	5,661
2005	1,446	4,407	26,200
2006	2,165	7,331	12,546
2007	424	6,066	11,228
2008	792	5,327	13,657
2009	1,203	4,343	23,180
2010	732	3,587	26,352
2011	2,304	1,724	8,437
2012	609	4,864	2,449
2013	2,566	9,616	11,113
2014	1,376	3,254	2,409
2015	-	1,748	3,594

Table 12. Beginning of year population weights at age (kg) derived from DFO and NMFS spring surveys. The weight at age for age group 10+ was derived from catch number weighted fishery weight at age.

Year	**Age**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
1970	0.093	0.838	1.735	2.597	4.797	5.644	8.153	7.990	11.427	14.635
1971	0.116	0.811	1.798	2.347	4.372	5.377	6.450	7.990	7.384	14.635
1972	0.085	0.866	1.979	2.959	3.482	5.212	5.608	6.539	13.806	14.635
1973	0.085	0.802	1.890	2.958	3.247	3.434	7.722	7.129	9.998	14.635
1974	0.149	0.606	1.705	2.641	4.173	5.806	7.452	7.754	8.153	14.635
1975	0.109	1.132	2.354	2.745	3.734	5.184	7.714	7.567	9.150	14.635
1976	0.138	0.946	2.156	2.999	3.753	5.342	8.011	7.384	9.150	14.635
1977	0.124	0.905	2.130	3.365	6.182	5.503	6.667	5.664	9.150	14.635
1978	0.112	0.886	1.624	3.564	5.414	6.247	8.626	8.973	10.226	14.635
1979	0.112	0.868	1.740	2.995	4.565	5.188	9.629	10.885	10.976	14.635
1980	0.276	0.706	1.892	2.786	5.244	6.281	5.919	8.973	11.762	14.635
1981	0.095	0.852	1.826	3.342	4.971	6.862	8.184	12.712	11.262	14.635
1982	0.092	0.869	2.219	3.050	4.114	6.427	8.061	8.828	10.776	14.635
1983	0.224	1.131	1.871	2.263	3.132	6.011	8.153	8.653	10.525	14.635
1984	0.050	0.582	1.954	2.443	2.699	4.121	5.890	8.973	10.279	14.635
1985	0.087	0.646	1.926	3.205	3.781	5.834	8.771	9.866	14.114	14.635
1986	0.131	0.770	1.742	3.217	4.920	5.698	7.439	8.988	10.684	14.635
1987	0.150	0.845	1.701	2.686	5.672	7.487	7.480	6.659	10.100	14.635
1988	0.152	0.931	1.785	3.020	4.169	6.268	8.438	8.724	12.330	14.635
1989	0.142	0.832	1.705	2.759	4.306	6.432	7.615	7.813	11.320	14.635
1990	0.215	0.787	1.843	2.899	4.362	6.003	8.589	9.518	13.493	14.635
1991	0.088	0.897	1.952	3.167	4.243	4.895	7.544	10.059	9.973	14.635
1992	0.127	0.846	2.045	2.793	4.163	6.127	6.979	8.555	10.448	14.635
1993	0.070	0.955	1.845	2.907	4.513	5.889	6.999	7.383	9.341	14.635
1994	0.143	0.657	1.433	2.629	3.954	7.458	7.330	8.661	9.211	14.635
1995	0.183	0.794	1.587	2.245	3.474	4.697	6.692	7.920	11.833	14.635
1996	0.088	0.838	1.553	2.597	3.908	6.112	5.458	12.028	11.920	14.635
1997	0.190	0.717	1.694	2.176	3.218	6.200	6.204	9.796	10.174	14.635
1998	0.078	0.650	1.382	2.258	3.034	4.516	5.831	7.787	8.211	14.635
1999	0.111	1.001	1.350	2.237	2.973	4.635	6.513	8.250	8.568	14.635
2000	0.060	0.896	1.587	2.326	3.234	4.461	6.501	8.211	11.523	14.635
2001	0.010	0.771	1.418	2.584	3.602	5.089	6.909	7.552	10.089	11.653
2002	0.016	0.495	1.214	2.269	3.538	4.385	5.856	8.436	10.001	11.653
2003	0.016	0.441	1.141	1.882	3.046	3.361	5.120	6.702	7.661	11.653
2004	0.022	0.288	1.454	2.447	3.449	4.086	4.312	6.320	9.923	11.653
2005	0.058	0.589	1.167	1.770	2.972	3.297	3.936	7.655	6.448	11.653
2006	0.031	0.307	1.151	1.574	2.621	3.182	4.615	4.684	5.729	11.653
2007	0.054	0.625	1.073	1.764	2.622	4.098	5.789	6.810	7.981	11.653
2008	0.046	0.577	1.450	2.041	2.504	3.465	4.165	7.931	10.050	11.653
2009	0.114	0.724	1.470	2.482	2.701	3.527	4.479	5.594	8.285	11.653
2010	0.079	0.657	1.575	2.214	3.194	3.501	3.963	5.380	6.520	11.653
2011	0.038	0.482	1.193	2.036	2.709	3.581	3.670	4.484	5.080	11.653
2012	0.020	0.508	1.189	2.158	2.907	3.760	5.106	6.329	5.300	11.653
2013	0.029	0.685	1.216	2.016	2.785	3.557	4.343	5.350	7.047	11.653
2014	0.079	0.565	1.243	1.821	3.116	4.745	4.724	6.580	7.050	11.653
2015	0.043	0.493	1.124	2.352	2.813	3.586	5.620	6.086	7.050	11.653
Average	0.100	0.746	1.643	2.561	3.768	5.089	6.525	7.912	9.654	13.707
Minimum	0.010	0.288	1.073	1.574	2.504	3.182	3.670	4.484	5.080	11.653
Maximum	0.276	1.132	2.354	3.564	6.182	7.487	9.629	12.712	14.114	14.635

Table 13. Statistical properties of estimates for population abundance (numbers in thousands) at beginning of year 2015 (row numbers 1 to 9) and survey catchability (dimensionless, row numbers 10 to 38) from the "M 0.8" benchmark model formulation for eastern Georges Bank cod obtained from a bootstrap with 1000 replications.

Row Number	**Parameter**	**Estimate (thousands)**	**Standard Error**	**Relative Error**	**Relative Bias**
1	N[2014 9]	93	22	24%	1%
2	N[2015 2]	2983	1676	56%	14%
3	N[2015 3]	309	139	45%	8%
4	N[2015 4]	771	274	36%	6%
5	N[2015 5]	1820	550	30%	4%
6	N[2015 6]	390	118	30%	4%
7	N[2015 7]	93	29	31%	3%
8	N[2015 8]	67	22	32%	4%
9	N[2015 9]	44	14	31%	1%
10	DFO age 1	0.01	0.003	21%	2%
11	DFO age 2	0.10	0.02	19%	1%
12	DFO age 3	0.53	0.10	19%	2%
13	DFO age 4	0.85	0.15	18%	1%
14	DFO age 5	0.91	0.17	19%	2%
15	DFO age 6	0.81	0.15	19%	2%
16	DFO age 7	0.82	0.16	20%	2%
17	DFO age 8	1.09	0.21	19%	1%
18	NMFS Spring Y41 age 1	0.02	0.00	58%	14%
19	NMFS Spring Y41 age 2	0.19	0.02	72%	17%
20	NMFS Spring Y41 age 3	0.22	0.06	61%	13%
21	NMFS Spring Y41 age 4	0.21	0.08	61%	14%
22	NMFS Spring Y41 age 5	0.31	0.08	57%	13%
23	NMFS Spring Y41 age 6	0.30	0.06	64%	10%
24	NMFS Spring Y41 age 7	0.38	0.18	61%	15%
25	NMFS Spring Y41 age 8	0.33	0.16	61%	14%
26	NMFS Spring Y36 age 1	0.02	0.01	22%	2%
27	NMFS Spring Y36 age 2	0.11	0.04	18%	2%
28	NMFS Spring Y36 age 3	0.32	0.07	18%	2%
29	NMFS Spring Y36 age 4	0.49	0.08	17%	2%
30	NMFS Spring Y36 age 5	0.46	0.10	19%	2%
31	NMFS Spring Y36 age 6	0.35	0.11	19%	2%
32	NMFS Spring Y36 age 7	0.38	0.09	19%	2%
33	NMFS Spring Y36 age 8	0.44	0.10	21%	2%
34	NMFS Fall age 1	0.05	0.01	17%	1%
35	NMFS Fall age 2	0.08	0.03	18%	1%
36	NMFS Fall age 3	0.12	0.05	17%	1%
37	NMFS Fall age 4	0.09	0.05	17%	2%
38	NMFS Fall age 5	0.07	0.05	19%	1%

Table 14. a) the Mohn's rho values for Age-1 recruitment, SSB, and F with 7-year peels for the VPA "M 0.8" model and b) the sensitivity run "est 2003 yc"

a)

Peel	Age-1	3+ Biomass	F
1	-0.15	0.17	-0.14
2	-0.33	0.26	-0.02
3	0.32	0.38	-0.20
4	-0.16	0.35	-0.31
5	0.64	0.56	-0.45
6	-0.09	0.73	-0.65
7	-0.09	1.03	-0.62
Mohn's Rho	-0.24	0.50	-0.34

b)

Peel	Age-1	3+ Biomass	F
1	-0.14	0.16	-0.14
2	-0.32	0.24	-0.02
3	0.18	0.16	-0.06
4	-0.25	0.11	-0.04
5	0.46	0.07	0.05
6	-0.19	-0.12	0.25
7	-0.19	-0.06	0.27
Mohn's Rho	-0.23	0.08	0.04

Table 3. Beginning of year population biomass (mt) for Eastern Georges Bank cod during 1978-2015 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2015. The dash (-) at age 1 in 2015 indicates that age 1 in the final year is not estimated in the model.

Year	Age											
	1	2	3	4	5	6	7	8	9	10+	1+	3+
1978	1391	2962	17458	14216	7106	4461	5335	946	1135	1463	56474	52120
1979	1174	8843	4591	16585	10125	3742	4220	4264	729	2098	56372	46354
1980	2778	6032	14275	4181	16615	8341	2526	2623	3132	2289	62791	53981
1981	1654	7011	11170	15681	4761	11839	6296	3330	2431	4181	68356	59691
1982	524	12411	13223	10171	10866	3433	7952	4124	1382	4906	68993	56058
1983	1144	5256	15969	7040	4992	7152	2137	3897	2561	4256	54403	48003
1984	719	2420	6058	11564	3744	3299	3635	981	2117	4143	38681	35542
1985	460	7539	6160	5816	10057	3773	2802	2528	774	3778	43685	35687
1986	3159	3319	12155	4375	4397	7369	2139	1462	1189	2994	42558	36081
1987	1236	16627	5312	9886	3333	3178	4867	1161	912	3244	49756	31892
1988	2152	6261	22150	5426	8270	2095	1932	3283	1311	3270	56151	47738
1989	730	9610	8948	17664	3711	5529	1198	654	1649	2771	52464	42124
1990	1600	3296	16301	10338	15105	3006	3178	746	444	2889	56903	52006
1991	847	5459	5413	14110	8436	7859	2109	1672	530	2204	48639	42332
1992	464	6638	8369	3822	8013	5027	4525	1154	775	1811	40598	33496
1993	332	2800	7579	6146	3194	4607	2735	1844	654	1774	31664	28532
1994	511	2536	2795	4397	3631	2328	2344	1739	1085	1706	23071	20024
1995	384	2316	4758	2611	2312	2392	747	828	842	1322	18512	15812
1996	316	1438	3628	5819	3390	2752	1184	548	529	1025	20628	18874
1997	1073	2110	2319	3703	4752	3960	1014	869	184	721	20706	17523
1998	171	3001	3147	2115	3250	4006	1360	387	258	393	18086	14914
1999	542	1787	4978	3538	1848	3405	2034	744	119	325	19321	16992
2000	115	3580	2207	6011	3207	1832	1891	854	363	207	20266	16572
2001	12	1199	4558	2684	6385	3442	1108	878	391	213	20869	19658
2002	38	484	1427	4927	2338	4793	1385	436	411	240	16479	15957
2003	9	863	904	1599	4192	1491	2002	583	135	257	12034	11163
2004	96	136	2283	1260	1647	3118	635	753	268	165	10361	10129
2005	40	2139	437	2052	850	853	1000	335	222	151	8080	5901
2006	113	175	3351	418	2013	603	436	429	75	196	7810	7521
2007	135	1882	483	3845	387	1858	318	212	239	123	9483	7465
2008	62	1189	3502	639	3520	313	623	138	94	159	10239	8988
2009	100	809	2420	4592	545	3270	139	257	43	98	12273	11363
2010	113	467	1379	2587	4436	434	1303	44	91	56	10909	10329
2011	167	561	648	1287	2078	3833	170	562	10	84	9399	8670
2012	30	1821	1085	812	1261	1972	2368	83	273	44	9751	7900
2013	13	839	3494	1315	734	1170	953	1093	37	284	9932	9081
2014	250	206	1215	4101	1519	978	678	642	645	155	10389	9932
2015	94	1268	320	1707	4925	1341	506	391	308	549	11316	10048

Table 4. Beginning of year population abundance (numbers in thousands) for Eastern Georges Bank cod during 1978-2015 from the “M 0.8” model formulation using the bootstrap bias adjusted population abundance at the beginning of 2015. The dash (-) at age 1 in 2015 indicates that age 1 in the final year is not estimated in the model.

Year	**Age**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	**1+**
1978	12459	3342	10752	3989	1312	714	618	105	111	100	33504
1979	10450	10193	2639	5537	2218	721	438	392	66	143	32798
1980	10052	8542	7543	1501	3169	1328	427	292	266	156	33276
1981	17482	8224	6117	4692	958	1725	769	262	216	286	40731
1982	5693	14281	5958	3334	2641	534	986	467	128	335	34359
1983	5107	4648	8533	3111	1594	1190	262	450	243	291	25428
1984	14264	4161	3100	4733	1387	801	617	109	206	283	29662
1985	5274	11663	3199	1815	2660	647	319	256	55	258	26146
1986	24078	4309	6978	1360	894	1293	288	163	111	205	39679
1987	8243	19676	3122	3681	588	424	651	174	90	222	36871
1988	14135	6729	12407	1797	1984	334	229	376	106	223	38320
1989	5133	11552	5248	6402	862	860	157	84	146	189	30634
1990	7454	4187	8845	3566	3463	501	370	78	33	197	28693
1991	9651	6088	2774	4455	1988	1606	280	166	53	151	27211
1992	3657	7844	4092	1368	1925	820	648	135	74	124	20688
1993	4729	2933	4109	2114	708	782	391	250	70	121	16206
1994	3569	3863	1951	1672	918	312	320	201	118	117	13040
1995	2097	2917	2998	1163	666	509	112	105	71	90	10728
1996	3602	1716	2336	2241	867	450	217	46	44	70	11590
1997	5649	2944	1369	1702	1477	639	163	89	18	49	14099
1998	2187	4616	2277	937	1071	887	233	50	31	27	12316
1999	4892	1785	3688	1581	622	735	312	90	14	22	13741
2000	1902	3997	1391	2584	992	411	291	104	32	14	11716
2001	1199	1554	3215	1039	1773	676	160	116	39	18	9790
2002	2391	979	1176	2172	661	1093	237	52	41	21	8821
2003	576	1957	792	850	1376	443	391	87	18	22	6512
2004	4463	471	1570	515	478	763	147	119	27	14	8567
2005	701	3633	375	1159	286	259	254	44	34	13	6759
2006	3679	571	2911	266	768	190	94	92	13	17	8600
2007	2519	3009	450	2180	148	453	55	31	30	11	8886
2008	1366	2061	2415	313	1405	90	150	17	9	14	7841
2009	877	1117	1647	1850	202	927	31	46	5	8	6710
2010	1424	711	875	1168	1389	124	329	8	14	5	6047
2011	4389	1163	543	632	767	1070	46	125	2	7	8746
2012	1497	3586	913	376	434	525	464	13	52	4	7863
2013	448	1224	2875	652	264	329	219	204	5	24	6244
2014	3146	366	977	2252	487	206	143	98	92	13	7780
2015	2193	2571	284	726	1751	374	90	64	44	47	5952

Table 17. Annual fishing mortality rate for Eastern Georges Bank cod during 1978-2014 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2015.

Year	Age									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	**F4-9**
1978	0.00	0.04	0.46	0.39	0.40	0.29	0.26	0.26	0.26	0.11	0.36
1979	0.00	0.10	0.36	0.36	0.31	0.32	0.20	0.19	0.20	0.05	0.33
1980	0.00	0.13	0.27	0.25	0.41	0.35	0.29	0.10	0.21	0.16	0.33
1981	0.00	0.12	0.41	0.37	0.38	0.36	0.30	0.51	0.35	0.10	0.37
1982	0.00	0.32	0.45	0.54	0.60	0.51	0.58	0.45	0.54	0.18	0.56
1983	0.00	0.20	0.39	0.61	0.49	0.46	0.67	0.58	0.62	0.30	0.55
1984	0.00	0.06	0.34	0.38	0.56	0.72	0.68	0.49	0.65	0.31	0.48
1985	0.00	0.31	0.66	0.51	0.52	0.61	0.47	0.63	0.55	0.17	0.53
1986	0.00	0.12	0.44	0.64	0.54	0.49	0.30	0.39	0.33	0.07	0.53
1987	0.00	0.26	0.35	0.42	0.36	0.42	0.35	0.29	0.34	0.06	0.40
1988	0.00	0.05	0.46	0.53	0.64	0.55	0.81	0.75	0.77	0.20	0.61
1989	0.00	0.07	0.19	0.41	0.34	0.64	0.50	0.73	0.58	0.17	0.44
1990	0.00	0.21	0.49	0.38	0.57	0.38	0.60	0.19	0.53	0.18	0.47
1991	0.01	0.20	0.51	0.64	0.69	0.71	0.53	0.61	0.56	0.22	0.66
1992	0.02	0.45	0.46	0.46	0.70	0.54	0.75	0.46	0.70	0.11	0.61
1993	0.00	0.21	0.70	0.63	0.62	0.69	0.47	0.55	0.50	0.19	0.62
1994	0.00	0.05	0.32	0.72	0.39	0.23	0.32	0.24	0.29	0.03	0.51
1995	0.00	0.02	0.09	0.09	0.19	0.05	0.10	0.06	0.08	0.00	0.11
1996	0.00	0.03	0.12	0.22	0.11	0.21	0.09	0.12	0.10	0.01	0.18
1997	0.00	0.06	0.18	0.26	0.31	0.21	0.39	0.24	0.34	0.05	0.28
1998	0.00	0.02	0.16	0.21	0.18	0.24	0.15	0.47	0.21	0.12	0.21
1999	0.00	0.05	0.16	0.27	0.21	0.13	0.30	0.25	0.29	0.05	0.23
2000	0.00	0.02	0.09	0.18	0.18	0.14	0.12	0.19	0.14	0.07	0.17
2001	0.00	0.08	0.19	0.25	0.28	0.25	0.33	0.24	0.29	0.08	0.27
2002	0.00	0.01	0.12	0.26	0.20	0.23	0.20	0.28	0.21	0.26	0.24
2003	0.00	0.02	0.23	0.38	0.39	0.30	0.39	0.37	0.38	0.12	0.37
2004	0.01	0.03	0.10	0.39	0.41	0.30	0.41	0.44	0.43	0.24	0.37
2005	0.01	0.02	0.14	0.21	0.21	0.21	0.22	0.41	0.25	0.20	0.22
2006	0.00	0.04	0.09	0.39	0.33	0.44	0.31	0.32	0.31	0.18	0.35
2007	0.00	0.02	0.16	0.24	0.29	0.31	0.35	0.40	0.37	0.08	0.26
2008	0.00	0.02	0.06	0.24	0.21	0.27	0.38	0.41	0.38	0.10	0.23
2009	0.01	0.04	0.14	0.08	0.29	0.23	0.54	0.38	0.44	0.12	0.15
2010	0.00	0.07	0.12	0.21	0.06	0.18	0.16	0.64	0.17	0.11	0.13
2011	0.00	0.04	0.16	0.16	0.17	0.03	0.45	0.08	0.18	0.05	0.11
2012	0.00	0.02	0.13	0.15	0.07	0.07	0.02	0.10	0.02	0.01	0.07
2013	0.00	0.02	0.04	0.09	0.04	0.03	0.01	0.01	0.01	0.004	0.05
2014	0.00	0.04	0.09	0.05	0.06	0.03	0.002	0.001	0	0	0.04

Table 5. Projection inputs for Eastern Georges Bank cod.

Parameter	Age									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
Natural Mortality										
2015-2017	0.2	0.2	0.2	0.2	0.2	0.8	0.8	0.8	0.8	0.8
Fishery Partial Recruitment (" M 0.8" model)										
2015-2017	0.02	0.3	0.7	1	0.8	0.6	0.6	0.4	0.2	0.2
Fishery Weight at Age										
2015-2017	0.30	0.97	1.87	2.67	3.63	4.48	5.42	6.61	7.69	11.65
Population Beginning of Year Weight at Age										
2015	0.04	0.49	1.12	2.35	2.81	3.59	5.62	6.09	7.05	11.65
2016-2018	0.05	0.58	1.19	2.06	2.90	3.96	4.90	6.01	7.05	11.65

Table 6. Deterministic projection results for Eastern Georges Bank cod based on F reference point 0.11 from the “M 0.8” model. Shaded values are the 2010 year class (dark grey cells) and the 2013 year class (light grey cells). Bolded values show the year classes with assumed recruitments. A dash (-) indicates that this value was not calculated.

Parameter	Age												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	**1+**	**3+**	**4+**
Fishing Mortality													
2015	0.002	0.024	0.055	0.078	0.063	0.047	0.047	0.031	0.016	0.016	-	-	-
2016	0.002	0.033	0.077	0.11	0.088	0.066	0.066	0.044	0.022	0.022	-	-	-
2017	0.002	0.033	0.077	0.11	0.088	0.066	0.066	0.044	0.022	0.022	-	-	-
Projected Population Numbers													
2015	**2193**	2571	284	726	1751	374	90	64	44	47	-	-	-
2016	**2193**	**1793**	2056	220	550	1346	160	39	28	40	-	-	-
2017	**2193**	**1792**	**1420**	1559	162	412	566	67	17	30	-	-	-
2018	**2193**	**1792**	**1419**	**1076**	1143	121	173	238	29	20	-	-	-
Projected Population Biomass													
2015	**88**	1260	319	1706	4920	1342	506	392	308	548	-	10042	9724
2016	**110**	**1040**	2447	454	1594	5332	785	232	197	468	-	11510	9063
2017	**110**	**1039**	**1690**	3211	469	1632	2775	405	117	349	-	10648	8958
2018	**110**	**1039**	**1689**	**2218**	3315	480	849	1432	204	239	-	10426	8737
Projected Catch Numbers													
2015	**3**	54	14	50	97	12	3	1	0	1	-	-	-
2016	**4**	**53**	138	21	42	59	7	1	0	1	-	-	-
2017	**4**	**53**	**96**	147	12	18	25	2	0	0	-	-	-
Projected Catch Biomass													
2015	**1**	53	26	133	351	53	16	9	4	6	650	-	-
2016	**1**	**51**	259	56	153	266	38	8	3	7	842	-	-
2017	**1**	**51**	**179**	394	45	82	136	13	2	5	907	-	-

Table 7. Projection and risk analysis result for Eastern Georges Bank cod from the "M 0.8" model formulations: a) risk of fishery catch will exceed F reference point 0.11 in 2016 and 2017; and b) risk of ages 3+ biomass will not increase from 2016 to 2017 and from 2017 to 2018.

a)

Probability	**0.25**	**0.5**	**0.75**
2016	600 mt	675 mt	775 mt
2017(F_{2016}=0.11)	640 mt	725 mt	850 mt
2017(2016 catch=600mt)	650 mt	750 mt	875 mt

b)

Probability	**0.25**	**0.5**	**0.75**
2016 to 2017	0 mt	0 mt	475 mt
2017 to 2018 (F_{2016}=0.11)	225 mt	625 mt	1,025 mt
2017 to 2018 (2016 catch=600mt)	175 mt	575 mt	1,025 mt

Table 8. Consequence analysis of risks of different management actions taken for Atlantic Cod from Eastern Georges Bank. Projected catch and biomass are presented for each of two ‘true state of nature’ management models: VPA “M0.8” model with F = 0.11 and ASAP M = 0.2 model with F_{ref} = 0.18 during 2016- 2018 on the main diagonal (“true state”). The risks of the alternative management actions “alternate state” are on the counter diagonal (see text). Fishing mortality (F), January 1 stock biomass, and percent change in biomass (% B) from the previous year are presented for each projection.

