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Assessment of Eastern Georges Bank Cod in 2013

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ABSTRACT

The combined 2012 Canada/USA Atlantic Cod catches were 614 mt with a quota of 675 mt, which was the lowest catch since 1978. Catches from the 2013 Fisheries and Oceans Canada (DFO) and National Marine Fisheries Service (NMFS) spring surveys increased from 2012, but all three bottom travel surveys catch were still at lower levels. Both the fishery and the survey catches showed truncated age structure in recent years.

The VPA "M 0.8" model from the 2013 benchmark assessment was used to provide catch advice. In this model, natural mortality (M) was assumed to be 0.2 except M=0.8 for ages 6+ since 1994. A consequence analysis to understand the risks associated with assumptions of the VPA "M 0.8" and ASAP "M 0.2" model (with constant M as 0.2) was examined in the projection and risk analysis.

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 2013 was estimated at 11,160 mt, which was about 20% of the adult biomass in 1978. Fishing mortality was high prior to 1994 (0.33-0.66) and was estimated to be 0.07 in 2012. Recruitment at age 1 has been low in recent years. The 2003 year class was estimated to be the highest recruitment since 2000 (excluding the 2010 year class). The initial estimate of the 2010 year class was stronger than the 2003 year class based on the 2013 assessment. Lower weights at age in the population in recent years and poor recruitment have contributed to the lack of rebuilding.

Considering F_{ref}=0.18 is not consistent with the assessment VPA "M 0.8" model, it is inappropriate for the catch advice. TRAC recommends basing catch advice on an F lower than F_{ref} until a different F_{ref} is negotiated. An F=0.11 was used for the catch advice. A 50% probability of not exceeding an F =0.11 implies catches less than 1,225 mt. However, given the extremely low SSB and realizing the growth potential from the 2010 year class, catches not exceeding 600 mt would be required in order to not exceed F=0.11, and to achieve a 10% increase in 3+ biomass between 2014 and 2015.

The consequence analysis showed that under both sets of model assumptions, a projected catch of about 600 mt in 2014 would result in low exploitation while achieving a 10% increase in ages 3+ biomass between 2014 and 2015.

RÉSUMÉ

En 2012, les prises de morues franches combinées du Canada et des États-Unis se sont chiffrées à 614 tm, sur un quota de 675 tm, le total le plus bas depuis 1978. Les prises des relevés de printemps de 2013 effectués par Pêches et Océans Canada (MPO) et le National Marine Fisheries Service (NMFS) ont augmenté par rapport à 2012, mais les prises des trois relevés au chalut de fond étaient toujours à des niveaux inférieurs. 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 » tiré de l'évaluation de référence de 2013 a été utilisé pour faire des recommandations en matière de prises. Dans ce modèle, la mortalité naturelle (M) est estimée à 0,2, sauf pour les âges 6+ où M = 0,8 depuis 1994. 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 ASAP « M =0,2 » (avec la constante M = 0,2).

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 11 160 tm au début de 2013, ce qui correspondait à environ 20 % de la biomasse des adultes de 1978. La mortalité par pêche était élevée avant 1994 (entre 0,33 et 0,66) et elle a été estimée à 0,07 en 2012. Le recrutement à l'âge 1 a été faible ces dernières années. On estime que la classe d'âge 2003 représente le plus fort recrutement depuis 2000 (à l'exclusion de la classe d'âge 2010). D'après l'évaluation de 2013, l'estimation initiale de la classe d'âge 2010 était plus élevée que celle de la classe d'âge 2003. Au cours des dernières années, les plus faibles poids selon l'âge au sein de la population, ainsi que le faible recrutement, ont nui au rétablissement du stock.

Comme une mortalité par pêche de référence Fréf de 0,18 ne correspond pas à la valeur calculée à l'aide du modèle d'APV « M = 0,8 », elle n'est pas appropriée pour les recommandations de prises. Selon le CERT, il faut baser la recommandation de prises sur une mortalité par pêche F inférieure à Fréf jusqu'à ce qu'une autre mortalité par pêche de référence Fréf soit négociée. Une valeur de F = 0,11 a été utilisée pour les recommandations de prises. Une probabilité de 50 % que la mortalité par pêche ne dépasse pas F = 0,11 suppose des prises inférieures à 1 225 tm. Cependant, étant donné l'extrême faiblesse de la biomasse du stock reproducteur et le potentiel de croissance de la classe d'âge 2010, les prises devraient être inférieures à 600 tm pour ne pas dépasser F = 0,11 et parvenir à une augmentation de 10 % de la biomasse des âges 3+ entre 2014 et 2015.

L'analyse des conséquences a révélé que selon les deux séries d'hypothèses de modèle, des prises prévues d'environ 600 tm en 2014 entraîneraient un faible taux d'exploitation tout en permettant une augmentation de 10 % de la biomasse des âges 3+ de 2014 à 2015.

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 USA has a requirement for management advice for the Georges Bank cod stock (5Z + SubArea 6). The status quo has been to use an assessment of cod in 5Zjm for transboundary management advice and an assessment of cod in 5Z+6 for USA domestic management advice. While other options could be followed, this option is less disruptive to the existing processes. This approach requires concurrent assessment reviews of 5Zjm and of 5Z+6 to harmonize results.

The model formulations established by the 2009 Eastern Georges Bank cod benchmark assessment (Wang et al., 2009) were used for the eastern Georges Bank cod assessment from 2009 to 2012. In recent assessments the results exhibited persistent strong retrospective pattern. The retrospective analysis showed a tendency to overestimate biomass and underestimate fishing mortality in recent years (Wang and O'Brien, 2012). An Eastern Georges Bank cod benchmark assessment was conducted in 2013 to address these concerns and the details of the model formulation that was agreed upon were documented in the proceedings (Claytor and O'Brien, 2013).

The current assessment applied the 2013 benchmark formulations using Canadian and USA fishery information updated to 2012 including commercial landings and discards, the Fisheries and Oceans Canada (DFO) survey updated to 2013, the National Marine Fisheries Services (NMFS) spring survey updated to 2013 and the NMFS fall survey updated to 2012.

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 2012 were 614 mt, including 128 mt of discards (Table 1, Figure 2). Catches include 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, including the introduction of the cod separator panel for bottom trawls in 1999 (Table 2). From 1995-2011, Canadian catches fluctuated between 743 mt and 3,405 mt (Table 1). In 2012, total catch (extracted landings on May. 26, 2013, 395 mt) including discards were 468 mt against a quota of 513 mt, taken primarily between July and December by otter trawl and longline (Table 3, Figure 4 and 5). All 2012 landings were subject to dockside monitoring and at sea observers monitored close to 42% by weight of the mobile gear fleet landings, 26% by weight of the fixed gear landings and 35% of the gillnet fleet landings.

Canadian regulations prohibit the discarding of undersized fish from the groundfish fishery. For the Canadian groundfish fishery on eastern Georges Bank during 1978 – 1996, a review was conducted at the 2013 benchmark meeting to evaluate cod discards (unreported catch). Comparison of length frequencies of observer and port samples did not provide evidence of discarding. Since there was little quota regulation of the Canadian Georges Bank cod fishery prior to 1995, landings generally were well below the quota, it was concluded that there was no indication of discarding before 1996 (Claytor and O'Brien, 2013). For the Canadian groundfish fishery from 1997 to 2012, 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; Gavaris et al., 2006, 2007a)(Table1). In 2007, no discards were attributed to the mobile gear fleet because of the high observer coverage (99%) and discards for the fixed gear fleet could not be calculated because of the low observer coverage but were assumed to be negligible as discards had not been detected in previous years (Clark et al., 2008). Cod discards from the 2012 Canadian groundfish fishery were estimated at 31 mt from the mobile gear fleet, no discards were detected from the fixed gear fishery (Table 1).

Since 1996, the Canadian scallop fishery has not been permitted to land cod. Landings until 1995 included those catches reported by the scallop fishery. The 3-month moving average observed discards rate has been applied to scallop effort to estimate discards from scallop fishery since 2005 (Gavaris et al., 2007b). Estimated discards of cod by the Canadian scallop fishery ranged between 29 mt to 200 mt annually since 1978 (Van Eeckhaute et al., 2005). In 2012, estimated discards of cod by the Canadian scallop fishery were 42 mt (Table 1).

USA catches increased from 5,502 mt in 1978 to 10,550 mt in 1984. With the implementation of the International boundary (the 'Hague Line') between Canada and the United States in 1984 (International Court of Justice 1984), catches declined and subsequently fluctuated around 6,000 mt between 1985 and 1993 (Table 1, Figure 3). Since December 1994, a year-round closure of Area II (Figure 1) has been in effect, with the exception of less than 3 scallop trips per year in 1999-2000, 2004-2006, 2009, and 2011-2013 and a haddock Special Access Program in 2004 (from August 1st to the following January 31st) and since 2010. Minimum mesh size limits were increased in 1994, 1999 and 2002. Quotas were introduced in May 2004. Limits on sea days, as well as trip limits, have also been implemented (Table 2). With the implementation of a catch share system in 2010, most of the fleets are now managed by quotas. USA catches during 1994-2000 ranged between 544 mt and 1,204 mt and increased to 1,935 mt in 2003, then subsequently declined. Total USA catch (landings and discards combined) was 146 mt for calendar year 2012. 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 92% and longline gear about 6% of the landings, with the remainder taken by gillnet and other unknown gears during 2012.

Discards by USA groundfish fleets occur because of trip limits and minimum size restrictions. In September 2008, the 'Ruhle trawl', which reduces by-catch of cod, was authorized for use on eastern Georges Bank. Cod discarded in the eastern Georges Bank area by otter trawl and scallop fisheries were estimated using the NEFSC Observer data from 1989-2012. A ratio of discarded cod to total kept of all species (d:k) was estimated on a trip basis. 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, '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 55 mt in 2012, a 175% increase from 20 mt discarded in 2011 (Table 1, Figure 3).

SIZE AND AGE COMPOSITION

The size and age compositions of the 2012 Canadian groundfish fishery landings were derived from port and at-sea samples from all principal gears and seasons (Table 4, Figure 6). There were representative samples from the mobile gear and fixed gear fishery over all the fishing months. When an observer is on the fishing trip, fish are not discarded. Comparison of port and at-sea length frequencies did not indicate any discrepancies for otter trawlers (Figure 7).

However, fixed gear observer samples had more small fish than the port sample in four of the five months presented (Figure 7). For trips sampled by both port and at sea observers, comparison of length frequencies also indicated some discrepancy (Figure 8). It was suspected that the discrepancies between port and observer samples for fixed gears might be caused by non-randomness of port or observer sampling, or discarding might have occurred although discarding could not be inferred using the ratio of cod to haddock method. At-sea samples were pooled with port samples to derive catch at length and age. Landings peaked at 52 cm (20 in) for bottom trawlers and 70 cm (28 in) for longliners. Gillnetters caught fewer cod but these fish were larger, peaking at 73 cm (29 in) (Figure 9). The combined landings for all gears peaked at 52 cm (20 in) (Figure 10). The size composition of cod discards from the 2012 Canadian scallop fishery was derived from at-sea sampling. Cod discards from the scallop fishery peaked at 40 cm (16 in) (Figure 8). The discards from the groundfish fishery were assumed to have the same size composition as the groundfish landings. The Canadian combined cod discards in 2012 from the otter trawl and scallop fisheries peaked at 40 to 55 cm (16 to 22 in) (Figure 10).

The size and age compositions of the 2012 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 (Table 4). The size and age composition of discarded fish were estimated using at-sea observer samples of length frequency and commercial and NEFSC survey age keys from the same area and season. Landings in 2012 peaked at 56 cm (22 in) and discards peaked at 47 cm (19 in) (Figure 11).

The total catch composition of combined landings and discards for Canada and the USA is shown in Figure 12. Canadian catches peaked at 52 cm (20 in); and USA catches peaked at 56-59 cm (22 to 23 in).

Otoliths taken from port and at-sea observer samples were used for age determinations. Comparisons have indicated generally good agreement between DFO and NMFS age readers except for two samples with 26 and 41 otoliths, respectively. There was better agreement between DFO inter reader comparisons (Table 5). Further work and detailed discussions on these two samples are needed in the future.

Canadian catch-at-age composition was obtained by applying quarterly fishery age-length keys to the size composition. The age-length key from the 2012 DFO survey was used to augment the first quarter key.

The age composition of the 2012 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 1 sample per 100 mt of landings (i.e. where 1 length sample=100 fish and 1 age sample=20-25 fish). The 2012 age-length keys were supplemented with age samples from statistical areas 522 and 525 for the catch at age calculations.

Total discards at age from the USA groundfish and scallop fisheries (1989-2012), the Canadian groundfish fishery (1997-2012) and the Canadian scallop fishery (1978-2012) were all included in the assessment.

The 2012 combined Canada/USA fishery age composition, by number, was dominated by the 2009 year class at age 3 (40%), followed by the 2010 year class at age 2 (22%) and the 2008 year class at age 5 (17%). The 2003 year class at age 9 made little contribution to the 2012 catch (0.3%) (Table 6, Figure 13). By weight, the 2009 year class dominated the 2012 fishery (30%) followed by the 2008 (21%) and 2007 year classes (17%) (Figure13). The contribution of age 7 and older fish continued to be small in recent years, 3% by number and 6% by weight in 2012 (Table 6, Figure 14).

Fishery weights at age showed a declining trend starting in the early 1990s (Table 7, Figure 15). Compared to 2011, the weights at age in 2012 decreased except for ages 1, 4, 5 and 7 and still at low levels.

ABUNDANCE INDICES

RESEARCH SURVEYS

Surveys of Georges Bank have been conducted by DFO each year (February/March) since 1986 and by NMFS each fall (October) since 1963 and each spring (April) since 1968. All surveys use a stratified random design (Figures 16 and 17). Most of the DFO surveys have been conducted by the *CCGS Alfred Needler*. A sister ship, the *CCGS Wilfred Templeman*, conducted the survey in 1993, 2004, 2007 and 2008 and another vessel, the CCGS Teleost, conducted 6 of the sets in 2006. No conversion factors were applied. 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 (Table 8) 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 (*FSV Henry B. Bigelow*), with revised station protocols have been used to conduct the NMFS spring and fall surveys since 2009. Calibration factors by length were calculated for Atlantic cod for the data collected by the *FSV Henry B. Bigelow* to make the data equivalent to previous surveys conducted by *FRV Albatross IV*. The new research vessel/net combination tended to catch more cod at all lengths, but also proportionally more small cod. Length calibration factors (Brooks et al., 2010) were applied to the NMFS spring and fall survey results since 2009 (Table 9).

The spatial distribution of ages 3 and older cod caught during the 2012 NMFS fall, 2013 NMFS spring and 2013 DFO survey were similar to that observed from those surveys over the previous decade, with most fish concentrated on the northeastern part of Georges Bank (Figures 18-20).

The catch in numbers from the 2013 DFO survey was higher than 2012, near the average in the time series (1986-2012) (Table 10). The 2010 year class at age 3 was dominant (55% by number), followed by the 2009 year class at age 4 (32% by number). There was no catch of the 2012 year class at age 1 and no catch of fish older than 8 (Table 10, Figure 21).

Similar to the DFO survey, the 2012 NMFS spring survey catch increased from 2012 and was above the average of the 1978-2012 time series (Table 11). One large tow from stratum 21 accounted for 66% of the total catch. The 2010 year class at age 3 was dominant (65% by number), followed by the 2009 year class at age 4 (20% in number). There were no fish caught from the 2012 year class at age 1 and no catches of fish older than age 7 (Table 11, Figure 21).

The catch from the NMFS 2012 fall was among the lowest since 1978. The 2010 year class at age 2 was dominant (58% by number), followed by the 2009 year class at age 3 (28% by number). There were no catches of fish older than age 5 (Table 12).

The coefficient of variation (CV) of stratified mean catch number/tow for the three surveys is shown in Tables 13-15 and Figure 22. Median CV values indicated the most variable catch for ages 1 and 8 for DFO and NMFS spring surveys as well as ages 1 and 5 for the NMFS fall survey. The CVs were similar between the DFO and NMFS spring surveys 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 at low abundance.

With the exception of the 1996, 1998, 2003, and 2006 year classes and potentially the 2010 year class (all of which were below the time series average), the survey abundance at age

(Tables 10-12, Figure 21) shows poor recruitment since the 1990 year class in all three surveys. The 2003 year class has appeared strong in the DFO and spring surveys until age 7 and in the fall surveys until age 3, however they were disappearing very fast after age 9 from DFO survey and from age 8 from NMFS spring survey. The 2010 year class was prominent in all three surveys. Compared with pre-1990 surveys, representation at older ages and younger ages in recent years continues to be poor (Figure 21).

Biomass indices at age were calculated by applying weight at age to the abundance indices at age. The survey biomass in the 2012 fall survey was lower than last year. DFO survey biomass has been fluctuating with no strong trend. NMFS spring and fall surveys biomass indices have been low since the mid-1990s (Figure 23).

The 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 16, Figure 24). Weights at age in 2013 are lower than in 2012 except for ages 2 and 3.

Fulton's condition factor (K), an indicator which uses observed weight and length to measure fish condition, was calculated using the data from all three surveys. In order to reduce the impact of gonad weight, the post-spawning fish samples were used for the Fulton's K calculation. It showed notable downward trends in recent years from DFO and NMFS spring samples. There were limited catches from the NMFS fall survey (Table 17), and the trend from those samples was not clear (Figure 25).

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). When stock conditions are poor, fishing mortality rates should be further reduced to promote rebuilding.

ESTIMATION AND DIAGNOSTICS

CALIBRATION OF VIRTURAL POPULATION ANALYSIS (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) model (Claytor and O'Brien, 2013). The VPA used fishery catch statistics and size and age composition of the catch from 1978 to 2012 (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: NMFS spring, NMFS fall and DFO. Computational formulae used in ADAPT are described by 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 to 2012, 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… 2012.17, 2013.00

$I_{2,a,t}$ = 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… 2012.28, 2013.00

$I_{4,a,t}$ = NMFS fall survey, ages a = 1 to 5 and time t = 1978.69, 1979.69… 2011.69, 2012.69

The population was calculated to the beginning of 2013; therefore the DFO and NMFS spring survey indices for 2013 were designated as occurring at the beginning of the year, i.e. 2013.00. 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 to 2012 was assumed to be equal to the population weighted average fishing mortality on ages 7 and 8.

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:

$v_{a,t}$ = ln $N_{a,t}$ = ln population abundance for a = 2 to 9 at beginning of 2013

$K_{1,\mathrm{a}}$ = ln DFO survey catchability for ages a = 1 to 8 at time t = 1986 to 2013

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

$K_{3,a}$ = ln NMFS spring survey (Yankee 36) catchability for ages a = 1 to 8 at time t = 1982 to 2013

$K_{4,a}$ = ln NMFS fall survey catchability for ages a = 1 to 5 at time t = 1978 to 2012

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

The population abundance estimate of the 2011 and 2010 year classes at age 2 and 3 at beginning of 2013 exhibited the largest relative bias of 11% and 9%, respectively. The relative bias for other ages ranged between 3% and 5%. The relative error ranged between 59% and 25% (Table 18). Survey catchability (q) at age progressively increased until age 5 for DFO and NMFS spring surveys (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 which suggested obvious year effects (Figure 28). Average fishing mortality (F4-9) by time blocks for 1978-1993, 1994-2007 and the recent 5 years (2008-2012) was 0.49, 0.27 and 0.15, respectively. The temporal trend of fishing mortality was consistent with fishery management effort trend. There was relatively flat fishery partial recruitment pattern except for the 10+ group (Figure 29).

Retrospective analysis was used to detect any bias of consistently overestimating or underestimating fishing mortality, biomass and recruitment relative to the terminal year estimates. With catch data through 2011, the VPA “M 0.8” model did not show any retrospective pattern, suggesting that model assumptions on natural mortality are appropriate and that the fishery catch at age is consistent with the survey indices. However, in the assessment with catch data through 2012, 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. It was estimated at 4.1 million at age 1 in the 2013 assessment compared with 13.5 million with one less year of data (Figures 30 and 31). Residuals from the VPA predicted survey values for each of the three surveys were predominantly positive, which means that the 2003 year class was underestimated in the 2013 assessment (Figure 32).