CONSEQUENCE ANALYSIS

Catch 2014	574 mt		
Quota 2015	650 mt		
		VPA 0.8	**ASAP**
2014 biomass (3+)		9,932 mt	2,422 mt
2015 biomass (3+)		10,048 mt	na
Projected catch(mt)			
VPA F=0.11		"true state"	"alternate state"
2016 catch = 675	2016 F	0.11	0.65
	2017 Biomass (mt)	9,425	2,532
	% B from 2016	-6.2%	21%
2017 catch = 725	2017 F	0.11	0.66
	2018 Biomass (mt)	9,368	3,312
	% B from 2017	-0.6%	31%
ASAP F=0.18		"alternate state"	"true state"
2016 catch = 223	2016 F	0.028	0.18
	2017 Biomass (mt)	9,767	2,977
	% B from 2016	-2.8%	42%
2017 catch = 304	2017 F	0.034	0.18
	2018 Biomass (mt)	9,679	4,180
	% B from 2017	2.7%	40%

🟩	F<=Fref & 10% biomass increase
🟦	F< =Fref & biomass increase < 10%
🟧	F> Fref and biomass increaase > 10%

Table 22. Comparison of TRAC catch advice, TMGC quota decision, actual catch, and resulting fishing mortality and biomass changes for Eastern Georges Bank cod.

TRAC	**Catch Year**	**TRAC Analysis/Recommendation**		**TMGC Decision**		**Actual Catch(1) /Compared to Risk Analysis**	**Actual F Result(2)**
		Amount	**Rationale**	**Amount**	**Rationale**		
1999(3)	1999	3,100 mt		NA	NA	3,000 mt	*Near* $F_{0.1}$
2000	2000	3,750 mt	$F_{0.1}$	NA	NA	2,250 mt	*Less than* $F_{0.1}$
2001	2001	3,500 mt	$F_{0.1}$	NA	NA	3,500 mt	*Above* $F_{0.1}$
2002	2002	1,900 mt	$F_{0.1}$	NA	NA	2,800 mt	*F = 0.23*
Transition to TMGC process in following year; note catch year differs from TRAC year in following lines							
2003	2004	1,300 mt	Neutral risk of exceeding F_{ref}. 20% chance of decrease in biomass from 2004-2005.	1,300 mt	Neutral risk of exceeding F_{ref}. 20% chance of decrease in biomass from 2004-2005.	2,332 mt Exceed F_{ref} and biomass to decline	*F = 0.16* *Biomass decreased 23%* Now F = 0.37 Biomass decreased 23% 04 - 05
2004	2005	1,100 mt	Neutral risk of exceeding F_{ref}. Greater than 50% risk of decline in biomass from 2005 - 2006.	1,000 mt	Low risk of exceeding F_{ref}, neutral risk of stock decline	1,287 mt Greater than neutral risk of exceeding $F_{0.1}$; biomass expected to decline 10%	*F = 0.10* *Biomass stabled* Now F = 0.22 Biomass decreased 4% 05 - 06
2005	2006	2,200 mt	Neutral risk of exceeding F_{ref}. Low risk of less than 10% biomass increase from 2006 - 2007.	1,700 mt	Low risk of exceeding F_{ref}, 75% probability of stock increase of 10%	1,705 mt Approx 25% risk of exceeding F_{ref}; biomass increase not likely to be 20%	*F = 0.15* *Biomass stabled* Now F = 0.35 Biomass increased 19% 06 - 07
2006(4)	2007	(1) 2,900 mt (2) 1,500 mt	(1) Neutral risk of exceeding F_{ref}. (2) Neutral risk of biomass decline from 2007 – 2008.	1,900 mt	Low risk of exceeding F_{ref}, nominal decline in stock size	1,811 mt No risk of exceeding F_{ref}; neutral risk of biomass decline	*F = 0.13* *Biomass stabled* Now F = 0.26; Biomass decreased 5% 07-08

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch(1) /Compared to Risk Analysis	Actual F Result(2)
		Amount	Rationale	Amount	Rationale		
2007(4)	2008	2,700 mt	Neutral risk of exceeding F_{ref} and a neutral risk of stock decline from 2008 - 2009	2,300 mt	Low risk of exceeding F_{ref}, nominal stock size increase	1,780 mt No risk of exceeding F_{ref}; biomass not expected to increase 10%	*F = 0.25 or 0.17* *Biomass increased 16%/19%* Now 0.23; Biomass increased 16% 08-09
2008(4)	2009	(1) 2,100 mt (2) 1,300 mt	(1) Neutral risk of exceeding F_{ref} (2) neutral risk of stock decline from 2009 - 2010	1,700 mt	Low risk of exceeding F_{ref}, high risk biomass will not increase	1,837 mt Slightly less than neutral risk of exceeding F_{ref}; biomass almost certain not to increase	*F = 0.33 or 0.20* *Biomass stable or declined 7%* Now F = 0.16; Biomass decreased 10% 09-10
2009(4)	2010	(1) 1,300 – 1,700 mt (2) 1,800 – 900 mt	(1) Neutral risk of exceeding F_{ref} (2) Neutral risk of stock decline from 2010 - 2011	1,350 mt	Neutral risk of biomass decline	1,326 mt	*F = 0.41 or 0.25* *Biomass decreased 15%/ 17%* Now F = 0.14; Biomass decreased 14% 10-11
2010(4)	2011	(1) 1,000 – 1,400 mt (2) 1,850 – 1,350 mt	(1) Neutral risk of exceeding F_{ref} (2) Neutral risk of stock decline from 2011 - 2012	1,050 mt	Low risk of exceeding F_{ref}, and biomass growth of up to 10%.	1,037 mt	*F = 0.49 or 0.28* *Biomass increased 6%/stable* Now F = 0.12; Biomass increased 22% 11-12
2011	2012	(1) 600 – 925 mt (2) 1,350 – 900 mt	(1) Neutral risk of exceeding F_{ref} (2) Neutral risk of stock decline from 2012 – 2013	675 mt	Low risk of exceeding F_{ref}, and low to neutral risk of biomass decline	614 mt	*F = 0.07;* *Biomass increased 16%* Now F = 0.07; Biomass increased 27% 12-13
2012	2013	(1) 400 – 775 mt	(1) Neutral risk of exceeding F_{ref} (2) Neutral risk of	600mt	Neutral risk of exceeding F_{ref}, and stock biomass	463 mt	*F = 0.07;* *Biomass increased 9%*

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch(1) /Compared to Risk Analysis	Actual F Result(2)
		Amount	Rationale	Amount	Rationale		
		(2) 400 – 575 mt	stock not increase by 20% from 2013 – 2014		increase more than 10%		
2013	2014	600 mt	(1) low risk of exceeding F_{ref} (2) Neutral risk of stock not increase by10% from 2014 – 2015	700mt	Low risk of exceeding F_{ref}, and stock biomass increase close to 10%	574 mt	*F = 0.04;* *Biomass increased 10%*
2014	2015	<675 mt	(1) Neutral risk of exceeding F_{ref} but even with no fishing in 2016 there is a greater than 50% risk of a decrease in adult biomass from 2016 to 2017				

(1) All catches are calendar year catches

(2) Values in italics are assessment results in year immediately following the catch year; values in normal font are results from this assessment

(3) Prior to implementation of US/CA Understanding

(4) Advice and results reported for two assessment models

Table 23. Comparison of deterministic and stochastic projections results for assessments since 2009 for Eastern Georges Bank cod.

Model	**Deterministic Projection (mt)**	**Stochastic Projection (mt) (Neutral Risk Catch > F_{ref})**	**Relative Difference**
2009 “Split M 0.2”	1,323	1,300	2%
2009 “Split M 0.5”	1,628	1,700	-4%
2010 “Split M 0.2”	979	1,000	-2%
2010 “Split M 0.5”	1,259	1,400	-11%
2011 “Split M 0.2”	613	600	2%
2011 “Split M 0.5”	960	1,050	-9%
2012 “Split M 0.2”	850	875	-3%
2012 “Split M 0.5”	1,414	1,400	1%
2013 “M 0.8”	1,273	1,225	4%
2014 “M 0.8”	1,235	1,150	7%
2015 “M 0.8”	842	675	20%

FIGURES

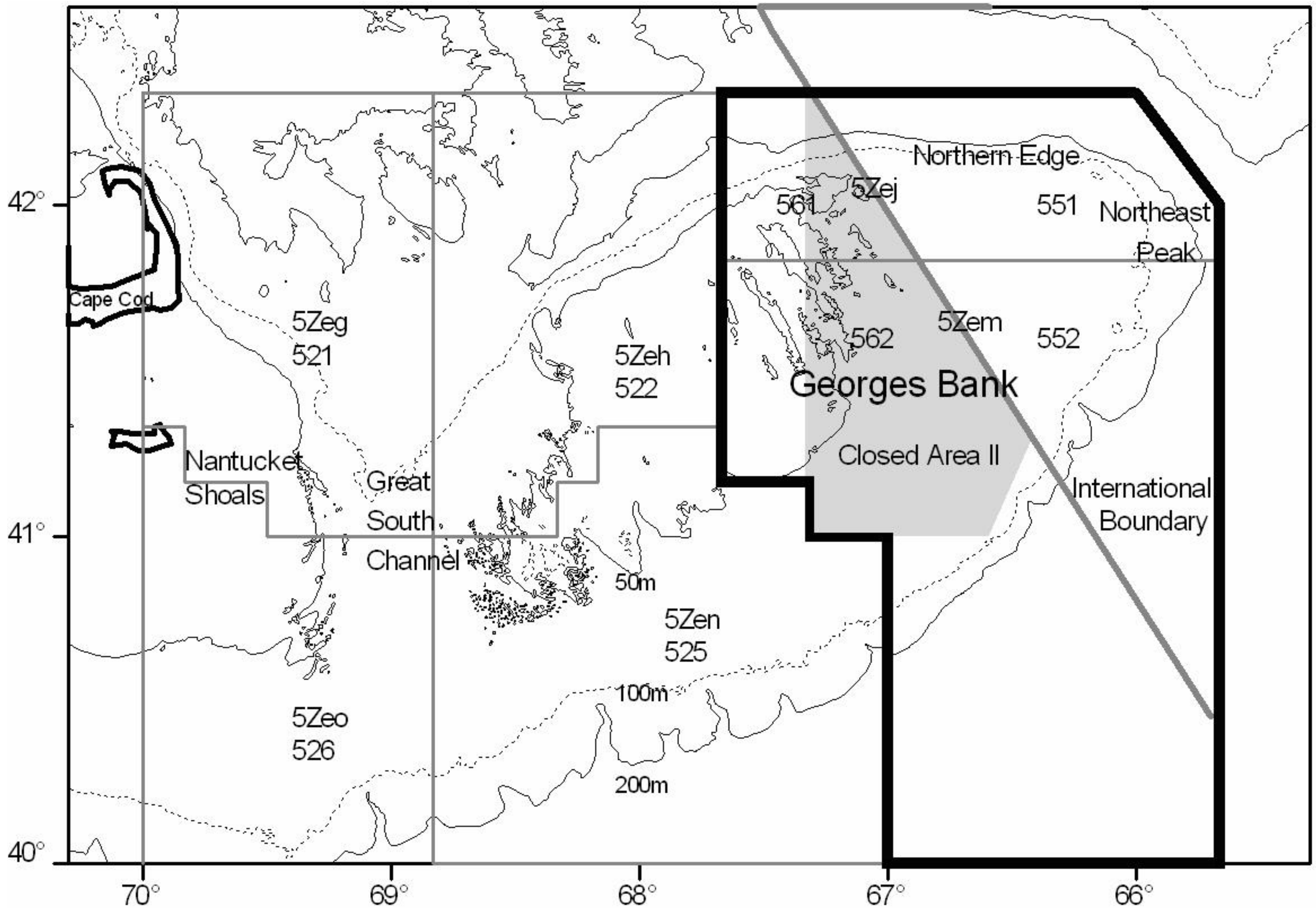


Figure 1. Fisheries statistical areas (Canada and USA) in NAFO Subdivision 5Ze. The Eastern Georges Bank Atlantic Cod management unit is outlined by a heavy black line.

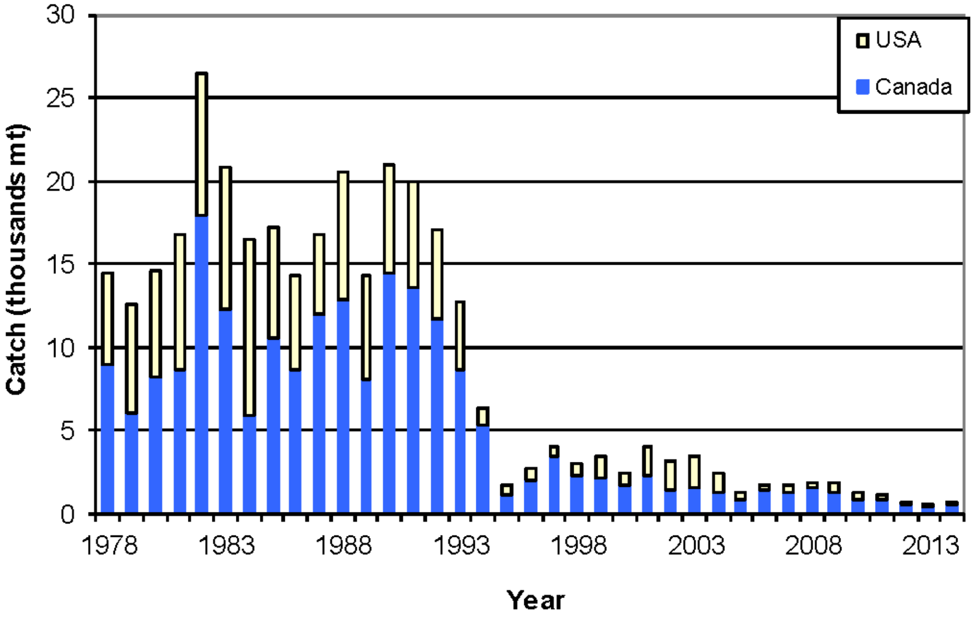


Figure 2. Catches Eastern Georges Bank cod, 1978 to 2014.

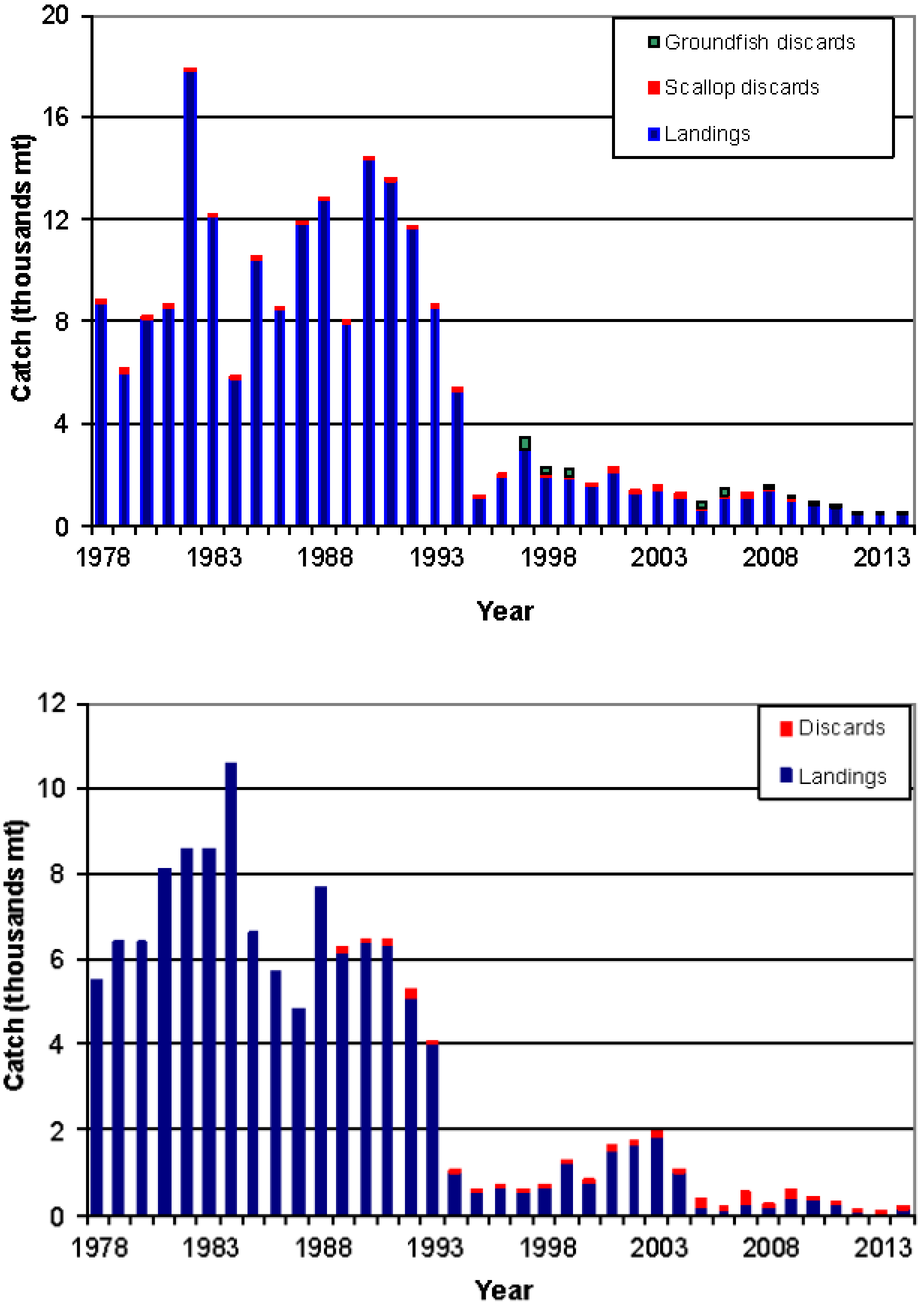


Figure 3. Canadian (upper) and USA (lower) landings and discards of Eastern Georges Bank cod, 1978 to 2014.

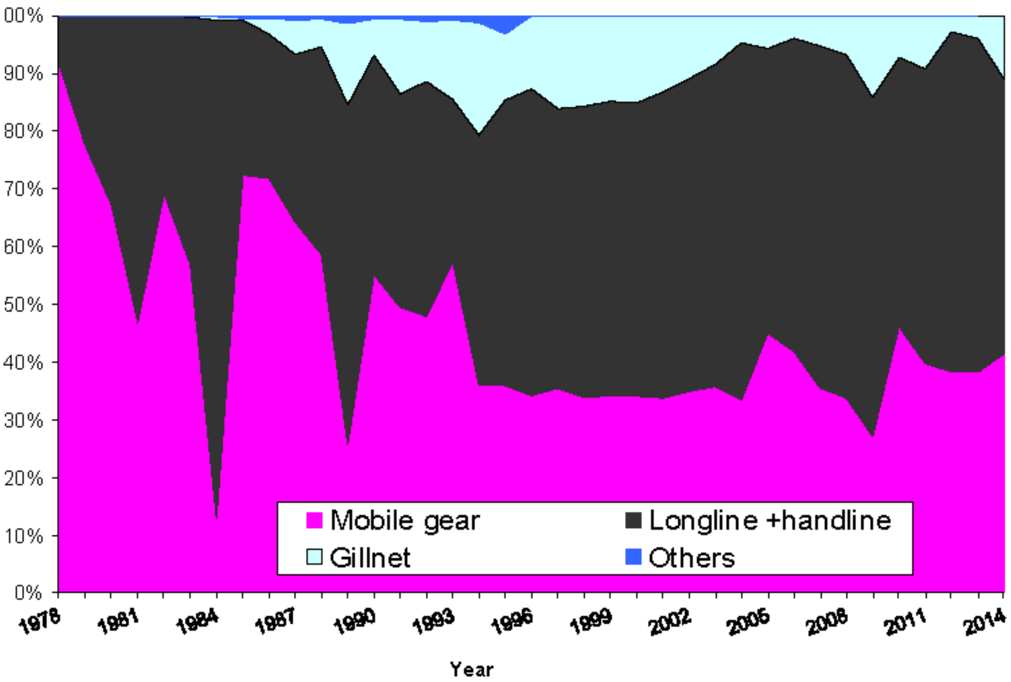


Figure 4. Proportion of Canadian gear specific landings of cod from Eastern Georges Bank for 1978 to 2014.

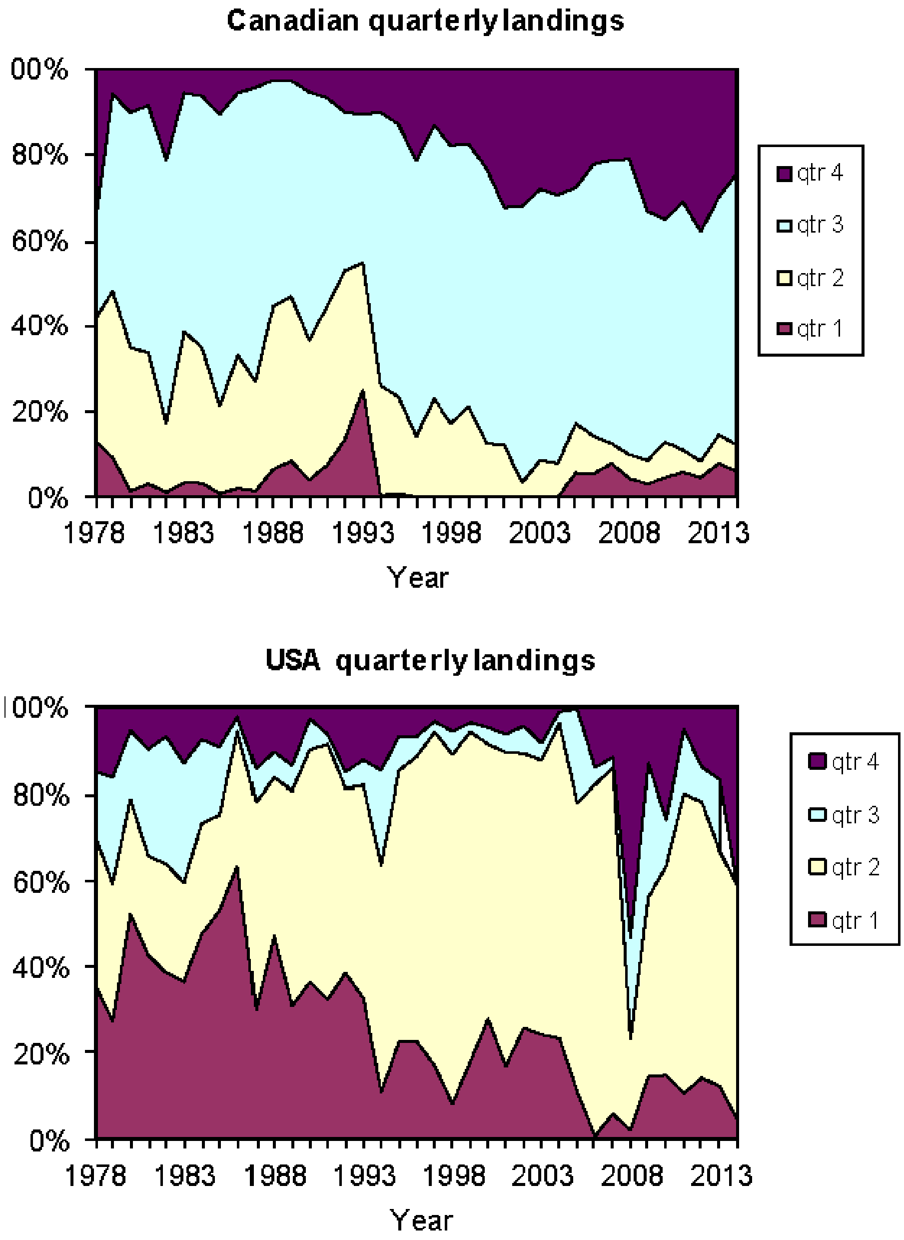


Figure 5. Proportion of Canadian (upper) and USA (lower) quarterly landings of cod from Eastern Georges Bank, 1978 to 2014.

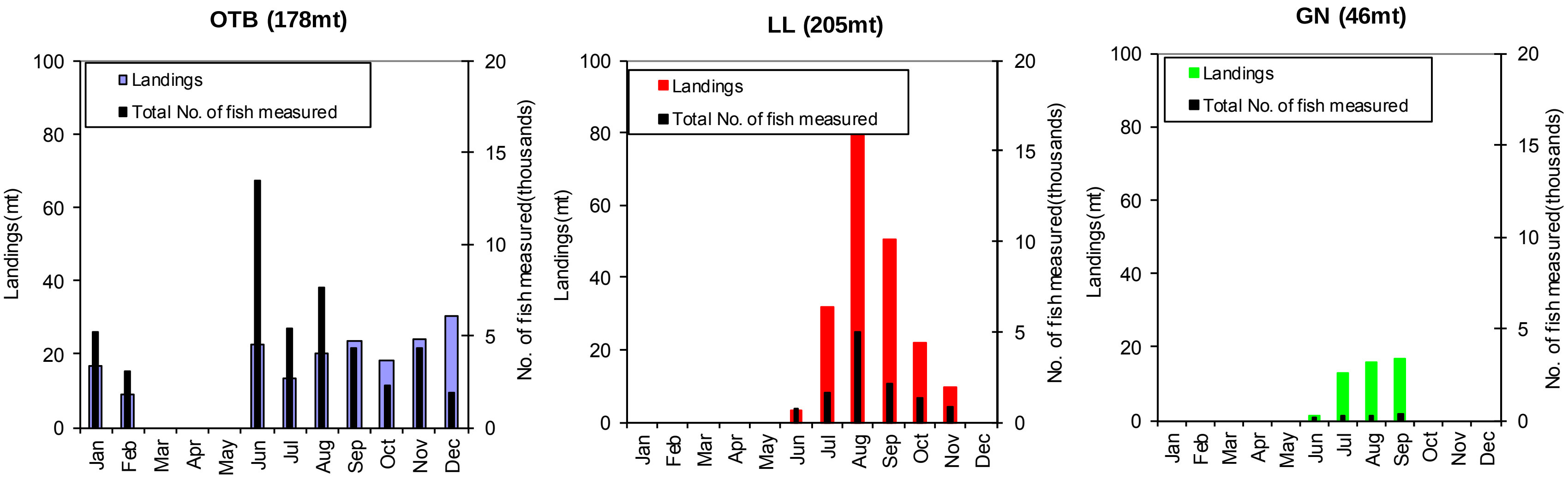


Figure 6. Landings (wide bars) and sampling (narrow dark bars) of cod by gear and month from the 2014 Canadian bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on Eastern Georges Bank.