Possible reasons for the appearance of a retrospective bias after adding one more year of data were explored. At the benchmark model review, with catch data through 2011 as described above, the age 9 in 2012 (2003 year class) was estimated directly as a model parameter. Since only ages 1-8 from the DFO and NMFS spring surveys and ages 1-5 from the fall survey are used to calibrate the catch-at-age matrix, the determination of the 2003 year class in the 2013 assessment relied on the 2012 fishery age 9 (2003 year class) catch and the assumption that F9 is equal to the population weighted average F on ages 7 and 8 of adjacent year classes.

The prevalence of age 9 fish in the 2012 fishery catch was expected to be high based on the abundance of the 2003 cohort in each of the previous age classes. However, a proportionately low value of age 9 catch accounted for only 0.3% in number in the 2012 fishery catch, which led to a much lower estimate of this cohort and contributed to a retrospective bias.

Another possible reason for the retrospective bias is if the actual M experienced by the 2003 year class between ages 8 and 9 was higher than that assumed (0.8). Using the assumed M 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, 7 and 8). Sensitivity runs were conducted to explore the uncertainties in estimation of the 2003 year class. The impact on the estimate of terminal year (2013) population abundance of other year classes, the retrospective pattern, as well as the implication for the projection were also investigated.

Sensitivity Analyses

In the following sensitivity runs, the model set up was the same as the VPA “M 0.8” model formulation described above for the 2013 assessment except for:

- Run 1: Estimating the 2003 year class at age 9 (‘estimate 2003yc’ model). In this model, the abundance of the 2003 year class at age 9 in 2012 was estimated as a parameter. Thus, neither age 9 fishery catch nor the assumption on F at age 9 as an average of adjacent year classes was used in the estimation of the age 9 population number of the 2003 year class.
- Run 2: Removing the 2003 year class survey data entirely from the data input (‘without 2003yc’ model). In this sensitivity run, the abundance of the 2003 year class at age 1 was fixed at a value of 4.1 million, which is the same value as 2013 assessment output from the “M 0.8” model . Since no 2003 year class survey data were used in the calibration and objective function, this fixed value has no impact on other year class estimations.

The estimated 2003 year class numbers at age from run 1 were compared with the 2012 and 2013 assessments. The 2003 year class from the “estimate 2003yc” model was very close to the 2012 assessment, about 13.5 million fish at age 1, well above 4.1 million age 1 fish from the 2013 assessment (Figure 33). Also, the estimate of biomass and fishing mortality of 1978-2012 from run 1 were much closer to the 2012 assessment (Figure 30).

For both run 1 and run 2, the estimated terminal year population abundance at age was compared with the 2013 assessment and the estimated recruitments for the past years were compared with the 2012 and 2013 assessment. For the terminal year 2013 population numbers at age, there were very minor differences between the three model formulations for most of the ages except for the 2010 year class at age 3 and age 10+ (Table 19 and Figure 34). The 2013 assessment with “M 0.8” model estimated the 2010 year class at 4.2 million compared with about 4.4 and 4.9 million from the 2 sensitivity runs (Table 19).

The “estimate 2003 yc” model has the highest estimation of ages 10+ at 168,000 with deeply dome shaped PR compared with 19,000 from the 2013 assessment using VPA “M 0.8” model.

However, the difference in the terminal year ages 3-9 biomass is minor between the three model formulations (Table 19 and Figure 35). Although the 2013 assessment tended to underestimate the size of pre-2003 year classes, the estimated recruitment for the most recent 5 years was very similar among all models (Table 19 and Figure 36). The 2003 year class was underestimated in the 2013 assessment relative to the other model formulations (Table 19 and Figure 36).

STATE OF RESOURCE

The above sensitivity analyses suggest that the low estimate of the 2003 year class may be an outlier which then caused a retrospective bias in the 2013 assessment. However, it had little impact on the estimation of other year classes in the terminal year or recruitments in the most recent five years.The adult biomass, recruitment, and fishing mortality estimates (Tables 20-22) presented below were from the VPA “M 0.8” model.

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 20, Figure 37). Biomass has subsequently fluctuated between 5,800 mt and 18,800 mt. The estimate of 3+ biomass was 11,160 mt (80% confidence interval: 9,161 mt – 14,550 mt) at the beginning of 2013 (Table 20). The increase of 3+ biomass during 2005-2009 was largely due to the recruitment and growth of the 2003 year class (Figure 37). The increase in biomass since 2011 is largely due to the recruitment and growth of the 2010 year class. 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 23). The estimated adult population biomass at the beginning of 2013 from the VPA was about one fifth of the 1978 biomass (Figure 37).

Recruitment at age 1 has been low in recent years (Table 21, Figure 37). Since 2000, the 2003 year class at 4.1 million fish at age 1 (13.5 million fish at age 1 from the 2012 assessment), had been the highest recruitment estimated. However, the initial estimate of the 2010 year class at 6.4 million age 1 fish is stronger than the 2003 year class based on the 2013 assessment. The uncertainty in the 2010 year class estimate is high, with a 40% relative standard error on age 3. 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 21, Figure 37). Recruitment for the 2002 and 2008 year classes are the lowest on record. The current biomass is well below 25,000 mt, above which there is expected to be a better chance for higher recruitment (Figure 38). Recruitment indices from the research bottom trawl surveys for the 2012 year class could not be estimated; there were no fish of this year class caught in any of the three surveys.

Fishing mortality (population number weighted average of ages 4-9) was high prior to 1994 (Table 22, Figure 39). F declined in 1995 to F=0.11 due to restrictive management measures and then fluctuated between 0.07 and 0.38. F in 2012 was estimated to be 0.07 (80% confidence interval: 0.06-0.09). The assessment showed recent reductions in F, and the 2012 fishing mortality was below F_{ref} = 0.18. However, because the current F_{ref} was based on an assumption of M=0.2, the value is not appropriate for comparison with the VPA “M 0.8” model results (Claytor and O’Brien, 2013).

Yield exceeded surplus production during the early 1990s (Figure 40). Surplus production since the mid-1990s has remained considerably lower than that prior to 1990. Growth of ages 2 to 10 has typically accounted for the greatest percentage of the production. Occasionally, a strong incoming year-class at age 2 makes a greater contribution to production. The 2003 year class made such a contribution in 2005. In 2009 and 2010, yield exceeded surplus production (Figure 41).

PRODUCTIVITY

Recruitment, 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, total mortality has remained high and adult biomass has fluctuated at a low level. The current biomass is well below 25,000 mt; when biomass is above this threshold, there is a better chance for higher recruitment (Figure 38). 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 2012 fishery remains low (Table 16). The research survey spatial distribution patterns of adult (age 3+) cod have not changed over the past decade (Figures 19-21). Lower weights at age in the population in recent years and poor recruitment have contributed to the lack of rebuilding.

OUTLOOK

This outlook is provided in terms of consequences with respect to the harvest reference points for alternative catch quotas in 2014 (Gavaris and Sinclair, 1998; Rivard and Gavaris, 2003b). At the 2013 cod benchmark meeting (Claytor and O'Brien, 2013), it was agreed that the current F_{ref}=0.18 is not consistent with the VPA "M 0.8" model given that it was derived based on models with an M=0.2. Although no consensus was reached as to what an appropriate F_{ref} would be for the VPA "M 0.8" model, it was agreed that it should be lower. The TRAC agreed that projections would be run at the current F_{ref} of 0.18 and at a value less than the F_{ref}, and the assessment leads should pick the most meaningful values for the projection. Therefore a value of F=0.11 was used to provide catch advice for 2014. This value was derived from an age-disaggregated Sissenwine-Shepherd production model using M=0.8 that was presented at the April 2013 benchmark (Claytor and O'Brien, 2013). Although it was not accepted as F_{ref} value for the "M 0.8" model at the benchmark, the value of F=0.11 was used for the second projection analysis at the 2013 TRAC since it was below 0.18 and therefore in keeping with the advice.

Uncertainty about current biomass generates uncertainty in forecast results, which is expressed here as the probability of exceeding F_{ref} = 0.18 or F = 0.11 and as the change in adult biomass from 2014 to 2015. 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, partial recruitment to the fishery, natural mortality, systematic errors in data reporting, the possibility that the model may not reflect stock dynamics closely enough, and retrospective bias.

For projections, the average of the most recent three years of fishery and survey weights at age was used for fishery and beginning year population biomass for 2014 and 2015. The 2013 and 2014 partial recruitment pattern was based on the most recent five years of estimated partial recruitment (Table 23). The 2008-2012 geometric mean of recruitment at age 1 was used for 2013-2015 projections. The initial indication of the 2012 year class is very weak, thus the projection could be optimistic. Catch in 2013 was assumed to be equal to the 600 mt quota, and F=0.18 or F=0.11 in 2014.

PROJECTION BASED ON F_{REF}=0.18

Table 24 shows the deterministic projection results, where the projected catch at F_{ref}=0.18 would be 2,028 mt in 2014. Because F_{ref}=0.18 is not consistent with the "M 0.8" assessment model, it is inappropriate for catch advice. The stochastic projection indicates catch at F_{ref}=0.18 will not achieve a 10% increase in adult biomass (3+) in 2015 (Table 25, Figure 42).

PROJECTION BASED ON F=0.11

Both deterministic (Table 26) and stochastic (Table 25, Figure 42) projections based on F=0.11 are provided. A 50% probability of not exceeding F =0.11 implies a combined Canada/USA catch less than 1,225 mt (Table 25, Figure 42). Catches of 2,075 mt will result in a neutral risk (50%) that the 2015 adult biomass will be lower than 2014, a catch of 600 mt will result in a neutral risk (50%) that 2014 adult biomass will not increase by 10% (Figure 42).

SENSITIVITY ANALYSIS

To examine the effect of the uncertainties in the estimation of the 2003 year class, the "estimate 2003yc" model was used as a sensitivity analysis for projections. The strong dome-shaped partial recruitment for ages 10+ from the model results was applied in the projection (Table 23). Deterministic (Table 26) and stochastic (Table 25, Figure 43) projections are provided. Catches of 750 mt will result in a neutral risk (50%) that the 2015 adult biomass will be lower than 2014, a catch of 650 mt will result in a neutral risk (50%) that 2014 adult biomass will not increase by 10% (Figure 43).

Given the extremely low biomass, management should try to realize the growth potential from the 2010 year class to rebuild the spawning stock biomass. In order to not exceed F=0.11, and to achieve a 10% increase in biomass, catches must not exceed 600 mt (Table 25, Figure 42). No fishing in 2014 implies an increase in adult biomass from 2014 to 2015 of about 15%.

CONSEQUENCE ANALYSIS

The risks associated with management actions taken during 2014 were examined with a consequence analysis by undertaking stock projections under the competing assumptions of the 'state of nature'. The two states of nature are the VPA "M 0.8" model and the ASAP M 0.2 model, both presented at the 2013 cod benchmark model meeting (Claytor and O'Brien, 2013) and updated through 2012 in this assessment and reviewed at the June 2013 TRAC. At the benchmark model meeting, the TRAC agreed to apply the VPA "M 0.8" model for providing catch advice, however, given that F_{ref}=0.18 is no longer consistent with that model, the TRAC also agreed to provide a consequence analysis of projected catch at two different fishing mortality rates from both models.

The analysis presents the consequences of management actions taken by setting projected catch according to the VPA "M 0.8" model if the true state of nature is such that M has remained unchanged at 0.2 and stock productivity is best reflected by the ASAP M 0.2 model, and conversely, if management actions were taken by setting projected catch according to the ASAP M 0.2 model (Appendix A) while the true state of nature is such that M has increased to 0.8 and stock productivity is best reflected by the VPA "M 0.8" model.

Data input to each model projection is as previously described for the VPA "M 0.8" and for ASAP M 0.2 (Appendix A). These are short term projections, for one year to 2014, and do not account for any longer-term consequences.

The column headers in Table 27 represent the 'true' states of nature:

- VPA M 0.8 M = 0.2 except M = 0.8 for ages 6+ from 1994 onward
- ASAP 0.2 M = 0.2 for all ages and all years

The row headers indicate the basis of the management action during the projected period (2014) for four different catches. The notation in parentheses indicates where that catch was derived, e.g., the row with a 1,225 mt catch was projected from the VPA "M 0.8" model at F=0.11.

The cells of the table indicate the projected 2014 fully recruited F and 2015 January 1 ages 3+ biomass, and the projected percent increase in biomass from 2014 to 2015.

If the VPA “M 0.8” model assumptions are the ‘true state of nature’, fishing at projected catch of 2,028 mt at F_{ref} = 0.18 would not allow for a biomass increase in 2015. A 10% increase in 2015 biomass is only expected fishing at an F=0.05 and a catch of 601 mt. If the ASAP M=0.2 model assumptions are the ‘true state of nature’, implementing the VPA 0.8 projected catch for F_{ref} results in F=0.75 and loss of 2015 biomass of about 20%. Fishing at ASAP projected catch of 601 mt at F_{ref}=0.18 results in projected biomass increase of 10%.

In summary, based on both model projections, 2014 catches at about 600 mt would allow for low exploitation of the stock and at least a minimum 10% increase in the 2015 projected biomass can likely be attained. A catch of 600 mt would be similar to the recent negotiated quota for fishing years 2012 and 2013.

The consequence analysis reflects the uncertainties in the assessment model assumptions. Despite these uncertainties, all assessment results indicate that low catches are needed to promote rebuilding.

SPECIAL CONSIDERATIONS

Table 28 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 management advice and performance since 1999 are summarized in Table 28, which was kindly provided by Tom Nies (staff member of the New England Fishery Management Council, NEFMC). The TRAC advice, TMGC quota decision, actual catch, and realized stock conditions for eastern Georges Bank cod are compared. The inconsistency of TRAC advice in the past with the realized stock conditions from the recent assessment was mainly due to the assessment model changes after the 2009 benchmark assessment, and the retrospective bias in the assessment also accounted for part of this inconsistency.

Cod and haddock are often caught together in groundfish fisheries, although they are not necessarily caught in proportion to their relative abundance because their catchabilities to the fisheries differ. Due to the higher haddock quota, discarding of cod may be high and should be monitored; at-sea observers are an essential component of this monitoring. Modifications to fishing gear and practices, with enhanced monitoring, may mitigate these concerns.

In July 2013, there will be a reduction in the minimum size for the US fishery from 22 inches to 19 inches. This is expected to result in reduced discards and a possible change in PR for the youngest ages.

It was agreed at the 2013 TRAC that projections would be run at the current Fref of 0.18 and at a value less than 0.18. A value of F=0.11 was used to provide catch advice for 2014. A consequence analysis was used to determine risks under alternative model assumptions. Further investigation will be required to determine an appropriate recommendation for an exploitation rate for the benchmark model.

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Table 1. Catches (mt) of cod from eastern Georges Bank, 1978-2012.

	Canada				USA			Total
Year	**Landings**	**Discards Scallop**	**Discards Grnfish**	**Total**	**Landings**	**Discards**	**Total**	
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	10,550		10,550	16,379
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	4,076	12,665
1994	5,277	63		5,340	998	5	1,003	6,342
1995	1,102	38		1,140	543	0.2	544	1,683
1996	1,924	56		1,980	676	1	677	2,657
1997	2,919	58	428	3,405	549	5	554	3,958
1998	1,907	92	273	2,272	679	6	685	2,957
1999	1,818	85	253	2,156	1,195	9	1,204	3,360
2000	1,572	69		1,641	772	16	788	2,429
2001	2,143	143		2,286	1,488	146	1,634	3,920
2002	1,278	94		1,372	1,688	9	1,697	3,069
2003	1,317	200		1,528	1,851	84	1,935	3,462
2004	1,112	145		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	225	1,671
2007	1,108	114		1,222	234	279	513	1,735
2008	1,390	36	103	1,529	224	20	244	1,773
2009	1,003	69	137	1,209	433	146	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	91	55	146	614
Minimum	630	29	0	743	131	0.2	225	1,030
Maximum	17,827	200	428	17,898	10,550	279	10,550	26,463
Average	5,751	82	182	5,881	3,535	70	3,585	9,466

Table 2. Canadian and USA fishery management history of cod on eastern Georges Bank, 1978-2011.

2a. Canadian Management History	
1978	Foreign fleets were excluded from the 200 mile exclusive economic zones of Canada and USA;
1984	Oct. 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. 31).
1994	TAC=6,000 mt, Spawning closures January to May 31st ; Mesh size was 130 mm square for cod, haddock and 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 and pollock for ITQ fleet; OT> 65’ could not begin fishing until July 1st; 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; 130 mm square mesh size for all mobile fleets; Small fish protocols continued; 100% dock side monitoring; Fixed gear vessels with a history since 1990 of 25 t 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 130mm 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 Februay mobile gear winter pollock fishery.
2000	TAC=1,600 mt January and February mobile gear winter pollock fishery
2001	TAC=2,100 mt
2002	TAC=1,192 mt
2003	TAC=1,301 mt;
2004	TAC=1,000 mt; Canada-USA resource sharing agreement on Georges Bank.

2a. Canadian Management History	
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 January 1st 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 Jan.uary 1st 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 1st 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 1st to February 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 1st 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.

2b. USA Management History

Year	Regulatory Actions
1953	ICNAF era
1973-1986	TAC implemented for Div 5Zcod; 35,000/year
1977	Groundfish Fishery Management Plan (FMP) Magnuson-Stevesn 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 DAS 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 EGB haddock and cod
	Eastern US/CA Area haddock Special Access Program (SAP) Pilot Progam
2005	DAS vessels limited to one trip/month in Eastern US/CA Area until April 30;
	Limited accesss DAS vessels required to use separator panel trawl in the area
2006	Haddock separator trawl or flounder net required in Eastern US/CA area
2008	Eastern US/CA Area access delayed until Aug 1, except longline gear
	Sept - Ruhle trawl (eliminator trawl) allowed in Eastern US/CA area
2009	Nov- Eastern US/CA area , trawl vessels requried to use separator/Ruhle south 41-40N
2010	Amendment 16, Framwork 44 implemented; Sector management ; Prohibition on discarding legal size fish
	US/CA area:prohibition on discarding legal size fish
	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) commecial 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

Year	Trip Limits
2004	GB cod: 1,000 lbs/day; 10,000 lbs/trip; EGB: hard TAC on cod
	500 lbs/day; 5,000 lbs/trip in Eastern US/CA area
2005	500 lbs/day; 5,000 lbs/trip in Eastern US/CA area
	Starting July, one trip/month in Eastern US/CA area until Apr. 30, 2006
2006	500 lbs/day; 5,000 lbs/trip in Eastern US/CA area
2007	1000 lbs/trip of cod in Eastern US/ CA area or Haddock SAP
2008	1000 lbs/trip of cod in Eastern US/ CA area fishing EGB exlclusively
2009	Mar-500 lbs/ trip of cod in Eastern US/CA area; back to 1000 in April
	Apr 16 - Eastern US/CA area closed until May 1
2010	GB Cod: 2000 lbs/ day; 20000/trip ; EGB cod: 500 lbs/day, 5000 lbs/trip
2011	March- 3,000 lbs day during April
	500 lbs/day after April in EGB area
	Closures
1970	Area 1(A) and 2 (B) Mar-Apr
1972-1974	Area 1(A) and 2 (B) Mar-May
1977	seasonal spawning closure
1987	modify closed area I to overlap with haddock spawning area
1994	Jan. CA II expanded, closed Jan-May, CA I closed to all vessels except sink gillnet
	Dec. CA I and II closed year round to all vessels
1999	scallopers allowed limited access to CA II
2004	May to Dec. access to northern corner of CLII & adjacent area to target haddock w/ separator trawl
	Oct - EGB area closed to multispecies DAS permits
2005	Jan - Eastern US/CA area reopened
	Apr-Eastern US/CA area closed until April 30
	Aug -Eastern US/CA area closed)GB cod TAC projected near 90%)
2006	Eastern US/CA haddock SAP delayed opening until Aug.1
2007	april 25 - Eastern US/CA area closed until Apr. 30
	Jun - Eastern US/CA area closed to limited access multispecies TAC (due to cod catch)
	Oct- Eastern US/CA area open to limited access multispecies TAC
	Nov- Eastern US/CA area closes
2008	May- Eastern US/CA area delayed opening until Aug. 1;
	Jun- Eastern US/CA area delayed opening until Aug. 1 for all gear (prevent catching 1st qtr cod TAC)
2009	May-Eastern US/CA area closed until Aug. 1 for trawl vessels
2010	Apr-Eastern US/CA area closed ; May 1 opening delayed until August

Table 3. Nominal landings (mt) of cod from eastern Georges Bank by gear and month for Canada, 2003-2012.