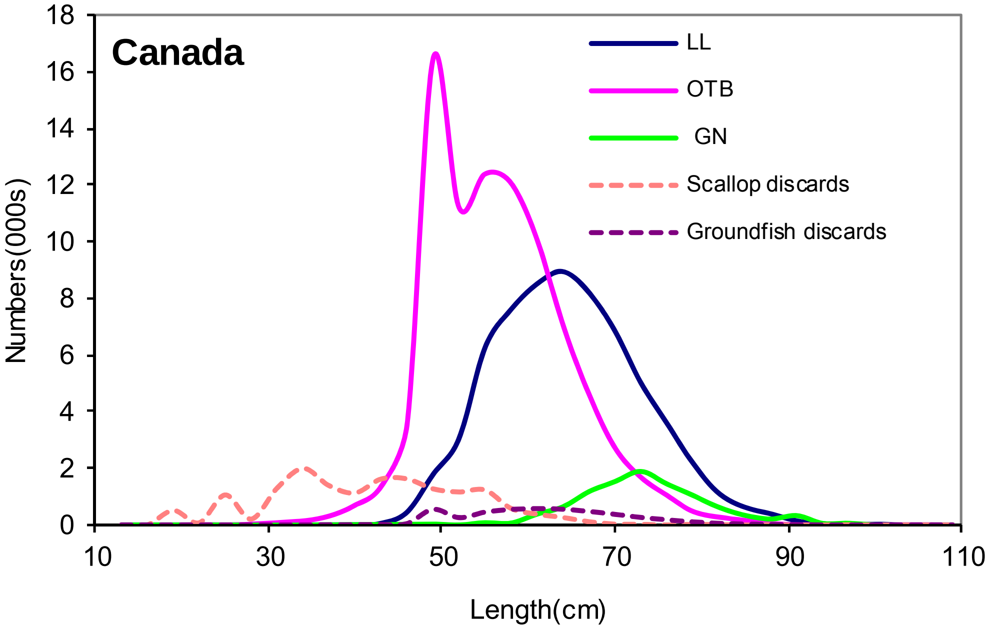


Figure 7. Cod catches at length by gear from the 2014 Canadian fisheries bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on Eastern Georges Bank

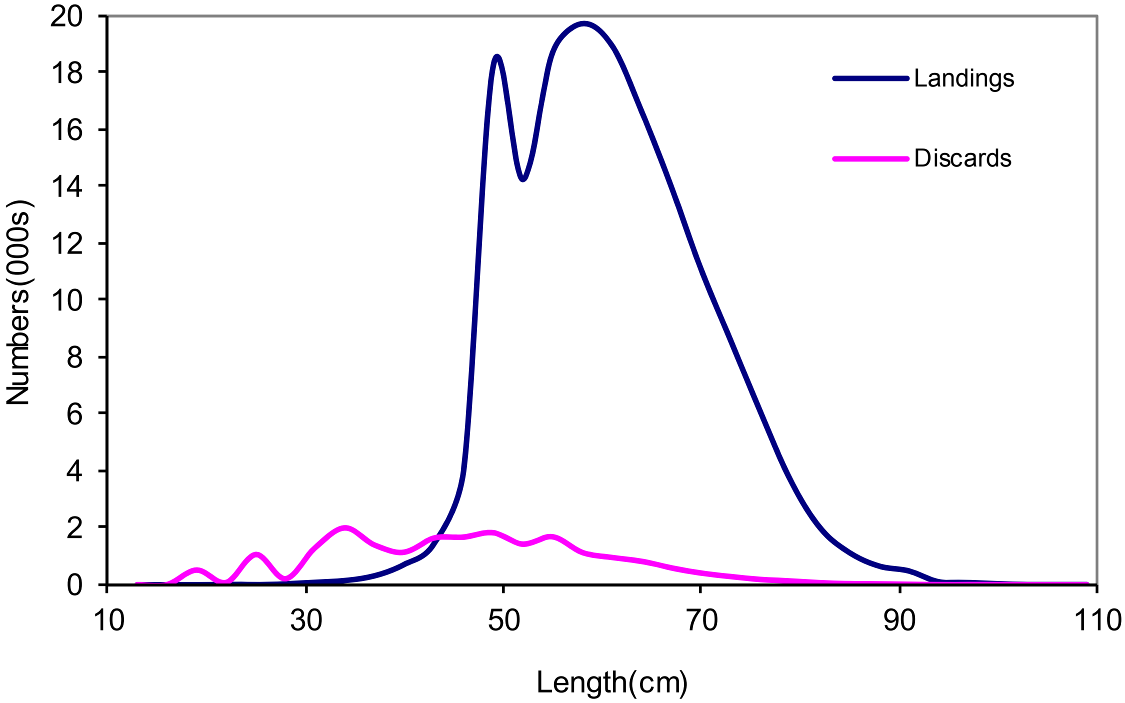


Figure 8. Cod landings and discards at length from the 2014 Canadian fisheries on Eastern Georges Bank.

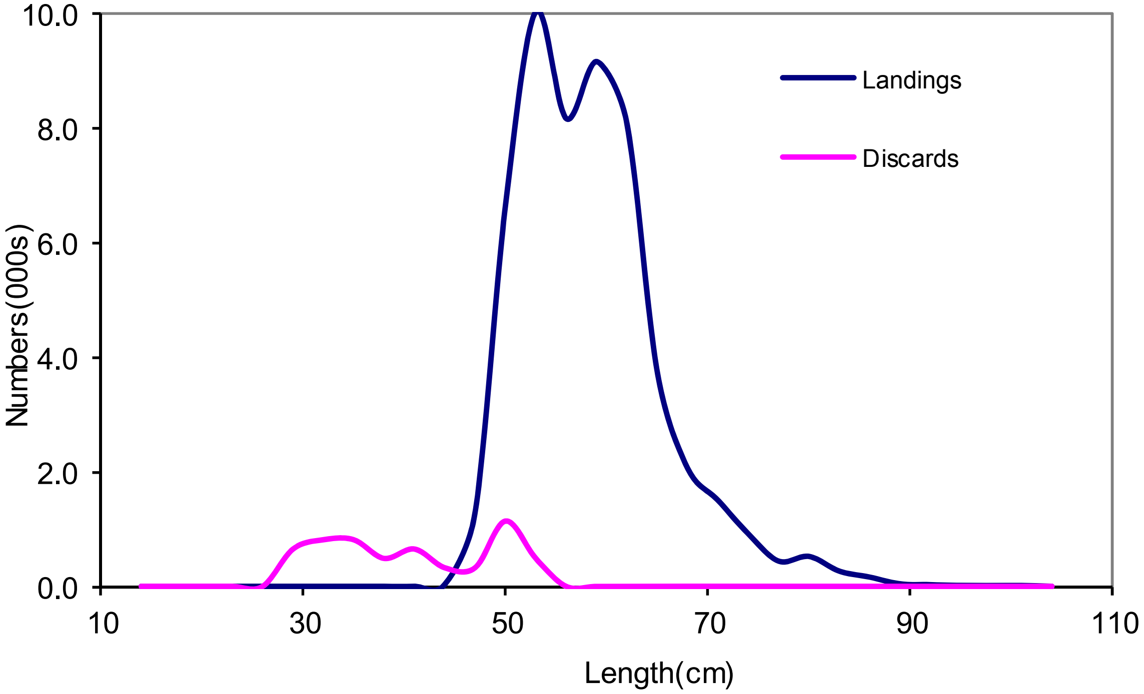


Figure 9. Cod landings and discards at length from the 2014 USA fisheries on Eastern Georges Bank.

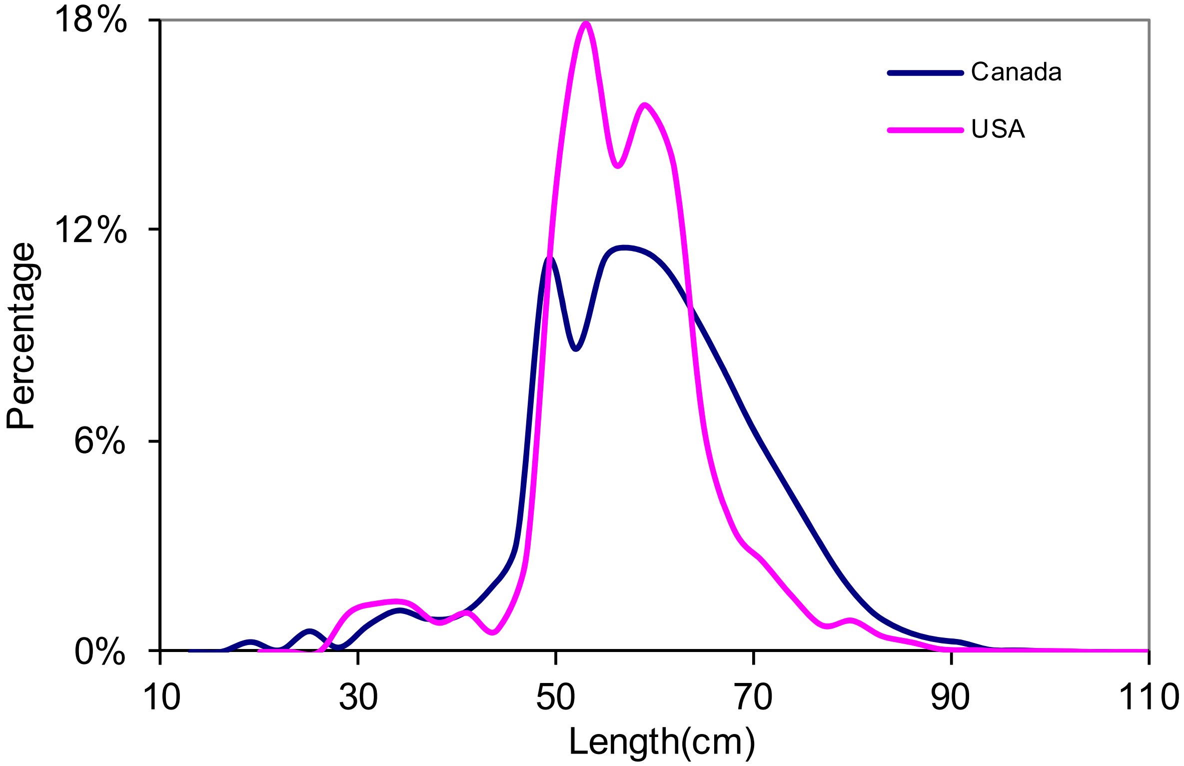


Figure 10. Cod length frequency from the 2014 Canadian and USA fisheries on Eastern Georges Bank.

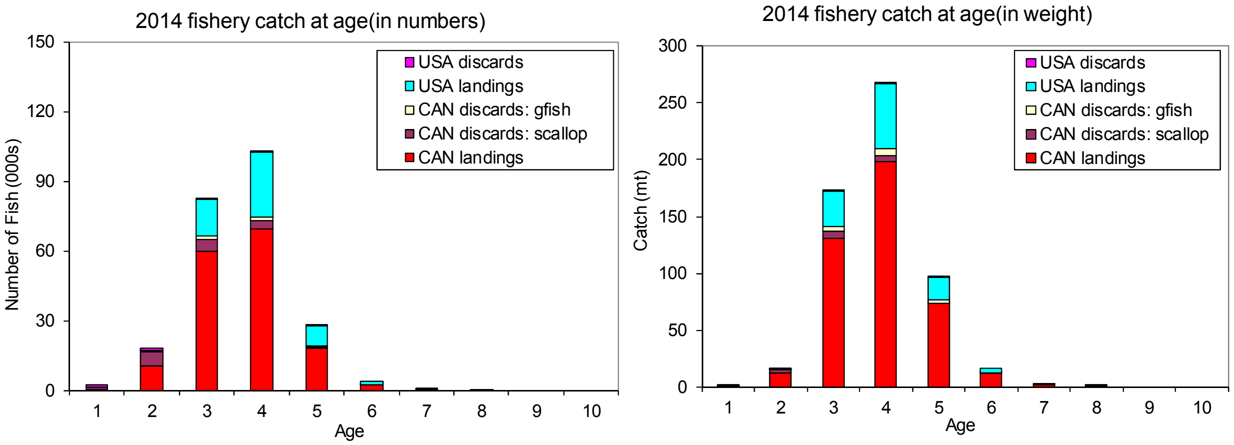


Figure 11. Catch at age in numbers (left) and weight (right) for landings and discards of cod from the 2014 Eastern Georges Bank fisheries.

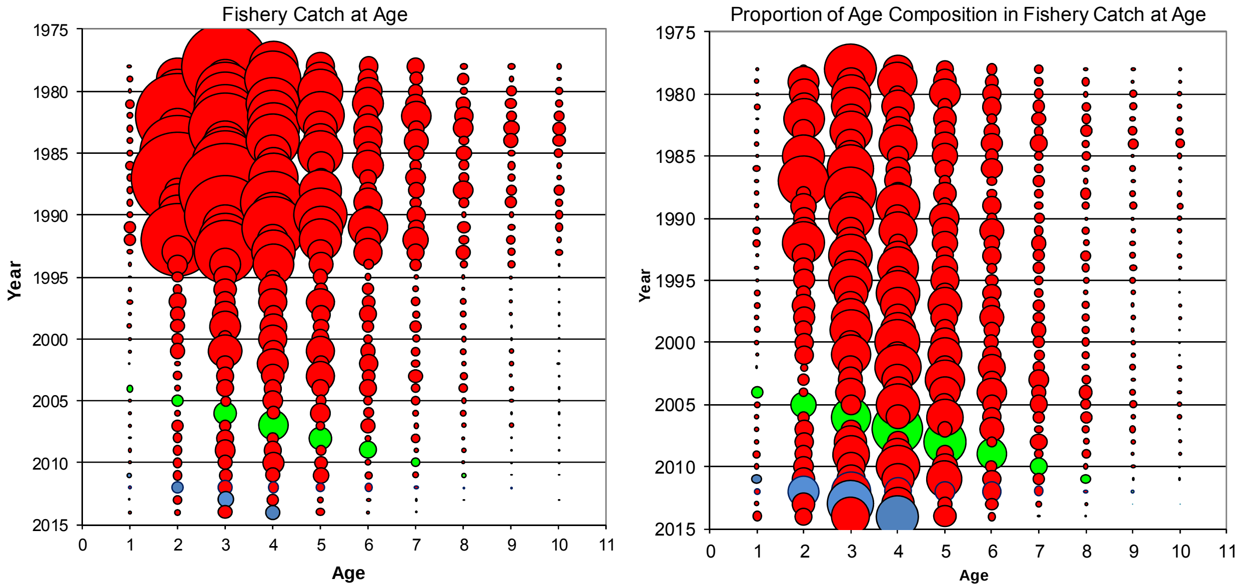


Figure 12. Total catch at age (numbers) of cod (left) and proportion of catch at age from Eastern Georges Bank for 1978-2014. The bubble area is proportional to the magnitude. The light green circles are the 2003 year class and the light blue circles are the 2010 year class.

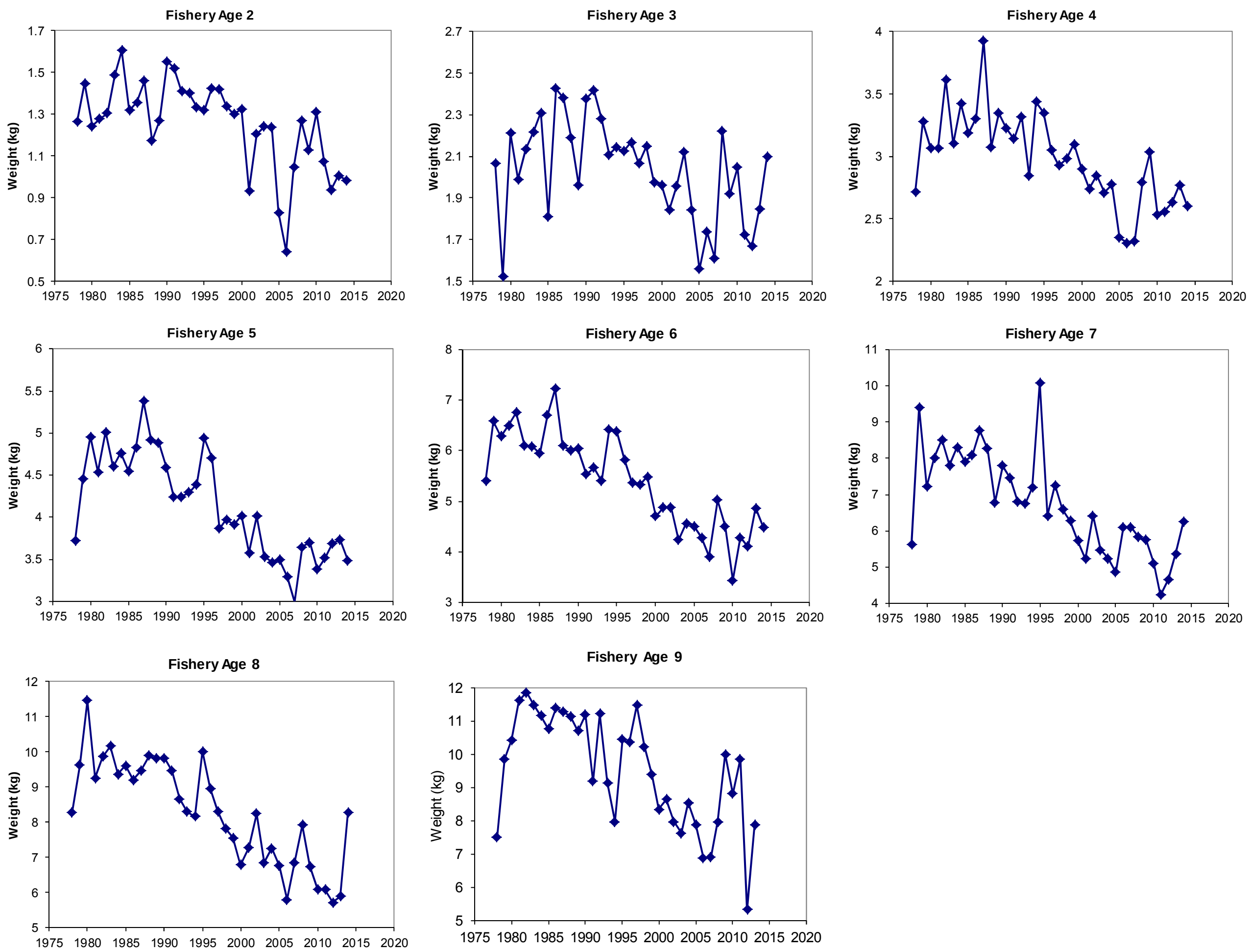


Figure 13. Average weight at age for ages 2 to 9 of cod from the Eastern Georges Bank fishery, 1978-2014.

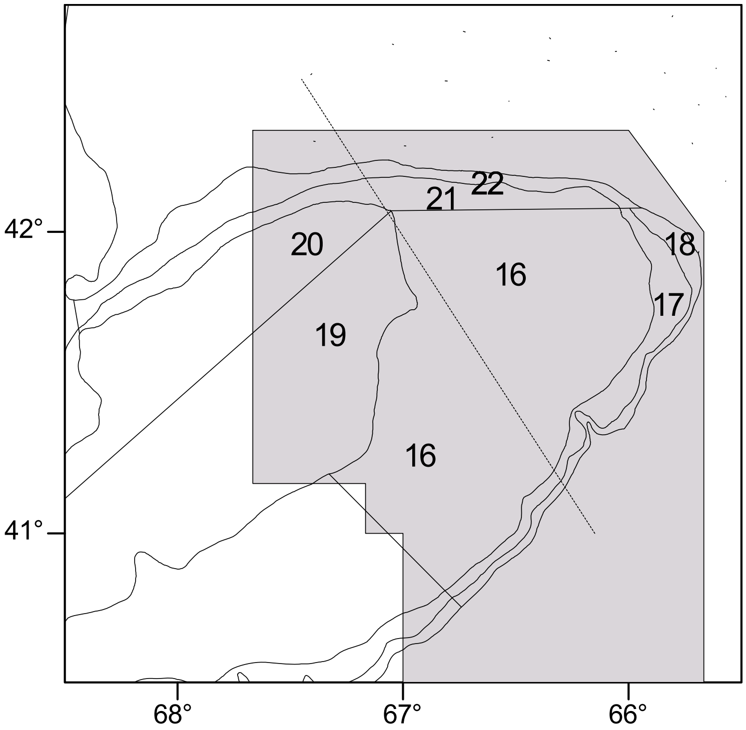


Figure 14. Stratification used for the NMFS surveys. The Eastern Georges Bank management unit is indicated by shading.

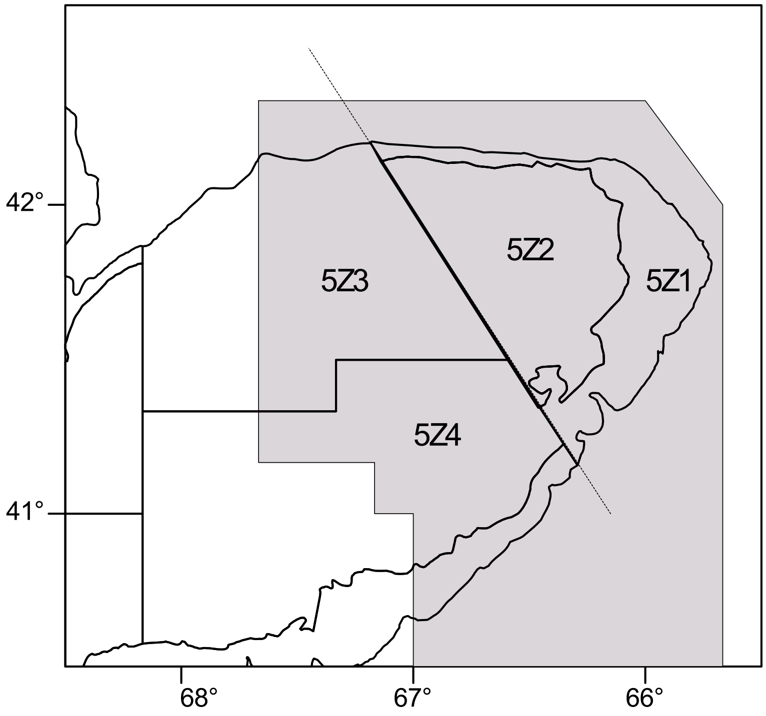


Figure 15. Stratification used for the DFO survey. The Eastern Georges Bank management unit is indicated by shading.

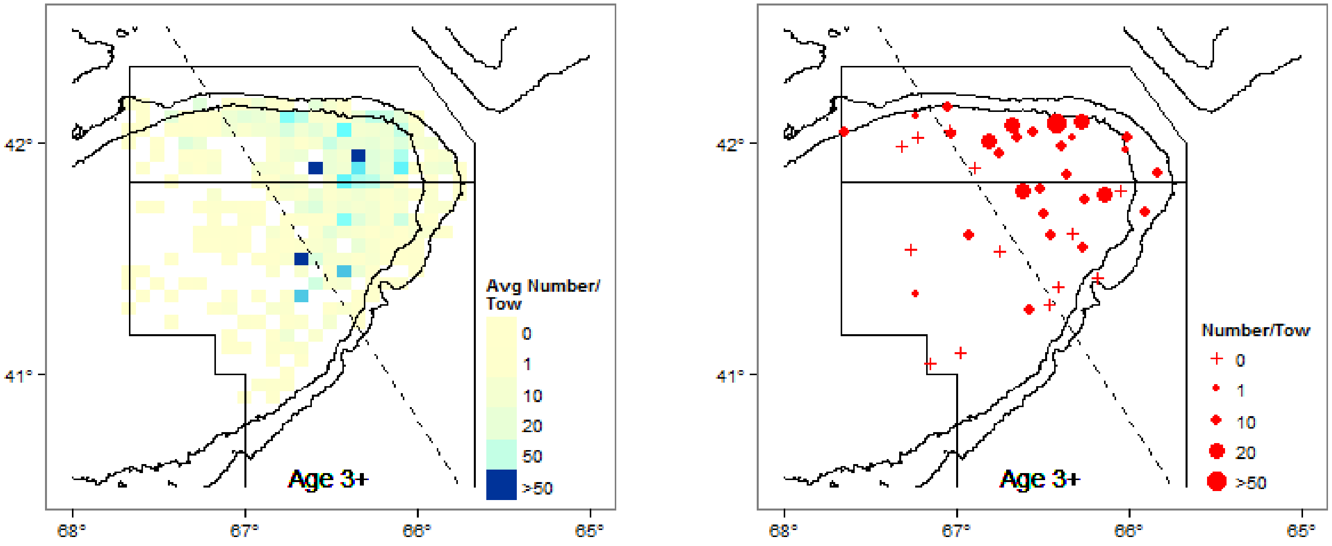


Figure 16. Spatial distribution of age 3+ cod on Eastern Georges Bank from the DFO survey for 2015 (right) compared to the average for 2005-2014 (left).

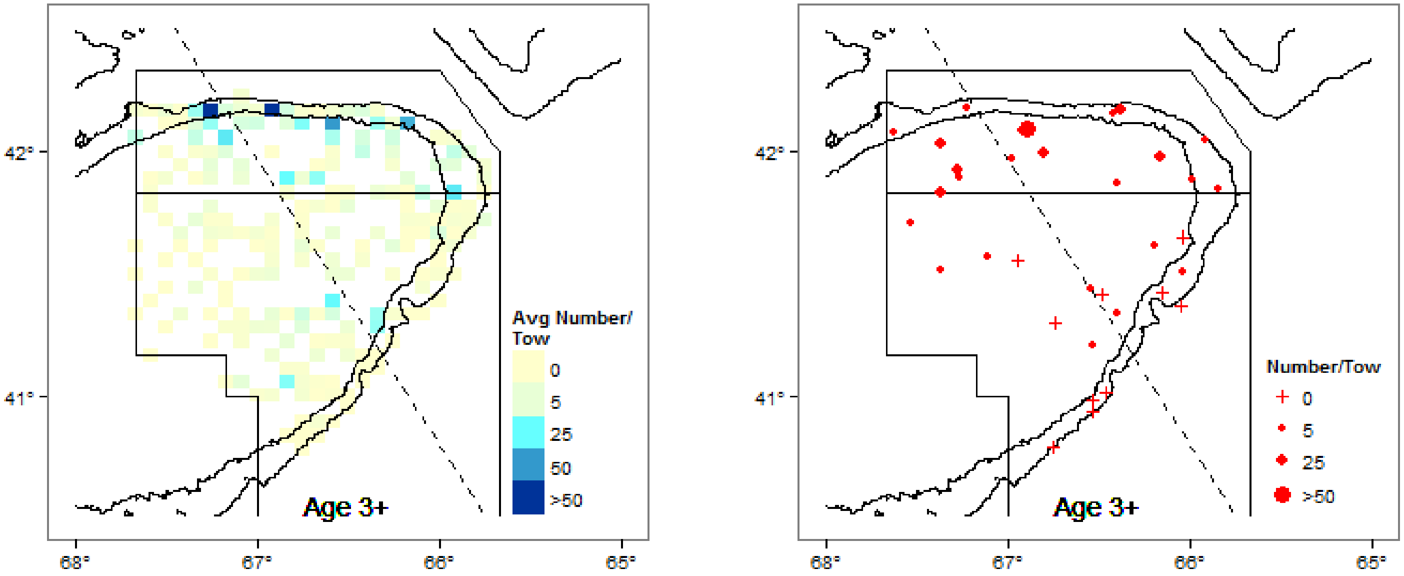


Figure 17. Spatial distribution of age 3+ cod on Eastern Georges Bank from the NMFS spring survey for 2015 (right) compared to the average for 2005-2014 (left).

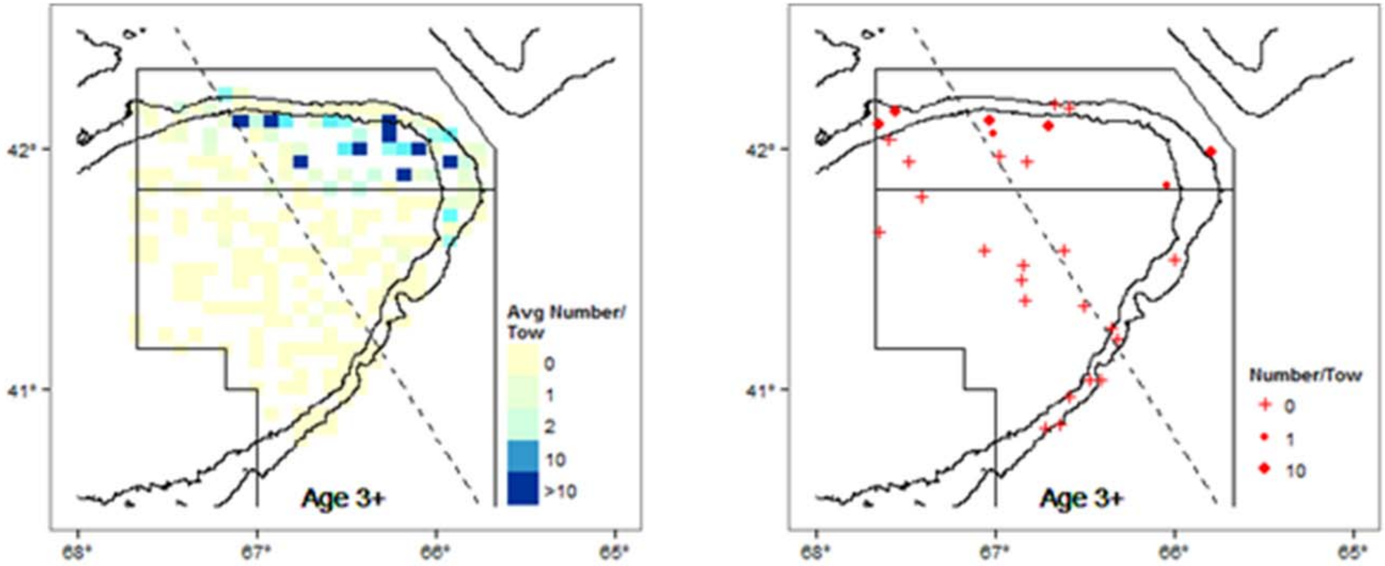


Figure 18. Spatial distribution of age 3+ cod on Eastern Georges Bank from the NMFS fall survey for 2014 (right) compared to the average for 2004-2013 (left).

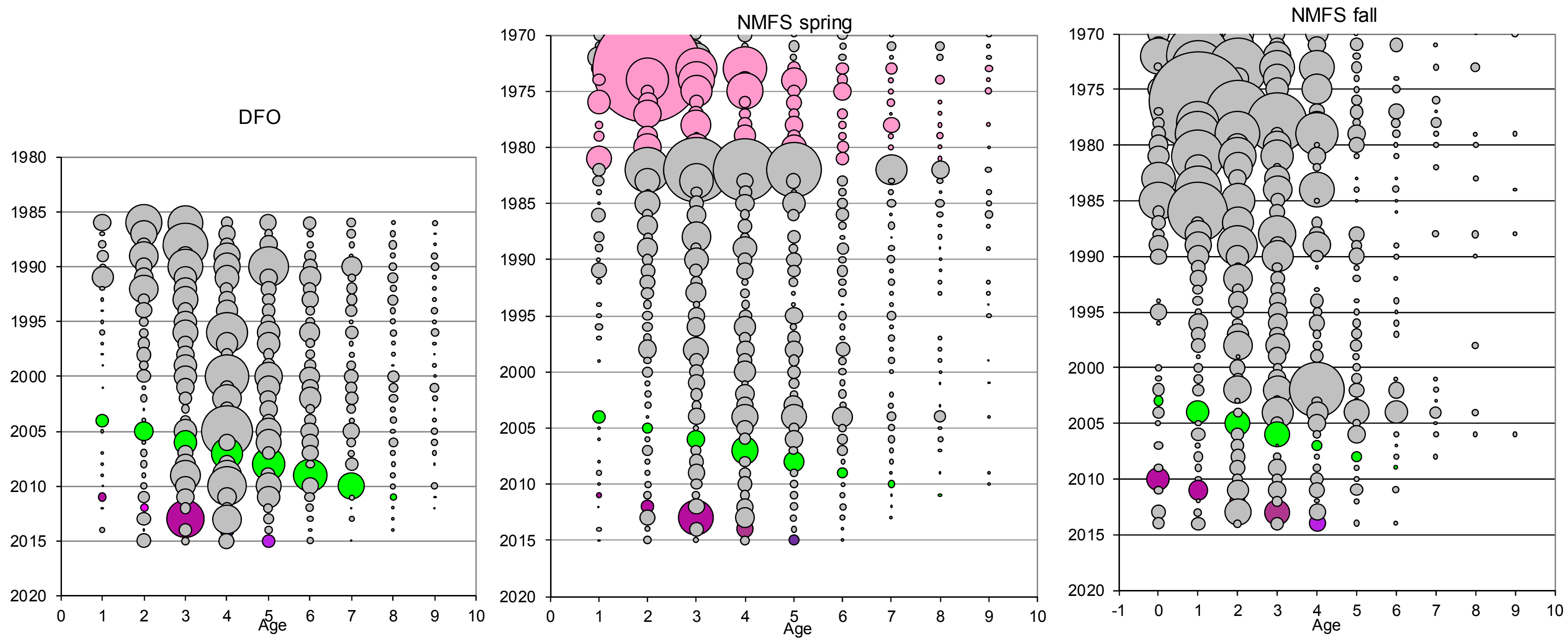


Figure 19. Survey abundance at age (numbers) of Eastern Georges Bank cod. The bubble area is proportional to magnitude within each survey. Conversion factors to account for changes in door type, net and survey vessel were applied to the NMFS surveys. The NMFS spring survey was conducted using a modified Yankee 41 during 1978-1981 (pink bubbles). The 2003 year class is identified with green bubbles and the purple bubbles show the 2010 year class.

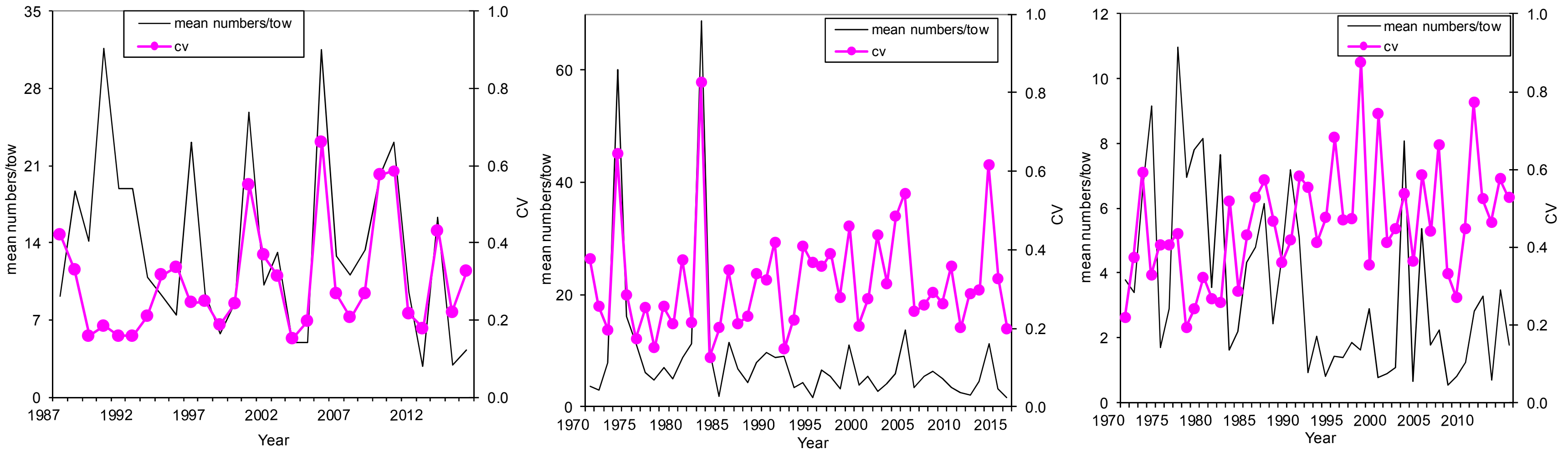


Figure 20. Stratified mean number per tow and coefficient of variation (CV) for DFO (left), NMFS spring (middle) and NMFS fall (right) survey catch of Eastern Georges Bank cod.

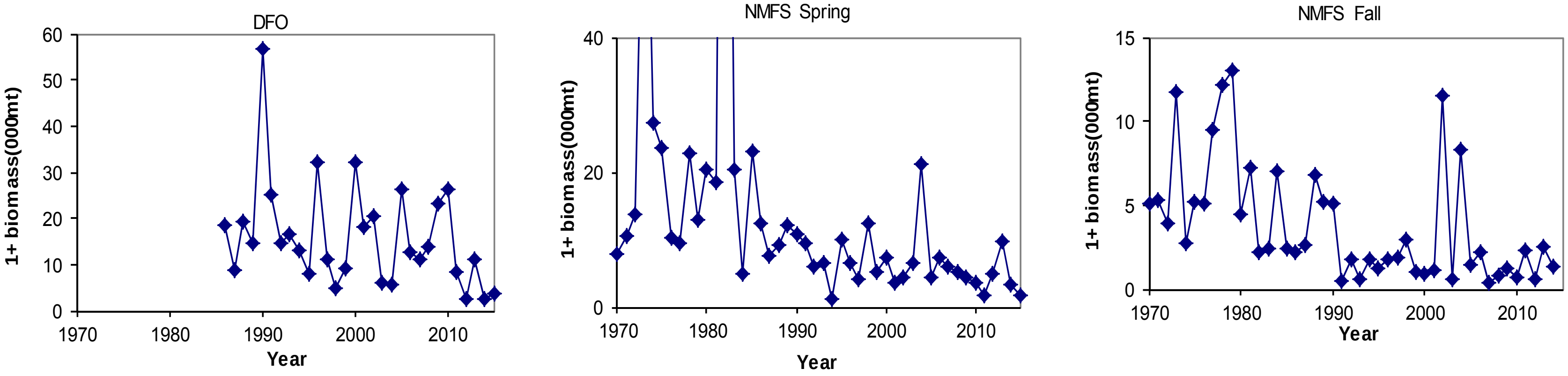


Figure 21. Survey biomass indices (ages 1+) for Eastern Georges Bank cod from the DFO spring (left), NMFS spring (middle) and NMFS fall (right) surveys, 1978-2015.

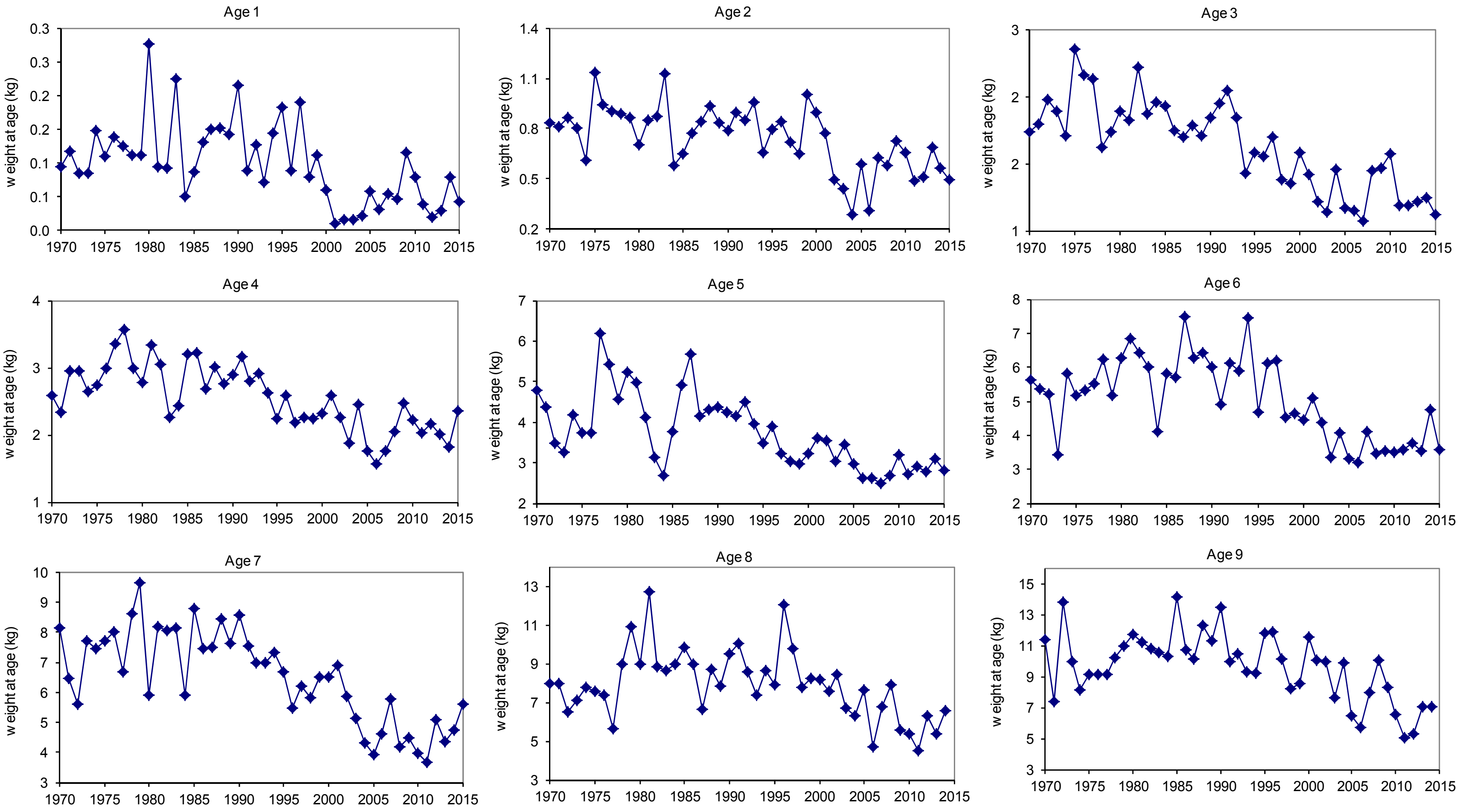


Figure 22. Beginning of year weight at age of Eastern Georges Bank cod from DFO and NMFS spring surveys.

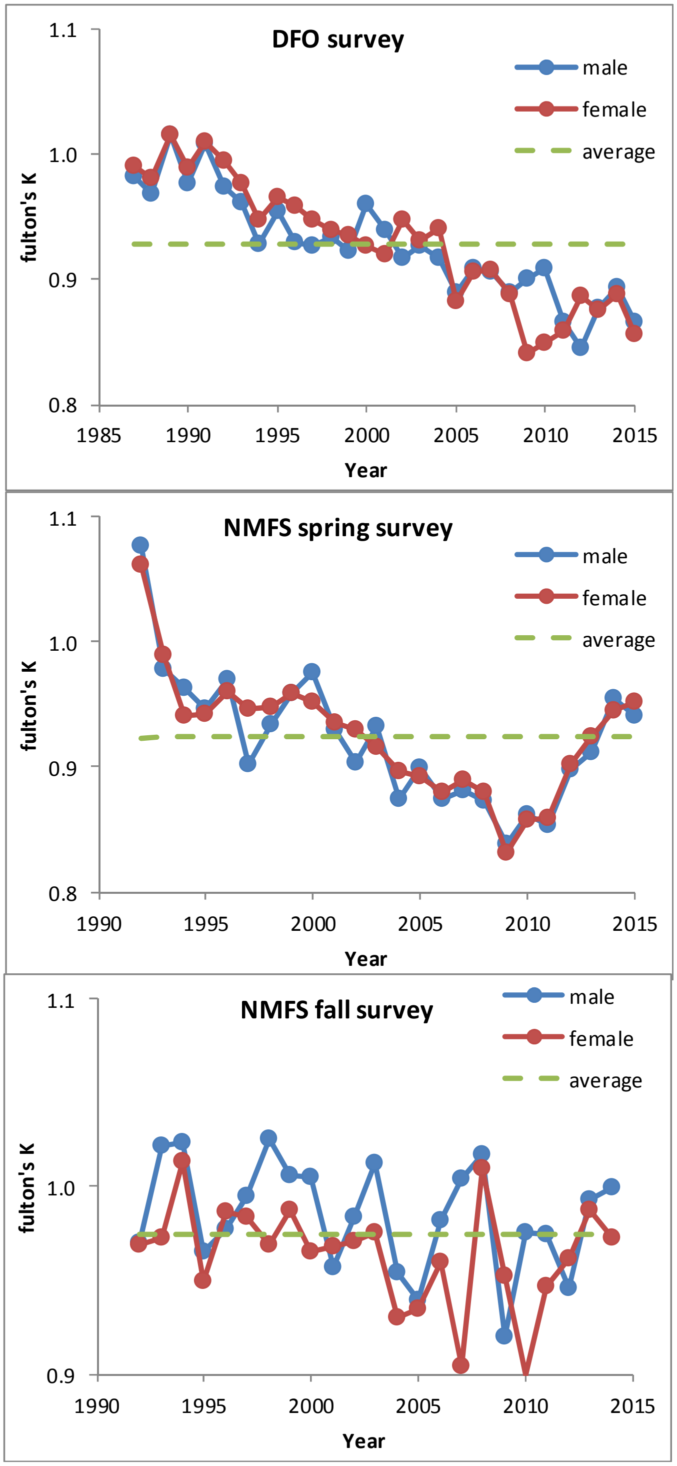


Figure 23. Fish condition (Fulton's K) for Eastern Georges Bank cod.

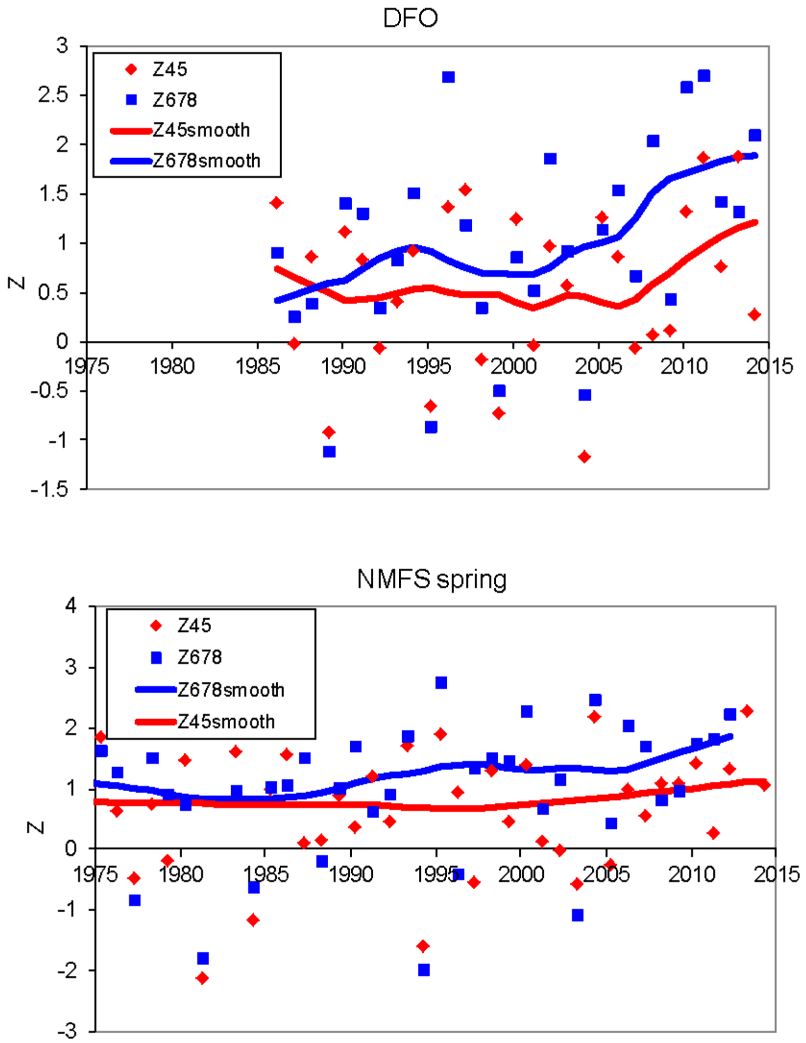


Figure 24. Total mortality(Z) calculated using the DFO and NMFS spring surveys data for Eastern Georges Bank cod.