Year	Gear	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2003	Mobile						87	81	55	65	67	74	45	474
	Gillnet						6	31	31	27	3	14	1	112
	Longline						20	166	252	136	124	30	14	742
	Total						114	277	338	228	194	117	59	1,328
2004	Mobile						78	82	50	47	56	42	16	371
	Gillnet						4	2	14	21		11		52
	Longline						6	85	231	168	89	97	14	689
	Total						88	169	294	236	145	150	30	1,112
2005	Mobile	12	22			3	50	49	31	27	28	31	30	283
	Gillnet						11	18		6				36
	Longline	1					9	44	101	71	52	29	4	311
	Total	13	22			3	70	111	133	105	80	60	34	630
2006	Mobile	41	16				88	73	74	63	39	24	39	458
	Gillnet							27	15					43
	Longline	3					7	126	173	147	91	34	14	595
	Total	44	16				96	226	262	211	130	58	53	1,096
2007	Mobile	68	18				44	84	55	31	49	14	28	393
	Gillnet							4	41	13				58
	Longline						7	116	173	219	102	39		657
	Total	68	18				51	205	268	263	152	53	28	1,108
2008	Mobile	40	21				69	100	55	67	46	43	28	468
	Gillnet						1	22	50	22				94
	Longline						7	190	280	177	136	38		827
	Total	40	21				77	312	384	265	182	81	28	1,390
2009	Mobile	23	7				51	32	17	10	59	46	25	271
	Gillnet						4	29	61	36	12			142
	Longline							68	135	198	124	53	13	590
	Total	23	7				55	129	213	244	195	99	38	1,003
2010	Mobile	26	8				56	56	26	31	51	54	36	345
	Gillnet						5	17	13	19				54
	Longline						1	21	100	107	72	47		349
	Total	26	8				62	95	139	158	123	102	36	748
2011	Mobile	33	7				18	35	33	42	38	27	45	279
	Gillnet						4	15	24	15	7			65
	Longline						14	56	109	79	65	34		358
	Total	33	7				36	107	165	136	111	61	45	702
2012	Mobile	10	8				15	29	32	17	15	5	19	151
	Gillnet						0.5	1	4	0.4	1	3		11
	Longline							39	44	44	90	15		233
	Total	10	8				16	70	81	62	105	24	19	395

Table 4. 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 to 1986 and DFO survey age samples for 1987-2012; the numbers are shown in brackets. The highlighted numbers include samples from western Georges Bank.

	USA		Canada	
Year	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)

Table 5. Results of inter-reader aging comparisons.

Sample Source	Stock	Test Type	Date Completed	Age Reader	Sample Size	Agreement (%)
DFO RV survey NED2012002	EGB	exchange	Sep. 2012	NS vs. BH	25	100
DFO comm. Sample Q2	EGB	exchange	Sep. 2012	NS vs. BH	26	28
DFO comm. Sample Q3	EGB	exchange	Sep. 2012	NS vs. BH	25	88
DFO comm. Sample Q4	EGB	exchange	Sep. 2012	NS vs. BH	87	92
NMFS RV survey 201105	EGB	exchange	Sep. 2012	NS vs. BH	50	90
NMFS comm. sample	EGB	exchange	Sep. 2012	NS vs. BH	153	88
NMFS comm. sample	EGB	exchange	Sep. 2012	NS vs. BH	55	88(93)
NMFS comm. sample	EGB	exchange	Sep. 2012	NS vs. BH	41	63(80)

[1]BH: Bette Hatt from DFO; NS: Nina Shepherd from NMFS.
[2]Red numbers show agreement between DFO readers Bette Hatt and Laura Brown.

Table 6. Annual catch at age numbers (thousands) for eastern Georges Bank cod for 1978-2012.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1978	1	8	108	3644	1167	394	163	127	22	23	6	2	1	0	0	0	0	5668
1979	1	15	890	735	1520	543	182	74	61	11	3	2	1	0	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	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	6055
1984	0	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	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	0	0	0	6680
1988	1	23	289	4189	680	855	130	116	182	52	21	13	4	1	0	0	0	6556
1989	1	8	689	812	1984	228	373	56	40	59	15	7	5	0	0	0	0	4278
1990	1	11	728	3111	1039	1374	145	153	12	12	24	3	2	1	0	0	0	6617
1991	0	55	997	1008	1929	904	746	105	69	21	11	8	4	2	0	1	0	5862
1992	0	49	2596	1379	462	889	314	315	45	34	3	5	2	1	0	0	0	6095
1993	0	8	497	1899	909	299	359	133	97	25	17	3	0	0	0	0	0	4245
1994	1	5	183	483	788	270	45	61	30	21	2	1	0	0	0	0	0	1889
1995	3	1	57	237	94	105	18	7	4	4	0	0	0	0	0	0	0	531
1996	0	5	40	234	398	79	60	13	4	3	0	0	0	0	0	0	0	837
1997	1	7	148	205	358	358	84	37	13	4	1	1	0	0	0	0	0	1216
1998	0	4	102	314	161	158	134	23	13	4	1	0	1	0	0	0	0	915
1999	0	6	80	484	337	109	61	57	14	2	1	0	0	0	0	0	0	1151
2000	1	2	64	111	381	151	37	22	12	3	0	0	0	0	0	0	0	785
2001	1	3	95	524	210	398	105	32	17	7	1	0	0	0	0	0	0	1395
2002	1	0	10	126	447	108	156	30	9	6	2	1	0	0	0	0	0	895
2003	13	0	25	154	246	406	82	89	19	4	1	0	0	0	0	0	0	1040
2004	0	20	10	142	152	148	139	35	30	7	1	1	0	0	0	0	0	685
2005	0	1	67	45	205	50	35	36	11	5	1	0	0	0	0	0	0	458
2006	0	2	20	223	78	197	47	18	17	2	2	0	0	0	0	0	0	607
2007	0	1	44	61	430	35	86	12	7	7	0	0	0	0	0	0	0	683
2008	0	1	41	145	61	249	15	33	4	2	1	0	0	0	0	0	0	553
2009	1	1	37	209	140	47	138	9	10	1	1	0	0	0	0	0	0	594
2010	0	1	25	107	215	74	15	35	3	2	0	0	0	0	0	0	0	477
2011	0	4	44	77	93	115	26	12	7	0	0	0	0	0	0	0	0	379
2012	0	2	62	116	48	29	25	6	1	1	0	0	0	0	0	0	0	290

Table 7. Average fishery weights at age (kg) of cod from eastern Georges Bank.

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	0.38	1.26	1.96	3.35	4.89	6.02	6.79	9.80	10.70	12.77
1990	0.67	1.55	2.38	3.22	4.59	6.04	7.80	9.81	11.19	12.82
1991	0.73	1.51	2.42	3.14	4.24	5.53	7.45	9.46	9.18	13.28
1992	0.89	1.40	2.28	3.31	4.24	5.66	6.80	8.66	11.22	14.85
1993	0.64	1.40	2.10	2.84	4.29	5.40	6.76	8.29	9.14	11.13
1994	0.59	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	0.68	1.42	2.06	2.93	3.86	5.36	7.26	8.31	11.48	9.88
1998	0.69	1.33	2.15	2.98	3.97	5.33	6.59	7.82	10.23	12.88
1999	0.57	1.28	1.97	3.10	3.91	5.48	6.27	7.54	9.38	13.52
2000	0.58	1.32	1.96	2.89	4.02	4.70	5.72	6.77	8.35	14.05
2001	0.21	0.91	1.82	2.74	3.58	4.87	5.22	7.27	8.65	11.07
2002	0.34	1.20	1.96	2.84	4.01	4.89	6.41	8.23	7.98	10.11
2003		1.16	2.09	2.69	3.53	4.22	5.47	6.84	7.63	8.13
2004	0.23	1.22	1.82	2.77	3.46	4.56	5.23	7.24	8.54	8.64
2005	0.18	0.84	1.45	2.30	3.50	4.42	4.83	6.81	8.05	8.94
2006	0.09	0.59	1.75	2.31	3.28	4.29	6.10	5.79	6.89	7.20
2007	0.30	0.96	1.57	2.29	2.99	3.89	6.05	6.84	6.90	9.32
2008	0.13	1.23	2.20	2.78	3.64	5.00	5.82	7.92	7.97	8.73
2009	0.17	1.01	1.87	3.02	3.68	4.50	5.72	6.69	10.00	10.26
2010	0.42	1.15	1.97	2.51	3.38	3.43	5.1	6.08	8.80	10.86
2011	0.25	1.02	1.72	2.56	3.51	4.28	4.23	6.06	9.85	9.37
2012	0.29	0.89	1.59	2.63	3.69	4.1	4.64	5.70	5.33	5.23
Min	0.09	0.59	1.45	2.29	2.99	3.43	4.23	5.70	5.33	5.23
Max	0.90	1.60	2.43	3.93	5.38	7.23	10.10	11.46	11.86	15.35
Avg[1].	0.25	1.06	1.87	2.70	3.58	4.26	5.10	6.49	8.39	8.89

[1]for 2008-2012

Table 8. Conversion factors used to adjust for changes in door type and survey vessel for the NMFS surveys, 1978 to 2008.

Year	Door	Spring		Fall	
		Vessel	Conversion	Vessel	Conversion
1978	BMV	Albatross IV	1.56	Delaware II	1.2324
1979	BMV	Albatross IV	1.56	Delaware II	1.2324
1980	BMV	Albatross IV	1.56	Delaware II	1.2324
1981	BMV	Delaware II	1.2324	Delaware II	1.2324
1982	BMV	Delaware II	1.2324	Albatross IV	1.56
1983	BMV	Albatross IV	1.56	Albatross IV	1.56
1984	BMV	Albatross IV	1.56	Albatross IV	1.56
1985	Polyvalent	Albatross IV	1	Albatross IV	1
1986	Polyvalent	Albatross IV	1	Albatross IV	1
1987	Polyvalent	Albatross IV	1	Albatross IV	1
1988	Polyvalent	Albatross IV	1	Albatross IV	1
1989	Polyvalent	Delaware II	0.79	Delaware II	0.79
1990	Polyvalent	Delaware II	0.79	Delaware II	0.79
1991	Polyvalent	Delaware II	0.79	Delaware II	0.79
1992	Polyvalent	Albatross IV	1	Albatross IV	1
1993	Polyvalent	Albatross IV	1	Delaware II	0.79
1994	Polyvalent	Delaware II	0.79	Albatross IV	1
1995	Polyvalent	Albatross IV	1	Albatross IV	1
1996	Polyvalent	Albatross IV	1	Albatross IV	1
1997	Polyvalent	Albatross IV	1	Albatross IV	1
1998	Polyvalent	Albatross IV	1	Albatross IV	1
1999	Polyvalent	Albatross IV	1	Albatross IV	1
2000	Polyvalent	Albatross IV	1	Albatross IV	1
2001	Polyvalent	Albatross IV	1	Albatross IV	1
2002	Polyvalent	Albatross IV	1	Albatross IV	1
2003	Polyvalent	Delaware II	0.79	Delaware II	0.79
2004	Polyvalent	Albatross IV	1	Albatross IV	1
2005	Polyvalent	Albatross IV	1	Albatross IV	1
2006	Polyvalent	Albatross IV	1	Albatross IV	1
2007	Polyvalent	Albatross IV	1	Albatross IV	1
2008	Polyvalent	Albatross IV	1	Albatross IV	1

Table 9. Calibration factors at length used to adjust for differences between the catches of cod by the NMFS research vessels FSV Henry B. Bigelow and FRV Albatross IV. The factors are applied to cod numbers at length collected on the Bigelow during spring and fall surveys since 2009.

Length (cm)	Calibration Factor
1 to 20	5.723743
21	5.600243012
22	5.476743024
23	5.353243035
24	5.229743047
25	5.106243059
26	4.982743071
27	4.859243082
28	4.735743094
29	4.612243106
30	4.488743118
31	4.365243129
32	4.241743141
33	4.118243153
34	3.994743165
35	3.871243176
36	3.747743188
37	3.6242432
38	3.500743212
39	3.377243223
40	3.253743235
41	3.130243247
42	3.006743259
43	2.88324327
44	2.759743282
45	2.636243294
46	2.512743306
47	2.389243318
48	2.265743329
49	2.142243341
50	2.018743353
51	1.895243365
52	1.771743376
53	1.648243388
54+	1.601603

Table 10. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the DFO survey.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
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

Table 11. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS spring survey. Conversion factors to account for vessel and trawl door changes have been applied. During 1973-1981 a Yankee 41 net was used rather than the standard Yankee 36 net.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
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	0	0	280	413	545	188	123	14	0	0	0	0	0	0	0	0	0	1563
2013	0	0	653	3864	1202	129	64	15	0	0	0	0	0	0	0	0	0	5926

Table 12. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS fall survey. Conversion factors to account for vessel and trawl door changes have been applied.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
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	126	600	472	260	177	110	32	0	0	0	0	0	0	0	0	0	0	1776
2012	0	14	188	90	13	20	0	0	0	0	0	0	0	0	0	0	0	324

Table 13. Coefficients of variation (CV) of mean catch number/tow for DFO survey.

Year\Age	1	2	3	4	5	6	7	8	CV of mean num/tow	mean num/tow
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	0.00	0.58	0.41	0.53	0.64	0.70	0.70	0.76	0.43	16.3
Median	**0.65**	**0.33**	**0.24**	**0.26**	**0.28**	**0.32**	**0.34**	**0.40**	**0.25**	**11.9**

Table 14. Coefficients of variation (CV) of mean catch number/tow for NMFS spring survey. During 1973-1981 a Yankee 41 net was used rather than the standard Yankee 36 net.

Year\Age	1	2	3	4	5	6	7	8	CV of mean num/tow	mean num/tow
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	0.30	3.05
2010	0.72	0.41	0.19	0.17	0.31	0.30	0.35	0.00	0.25	2.19
2011	0.38	0.40	0.29	0.36	0.37	0.41	0.49	0.77	0.24	1.19
2012	0.00	0.47	0.45	0.32	0.31	0.35	0.38	0.00	0.38	3.38
2013	0.00	0.52	0.67	0.58	0.42	0.70	1.00	0.00	0.62	11.18
Median	**0.39**	**0.41**	**0.36**	**0.35**	**0.31**	**0.36**	**0.48**	**0.49**	**0.28**	**5.50**

Table 15. Coefficients of variation (CV) of mean catch number/tow for NMFS fall survey.

Year\Age	1	2	3	4	5	CV of mean num/tow	mean num/tow
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	0.55	3.98
2010	0.41	0.60	0.43	0.34	0.75	0.43	2.48
2011	0.49	0.54	0.59	0.68	0.89	0.29	2.59
2012	0.61	0.49	0.39	0.44	0.89	0.47	0.70
Median	**0.59**	**0.45**	**0.50**	**0.51**	**0.74**	**0.43**	**2.59**

Table 16. 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	0.027	0.512	1.181	2.130	2.889	3.771	5.106	6.329	5.300	11.653
2013	0.033	0.685	1.216	2.016	2.785	3.557	4.343	5.350	5.190	11.653
Average	0.100	0.750	1.652	2.577	3.783	5.097	6.566	7.942	9.671	13.754
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 17. The number of survey samples used for Fulton's K calculation for eastern Georges Bank cod.

	Survey	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7+
male	DFO		201	770	797	727	297	368
	NMFS spring		77	330	340	204	97	65
	NMFS fall	10	68	112	61	29	11	
female	DFO		159	623	651	480	184	218
	NMFS spring		74	313	304	166	85	50
	NMFS fall	22	124	107	84	33	15	

Table 18. Statistical properties of estimates for population abundance (numbers in thousands) at beginning of year 2013 and survey catchability (unitless) from the "M 0.8" benchmark model formulation for eastern Georges Bank cod obtained from a bootstrap with 1000 replications.

Parameter	Estimate	Standard Error	Relative Error	Bias	Relative Bias
N[2013 2]	1526	893	59%	164	11%
N[2013 3]	4631	1838	40%	423	9%
N[2013 4]	987	337	34%	42	4%
N[2013 5]	456	151	33%	23	5%
N[2013 6]	329	101	31%	9	3%
N[2013 7]	178	64	36%	9	5%
N[2013 8]	139	34	25%	4	3%
N[2013 9]	25	8	32%	1	4%
DFO age 1	0.01	0.002	22%	0.000	2%
DFO age 2	0.10	0.02	19%	0.002	2%
DFO age 3	0.51	0.10	19%	0.011	2%
DFO age 4	0.86	0.17	19%	0.012	1%
DFO age 5	0.96	0.18	19%	0.020	2%
DFO age 6	0.87	0.17	19%	0.016	2%
DFO age 7	0.89	0.17	19%	0.006	1%
DFO age 8	1.10	0.21	19%	0.013	1%
NMFS Spring Y41 age 1	0.02	0.00	61%	0.002	12%
NMFS Spring Y41 age 2	0.19	0.02	72%	0.035	18%
NMFS Spring Y41 age 3	0.22	0.05	60%	0.028	13%
NMFS Spring Y41 age 4	0.21	0.08	61%	0.026	13%
NMFS Spring Y41 age 5	0.31	0.09	63%	0.043	14%
NMFS Spring Y41 age 6	0.30	0.07	57%	0.040	13%
NMFS Spring Y41 age 7	0.38	0.18	63%	0.063	17%
NMFS Spring Y41 age 8	0.33	0.16	57%	0.033	10%
NMFS Spring Y36 age 1	0.02	0.01	21%	0.001	2%
NMFS Spring Y36 age 2	0.10	0.04	18%	0.001	1%
NMFS Spring Y36 age 3	0.30	0.07	18%	0.003	1%
NMFS Spring Y36 age 4	0.47	0.08	18%	0.008	2%
NMFS Spring Y36 age 5	0.47	0.10	18%	0.006	1%
NMFS Spring Y36 age 6	0.37	0.11	18%	0.009	2%
NMFS Spring Y36 age 7	0.37	0.09	17%	0.002	1%
NMFS Spring Y36 age 8	0.44	0.10	21%	0.005	1%
NMFS Fall age 1	0.05	0.01	18%	0.001	2%
NMFS Fall age 2	0.08	0.03	17%	0.001	1%
NMFS Fall age 3	0.12	0.05	16%	0.001	1%
NMFS Fall age 4	0.08	0.05	17%	0.002	2%
NMFS Fall age 5	0.07	0.05	18%	0.001	2%

Table 19. Model results comparison for VPA “M 0.8” model and sensitivity runs for eastern Georges Bank cod.

Model runs	2013 assessment (VPA “M 0.8")	"without 2003yc"	"est 2003yc"	2012 assessment (VPA “M 0.8”)
terminal year(2013) population number(thousands)				
age 2	1362	1366	1519	NA
age 3	4209	4407	4884	NA
age 4	945	947	1077	NA
age 5	432	438	502	NA
age 6	320	316	383	NA
age 7	169	169	216	NA
age 8	135	33	48	NA
age 9	24	34	20	NA
age 10+	19	NA	168	NA
terminal year(2013) ages 3-9 biomass(thousands mt)	10.9	10.7	12.2	NA
recruitment(thousands)				
1994 year class	2093	2082	2256	2229
1995 year class	3591	3567	3950	3909
1996 year class	5628	5580	6356	6198
1997 year class	2179	2151	2561	2553
1998 year class	4897	4828	5985	5990
1999 year class	1876	1828	2477	2466
2000 year class	1210	1192	1576	1582
2001 year class	2328	2168	4300	4288
2002 year class	606	627	835	835
2003 year class	4126	NA	13435	13404
2004 year class	1268	1555	1138	1119
2005 year class	2748	1362	1557	1682
2006 year class	2232	2228	2509	2958
2007 year class	1340	1342	1509	1802
2008 year class	1226	1233	1380	1681
2009 year class	1951	1976	2180	1724
2010 year class	6526	6663	7325	5895
2011 year class	1616	1671	1841	

Table 20. Beginning of year population biomass (mt) for eastern Georges Bank cod during 1978-2013 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2013.

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	54402	48003
1984	719	2420	6058	11564	3744	3299	3635	981	2117	4143	38681	35542
1985	460	7538	6160	5816	10057	3773	2802	2528	774	3778	43685	35686
1986	3159	3319	12155	4375	4397	7369	2139	1462	1188	2994	42557	36080
1987	1237	16627	5311	9886	3332	3178	4866	1161	912	3244	49754	31891
1988	2155	6262	22150	5426	8270	2095	1932	3283	1311	3270	56153	47737
1989	730	9623	8949	17663	3711	5529	1198	654	1648	2771	52476	42123
1990	1599	3301	16308	10339	15103	3006	3177	746	444	2889	56912	52012
1991	848	5462	5419	14115	8434	7858	2108	1671	530	2203	48650	42339
1992	460	6656	8365	3827	8010	5025	4523	1154	734	1810	40565	33449
1993	331	2793	7586	6141	3192	4604	2732	1843	649	1773	31644	28520
1994	509	2534	2791	4395	3625	2325	2340	1737	1043	1705	23004	19961
1995	383	2310	4752	2606	2310	2387	746	826	844	1320	18484	15791
1996	315	1435	3619	5810	3382	2749	1181	547	528	1023	20590	18840
1997	1069	2104	2314	3694	4743	3950	1013	867	184	719	20656	17483
1998	170	2991	3137	2109	3238	3996	1356	386	257	392	18031	14870
1999	542	1782	4961	3525	1842	3390	2028	742	117	324	19253	16929
2000	113	3585	2198	5986	3192	1824	1882	850	361	206	20198	16500
2001	12	1183	4565	2671	6351	3422	1103	873	396	212	20788	19593
2002	37	489	1420	4910	2326	4759	1375	433	408	238	16394	15869
2003	10	840	913	1590	4172	1481	1985	578	133	255	11956	11107
2004	89	143	2234	1264	1623	3093	628	743	281	163	10262	10031
2005	73	1975	463	2001	852	834	989	329	217	148	7881	5833
2006	84	319	3091	447	1942	603	421	420	72	192	7590	7187
2007	120	1399	893	3523	425	1761	319	202	233	119	8995	7476
2008	62	1052	2599	1278	3127	350	576	137	88	153	9423	8309
2009	140	801	2140	3317	1236	2815	160	229	44	92	10975	10034
2010	156	655	1375	2223	3091	1164	1070	55	86	53	9928	9116
2011	243	778	948	1258	1703	2599	513	444	14	71	8569	7549
2012	45	2668	1513	1238	1218	1551	1578	348	211	43	10413	7700
2013		933	5116	1904	1203	1137	732	721	125	221	12093	11160

Table 21. Beginning of year population abundance (numbers in thousands) for eastern Georges Bank cod during 1978-2013 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2013. .

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	17481	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	5273	11663	3199	1815	2660	647	319	256	55	258	26145
1986	24078	4309	6978	1360	894	1293	288	163	111	205	39678
1987	8244	19676	3122	3681	588	424	651	174	90	222	36871
1988	14154	6729	12407	1797	1984	334	229	376	106	223	38340
1989	5129	11568	5249	6402	862	860	157	84	146	189	30646
1990	7452	4192	8849	3567	3462	501	370	78	33	197	28702
1991	9669	6091	2777	4457	1988	1605	279	166	53	151	27236
1992	3628	7866	4090	1370	1924	820	648	135	74	124	20679
1993	4722	2926	4113	2112	707	782	390	250	70	121	16192
1994	3559	3858	1948	1672	917	312	319	201	118	116	13019
1995	2093	2910	2994	1161	665	508	111	104	71	90	10707
1996	3591	1713	2331	2238	865	450	216	45	44	70	11563
1997	5627	2936	1366	1697	1474	637	163	88	18	49	14056
1998	2178	4601	2270	934	1067	885	233	50	31	27	12276
1999	4897	1780	3675	1576	619	731	311	90	14	22	13716
2000	1876	4003	1385	2573	987	409	289	104	31	14	11671
2001	1210	1534	3220	1034	1763	673	160	116	39	18	9766
2002	2327	988	1170	2164	657	1085	235	51	41	20	8739
2003	606	1905	800	845	1370	441	388	86	17	22	6479
2004	4119	496	1537	517	471	757	146	118	27	14	8200
2005	1270	3354	397	1131	287	253	251	43	34	13	7031
2006	2735	1039	2685	284	741	189	91	90	13	16	7883
2007	2228	2237	833	1997	162	430	55	30	29	10	8012
2008	1352	1824	1792	626	1249	101	138	17	9	13	7121
2009	1220	1106	1456	1336	458	798	36	41	5	8	6464
2010	1972	998	873	1004	968	332	270	10	12	5	6443
2011	6368	1613	794	618	629	726	140	99	3	6	10995
2012	1666	5209	1281	581	422	411	309	55	40	4	9978
2013		1362	4209	945	432	320	169	135	24	19	7613

Table 22. Annual fishing mortality rate for eastern Georges Bank cod during 1978-2012 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2013.

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	0.70	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	0.17	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	0.22	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	0.07	0.20	0.25	0.29	0.25	0.33	0.24	0.30	0.08	0.27
2002	0.00	0.01	0.13	0.26	0.20	0.23	0.20	0.28	0.22	0.26	0.24
2003	0.00	0.01	0.24	0.38	0.39	0.31	0.39	0.37	0.39	0.12	0.38
2004	0.01	0.02	0.11	0.39	0.42	0.30	0.42	0.45	0.43	0.25	0.37
2005	0.00	0.02	0.13	0.22	0.21	0.22	0.23	0.42	0.26	0.18	0.23
2006	0.00	0.02	0.10	0.36	0.34	0.44	0.32	0.32	0.32	0.19	0.36
2007	0.00	0.02	0.08	0.27	0.27	0.33	0.36	0.42	0.38	0.09	0.28
2008	0.00	0.02	0.09	0.11	0.25	0.24	0.41	0.42	0.41	0.11	0.22
2009	0.00	0.04	0.17	0.12	0.11	0.28	0.46	0.44	0.45	0.13	0.18
2010	0.00	0.03	0.14	0.26	0.08	0.06	0.20	0.48	0.21	0.12	0.16
2011	0.00	0.03	0.10	0.17	0.21	0.05	0.12	0.11	0.12	0.06	0.14
2012	0.00	0.01	0.09	0.09	0.07	0.08	0.03	0.02	0.03	0.01	0.07

Table 23. Projection inputs for eastern Georges Bank cod.

	Age Group									
	1	2	3	4	5	6	7	8	9	10+
Natural Mortality										
2013-2014	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)										
2013-2014	0.01	0.1	0.6	0.8	1	1	1	1	1	0.5
Fishery Partial Recruitment("estimate 2003 yc" model)										
2013-2014	0.01	0.1	0.8	1	1	1	1	1	0.03	0.01
Fishery Weight at Age										
2013	0.32	1.02	1.76	2.57	3.53	3.94	4.66	5.95	8.00	11.65
2014	0.32	1.02	1.76	2.57	3.53	3.94	4.66	5.95	8.00	11.65
Population Beginning of Year Weight at Age										
2014	0.03	0.56	1.20	2.06	2.79	3.64	4.37	5.39	5.19	11.65
2015	0.03	0.56	1.20	2.06	2.79	3.64	4.37	5.39	5.19	11.65

Table 24. Deterministic projection results for eastern Georges Bank cod based on Fref=0.18 from the "M 0.8" model. Shaded values show the 2010 year class (in purple) and the projected catch (in blue). The numbers in red show the year classes with assumed recruitments.

	Age Group											
	1	2	3	4	5	6	7	8	9	10+	1+	3+
Fishing Mortality												
2013	0.001	0.006	0.038	0.051	0.063	0.063	0.063	0.063	0.063	0.032		
2014	0.002	0.018	0.108	0.144	0.18	0.18	0.18	0.18	0.18	0.09		
Projected Population Numbers												
2013	2030	1319	4475	941	431	314	168	135	24	19		
2014	2030	1661	1073	3527	732	332	132	71	57	19		
2015	2030	1659	1336	789	2500	501	124	50	27	29		
Projected Population Biomass												
2013	61	910	5459	1900	1200	1116	729	723	127	222	12447	11476
2014	61	930	1288	7265	2043	1207	578	382	296	217	14266	13275
2015	61	929	1603	1625	6976	1822	544	267	138	338	14303	13314
Projected Catch Numbers												
2013	1	8	151	42	24	13	7	6	1	0		
2014	3	27	100	430	110	38	15	8	7	1		
Projected Catch Biomass												
2013	0	8	266	108	85	52	33	34	8	5	600	592
2014	1	27	176	1103	387	150	71	48	52	13	2028	1999

Table 25. Projection and risk analysis result for eastern Georges Bank cod from the "M 0.8" and the "estimate 2003 yc" model formulations. Considering F_{ref}=0.18 is not consistent with the assessment VPA "M 0.8" model, it is inappropriate for the catch advice (shown in grey font).

a. The probability of exceeding F_{ref}.			
Probability of exceeding F_{ref} in 2014	**0.25**	**0.5**	**0.75**
"M 0.8"(F =0.11)	1,075 mt	1,225 mt	1,425mt
"estimate 2003 yc"(F =0.11)	1,300 mt	1,500 mt	1,750 mt
"M 0.8"(F_{ref}=0.18)	1,800 mt	2,100 mt	2,400 mt

b. Changes in adult biomass from 2014 to 2015.		
Neutral risk (50%) that biomass will not increase by:	**0%**	**10%**
"M 0.8"	2,075 mt	600 mt
"estimate 2003 yc"	750 mt	650 mt

Table 26. Deterministic projection results for eastern Georges Bank cod based on F= 0.11 from the "M 0.8" and the "estimate 2003 yc" model formulations. Shaded values show the 2010 year class (in purple) and the projected catch (in blue). The numbers in red show the year classes with assumed recruitments.

a. "M 0.8" model

	Age Group 1	2	3	4	5	6	7	8	9	10+	1+	3+
Fishing Mortality												
2013	0.001	0.006	0.038	0.051	0.063	0.063	0.063	0.063	0.063	0.032		
2014	0.001	0.011	0.066	0.088	0.11	0.11	0.11	0.11	0.11	0.055		
Projected Population Numbers												
2013	2030	1319	4475	941	431	314	168	135	24	19		
2014	2030	1661	1073	3527	732	332	132	71	57	19		
2015	2030	1660	1345	823	2644	537	133	53	29	31		
Projected Population Biomass												
2013	61	910	5459	1900	1200	1116	729	723	127	222	12447	11476
2014	61	930	1288	7265	2043	1207	578	382	296	217	14266	13275
2015	61	930	1614	1694	7378	1955	583	287	148	360	15009	14018
Projected Catch Numbers												
2013	1	8	151	42	24	13	7	6	1	0		
2014	2	16	62	270	69	24	10	5	4	1		
Projected Catch Biomass												
2013	0	8	266	108	85	52	33	34	8	5	600	592
2014	1	17	109	692	244	94	44	30	33	8	1273	1256

b. "estimate 2003 yc" model

	Age Group 1	2	3	4	5	6	7	8	9	10+	1+	3+
Fishing Mortality												
2013	0	0.005	0.039	0.049	0.049	0.049	0.049	0.049	0.001	0		
2014	0.001	0.011	0.088	0.11	0.11	0.11	0.11	0.11	0.003	0.001		
Projected Population Numbers												
2013	2277	1496	4922	1055	504	384	213	47	20	168		
2014	2277	1863	1219	3874	822	393	164	91	20	84		
2015	2277	1862	1509	914	2841	603	158	66	37	47		
Projected Population Biomass												
2013	68	1032	6004	2132	1402	1366	925	254	104	1953	15241	14141
2014	68	1043	1462	7980	2295	1431	717	492	105	982	16576	15464
2015	68	1043	1811	1882	7927	2196	692	356	191	547	16711	15600
Projected Catch Numbers												
2013	1	7	173	46	22	13	7	2	0	0		
2014	2	18	93	366	78	28	12	7	0	0		
Projected Catch Biomass												
2013	0	7	304	118	78	50	33	9	0	1	600	593
2014	1	19	164	940	274	112	55	39	0	1	1605	1586

Table 27. Eastern Georges Bank Atlantic cod projected 2014 fishing mortality (F), 2015 January 1 stock biomass (ages 3+), and percent increase in biomass from 2014 to 2015, based on 2014 projected catch at F_{ref}=0.18 and F=0.11 for each of two 'true state of nature' management models: VPA "M0.8" and ASAP M=0.2, and the consequence analysis of the projections of the alternative management action. Considering F_{ref}=0.18 is not consistent with the assessment VPA"M 0.8" model, it is inappropriate for the catch advice (shown in top left dark grey shaded box font).

		VPA "M 0.8"	ASAP"M 0.2"
Catch 2012		*613 mt*	*613 mt*
quota 2013		600 mt	600 mt
2012 biomass (3+)		7,700 mt	2,091 mt
2013 biomass (3+)		11,160 mt	NA
PROJECTED CATCH (mt)			
2,028	2014 F	0.18	0.75
(VPA F=0.18)	2015 Biomass	13,314	3,328
	% inc B from 2014	0.4%	-20.2%
1,225	2014 F	0.11	0.40
(VPA F=0.11)	2015 Biomass	14,018	4,153
	% inc B from 2014	6%	-0.42%
601	2014 F	0.05	0.18
(ASAP F=0.18)	2015 Biomass	14,646	4,794
	% inc B from 2014	10%	15%
378	2014 F	0.03	0.11
(ASAP F=0.11)	2015 Biomass	14,858	5,029
	% inc B from 2014	12%	21%
(green)	$F<=F_{ref}$ and 10% biomass increase in 2015		
(light blue)	$F< =F_{ref}$ and biomass increase < 10% in 2015		
(red)	$F>F_{ref}$ and biomass increase < 10% in 2015		
(dark grey)	not feasible projection		

Table 278. 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 Fref, 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 = 0.23 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 = 0.36 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 = 0.28; Biomass decreased 5% 07-08
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 0.22; 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	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	*F = 0.33 or 0.20* *Biomass stable or declined 7%* Now F = 0.18;

TRAC	**Catch Year**	**TRAC Analysis/Recommendation**		**TMGC Decision**		**Actual Catch[1] /Compared to Risk Analysis**	**Actual F Result[2]**
		Amount	**Rationale**	**Amount**	**Rationale**		
			2009 - 2010			not to increase	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 = 0.16; 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= 0.14; 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_{re}f, and low to neutral risk of biomass decline	614 mt	*F = 0.07;* *Biomass increased 16%*
2012	2013	(1) 400 – 775 mt (2) 400 – 575 mt	(1) Neutral risk of exceeding F_{ref} (2) Neutral risk of stock not increase by 20% from 2013 – 2014	600 mt			

(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

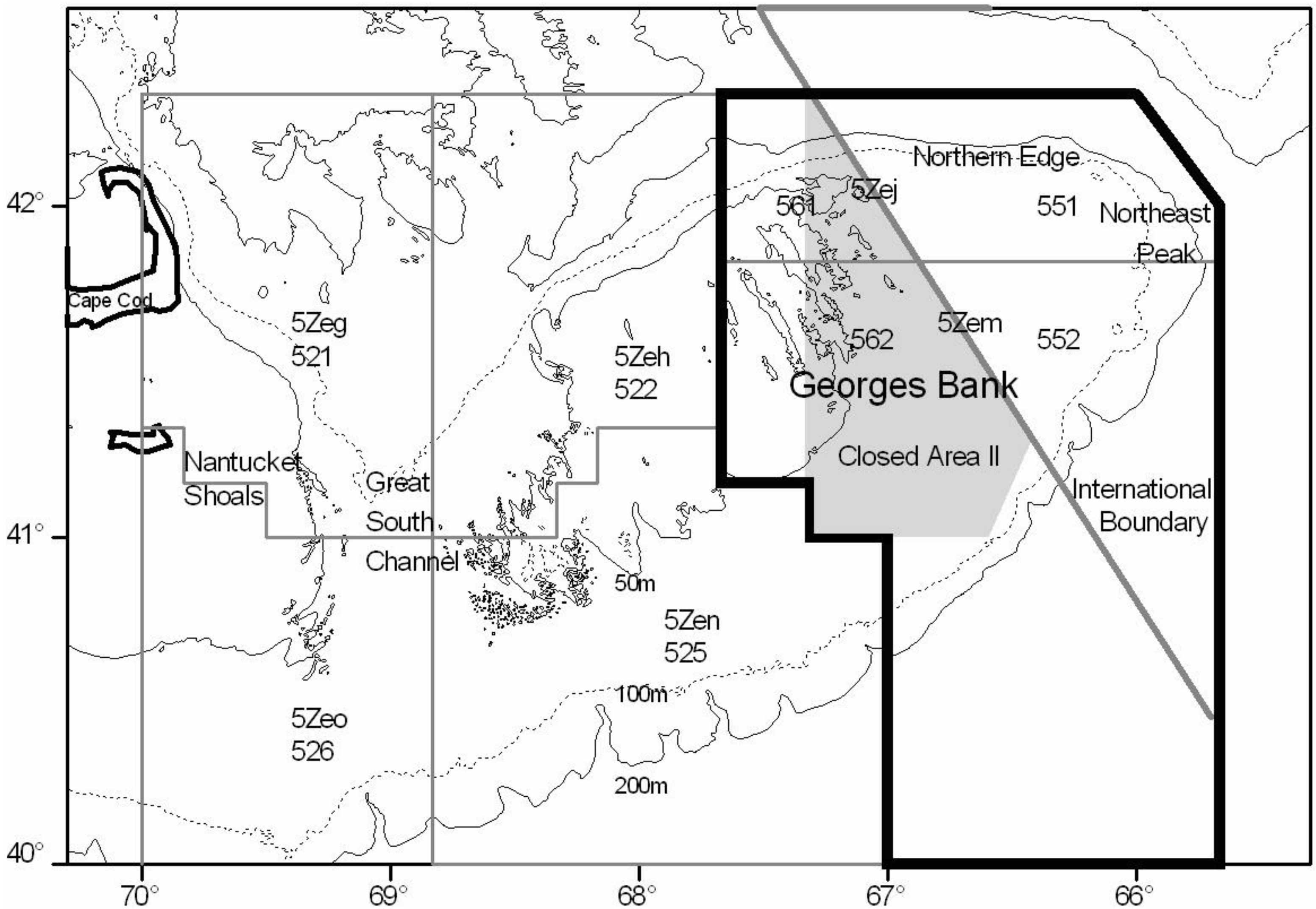


Figure 1. Fisheries statistical unit areas (CANADA and USA) in NAFO Subdivision 5Ze. The eastern Georges Bank management unit is outlined by a heavy black line.