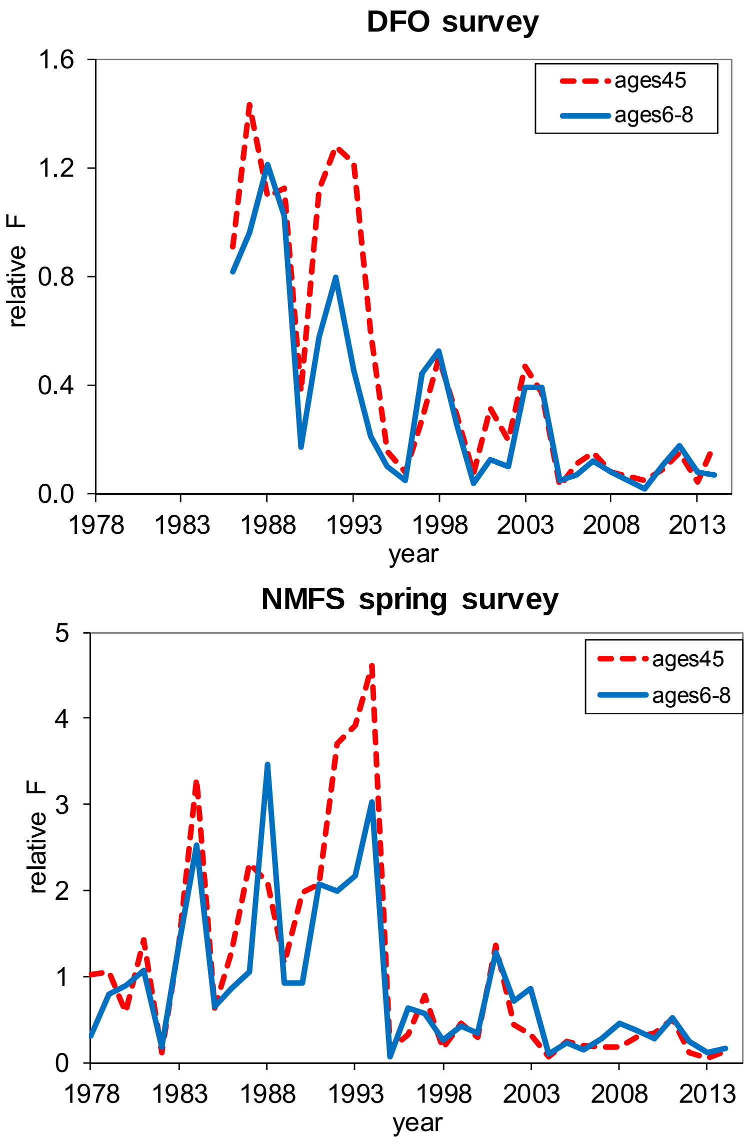


Figure 25. Relative F for Eastern Georges Bank cod.

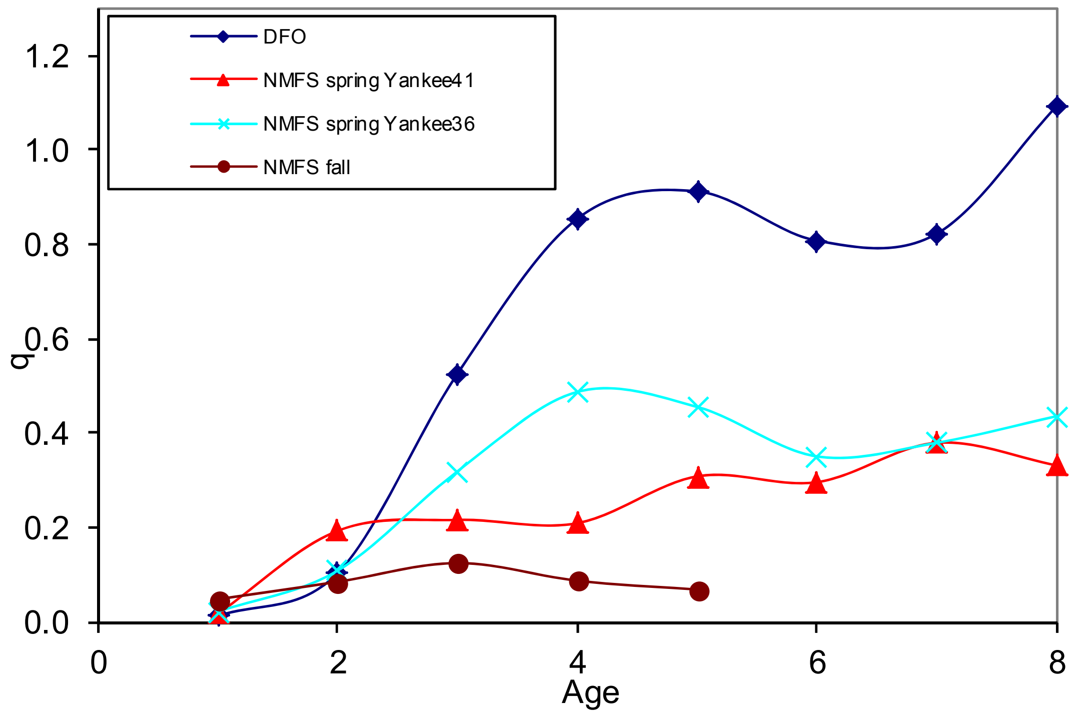


Figure 26. Survey catchability (q) of the DFO, NMFS spring and NMFS fall surveys for Eastern Georges Bank cod.

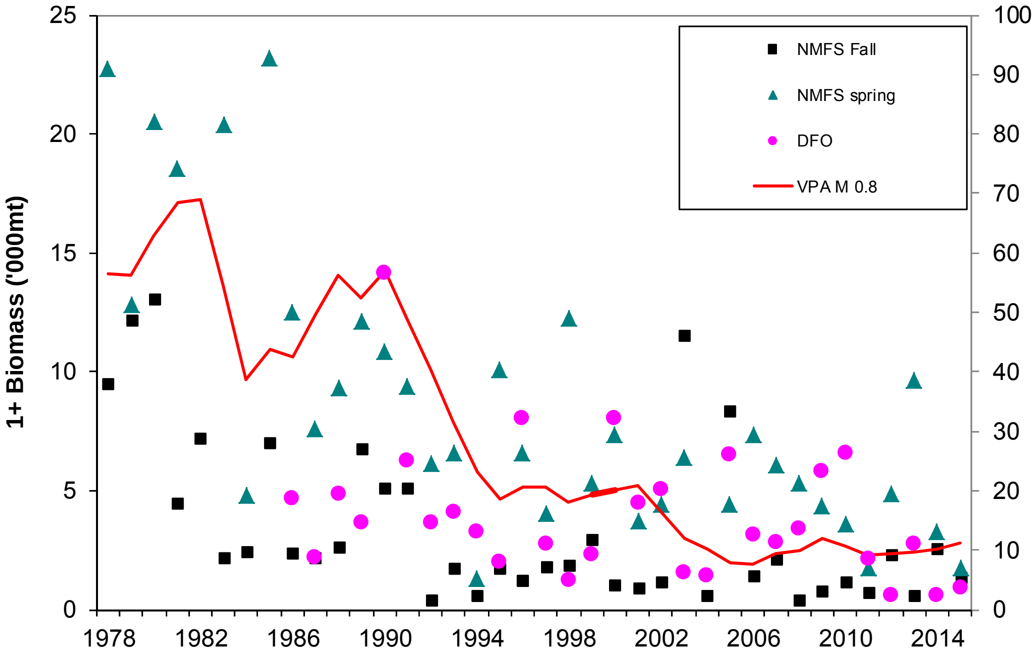


Figure 27. Age 1+ biomass from survey and VPA estimation.

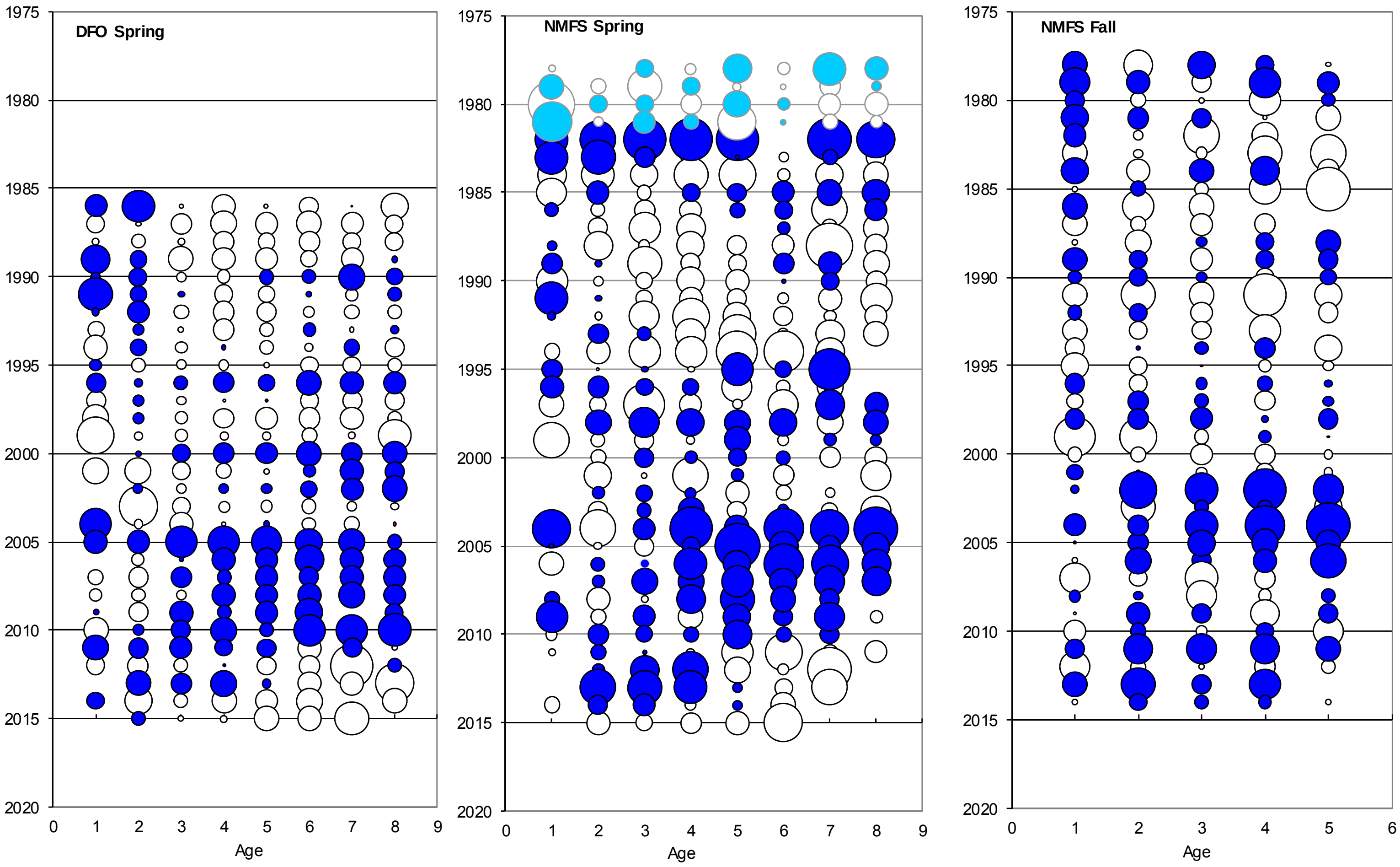


Figure 28. Residuals by year and age group from survey indices for Eastern Georges Bank cod. Solid bubbles indicate positive values, open bubbles indicate negative values and the bubble area is proportional to magnitude. The NMFS spring survey was conducted using a modified Yankee 41 from 1978 to 1981 (light blue bubbles).

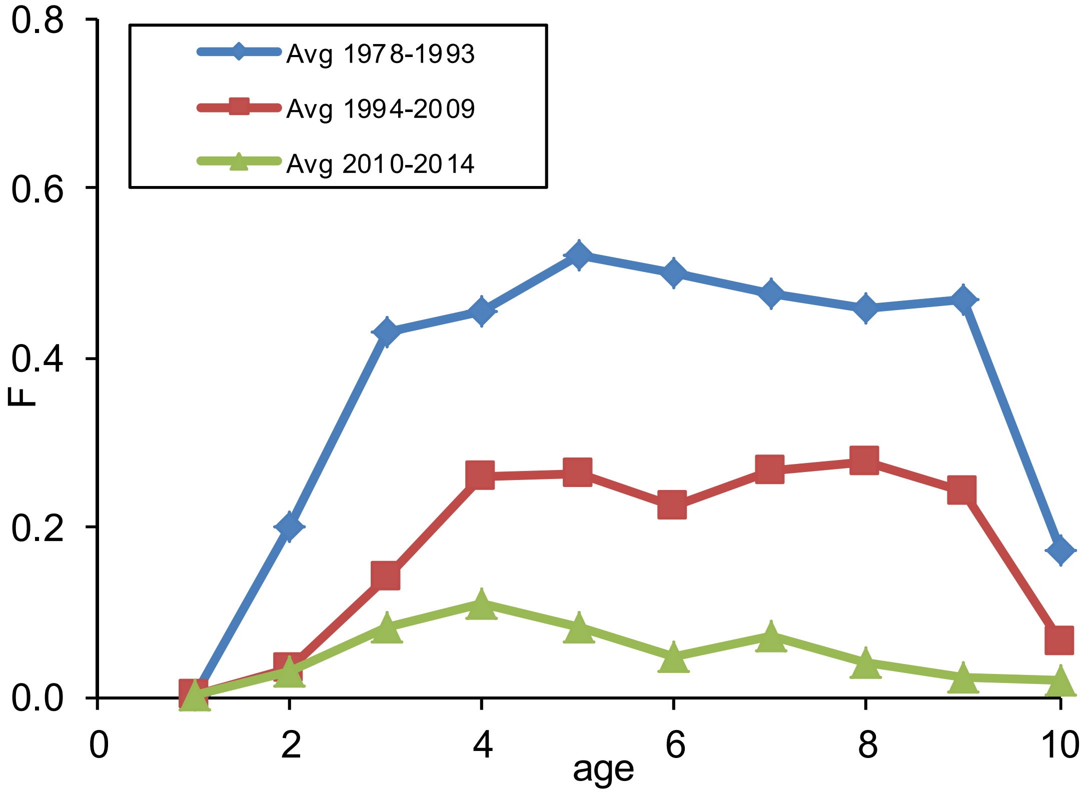


Figure 29. Average fishing mortality (F) for Eastern Georges Bank cod in three time series blocks (1978-1993, 1994-2009, 2010-2014).

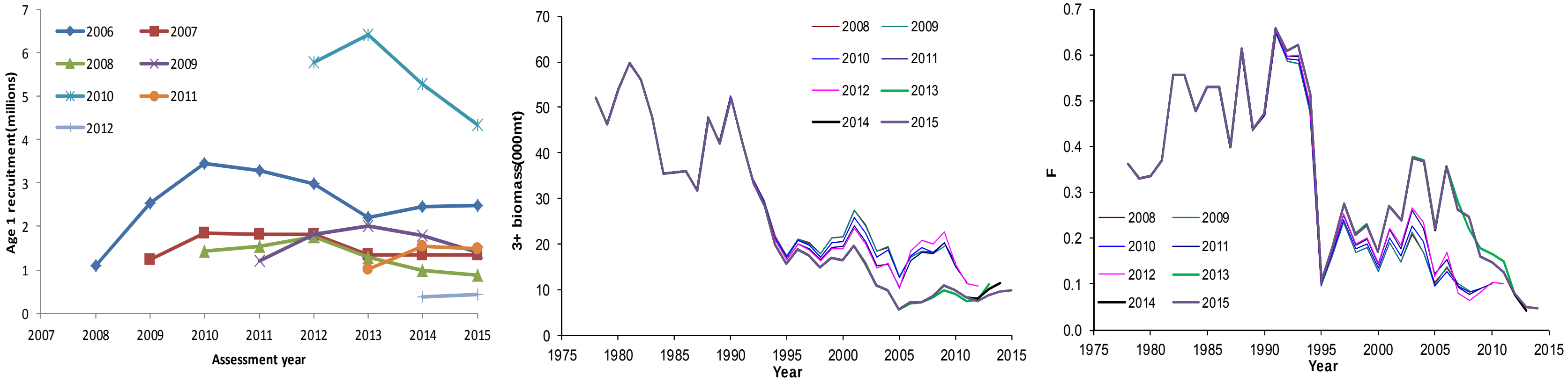


Figure 30. Retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of Eastern Georges Bank cod for the "M 0.8" model in 2015 assessment.

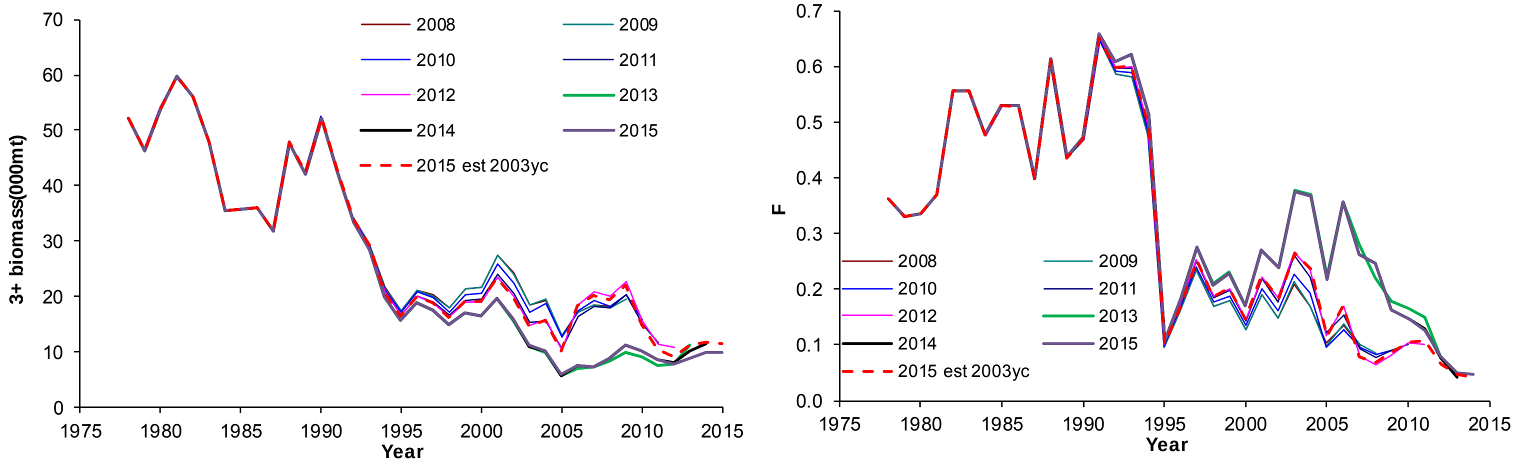
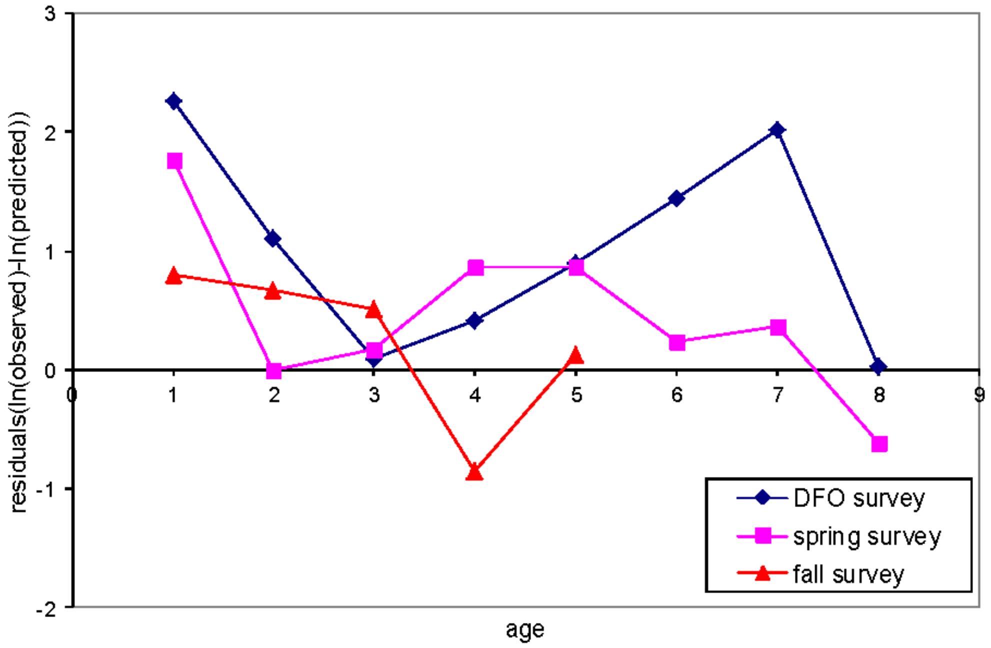


Figure 31. Comparison of sensitivity run "2015 est 2003yc" with the "M 0.8" model.



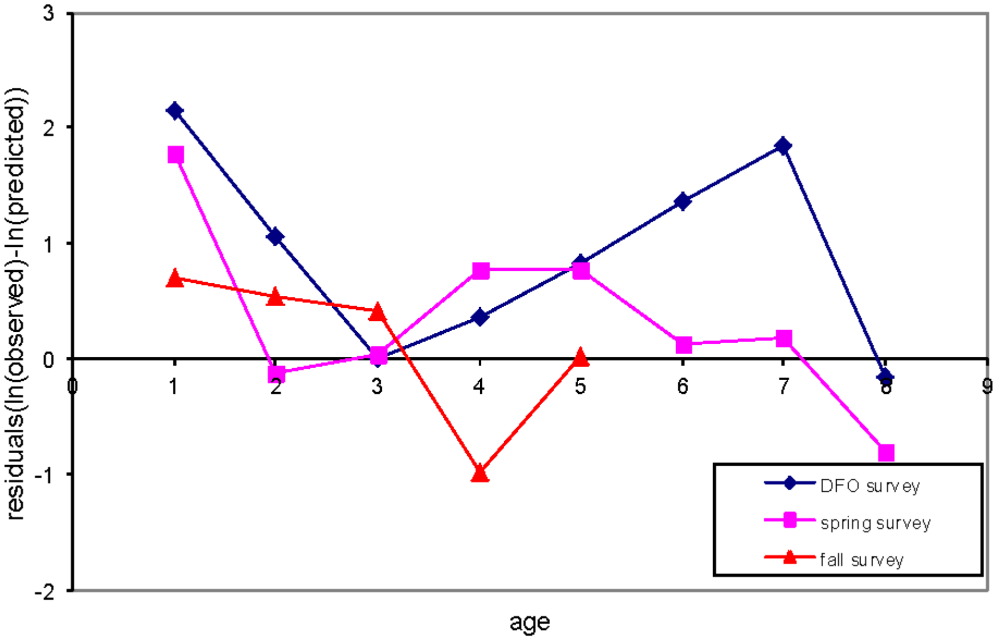


Figure 32. Residuals of the predicted survey values of the 2003 year class for the “M 0.8” model in 2013 (upper) and 2014 (lower) assessment.

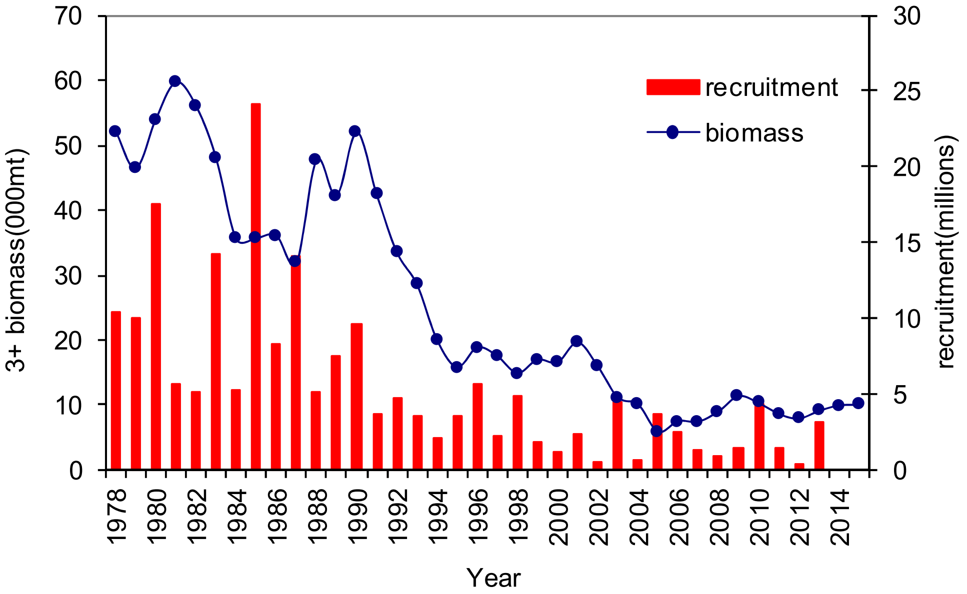


Figure 33. Adult biomass (ages 3+) and year class abundance at age 1 for Eastern Georges Bank cod.

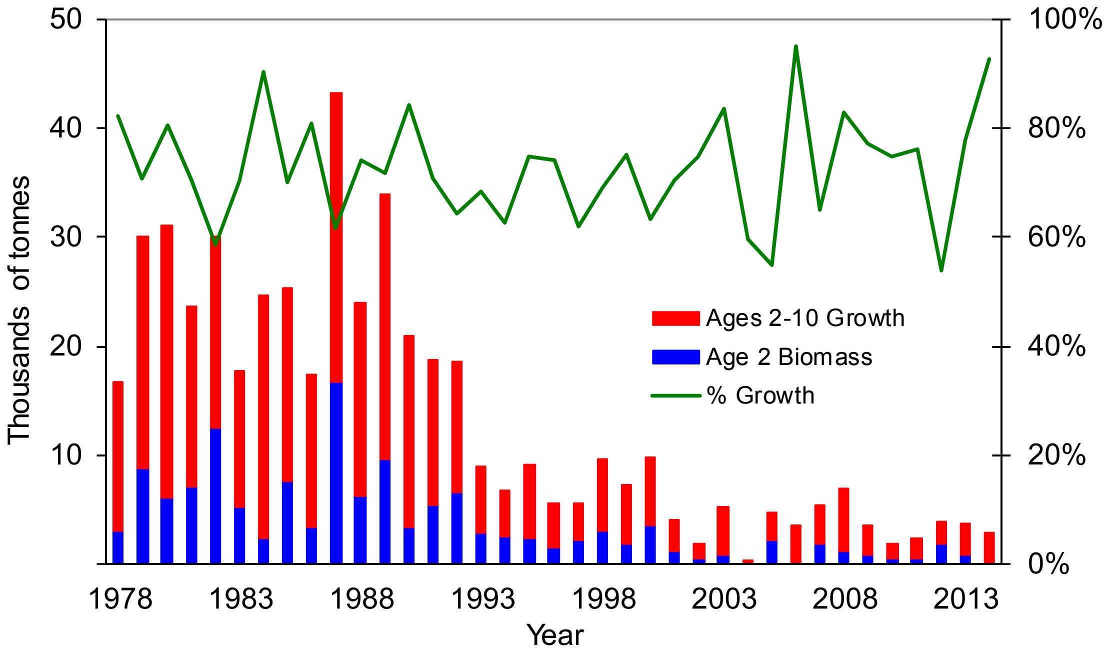


Figure 34. Components of annual production for Eastern Georges Bank cod attributable to growth of ages 2 to 10, and to the amount contributed by incoming year classes at age 2.

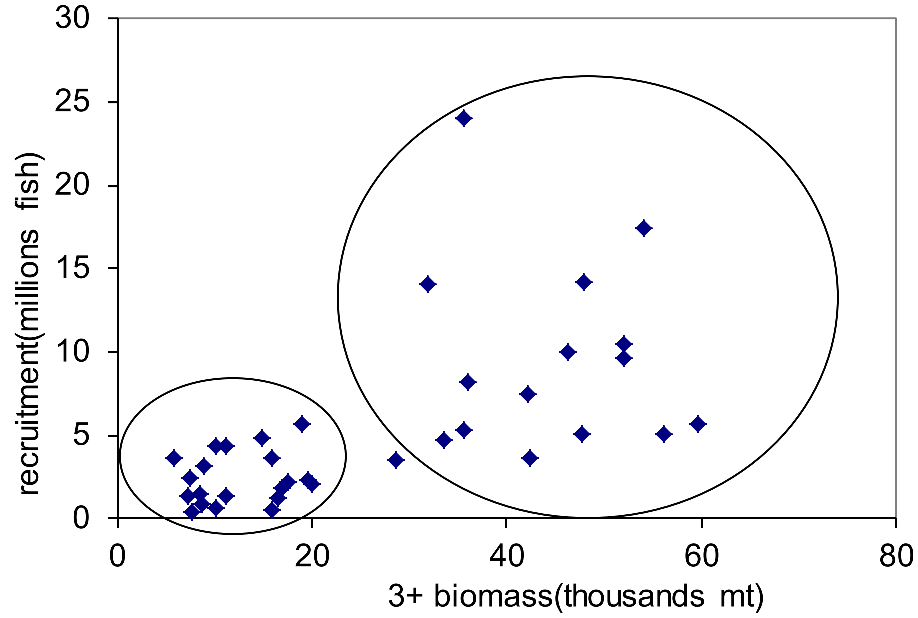


Figure 35. Relationship between adult biomass (ages 3+) and recruits at age 1 for Eastern Georges Bank cod. The red arrow indicate the 2010 year class at age 1.

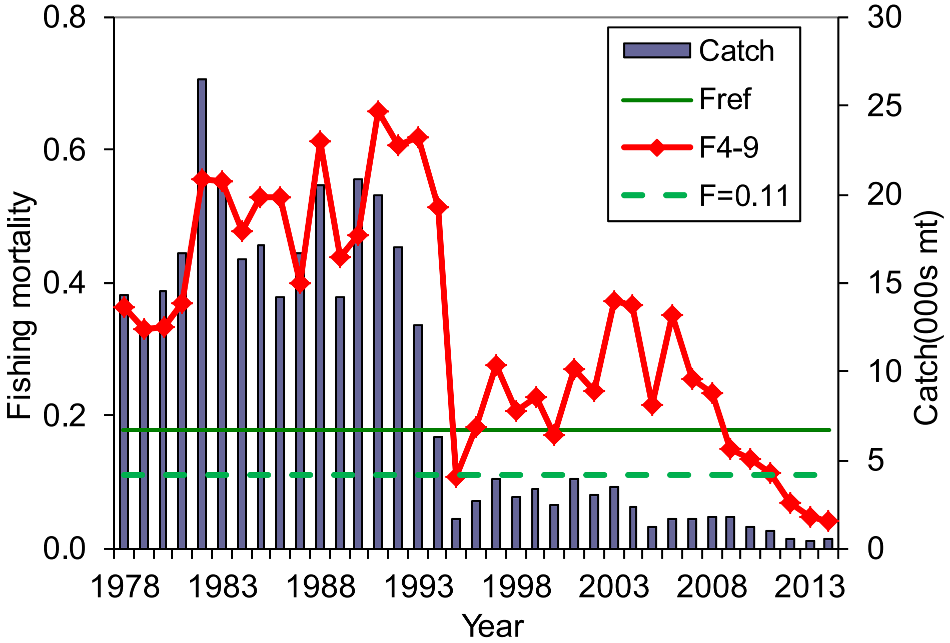


Figure 36. Average fishing mortality rate at ages 4 to 9 and catches for Eastern Georges Bank cod. The established fishing mortality threshold reference, F_{ref} = 0.18. The F reference point for the "M 0.8" model is 0.11.

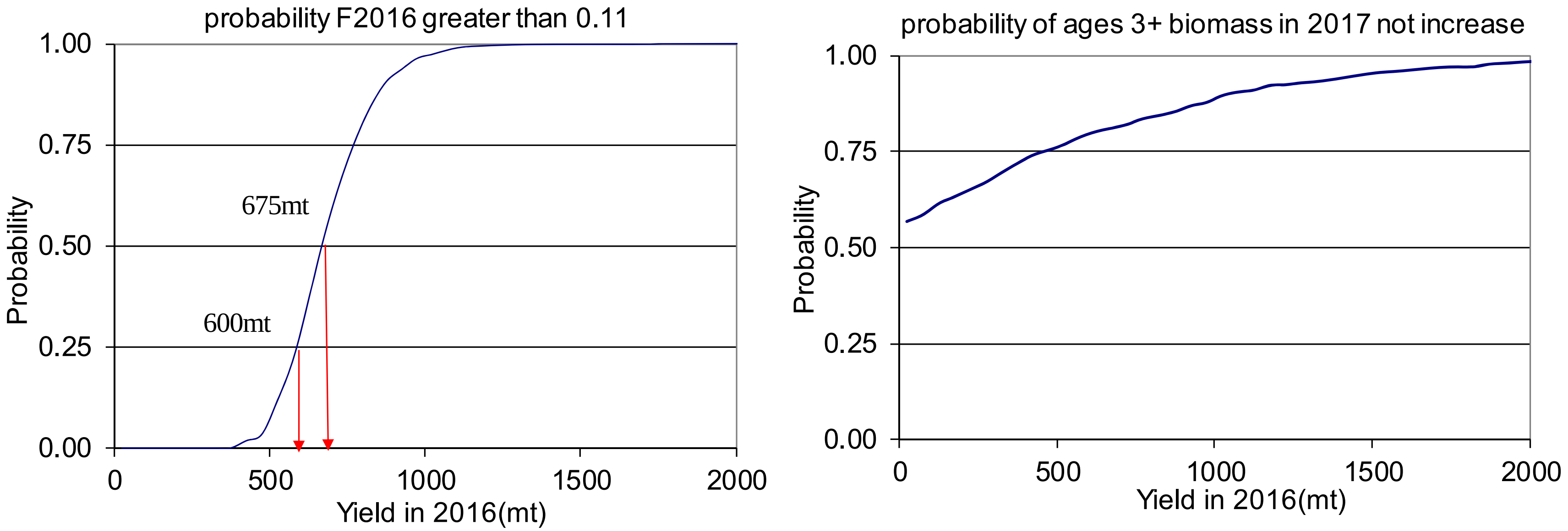


Figure 37. Risk of 2016 fishing mortality exceeding F reference point 0.11 and 2017 biomass not increasing from 2016 for alternative total yields of Eastern Georges Bank cod from the "M 0.8" model formulation.

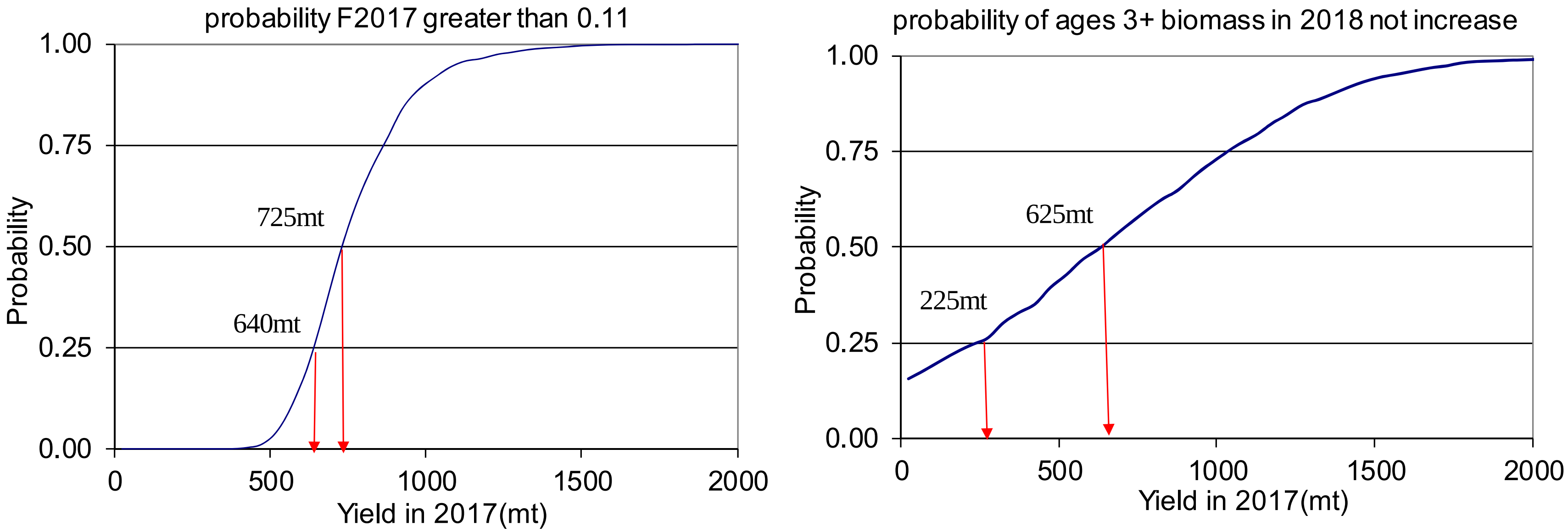


Figure 38. Assuming F2016 = 0.11, risk of 2017 fishing mortality exceeding F reference point 0.11 and 2018 biomass not increasing from 2017 for alternative total yields of Eastern Georges Bank cod from the "M 0.8" model formulation.

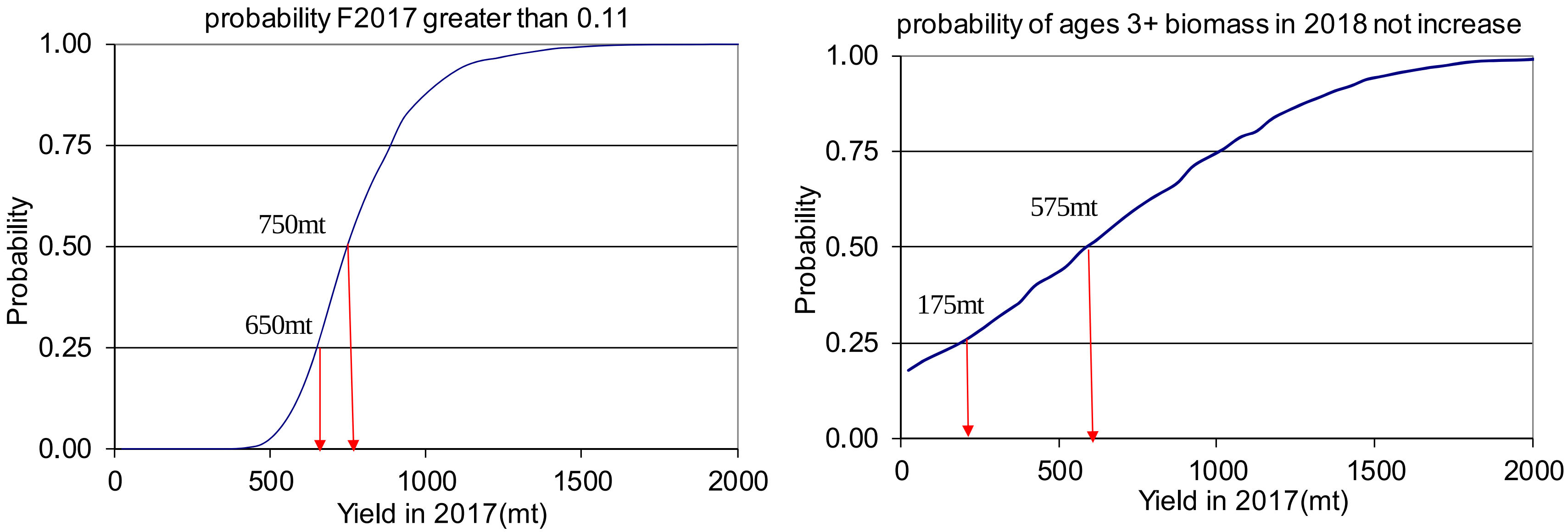


Figure 39. Assuming a catch of 600 mt in 2016, risk of 2017 fishing mortality exceeding F reference point 0.11 and 2018 biomass not increasing from 2017 for alternative total yields of Eastern Georges Bank cod from the "M 0.8" model formulation.

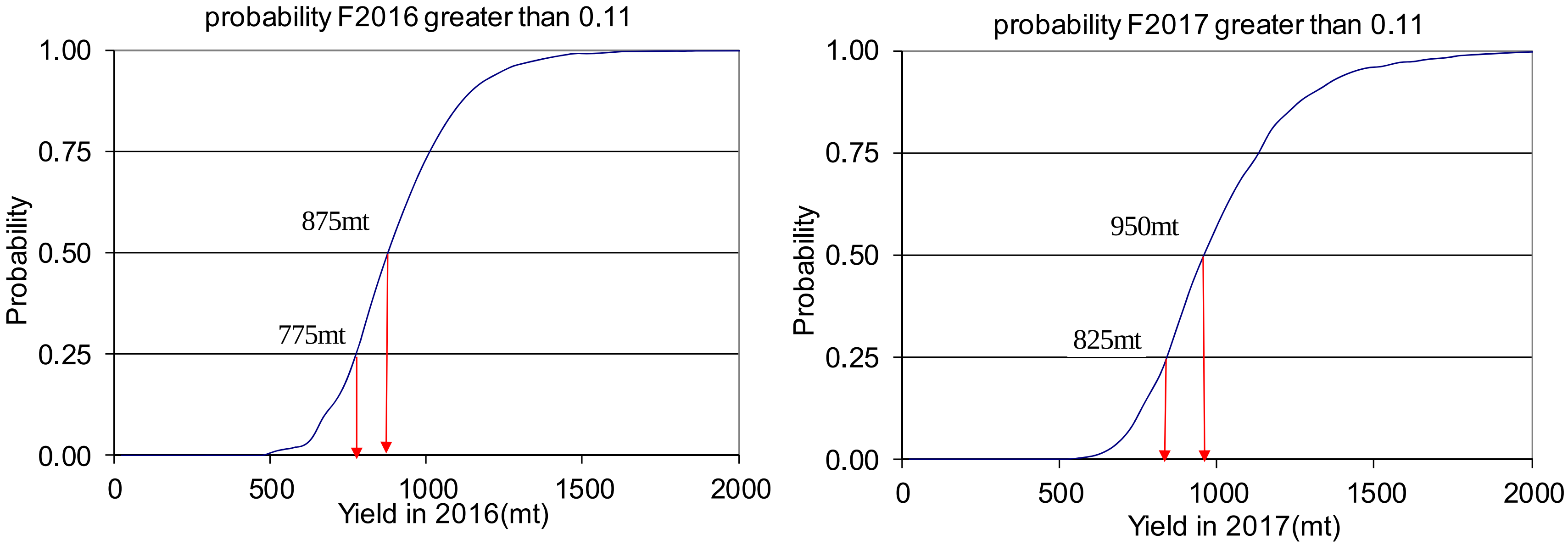


Figure 40. Risk of 2016 (left) and 2017 (right) fishing mortality exceeding F reference point 0.11 when U_{ref} = 10%, a value t calculated from M = 0.2 and F = 0.11, is used for alternative total yields of Eastern Georges Bank cod from the "M 0.8" model formulation.

APPENDICES

APPENDIX A. MANAGEMENT HISTORY OF EASTERN GEORGES BANK COD FISHERY (1978-2014).

a) Canadian fishery management history of cod on Eastern Georges Bank, 1978 to 2014.

Year	Canadian Management History
1978	Foreign fleets were excluded from the 200 mile exclusive economic zones of Canada and USA.
1984	October implementation of the maritime boundary between the USA and Canada in the Gulf of Maine Area.
1985	5Z cod assessment started in Canada; Set TAC; TAC = 25,000 mt.
1986	TAC = 11,000 mt
1987	TAC = 12,500 mt
1988	TAC = 12,500 mt
1989	TAC = 8,000 mt; 5Zjm cod assessment.
1990	Changes to larger and square mesh size; Changes from TAC to individual and equal boat quotas of 280,000 lbs with bycatch restrictions; Temporary Vessel Replacement Program was introduced.
1991	TAC = 15,000 mt; Dockside monitoring; Maximum individual quota holdings increased to 2% or 600t (whichever was less).
1992	TAC = 15,000 mt; Introduction of ITQs for the OTB fleet.
1993	TAC = 15,000 mt, ITQ for the OTB fleet not based on recommended catch quotas; OTB <65 fleet was allowed to fish during the spawning season (March–May 31st).
1994	TAC = 6,000 mt, Spawning closures January to May 31st; Mesh size was 130 mm square for cod, haddock an Pollock for ITQ fleet; Minimum mesh size of 6" was required for gillnets; Minimum fish size is 43 cm (small fish protocols) for cod, haddock an Pollock for ITQ fleet; OT> 65' could not begin fishing until July 1; Fixed gear must choose to fish either 5Z or 4X during June 1st to September 30th.
1995	TAC = 1,000 mt as a bycatch fishery; January 1st to June 18th was closed to all groundfish fishery; 130mm square mesh size for all mobile fleets; Small fish protocols continued; 100% dock side monitoring; Fixed gear vessels with a history since 1990 of 25mt or more for 3 years of cod, Haddock, Pollock, hake or Cusk combined can participate in 5Z fishery.
1996	TAC = 2,000 mt; Prohibition of the landing of groundfish (except monkfish) by the scallop fishery; ITQ vessel require minimum 130 mm square mesh for directed cod, Haddock and Pollock trips; Small fish protocols continued; For community management, quota allocation of each fixed gear based on catch history using the years 1986-1993; 100% mandatory dockside monitoring and weighout.
1997	TAC = 3,000 mt
1998	TAC = 1,900 mt
1999	TAC = 1,800 mt; Mandatory cod separator panel when no observer on board; January and February mobile gear winter Pollock fishery.
2000	TAC = 1,600 mt; January and February mobile gear winter Pollock fishery.
2001	TAC = 2,100 mt

Year	Canadian Management History
2002	TAC = 1,192 mt
2003	TAC = 1,301 mt
2004	TAC = 1,000 mt; Canada-USA resource sharing agreement on Georges Bank.
2005	TAC = 740 mt; Exploratory winter fishery January to February 18, 2005; Spawning protocol: 25% of maturity stages at 5 and 6.
2006	TAC = 1,326 mt; Exploratory winter fishery January to February 6, 2006; Spawning protocol: 30% of maturity stages at 5 to 7.
2007	TAC = 1,406 mt; Exploratory winter fishery January to February 15, 2007; High mobile gear observer coverage (99%); Spawning protocol: 30% of maturity stages at 5 to 7.
2008	TAC = 1,633 mt; Winter fishery from January1st to February 8, 2009; At-sea observer coverage 38% by weight of the mobile gear fleet landings and 21% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2009	TAC = 1,173 mt; Winter fishery from January 1 to February 21, 2009; At-sea observer coverage 23% by weight of the mobile gear fleet landings and 15% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2010	TAC = 1,350 mt; Winter fishery from January 1 to February 8, 2010; At-sea observer coverage 18% by weight of the mobile gear fleet landings and 6% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2011	TAC = 1,050 mt; Winter fishery from January 1 to Februay 5, 2011; At-sea observer coverage 19% by weight of the mobile gear fleet landings, 20% by weight of the fixed gear landings and 3% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2012	TAC = 513 mt; Winter fishery from January 1 to February 6, 2012; At-sea observer coverage 42% by weight of the mobile gear fleet landings, 26 % by weight of the fixed gear landings and 35% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2013	TAC = 504 mt; Winter fishery from January 1 to February 3, 2013; At-sea observer coverage 78% by weight of the mobile gear fleet landings, 29%by weight of the fixed gear landings and 19% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2014	TAC = 546 mt; Winter fishery from Januaryt 1 to February 9, 2014: A test project with alternative codend meshes of 125 mm square and 145 mm diamond for the purpose of imporving the catch rate of haddock and reducing cod bycatch relative to haddock catched; Spawning protocol: 30% of maturity stages at 5 to 7.

b) USA fishery management history of cod on Eastern Georges Bank, 1978 to 2014.