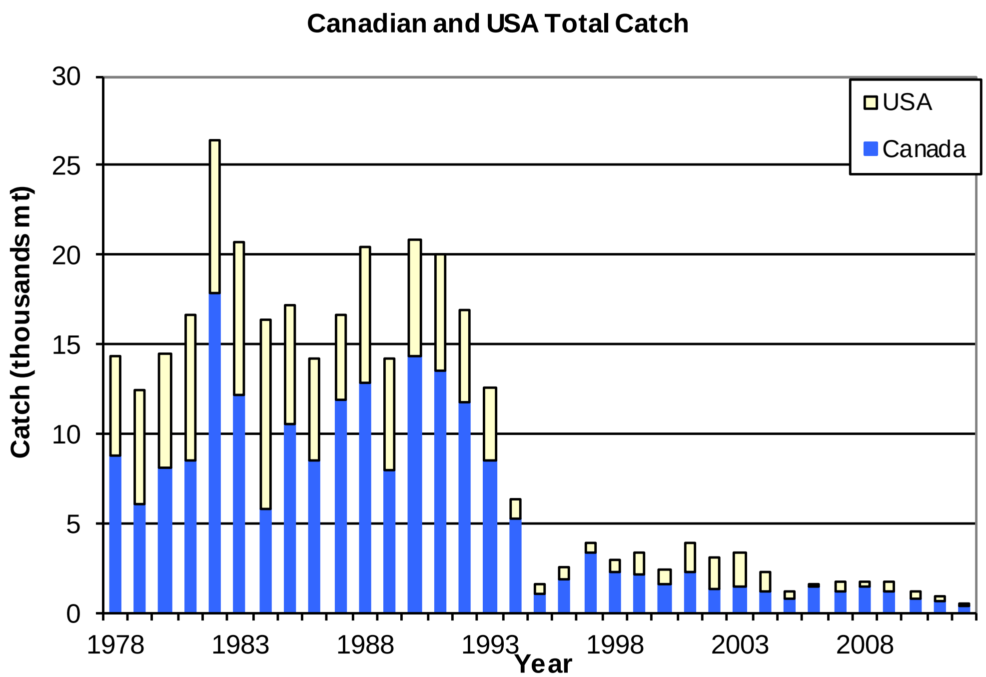


Figure 2. Catches of cod from eastern Georges Bank, 1978 to 2012.

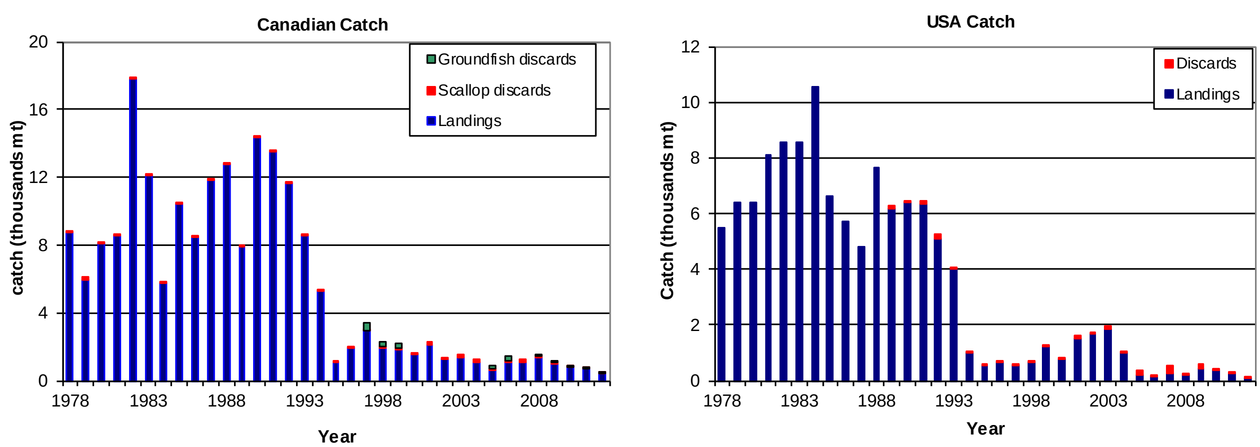


Figure 3. Canadian and USA landings and discards of cod from eastern Georges Bank, 1978 to 2012.

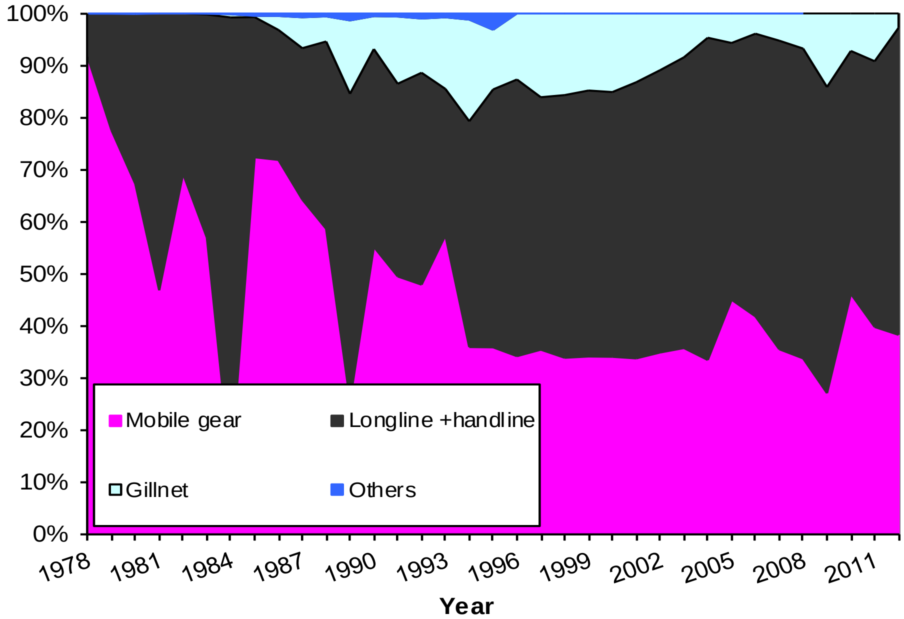
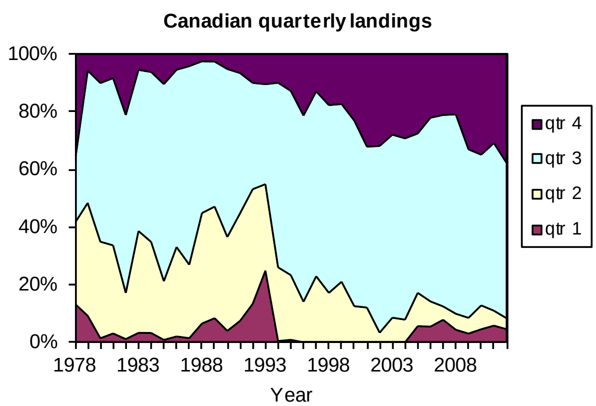


Figure 4. Proportion of Canadian gear specific landings of cod from eastern Georges Bank for 1978 to 2012.



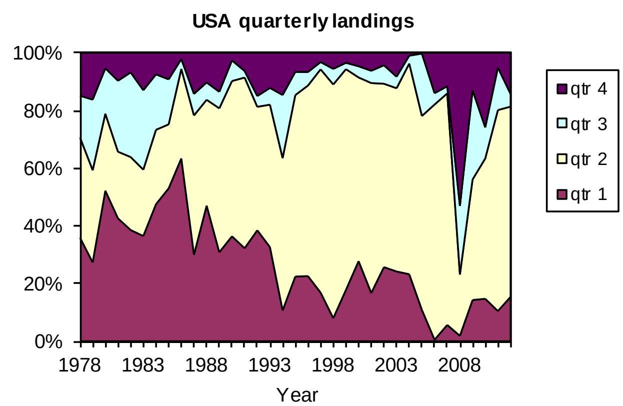


Figure 5. Proportion of Canadian and USA quarterly landings of cod from eastern Georges Bank, 1978 to 2012.

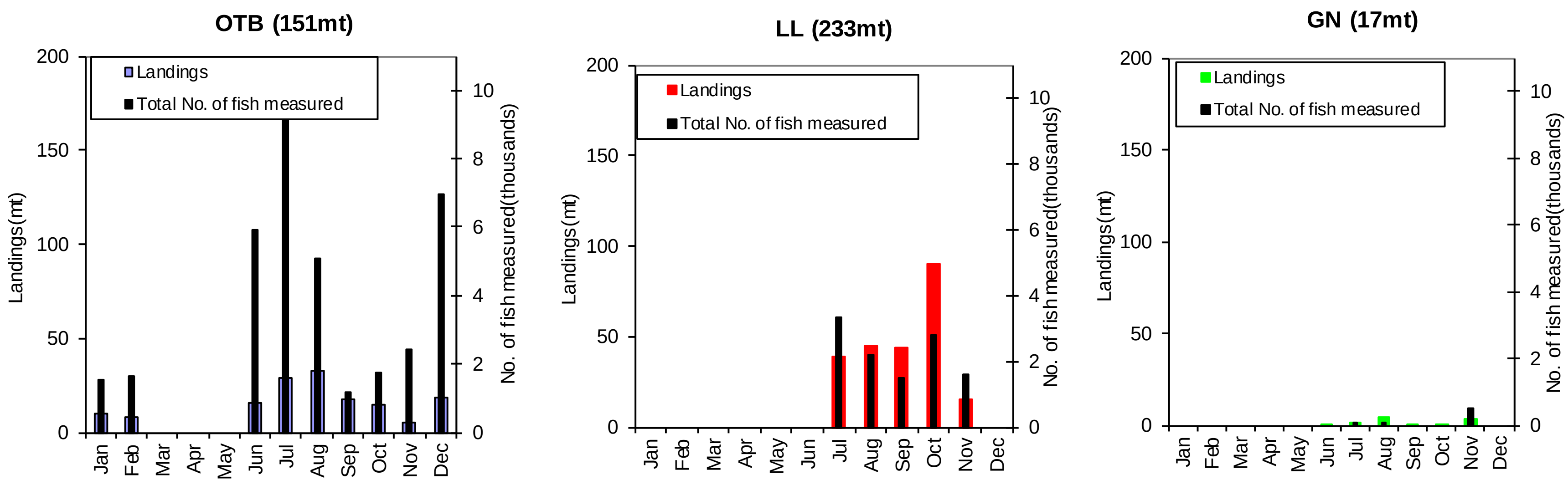


Figure 6. Landings (wide bars) and sampling (narrow dark bars) of cod by gear and month from the 2012 Canadian bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on eastern Georges Bank.

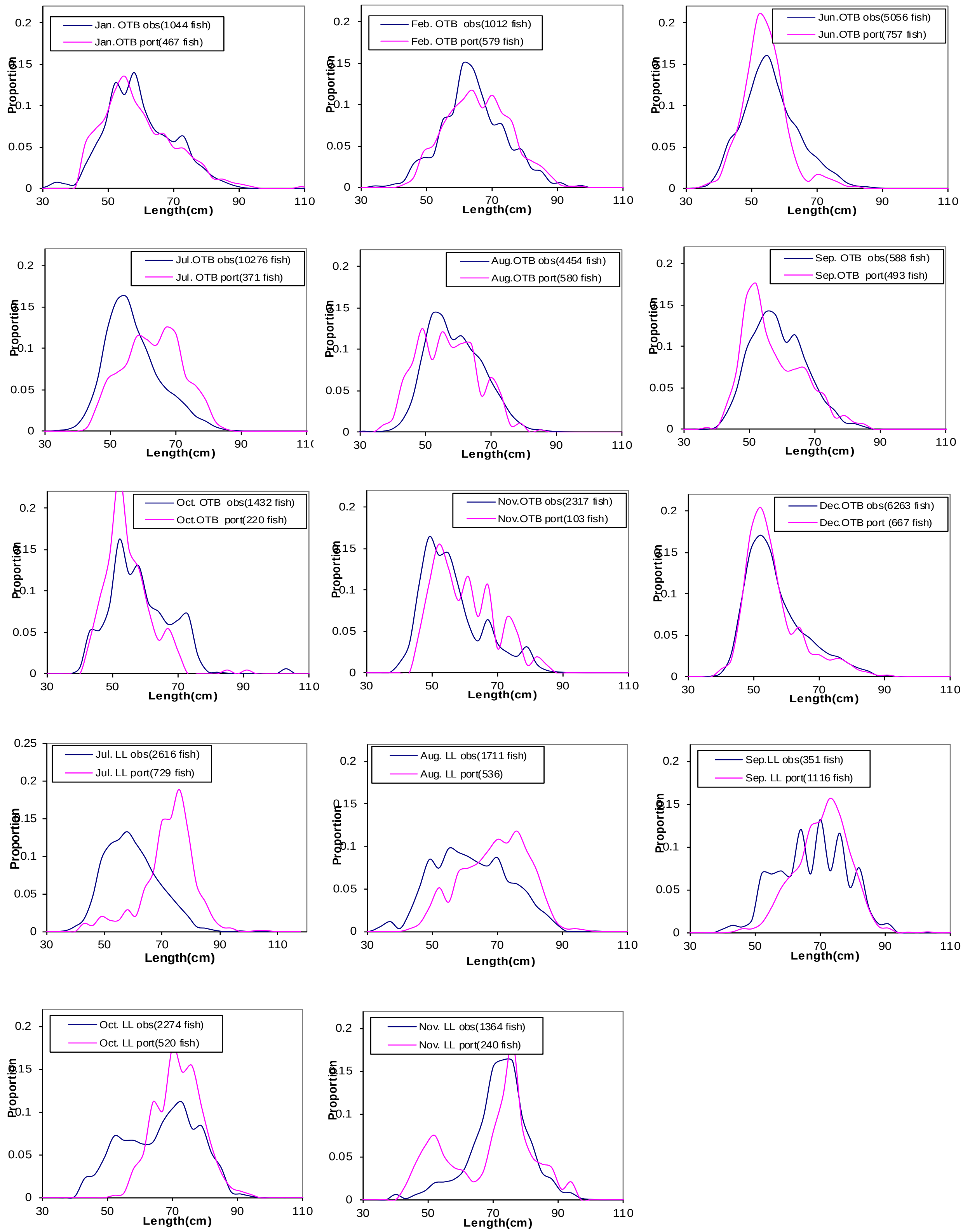


Figure 7. Comparison of cod length frequency composition from port and at sea observer sampling of the 2012 Canadian bottom trawl (OTB) and longline (LL) fisheries on eastern Georges Bank.

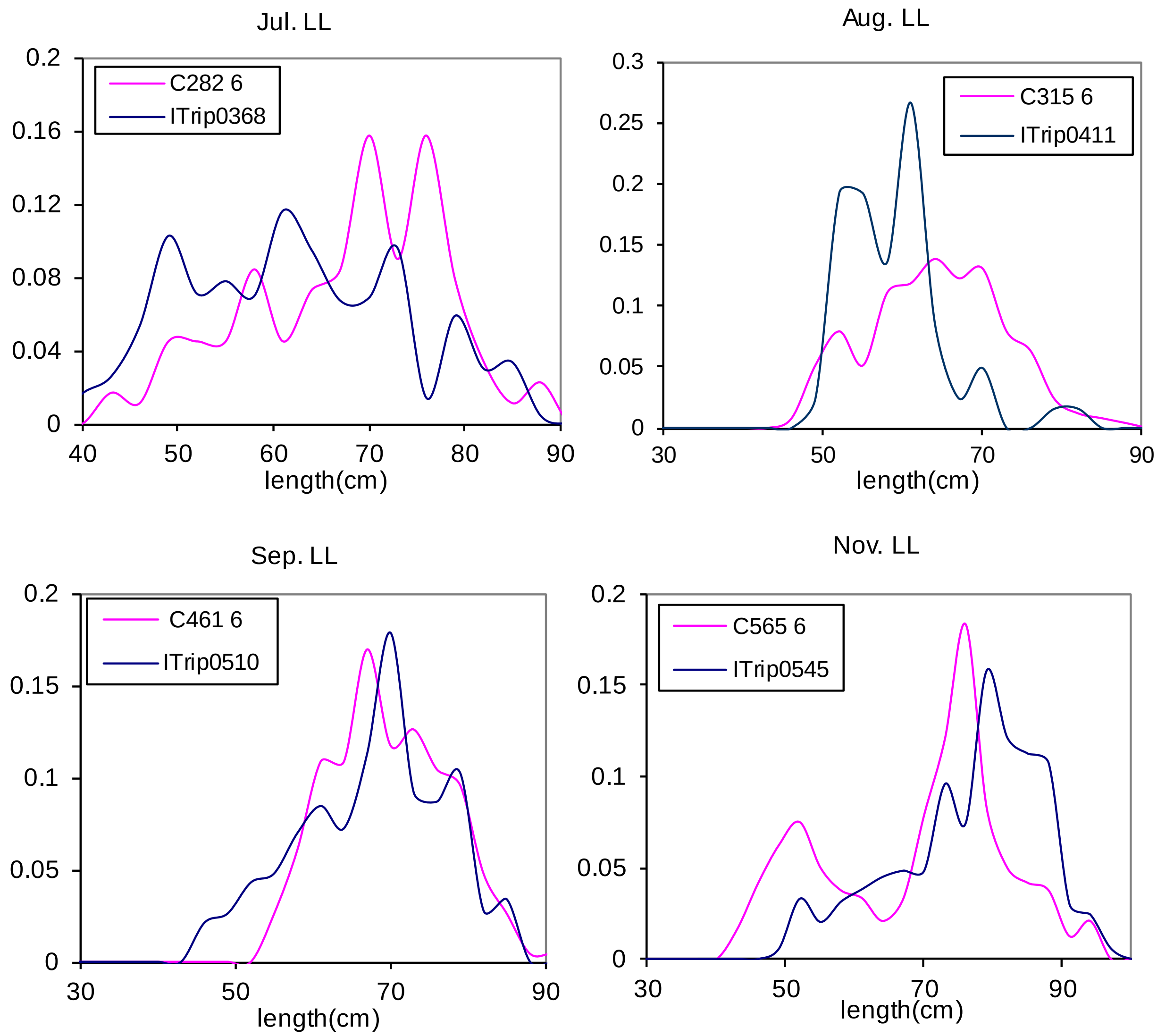


Figure 8. Comparison of cod length frequency composition from the longline fisheries trips sampled by both port and at sea observers on eastern Georges Bank.

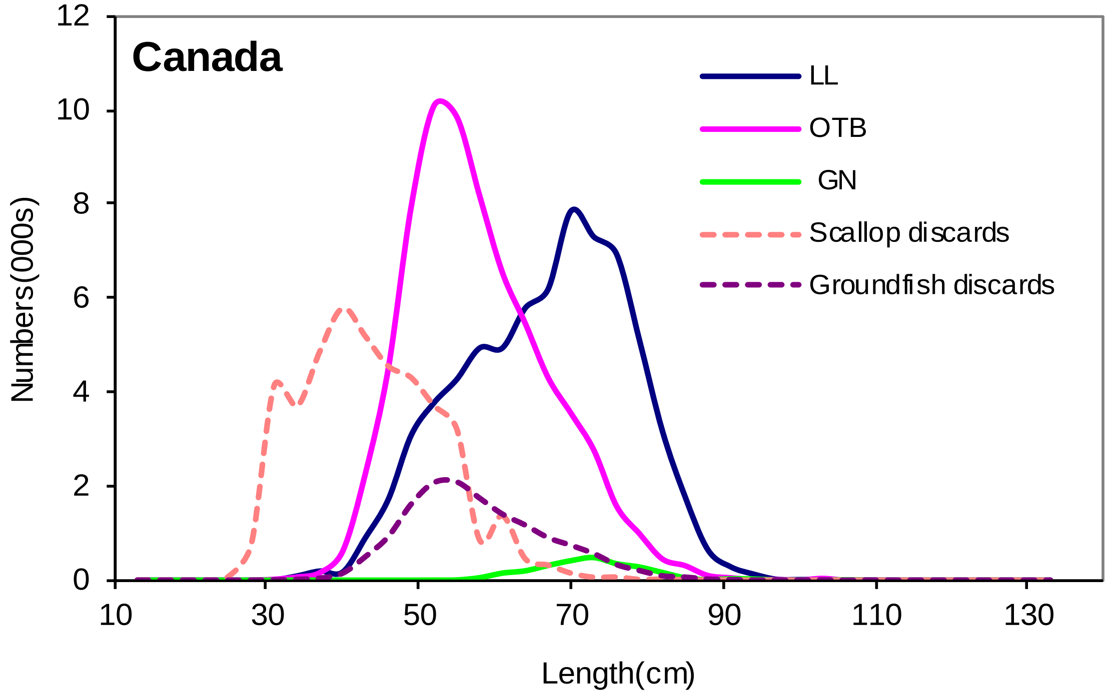


Figure 9. Cod catches at length by gear from the 2012 Canadian fisheries on eastern Georges Bank.

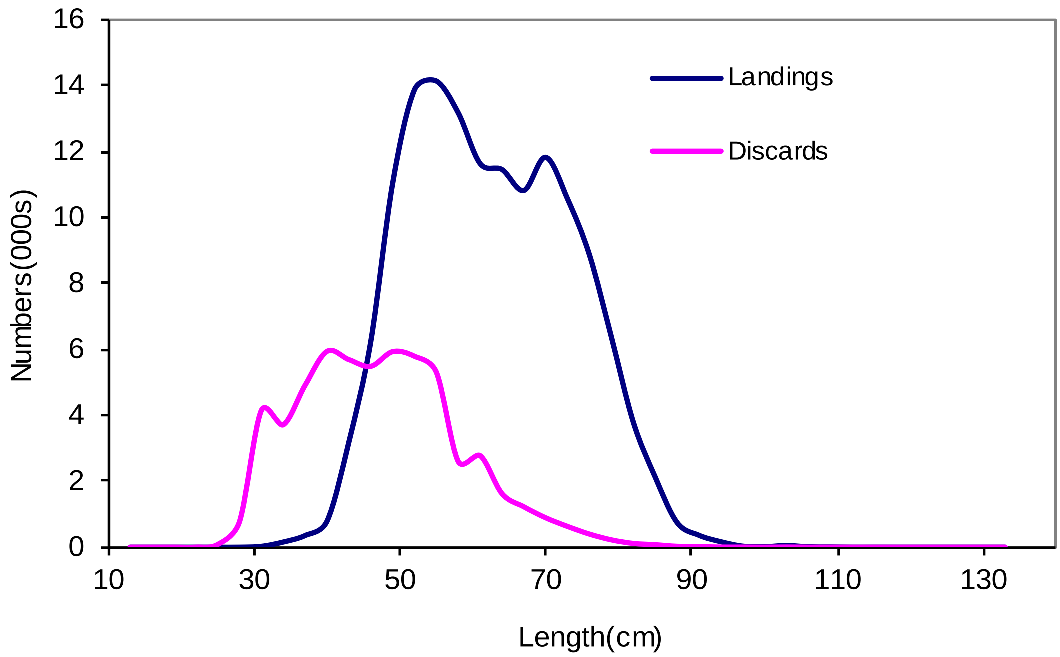


Figure 10. Cod landings and discards at length from the 2012 Canadian fisheries on eastern Georges Bank.

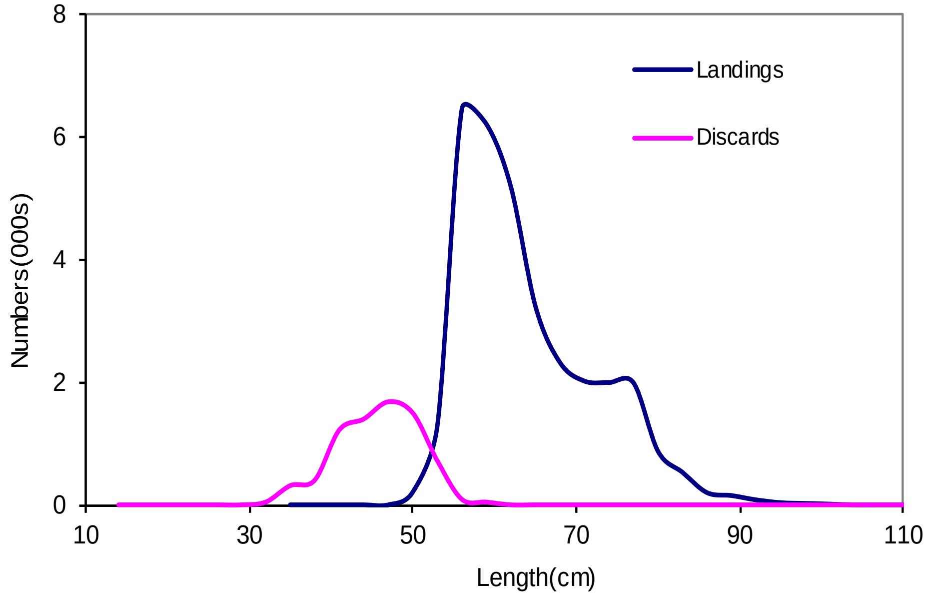


Figure 11. Cod landings and discards at length from the 2012 USA fisheries on eastern Georges Bank.

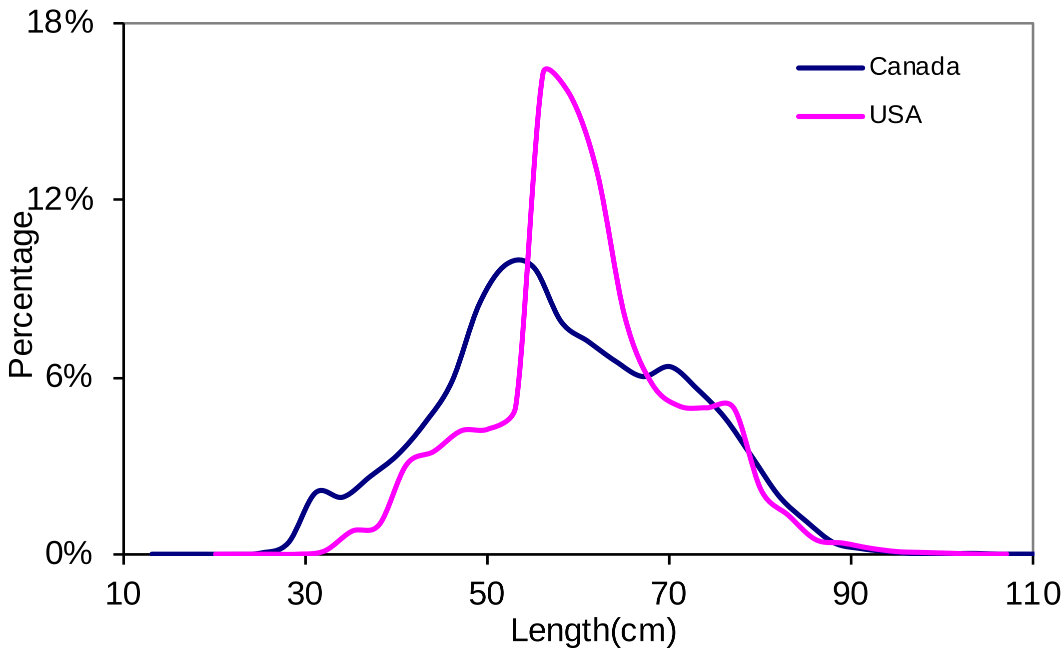


Figure 12. Length frequency of Eastern Georges Bank cod total catch from the 2012 Canadian and USA fisheries.

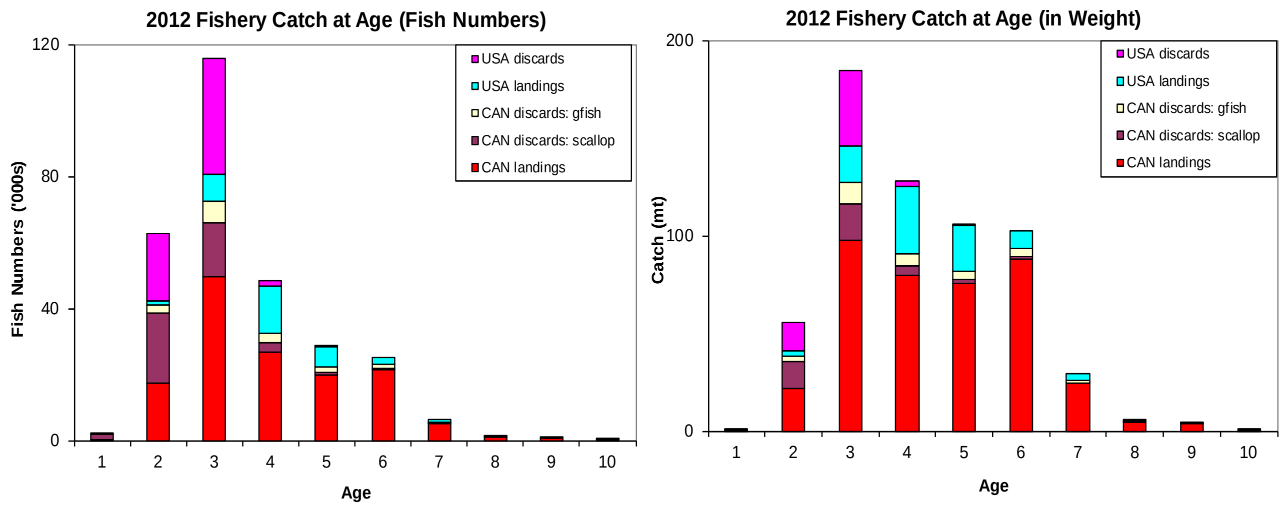


Figure 13. Catch at age in numbers (left) and weight (right) for landings and discards of cod from the 2012 eastern Georges Bank fisheries.

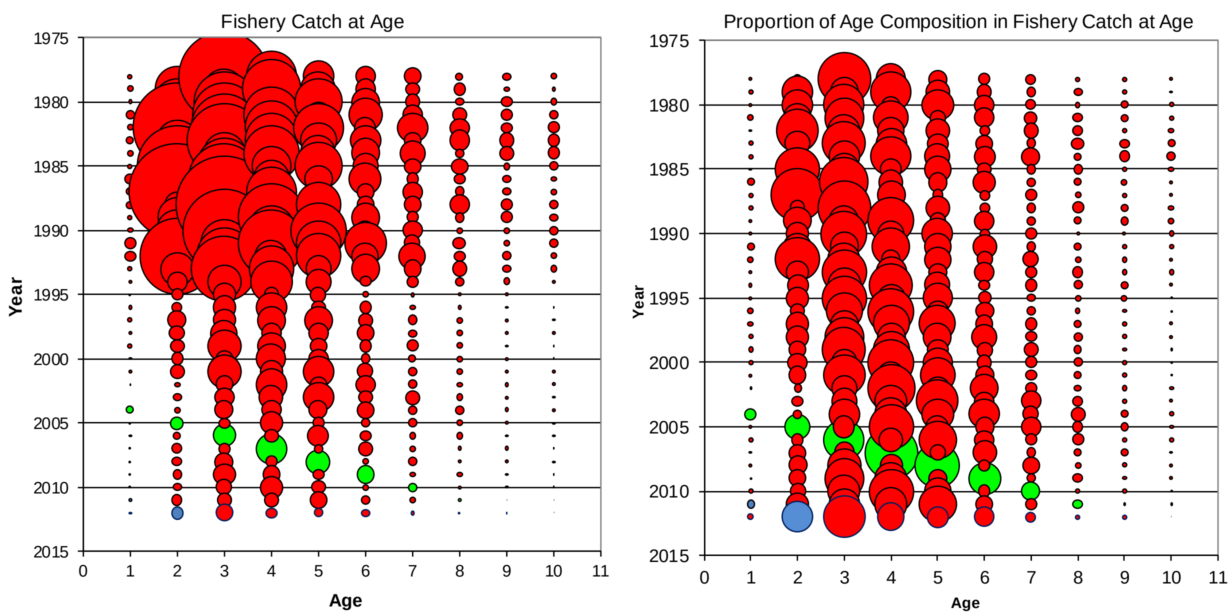


Figure 14. Total catch at age (numbers) of cod (left) and proportion of catch at age from eastern Georges Bank for 1978 to 2012. The bubble area is proportional to the magnitude. The light green circles are the 2003 year class and the light blue circles are the 2010 year class.

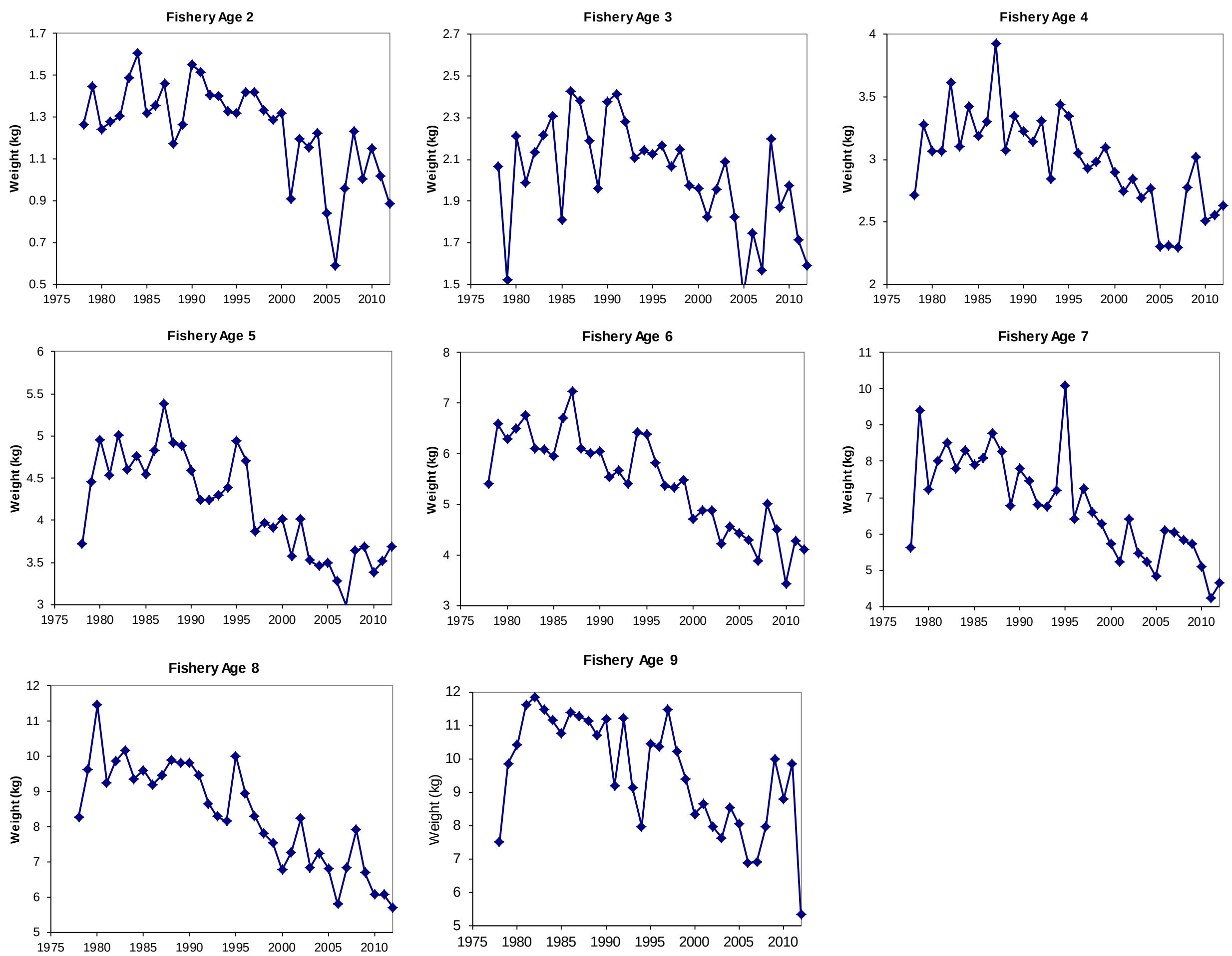


Figure 15. Average weight at age for age 2 to age 9 of cod from the eastern Georges Bank fishery, 1978 to 2012.

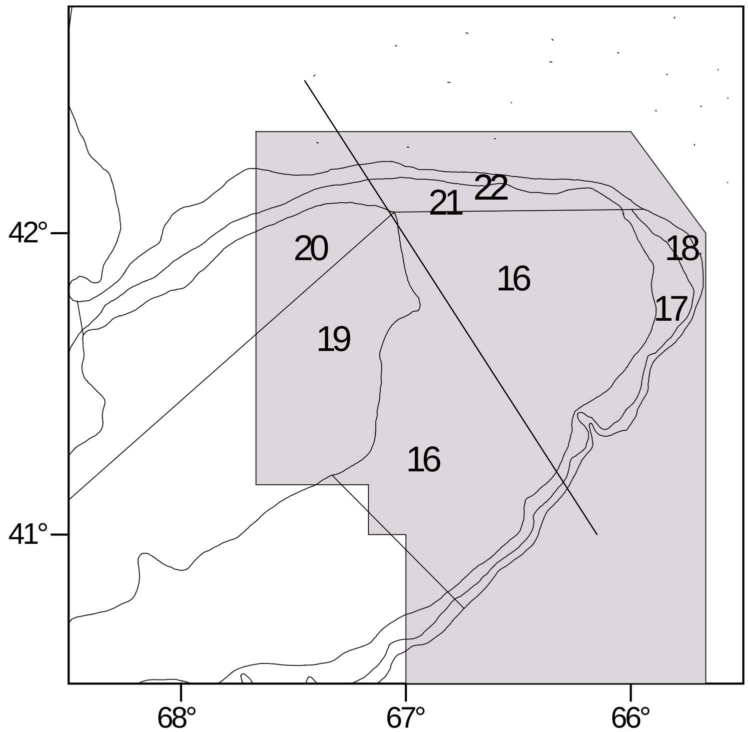


Figure 16. Stratification used for the NMFS surveys. The eastern Georges Bank management unit is indicated by shading.

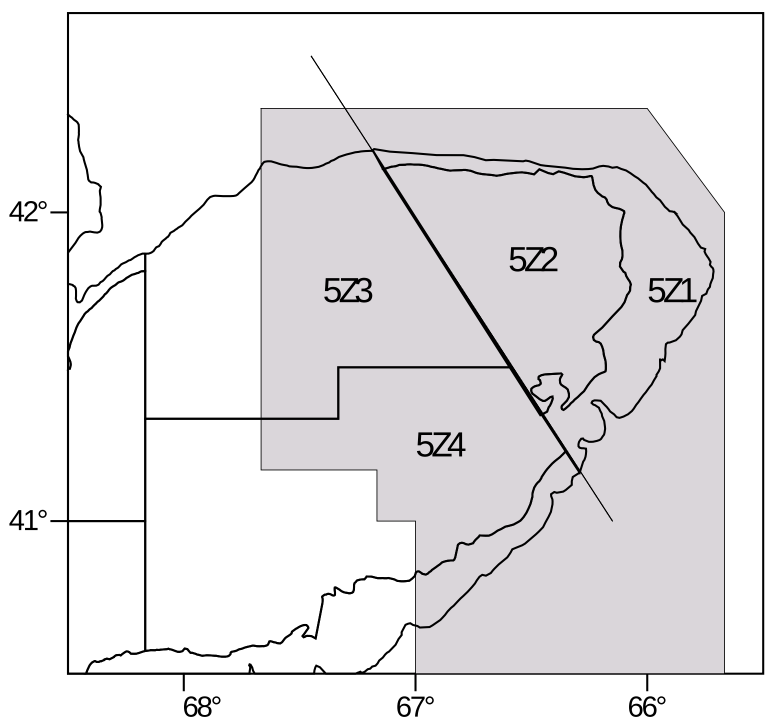


Figure 17. Stratification used for the DFO survey. The eastern Georges Bank management unit is indicated by shading.