Year	USA Management History
	Regulatory Actions
1953	ICNAF era
1973-1986	TAC implemented for Div. 5Z cod; 35,000/year
1977	Groundfish Fishery Management Plan (FMP Magnuson-Steveson Conservation management Act (MSCMA)
1982	Interim FMP
1984	Hague Line implemented
1985	Multi-species FMP
1989	Amendment 2
1994	Emergency Rule – December year-round closures in effect
1994	Amendment 5; Days at Sea (DAS) monitoring; Mandatory reporting; Vessel Trip Reports (VTR) Amendment 6
1996	Amendment 7; accelerated DSA reduction Sustainable Fisheries Act (SFA)
1999	Amendment 9
2002	Interim rule; 20% reduction in DAS
2004	Amendment 13; further reduction in DAS; hard TAC on eastern Georges Bank haddock and cod Eastern US/CAN Area haddock Special Access Program (SAP) Pilot Program
2005	DAS vessels limited to one trip/month in eastern US/CAN Area until April 30th Limited access DAS vessles required to use separator panel trawl in the area
2006	Haddock separator trawl or flounder net required in eastern US/CAN Area
2008	Eastern US/CAN Area access delayed until August 1st, except longline gear September – Ruhle trawl (eliminator trawl) allowed in eastern US/CAN Area
2009	November – Eastern US/CAN Area, trawl vessels required to use separator/Ruhle south 41-40N
2010	Amendment 16, Framework 44 implemented; Sector management; Prohibition on discarding legal size fish US/CAN Area: prohibition on discarding legal size fish
	Common pool: 500 lbs/day, 5,000 lbs/tr**ip**
2012	US/CAN area open May 1st for trawl gear: haddock separator, rhule or flounder trawl
2015	Inside US/CAN Georges Bank cod: common pool : 100 lb/DAS , 500 lb/trip
	Mesh Sizes (Inches)
1953	4.5
1977	5.125
1983	5.5
1987	6.0
1989	Eliminate 6 inch increase
1994	6.0
1999	6.5 square mesh / 6.0 diamond mesh
2000	6.5 square mesh / 6.5 diamond mesh
2002	6.5 square mesh / 6.5 diamond mesh / 6.5 gill net
	Minimum Size
1977	16 inches (40.6 cm) commercial and recreational
1982	17 inches (43.2 cm) commercial; 15 inches (38.1 cm) recreational
1986	19 inches (48.3 cm) commercial; 17 inches (43.2 cm) recreational
1988	19 inches (48.3 cm) commercial and recreational
1997	21 inches (53.3) recreational
2002	22 inches (55.9 cm) commercial; 23 inches (58.4 cm) recreational
2003	21 inches (53.3 cm) recreational
2013	19 inches (48.3 cm) commercial
	Trip Limits
2004	Georges Bank cod: 2,000 lbs/day; 10,000 lbs/trip; eastern Georges Bank: hard TAC on cod 500 lbs/day; 5,000 lbs/trip in eastern US/CAN Area

Year	USA Management History
2005	500 lbs/day; 5,000 lbs/trip in eastern UC/CAN Area Starting July, one trip/month in eastern US/CAN Area until April 30, 2006
2006	500 lbs/day, 5,000 lbs/trip in eastern US/CAN Area
2007	1,000 lbs/trip of cod in eastern US/CAN Area or Haddock SAP
2008	1,000lbs/trip of cod in eastern US/CAN Area, fishing eastern Geoges Bank exclusively
2009	March – 500 lbs/trip of cod in eastern US/CAN Area; back to 1,000 in April April 16th – eastern US/CAN Area closed until May 1st
2010	Georges Bank cod: 2,000 lbs/day; 20,000/trip; eastern Georges Bank cod: 500 lbs/day, 5,000 lbs/trip
2011	March – 3,000 lbs/day during April 500 lbs/day after April in eastern Georges Bank area
2012	Common pool: Georges Bank cod 1500 lbs/A DAS up to 4500 lbs/trip ; Handgear B 75 lb/trip
2013	January 1st: Common pool: Georges Bank cod 3000 lbs/A DAS up to 30,000 lbs/Trip ; Handgear B 125 lb/trip
2014	Common pool closure: Georges Bank cod August 18 through to April 30, 2015
	Closures
1970	Area 1(A) and 2(B) March-April
1972-1974	Area 1(A) and 2(B) March-May
1977	Seasonal spawning closure
1987	Modify Closed Area I to overlap with haddock spawning area
1994	January Closed Area II expanded, closed January –May, Closed Area I closed to all vessels except sink gillnet December Closed Area I and II closed year-round to all vessels
1999	Scallopers allowed limited access to Closed Area II
2004	May to December access to northern corner of Closed Area II and adjacent area to target haddock with separator trawl October – eastern Georges Bank closed to multi-species DAS permits
2005	January – eastern US/CAN Area reopened April – eastern US/CAN Area closed until April 30th August – eastern US/CAN area closed (Georges Bank cod TAC projected near 90%)
2006	Eastern US/CAN haddock SAP delayed opening until August 1st
2007	April 25th – eastern US/CAN Area closed until April 30th June – eastern US/CAN Area closed to limited access multi-species TAC (due to cod catch) October – eastern US/CAN Area open to limited access multi-species TAC November – eastern US/CAN Area closes
2008	May – eastern US/CAN Area delayed opening until August 1st; June – eastern US/CAN Area delayed opening until August 1st for all gear (prevent catching 1st quarter cod TAC)
2009	April 1st - eastern US/CAN Area closed; May – eastern US/CA area sloced until August 1st for trawl vessels
2010	Eastern US/CAN Area closed April 20th to 30th, TAC harvested; May 1st opening delayed untl August
2011	Eastern US/CAN Area closed from May-July for trawl gear (commonpool vessles only)
2013	Common pool closure: July 30th to August 31st for Geoges Bank cod

APPENEDIX B. 2015 STATISTICAL CATCH AT AGE (ASAP) MODEL UPDATE FOR EASTERN GEORGES BANK COD

INTRODUCTION

This assessment presents an update of the statistical catch at age model ‘Age Structured Assessment Program’ (ASAP) reviewed at the 2013 April Eastern Georges Bank cod benchmark model meeting. The ASAP model was not chosen by the TRAC as a benchmark model for stock status, however, the TRAC agreed to apply the ASAP model results in a consequence analysis (Table 21 above) of projection results to be provided to managers for catch advice.

The ASAP model for cod from Eastern Georges Bank (GB) is formulated as closely as possible to the NEFSC GB cod assessment, since the ASAP model was recently approved as the new benchmark model, replacing the VPA that had historically been applied (NEFSC 2013a; 2013b).

ASAP was used to derive estimates of instantaneous fishing mortality and stock size in 2014. A retrospective analysis was performed for terminal year fishing mortality, spawning stock biomass (SSB), and age 1 recruitment. Stochastic projections from model results provide estimated landings and SSB during 2016-2018.

ASSESSMENT MODEL FORMULATION

Model Description

ASAP, a forward projecting statistical catch at age model (Legault and Restrepo 1998), was applied in this assessment and can be downloaded from the NOAA Fisheries Toolbox (NFT, http://nft.nefsc.noaa.gov/). A brief description of the model can be found in the previous assessment (Wang et al. 2014) and, for further details, the reader is referred to the technical manual (Legault 2008).

Data Input

Input to the ASAP model is the same as for the VPA 0.8 model, with two exceptions. The ASAP uses beginning year weight-at-age that is back-calculated from the mid-year catch weight-at-age (Rivard 1982; see: Table B1) as in the NEFSC GB cod assessment, rather than using the weight estimated from an average of the DFO and NEFSC spring research survey weight-at-age (Table 16 above). The ASAP also does not use the most recent terminal year +1 survey (e.g. DFO 2015 and NMFS 2015 surveys) in the estimation.

Natural mortality (M) was age and time invariant and assumed to be 0.2 , which had been applied in earlier assessments, prior to 2013, for cod from eastern GB (Wang and O’Brien 2012).

Model Formulation

The ASAP model formulation (base_rivard) presented and reviewed at the June 2014 TRAC (Wang et al. 2014) was updated for the 2015 assessment. A multinomial distribution was assumed for both fishery catch at age and survey age compositions. The catch CV was set equal to 0.05 and the recruitment CV set equal to 0.5, however, the recruitment deviations were set with lambda = 0, so the deviations did not contribute to the objective function.

Both the fishery and survey selectivity was modeled as ‘flat-topped’. For the fisheries, two selectivity blocks were modeled as single logistic from 1978-1993 and 1994-2014.

The effective samples size (ESS) of the catch and surveys were adjusted based on interpretation of ‘Ianelli’ plots (McAllister and Ianelli 1997). The input ESS is compared to the model predicted ESS; an appropriate ESS is considered to be that which intersects the input ESS.

At the 2013 benchmark (O'Brien and Wang 2013) the CV for each survey was initially set at the value generated from the survey estimate of stratified mean number per tow (DFO STRANAL). The CVs averaged 0.31(0.15-0.66; DFO), 0.32 (0.13-0.83; NMFS spring), and 0.47(0.24-0.88; NMFS fall). Further examination of the model fits to the survey indices resulted in adding the following constant to each survey CV vector: 0.25 (DFO), 0.3 (NMFS spring #36), and 0.2 (NMFS fall), except the NMFS spring #41, which was not adjusted. These same values were added during this 2015 update.

Model Results

Model results, including the objective function (OF), components to the OF, the root mean square error (RMSE), computed from standardized residuals, SSB, fishing mortality (F), recruitment estimates at age 1 and the Mohn's rho retrospective bias adjustments are summarized in Table B2 for all model runs conducted.

A bridge ASAP run was conducted to include several changes to the input data. These included a slight modification to the estimation of USA discards in 2013 with the application of an annual length frequency rather than one by half-year and minor changes to the database in 1998, 2009 and 2012. The Canadian discards from the scallop fishery were recalculated using the new standardization of fishing effort, and the 2013 catch at age was re-estimated using a new length weight relationship from 2013 monthly port samples.

A comparison of the differences between the 2013 ASAP model results (2014 run1) and the bridge run (2014 run2) resulted in minor changes in the diagnostics and in the estimation of biomass (Table B2).

BASE 2014 ASAP

The bridge run was updated with 2014 catch estimates and survey data and the results (run 3) are described Table B2 and Figures B1-B12. Model diagnostics are very similar to last year's assessment (Wang et al. 2014). Patterns in residuals still persist in both the catch and in the surveys, although the patterning is less in the autumn survey (Figures B1-B8). The ESS is still appropriate for both catch and the surveys.

Fishing Mortality, SSB, and Recruitment

Fully recruited F (unweighted; ages 5+) was estimated at 0.33 in 2014 (Table B3; Figure B9), a 24% decrease from 2013. SSB in 2014 was estimated at 2,248 mt, a 47% increase from 2013 (Table B3; Figures B9-B10). Recruitment (millions of age 1 fish) of the 2010 year class is estimated at 1.2 million, the 2012 year class is the smallest year class estimated at 0.275million, and the 2013 year class is estimated at 1.1 million fish (Table B3; Figures B9-B10).

Retrospective Analysis

A retrospective analysis was performed to evaluate how well the ASAP calibration would have estimated F, SSB and recruits at age 1 for seven years (2006-2012) prior to the terminal year, 2014. The pattern of overestimating SSB and underestimating F relative to the terminal year persists in this assessment and there is a general pattern of underestimating recruitment relative to the terminal year estimate (Figure B11). The retrospective rho values, the average of the last 7 years of the relative retrospective peels, were 0.59 for SSB, -0.36 for $F_{5+,}$ and -0.18 for recruitment. Applying a retrospective adjustment ((1/(1+rho)) * estimate) results in estimates for 2014 of F = 0.58, SSB = 1,413 mt, and age 1 recruitment = 1.3 million fish.

Model Uncertainty - MCMC

A Monte Carlo Markov Chain (MCMC) simulation was performed to estimate uncertainty in the model estimates. Two MCMC chains of initial length of 5.0 million were simulated with every 2,500th value saved. The trace of each chain's saved draws suggests relatively good mixing for both SSB and F (Figure B12). The lagged autocorrelations showed variable correlation with increased lag, with correlations ≤0.1 beyond lag 0 for SSB and F. The 2014 SSB MCMC estimate of 2,247 mt has a 90% probability interval (PI) of 1,664-3,068 mt, and the 2014 MCMC average F_{5+} = 0.36 has a 90% PI of 0.26- 0.52.

BIOLOGICAL REFERENCE POINTS

Yield per Recruit Analysis

A yield per recruit (YPR) analysis was conducted at the 2013 Eastern Georges Bank cod model benchmark meeting (O'Brien and Wang 2013) using the methods of Thompson and Bell (1934). Results of YPR analysis are presented below. The current negotiated Eastern Georges Bank cod F reference point is F_{ref} = 0.18 (December 2002 meeting; TMGC 2002). The current GB cod F_{MSY} proxy = $F_{40\%}$ = 0.18.

F	value
F0.1	**0.19**
Fmax	**0.43**
F30%	**0.29**
F40%	**0.19**
F2014, adj	**0.58**

Eastern George Bank cod is not managed by biomass reference points, however, for background purposes, non-parametric estimates of Maximum Sustainable Yield (MSY) and SSB at MSY (SSB_{MSY}) based on $F_{40\%}$ were estimated (O'Brien and Wang 2013) using the 34-year time series mean recruitment (5.484 million age 1 fish), Y/R (1.22) and SSB/R (7.18) as:

$F_{40\%}$ = 0.19,

MSY = 6,677 mt, and

SSB_{MSY} = 39,353 mt.

The yield per recruit analysis was not updated with the 2015 ASAP results.

MSY Biological Reference Points

Long-term Stochastic Projection

For the 2013 Eastern Georges Bank cod model benchmark meeting, long term (100 years) stochastic projections were run using the same input data as the YPR with F_{ref} = 0.18. Following the GB cod accepted assessment projection formulation (NEFSC 2013b), recruitment was estimated from a 2-stage cumulative distribution function (CDF) based on either 19 low estimates or 14 high estimates of age 1 recruitment. Based on a visual examination of the stock recruit plot (Figure B10), when SSB is less than15,000 mt recruitment is drawn from the low recruitment CDF, and when SSB is greater than 15,000 mt then recruitment is drawn from the high recruitment CDF.

The long term projection provided the following non-parametric biomass reference points:

F_{REF} = 0.18,

MSY = 11,059 mt (80% CI: 2,065-14,180 mt), and

SSB_{MSY} = 30,622 mt (80% CI: 25,450-84,346 mt).

PROJECTIONS

Short term stochastic projections under $F_{40\%}$ were performed from the updated 2014 ASAP model results to estimate landings and SSB during 2016-2017. The input values for mean catch and stock weights and PR were estimated as 3-year averages from 2012-2014. Maturity is assumed to be knife-edge at 100% for ages 3+. Recruitment was estimated using the 2-stage CDF described above and associated with a SSB breakpoint of 15,000 mt. Catch in 2015 was estimated based on the assumption that the 2015 quota of 650 mt would be caught. Bootstrapped starting values were adjusted for retrospective bias by applying the SSB rho factor of 0.59 to derive the adjustment factor of 0.629.

The results of the adjusted short term projections indicate under the $F_{ref} = 0.18$ catch is projected to decrease in 2016 and then increase in 2017. SSB is projected to decrease in 2015, and then increase in 2016 and again in 2017.

Year	SSB	F	Catch
2015	1357	0.57	650
2016	1549	0.18	223
2017	1944	0.18	443

SUMMARY DISCUSSION

Productivity of Eastern Georges Bank cod has been low for the last two decades, with poor recruitment and truncated age structure. An increase in natural mortality may have contributed to the recent low productivity; however, food habits data do not support this hypothesis (NEFSC 2013b). Analysis of tagging data indicates minimal increase in M from the 1980s to the 2000s, and thus does not appear sufficient to explain the long term low productivity (Miller WP[1]). Lack of large numbers of older repeat spawners in the Eastern Georges Bank cod population since the mid-1980s may contribute to the long-term low productivity. Cod have a low success rate of hatching for first and second time spawners (13% and 62%) until the third spawning (100%), suggesting that an expanded age structure of fish that have spawned three or more times would contribute to higher productivity (Trippel 1998; Carr and Kaufman 2009). Long-term overfishing may have also had indirect effects. Fishing activity disrupts the spawning aggregation and thus behaviors and rituals of cod, reducing the potential of good recruitment (Dean 2012). Spawning of cod involves complex behaviors that have only recently been observed, including arrival and departure of fish on the spawning ground at different times dependent upon sex, age, and stage of maturity (Lawson and Rose 2000) and the formation of spawning leks where the males set up and defend territory (Windle and Rose 2007).

The 2015 updated model formulation provides similar results to the 2014 ASAP assessment (Wang et al. 2014), with an increase in the retrospective bias in F and SSB and a decrease in the retrospective bias for recruitment. In the ASAP formulation, additional variability is added to the survey abundance estimates; thus, placing more emphasis on the reported catch data.

LITERATURE CITED

Carr, J. P. and L. Kaufman (2009). Estimating the importance of maternal age, size, and spawning experience to recruitment of Atlantic Cod (*Gadus morhua*). Biol. Conserv. 142(3): 477-487

---

[1] (unpublished manuscript) Miller, T., D. Clark, and L. O'Brien. 2013. Estimates of Mortality and Migration from Atlantic Cod Tag-recovery Data in NAFO Areas 4X, 5Y, and 5Z in 1984-1987 and 2003-2006. TRAC WP 2013/02: 20 p.

Dean, M.J., W.S. Hoffman, and M.P. Armstrong. 2012. Disruption of an Atlantic Cod Spawning Aggregation Resulting from the Opening of a Directed Gill-Net Fishery. N. Am. J. Fish. Manage. 32: 124-134.

Lawson, G.L., and G.A. Rose. 2000. Small-scale Spatial and Temporal Patterns in Spawning of Atlantic Cod (*Gadus morhua*) in Coastal Newfoundland Waters. Can. J. FIsh. Aquat. Sci. 57: 1011-1024.

Legault, C.M. 2008. Technical Documentation for ASAP Version 2.0 NOAA Fisheries Toolbox (http://nft.nefsc.noaa.gov/).

Legault, C.M., and V.R. Restrepo. 1998. A Flexible Forward Age-structured Assessment Program. ICCAT. Col. Vol. Sci. Pap. 49: 246-253.

McAllister, M.K., and J.N. Ianelli. 1997. Bayesian Stock Assessment Using Catch-age Data and the Sampling-importance Resampling Algorithm. Can. J. FIsh. Aquat. Sci. 54: 284-300.

NEFSC. 2013a. 55th Northeast Regional Stock Assessment Workshop (55th SAW) Assessment Summary Report. Northe. Fish. Sci. Cent. Ref. Doc. 13-01: 43p.

NEFSC. 2013b. 55th Northeast Regional Stock Assessment Workshop (55th SAW) Assessment Report. US Dept. Commer., Northe. Fish. Sci. Cent. Ref. Doc. 13-11: 845p.

O'Brien, L., and Y. Wang. 2013. A Statistical Catch at Age Stock Assessment Model of Eastern Georges Bank Atlantic Cod (*Gadus morhua*). TRAC Ref.Doc. 2013/08.

Rivard, D. 1982. APL Programs for Stock Assessment (Revised). Can. Tech. Rep. Fish. Aquat. Sci. 1091:146p.

Thompson, W.F., and F.H. Bell. 1934. Biological Statistics of the Pacific Halibut Fishery. (2) Effect of Changes in Intensity upon Total Yield and Yield per Unit of Gear. Rep. Inter. Fish. Comm. No. 8: 49p.

Transboundary Management Groundfish Committee (TMGC). 2002. Development of a Sharing Allocation Proposal for Transboundary Resources of Cod, Haddock, and Yellowtail Flounder on Georges Bank. Fisheries Management Regional Report 2002/01: 60p.

Trippel, E.A. 1998. Egg Size and Viability and Seasonal Offspring Production of Young Atlantic Cod. Tran. Am. Fish. Soc. 127: 339-359.

Wang, Y., and L. O'Brien. 2012. Assessment of Eastern Georges Bank Atlantic Cod for 2012. TRAC Ref. Doc. 2012/05 : 83p.

Wang, Y., L. O'Brien, H. Stone and E. Gross. 2014. Assessment of Eastern Georges Bank Cod for 2014. TRAC Ref. Doc. 2014/03: 102p.

Windle, M.J.S., and G.A. Rose. 2007. Do Cod Form Apawning Leks? Evidence from a Newfoundland Spawning Ground. Mar. Biol. 150: 671–680.

TABLES

TABLES

Table B1. January 1 catch weight at age (kg) for ages 1-10+, for Eastern Georges Bank cod, 1978-2014.

	AGE									
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
1978	0.245	1.149	1.639	2.122	2.799	4.103	4.285	7.587	7.881	12.907
1979	0.564	0.801	1.386	2.601	3.477	4.954	7.137	7.347	9.036	14.362
1980	0.207	0.955	1.789	2.161	4.030	5.289	6.898	10.385	10.008	13.455
1981	0.331	0.697	1.572	2.603	3.731	5.675	7.102	8.169	11.537	15.920
1982	0.340	0.826	1.651	2.681	3.919	5.536	7.438	8.895	10.471	16.018
1983	0.674	0.910	1.699	2.572	4.077	5.528	7.262	9.298	10.636	15.040
1984	0.487	1.202	1.853	2.753	3.843	5.291	7.116	8.545	10.646	13.621
1985	0.337	0.945	1.704	2.711	3.946	5.322	6.938	8.930	10.030	13.758
1986	0.327	0.853	1.787	2.446	3.922	5.522	6.933	8.529	10.454	12.262
1987	0.409	0.886	1.797	3.086	4.215	5.908	7.662	8.744	10.183	13.811
1988	0.435	0.825	1.787	2.705	4.393	5.725	7.731	9.308	10.266	13.719
1989	0.392	0.889	1.516	2.706	3.877	5.437	6.434	9.003	10.286	13.839
1990	0.469	0.981	1.738	2.513	3.921	5.435	6.849	8.163	10.475	13.416
1991	0.544	1.027	1.937	2.732	3.695	5.041	6.711	8.587	9.494	13.813
1992	0.675	1.026	1.861	2.831	3.650	4.898	6.130	8.033	10.299	15.042
1993	0.404	1.097	1.723	2.544	3.773	4.787	6.186	7.504	8.896	12.002
1994	0.410	0.895	1.731	2.691	3.532	5.249	6.232	7.420	8.124	12.629
1995	0.153	0.893	1.682	2.679	4.119	5.294	8.051	8.482	9.223	17.374
1996	0.307	0.677	1.690	2.543	3.970	5.365	6.399	9.511	10.178	10.964
1997	0.474	0.852	1.715	2.519	3.430	5.022	6.505	7.303	10.140	11.130
1998	0.511	0.947	1.745	2.480	3.409	4.536	5.944	7.535	9.220	13.567
1999	0.342	0.952	1.625	2.578	3.413	4.666	5.780	7.050	8.566	13.926
2000	0.487	0.843	1.597	2.392	3.527	4.288	5.599	6.517	7.936	13.056
2001	0.086	0.751	1.561	2.319	3.220	4.423	4.954	6.449	7.654	10.674
2002	0.170	0.501	1.351	2.288	3.316	4.180	5.588	6.554	7.616	11.169
2003	0.138	0.639	1.598	2.303	3.169	4.123	5.167	6.622	7.924	8.729
2004	0.133	0.595	1.511	2.425	3.062	4.013	4.709	6.294	7.643	9.942
2005	0.312	0.450	1.387	2.079	3.112	3.948	4.703	5.941	7.556	9.800
2006	0.134	0.505	1.198	1.894	2.780	3.866	5.240	5.297	6.817	7.372
2007	0.277	0.526	1.016	2.006	2.625	3.588	5.108	6.458	6.318	9.557
2008	0.156	0.763	1.523	2.118	2.908	3.879	4.769	6.946	7.382	9.084
2009	0.470	0.582	1.559	2.595	3.214	4.055	5.374	6.259	8.897	10.910
2010	0.315	0.930	1.519	2.203	3.201	3.565	4.796	5.909	7.699	11.270
2011	0.177	0.714	1.501	2.287	2.982	3.803	3.809	5.561	7.738	9.627
2012	0.153	0.536	1.338	2.127	3.070	3.798	4.457	4.909	5.685	5.230
2013	0.190	0.545	1.340	2.167	3.147	4.294	4.880	5.306	6.790	7.174
2014	0.142	0.569	1.468	2.237	3.134	4.114	5.586	6.925	6.859	7.343

Table B2. ASAP model diagnostics and results for three model formulations: total objective function (OF) value, contribution to the OF by components, root mean square error (RMSE) of the standardized residuals, catch and survey coefficient of variation (CV) and effective sample size (ESS) and the spawning stock biomass and fishing mortality of unweighted ages 5+ for the terminal year (TY), and the Mohn's rho retrospective bias adjustments.

		run 1	run2	run 3
		TY=2013	TY=2013	TY=2014
Model		base_repeat	bridge	base_rivard
objective function		3163.31	3152.52	3233.15
components of				
obj. function	**catch total**	234.975	234.975	239.483
		0.00	0.00	0.00
	index fit total	914.99	915.78	945.88
	catch age composition	588.49	584.60	601.90
		0.00	0.00	0.00
	Index age composition	1424.86	1417.17	1445.89
	Recruit deviations		0	
RMSE	**Catch fleet**	0.33	0.33	0.34
	total catch	0.33	0.33	0.34
	discards	0.00	0.00	0.00
	total discards	0.00	0.00	0.00
	DFO	1.53	1.54	1.57
	Autumn	1.34	1.34	1.37
	Spring 41	0.78	0.78	0.78
	Spring 36	1.50	1.50	1.54
	Index total	1.43	1.43	1.47
CV	**catch**	0.05	0.05	0.05
	dfo	0.25+	0.25+	0.25+
	fall	0.2+	0.2+	0.2+
	spring #41	1x	1x	1x
	spring #36	0.3+	0.3+	0.3+
ESS	catch	75/125('96)	75/125('96)	75/125('96)
	dfo	50	50	50
	fall	50	50	50
	41	50	50	50
	36	50	50	50
Jan 1 biomass		2729	2650	2702
SSB TY mt		2142	2126	2248
SSB TY retro bias adj		1470	1456	1413
F TY (age 5+)		0.33	0.33	0.37
F TY retro bias adj.		0.49	0.49	0.58
TY age 1 (millions)		0.125	0.145	1.072
TY age 1 retro bias adj.		0.166	0.191	1.303
rho F		-0.32	-0.32	-0.36
rho SSB	`	0.46	0.46	0.59
rho rct		-0.25	-0.24	-0.18

Table B3. ASAP model results for January 1 biomass (mt), spawning stock biomass (SSB (mt), age 3+), fishing mortality (F) and recruitment (age 1,000s fish), 1978-2014.