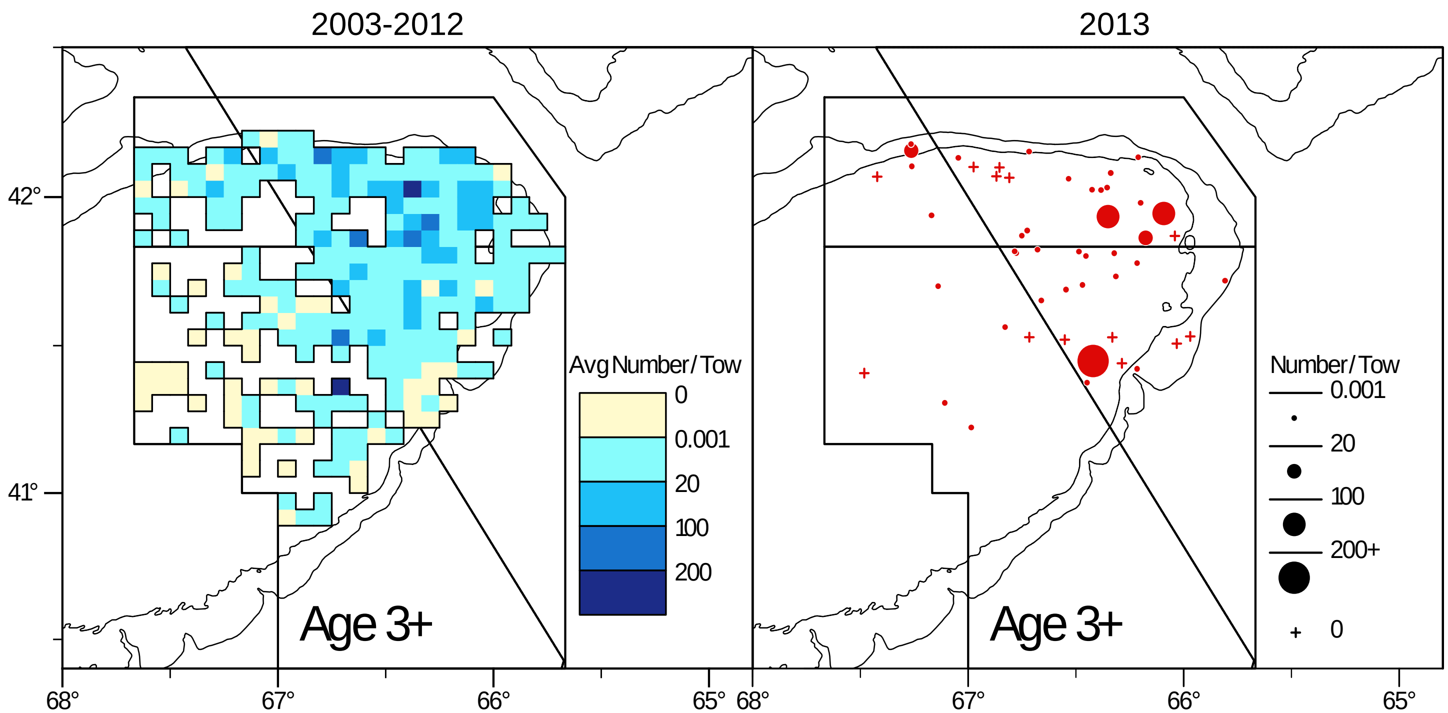


Figure 18. Spatial distribution of age 3+ cod on eastern Georges Bank from the DFO survey for 2013 (right panel) compared to the average for 2003 to 2012 (left panel).

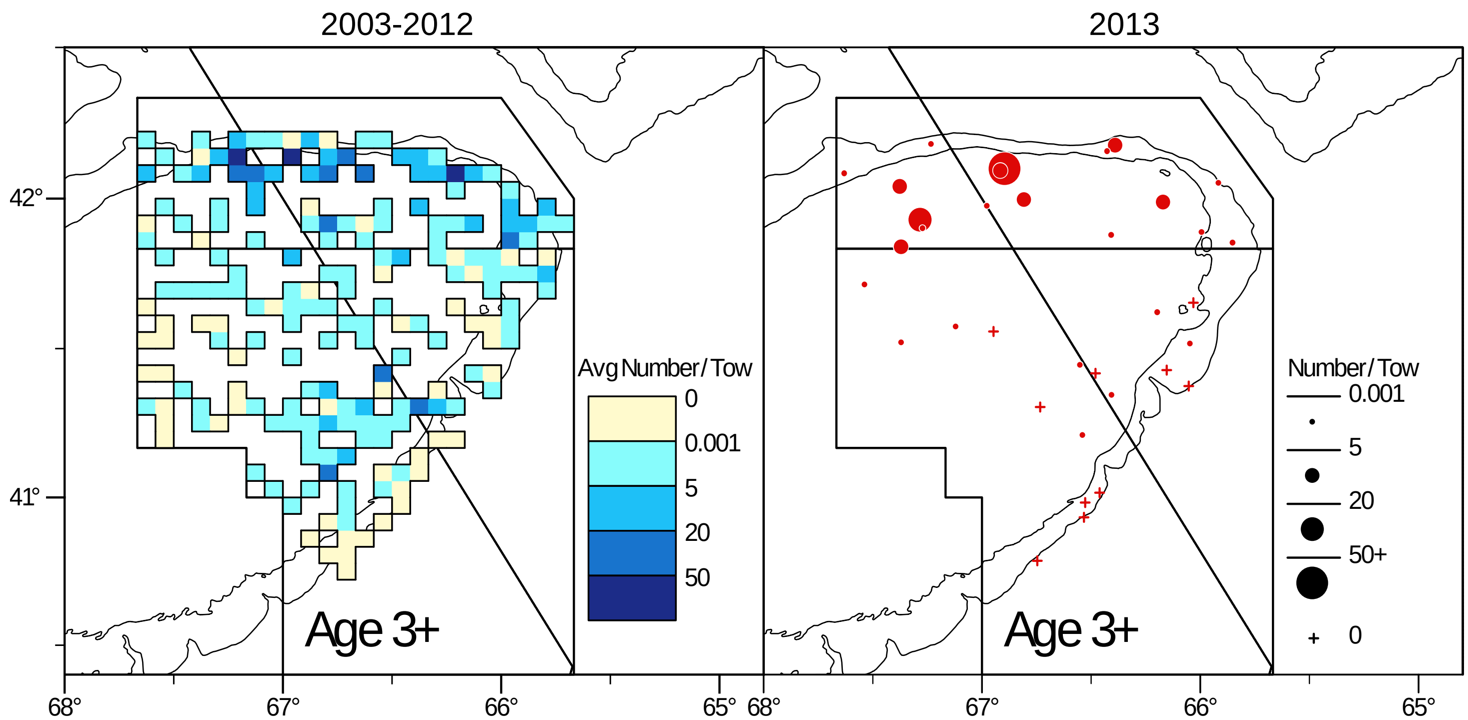


Figure 19. Spatial distribution of age 3+ cod on eastern Georges Bank from the NMFS spring survey for 2013 (right panel) compared to the average for 2003-2012 (left panel).

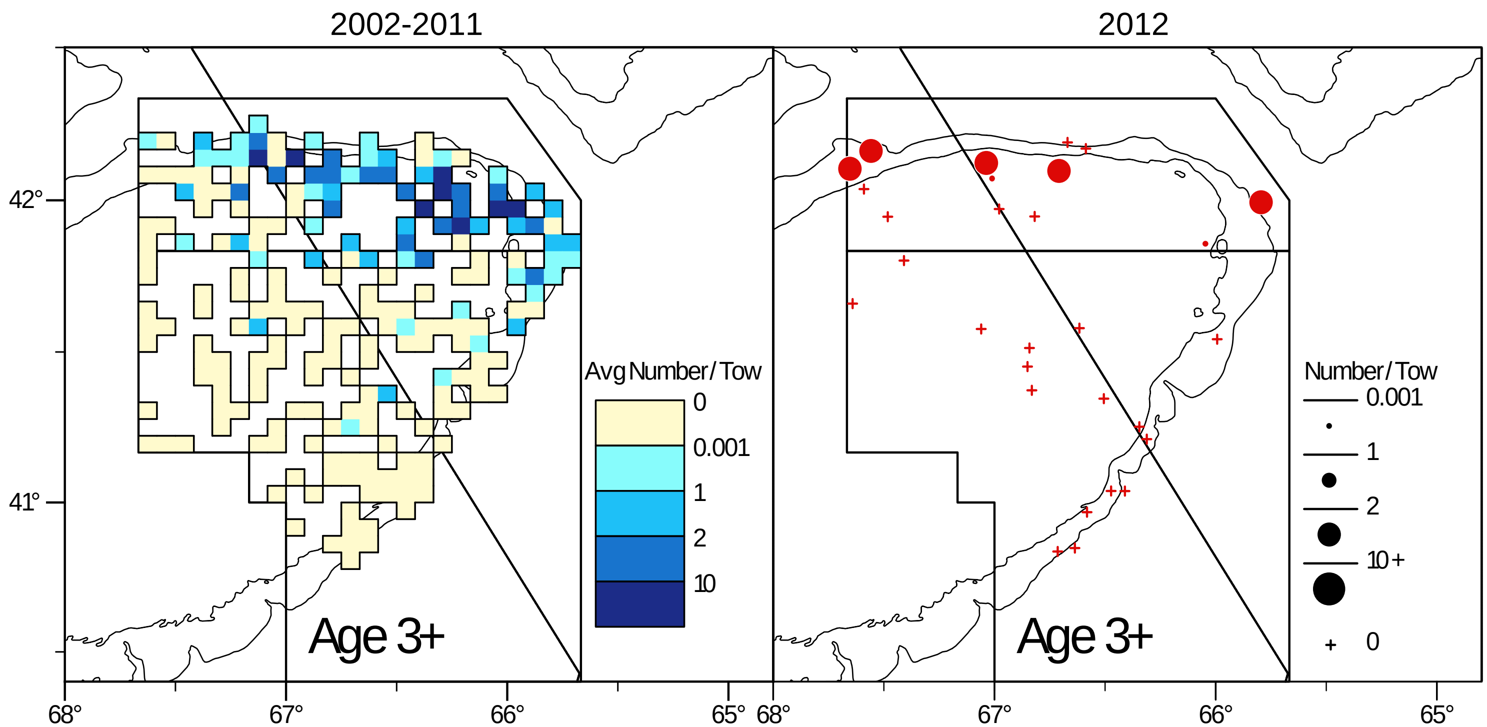


Figure 20. Spatial distribution of age 3+ cod on eastern Georges Bank from the NMFS fall survey for 2012 (right panel) compared to the average for 2002-2011 (left panel).

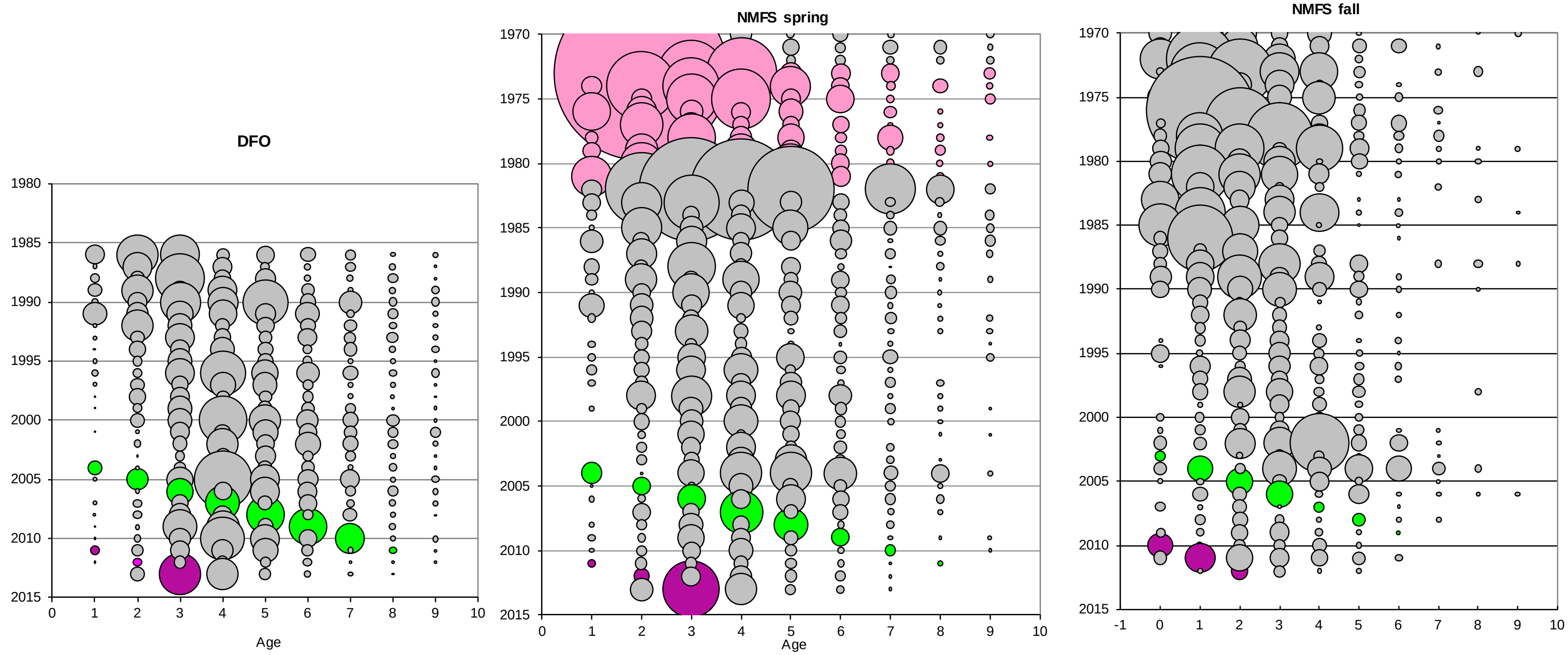
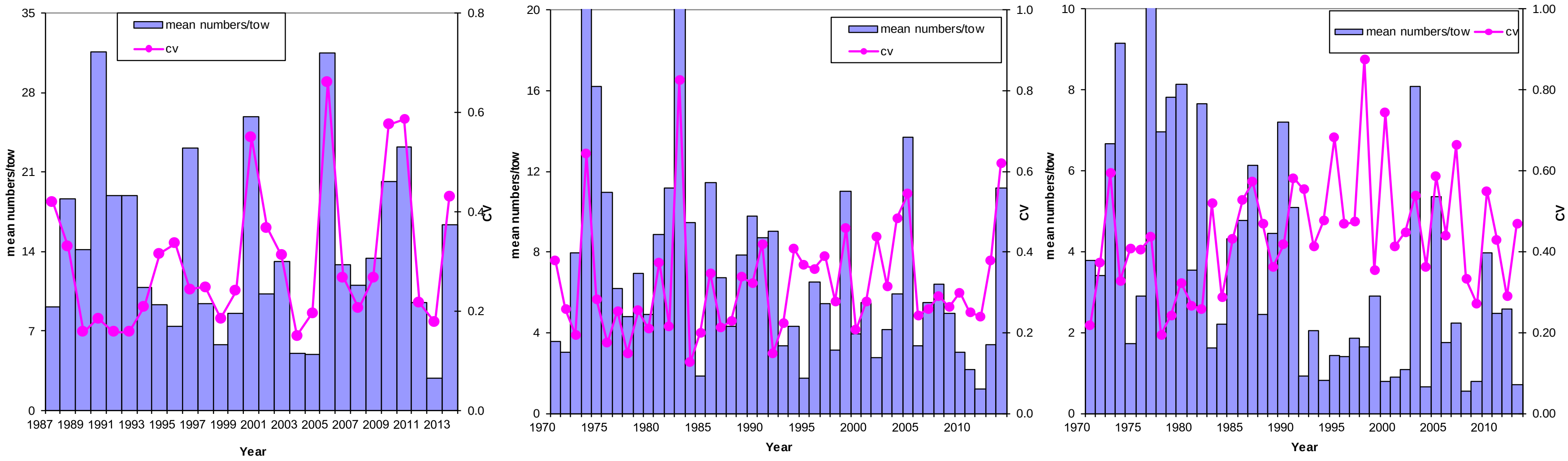


Figure 21. Survey abundance at age (numbers) of eastern Georges Bank cod. The bubble area is proportional to magnitude within each survey. Conversion factors to account for changes in door type, net and survey vessel were applied to the NMFS surveys. The NMFS spring survey was conducted using a modified Yankee 41 during 1978 to 1981 (lighter bubbles). The 2003 year class is identified with green bubbles and the fuschia bubbles show 2010 year class.



DFO NMFS spring NMFS fall

Figure 22. Stratified mean number/tow and coefficient of variation (CV) for DFO, NMFS spring and fall survey catch of EGB cod.

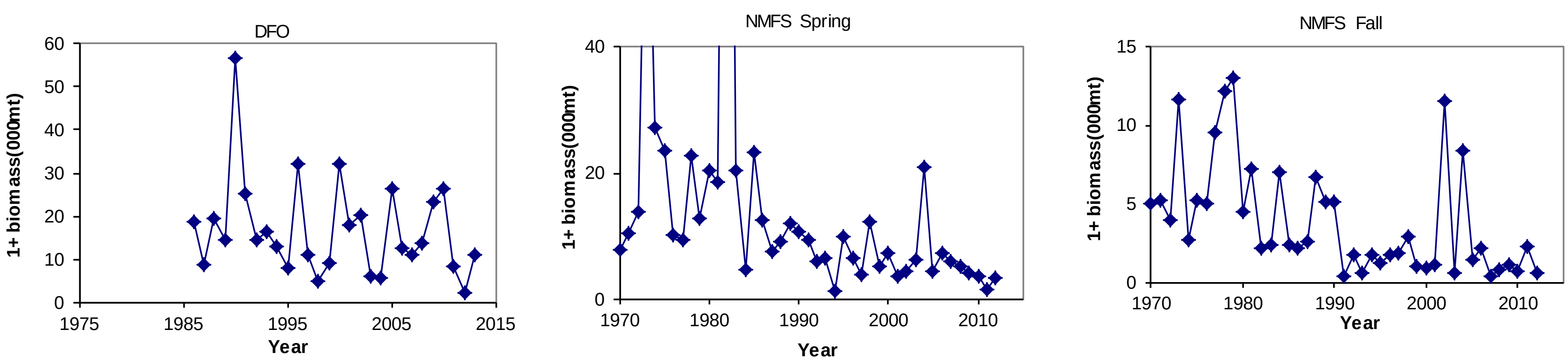


Figure 23. Survey biomass indices (ages 1+) for eastern Georges Bank cod from the DFO spring and NMFS spring and fall surveys, 1978-2013.