Year	Jan 1 Biomass	SSB	F	Recruitment
1978	38952	30781	0.44	10962
1979	44127	28208	0.37	10562
1980	47735	34109	0.39	9104
1981	50625	35018	0.45	19334
1982	53203	32323	0.71	7419
1983	45752	33066	0.61	3595
1984	41725	27649	0.59	13695
1985	35498	19499	0.82	5401
1986	35427	20081	0.65	26183
1987	42363	18222	0.59	6478
1988	48420	33090	0.64	13921
1989	41121	25779	0.46	5741
1990	42864	30479	0.64	6807
1991	39062	22580	0.90	11461
1992	29187	14620	1.02	2532
1993	19350	12676	1.15	3077
1994	10948	6351	1.53	1960
1995	8173	6093	0.41	1226
1996	9573	7364	0.51	2606
1997	11089	6584	0.84	3508
1998	10498	6429	0.67	1225
1999	10977	7965	0.68	3405
2000	10875	7123	0.43	1536
2001	10461	8352	0.74	1055
2002	8453	6990	0.55	1492
2003	7657	5894	0.82	391
2004	5720	4579	0.75	2426
2005	4523	3167	0.48	423
2006	4571	3842	0.66	857
2007	4372	3234	0.71	1156
2008	4123	2904	0.77	534
2009	3833	2913	1.02	390
2010	2789	1964	1.05	566
2011	2087	1260	1.36	1189
2012	1722	928	1.11	822
2013	2070	1532	0.48	276
2014	2702	2248	0.37	1073

FIGURES

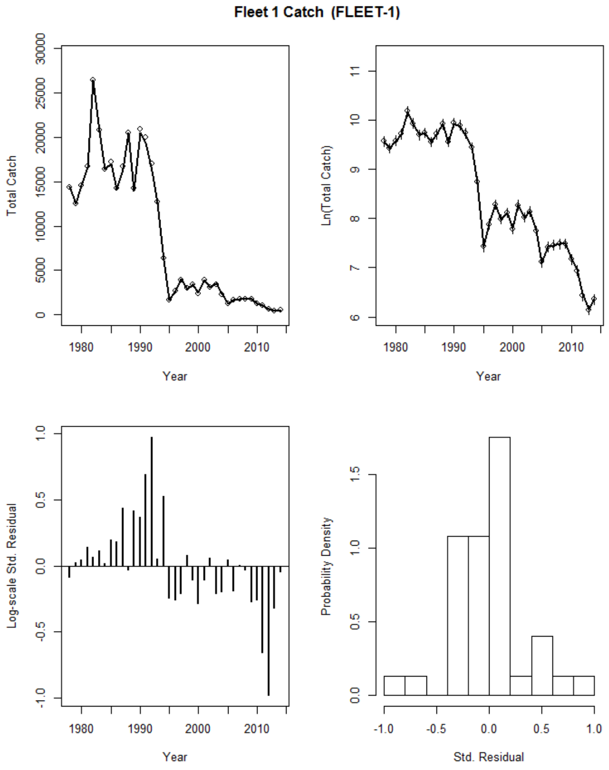


Figure B1. ASAP model fit to total catch of Eastern Georges Bank cod, 1978-2014.

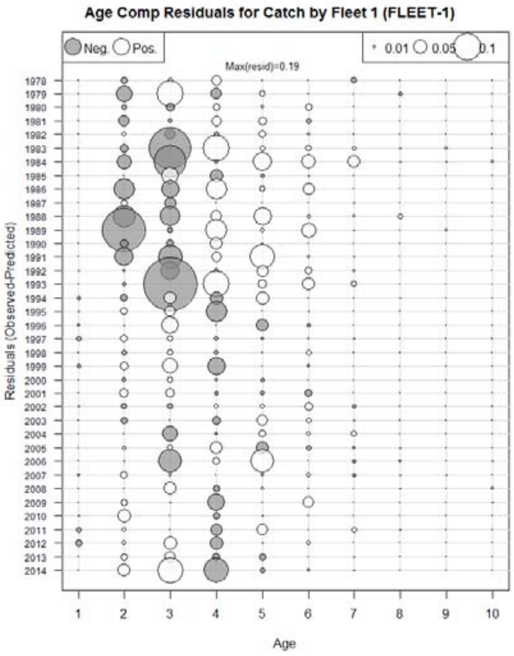


Figure B2. ASAP model residuals for the commercial catch age composition of Eastern Georges Bank cod, 1978-2014.

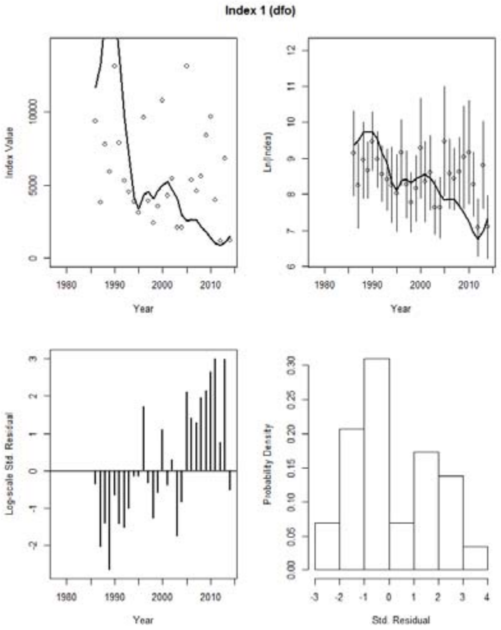


Figure B3. ASAP model fit to DFO survey indices of Eastern Georges Bank cod, 1986-2014.

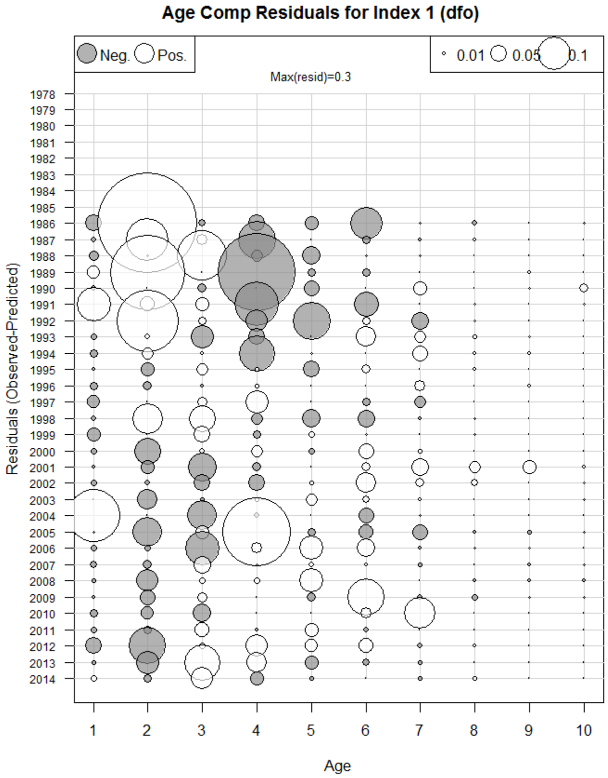


Figure B4. ASAP model run age composition residuals for DFO survey index of Eastern Georges Bank cod, 1986-2014.

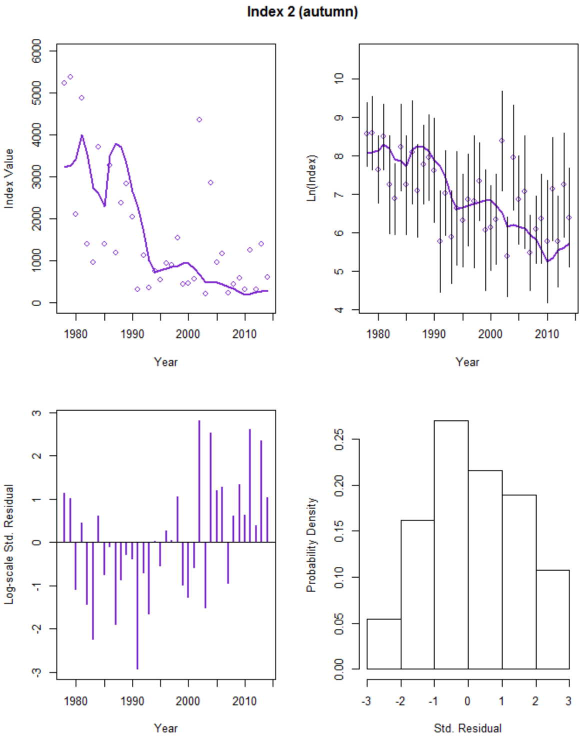


Figure B5. ASAP model fit to NEFSC autumn survey indices of Eastern Georges Bank cod, 1978-2014.

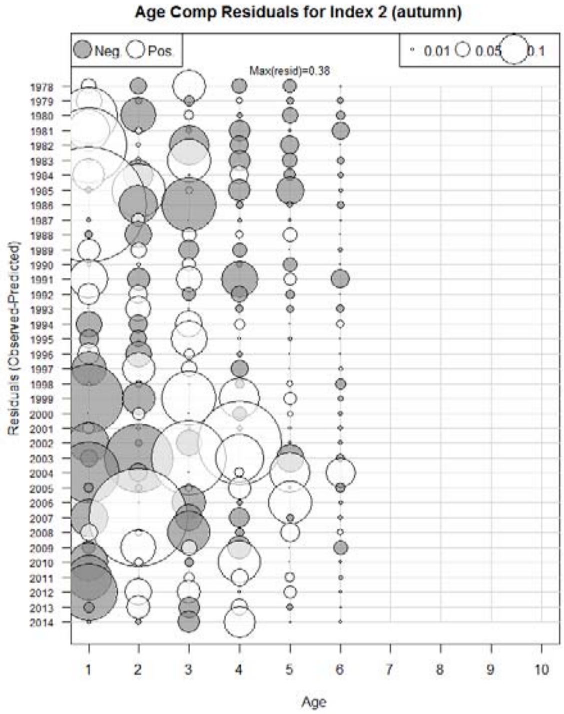


Figure B6. ASAP model age composition residuals for NEFSC autumn survey index of Eastern Georges Bank cod, 1978-2014.

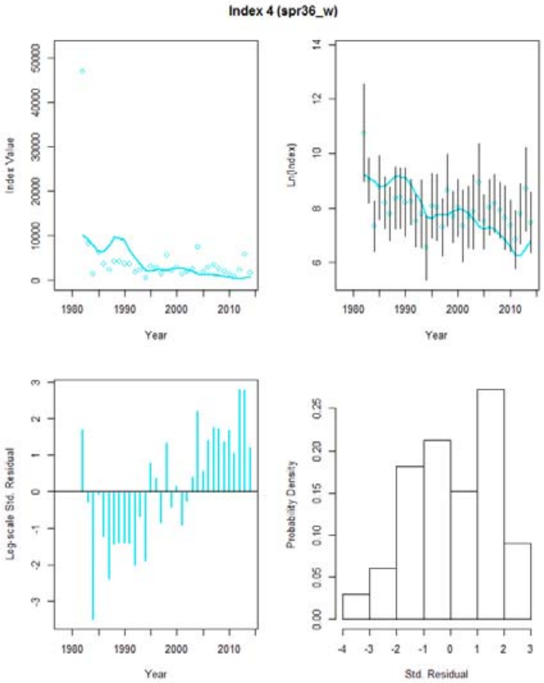


Figure B7. ASAP model fit to NEFSC spring Yankee #36 trawl survey indices of Eastern Georges Bank cod, 1982-2014.

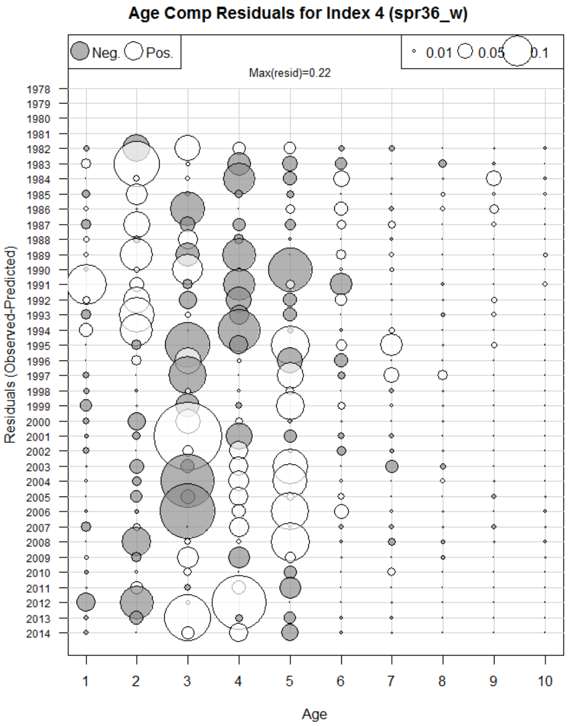


Figure B8. ASAP model age composition residuals for NEFSC spring Yankee #36 trawl survey index of Eastern Georges Bank cod, 1982-2014.

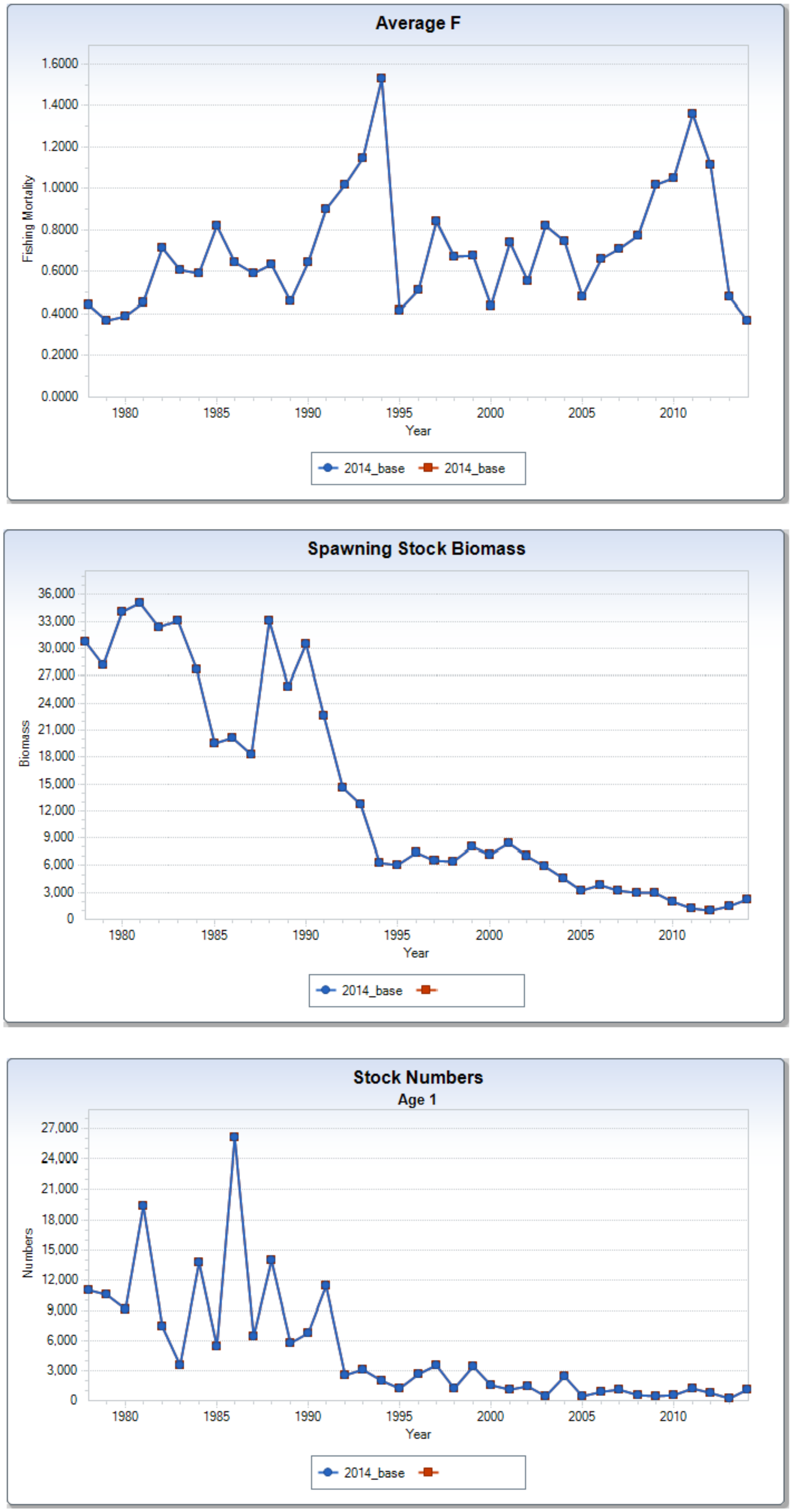


Figure B9. ASAP model results for fishing mortality (ages 5+), spawning stock biomass and recruitment (age1, 000s fish), 1978-2014.

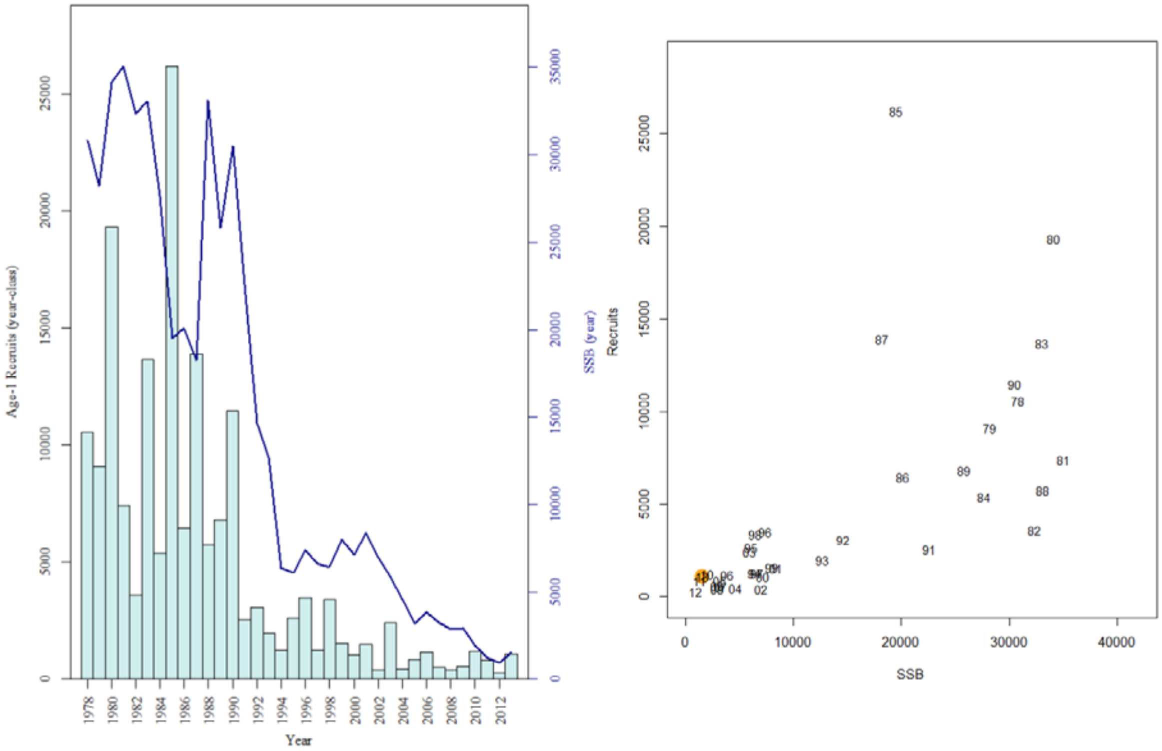


Figure B10. ASAP model results (left) for spawning stock biomass (mt, line) and recruitment (age1, 000s fish, bars) and the stock-recruitment plot (right) with year-class designation, 1978-2014.

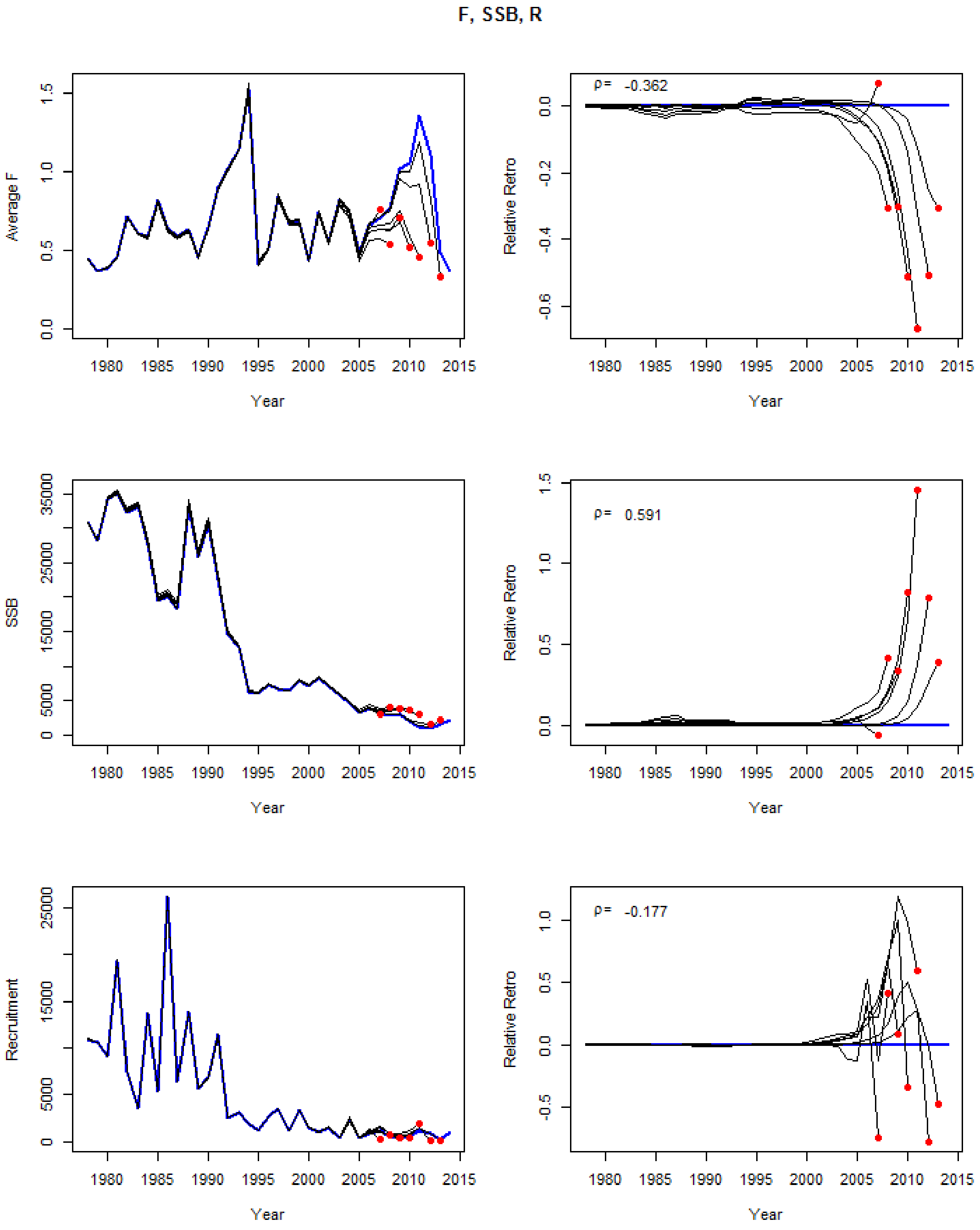


Figure B11. ASAP model results of retrospective bias of fishing mortality (F), spawning stock biomass (SSB), and age1 recruitment. Retrospective bias adjustment for F = -0.36, SSB = 0.59, and age 1 recruitment = -0.18.

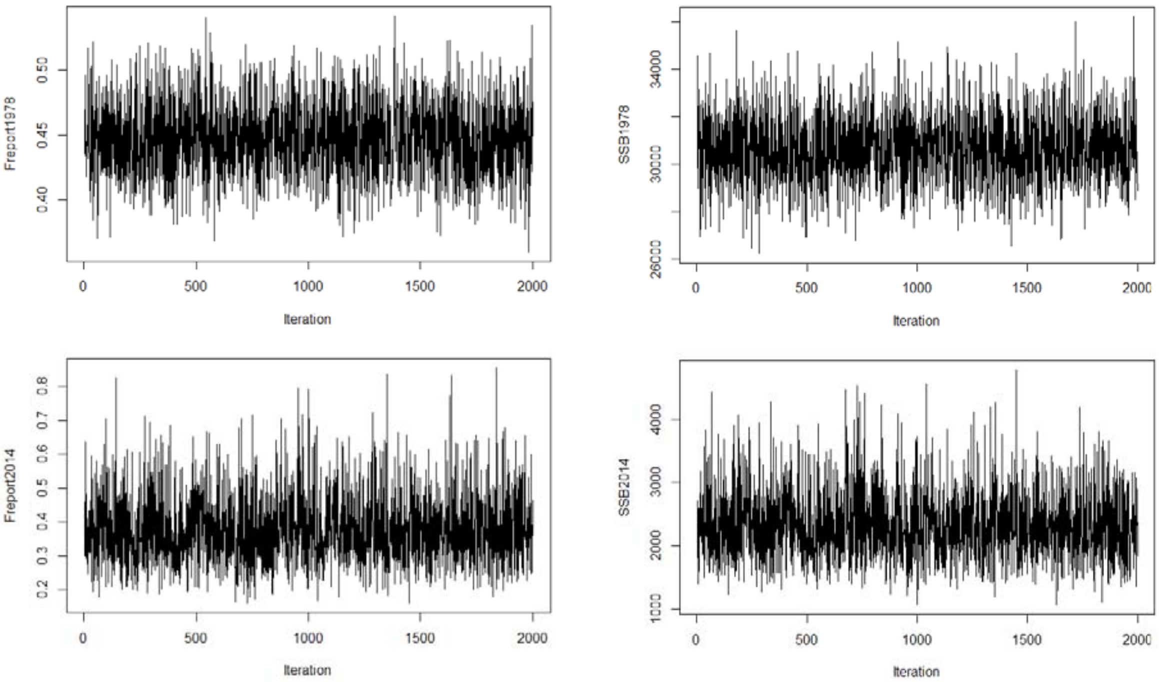


Figure B12. ASAP model results of trace of MCMC chains for Eastern Georges Bank cod fishing mortality (left) and spawning stock biomass (right) for 1978 and 2013. Each chain had an initial length of 5.0 million and was thinned at a rate of one out of every 2,500th resulting in a final chain length of 2000.