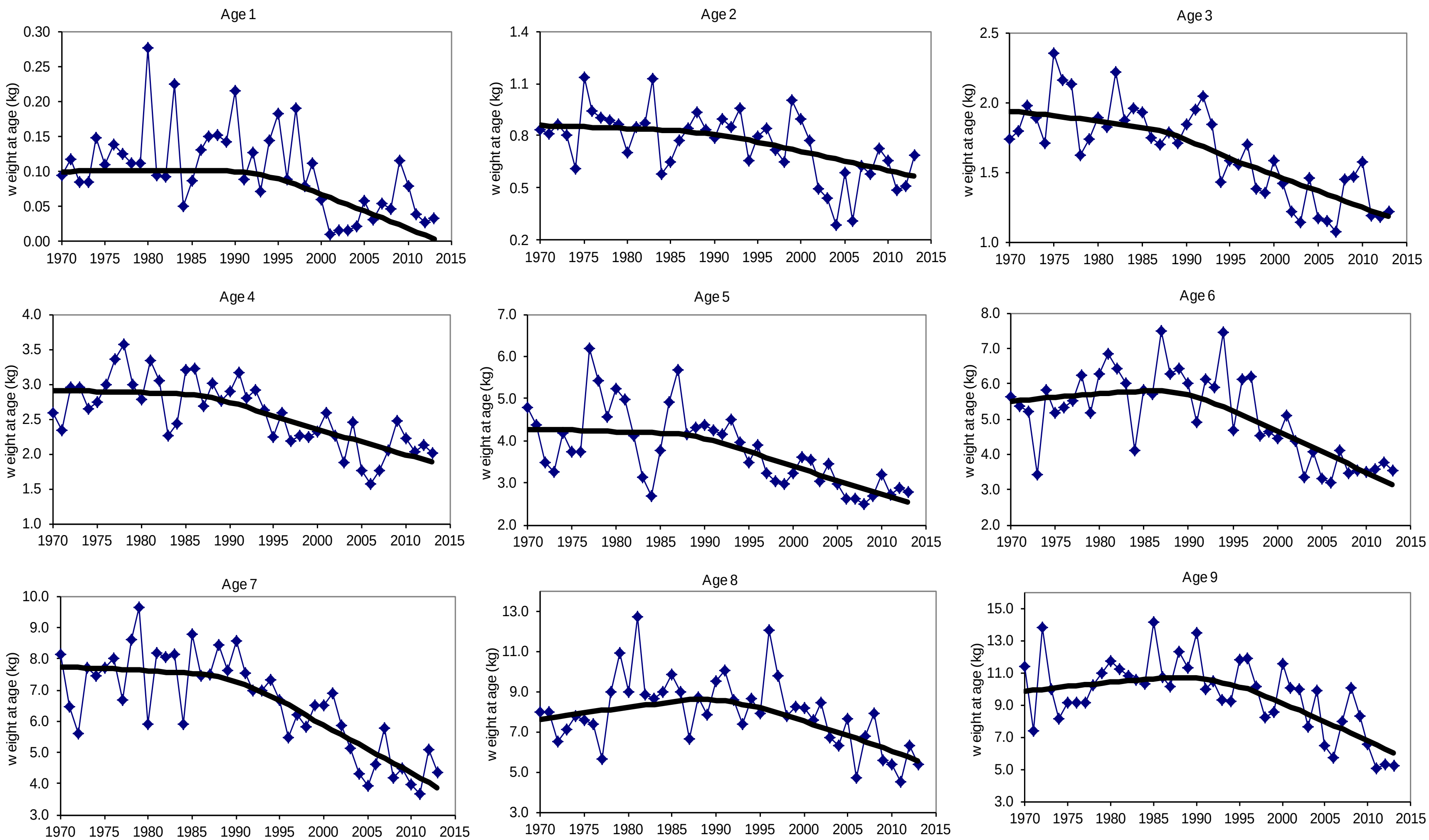
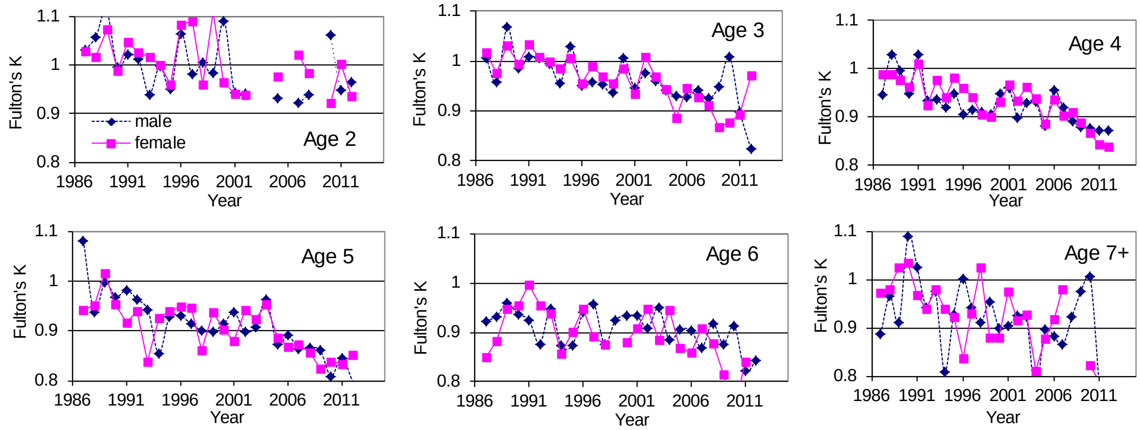
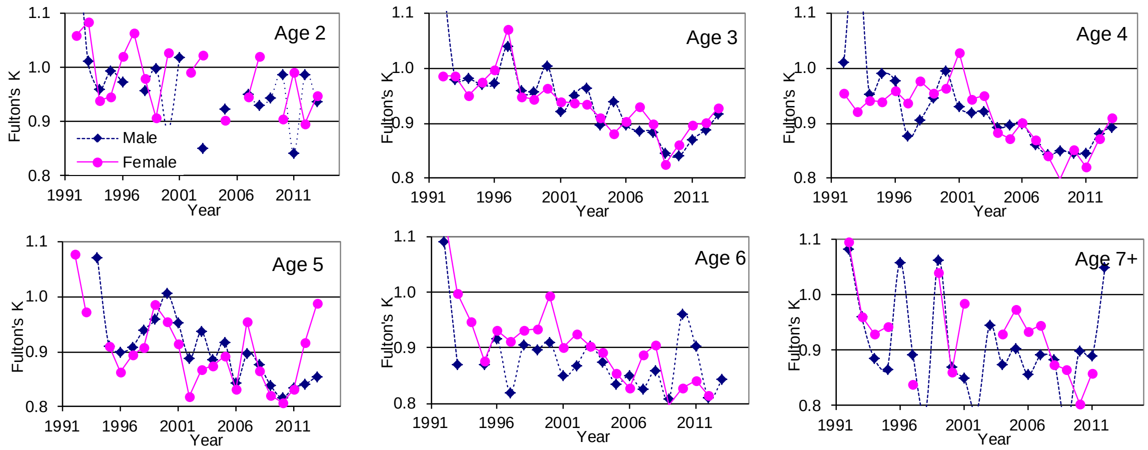


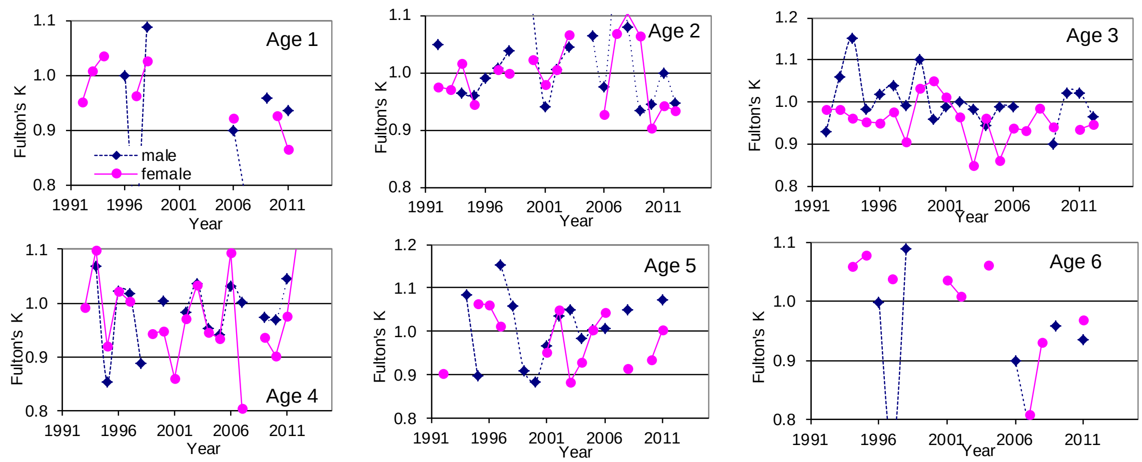
Figure 24. Beginning of year weight at age of eastern Georges Bank cod from DFO and NMFS spring surveys. The lines show the smoothed values using the LOESS method.



DFO survey



NMFS spring survey



NMFS fall survey

Figure 25. Fish condition (Fulton's K by age) for eastern Georges Bank cod.

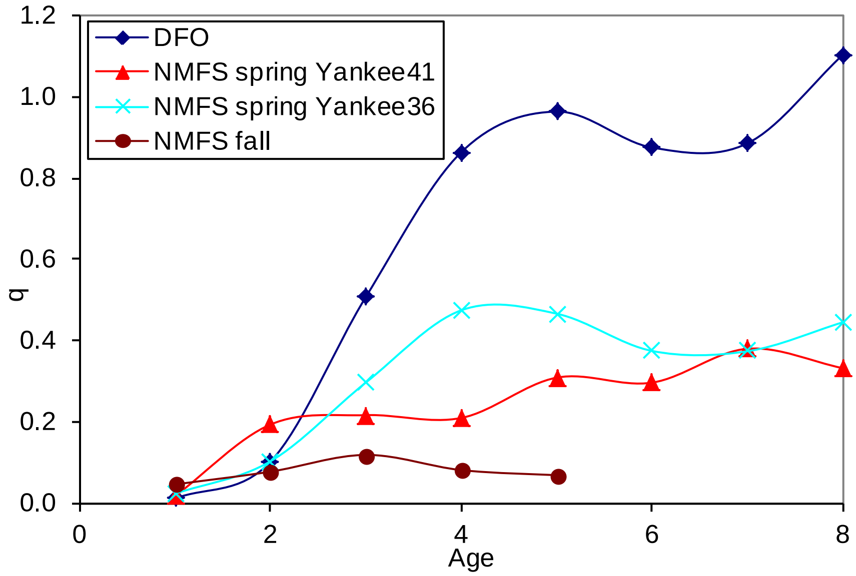


Figure 26. Survey catchability (q) for the DFO, NMFS spring and NMFS fall surveys for eastern Georges Bank cod.

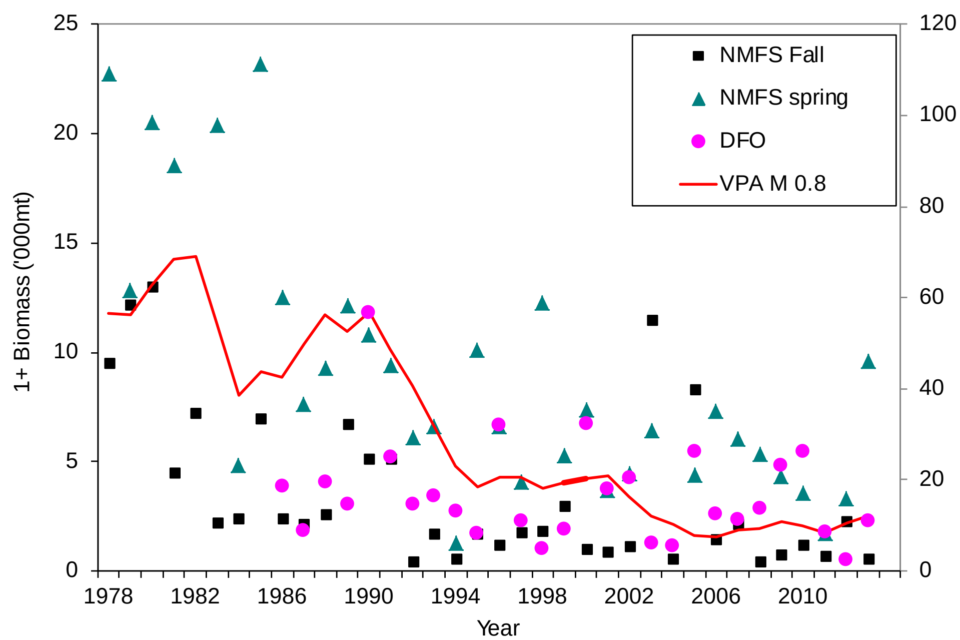


Figure 27. Age 1+ biomass from survey and VPA estimation.

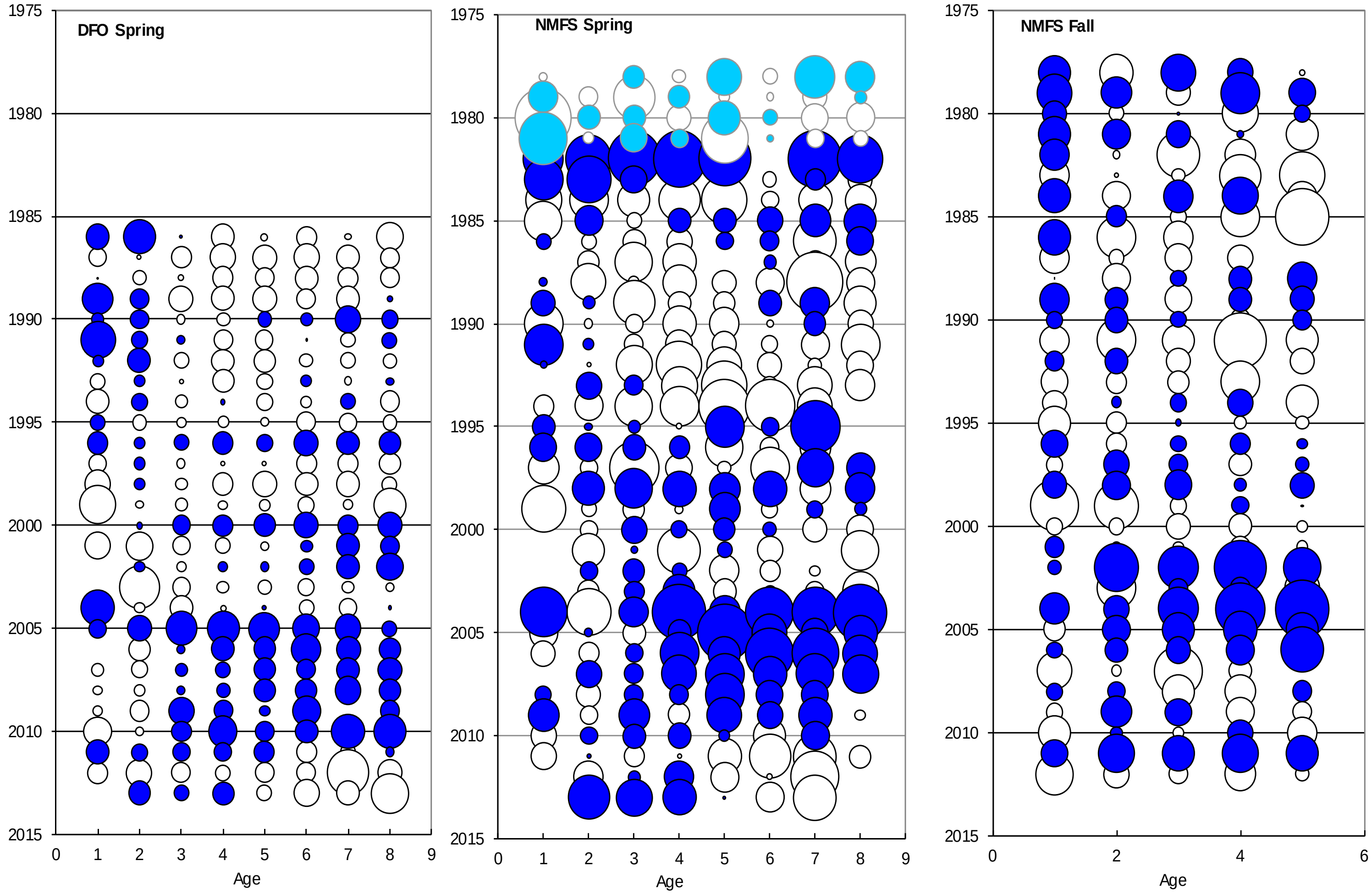


Figure 28. Residuals by year and age group from survey indices for eastern Georges Bank cod. Solid bubbles indicate positive values, open bubbles indicate negative values and the bubble area is proportional to magnitude. The NMFS spring survey was conducted using a modified Yankee 41 from 1978 to 1981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

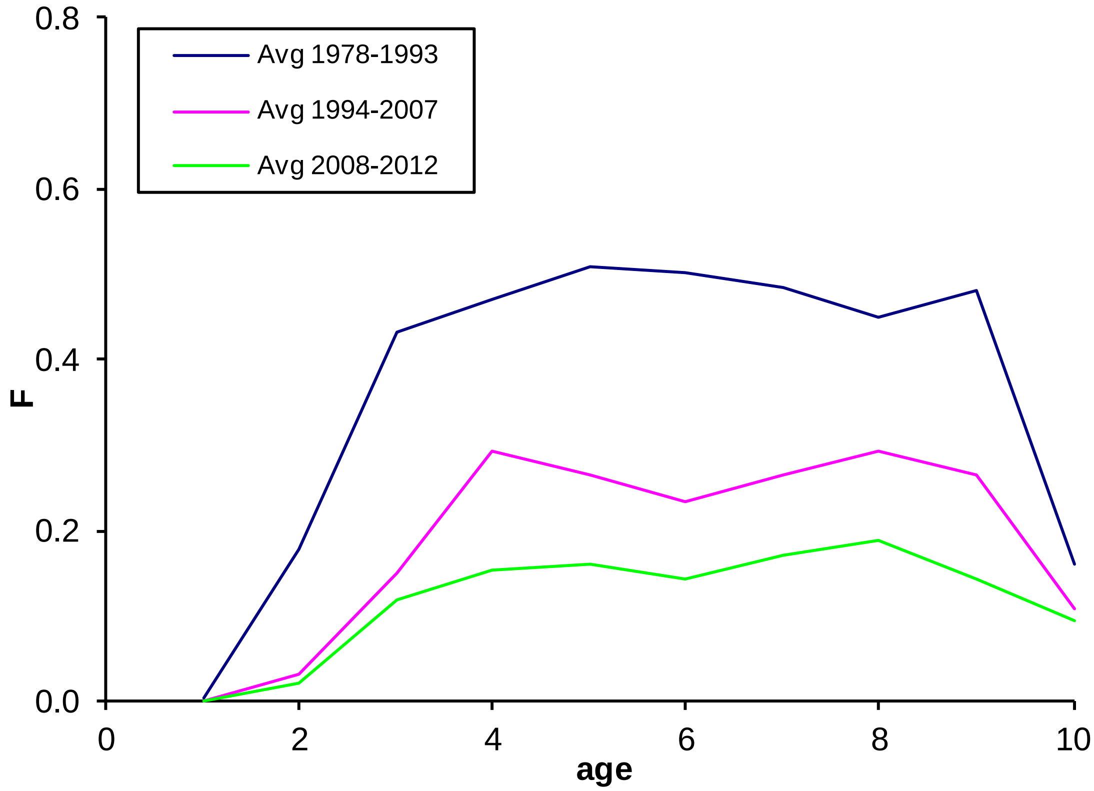


Figure 29. Average fishing mortality (F) for eastern Georges Bank cod in three time series blocks (1978-1993, 1994-2007, 2008-2012).

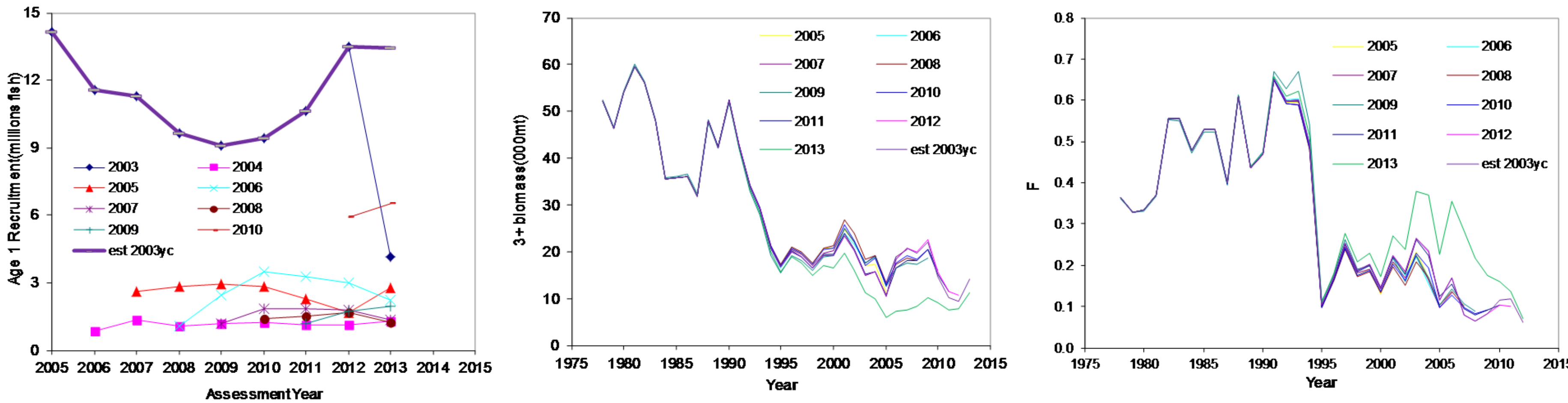


Figure 30. Retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the "M 0.8" model in 2013 assessment. 'estimate 2003yc' is the sensitivity run in 2013.

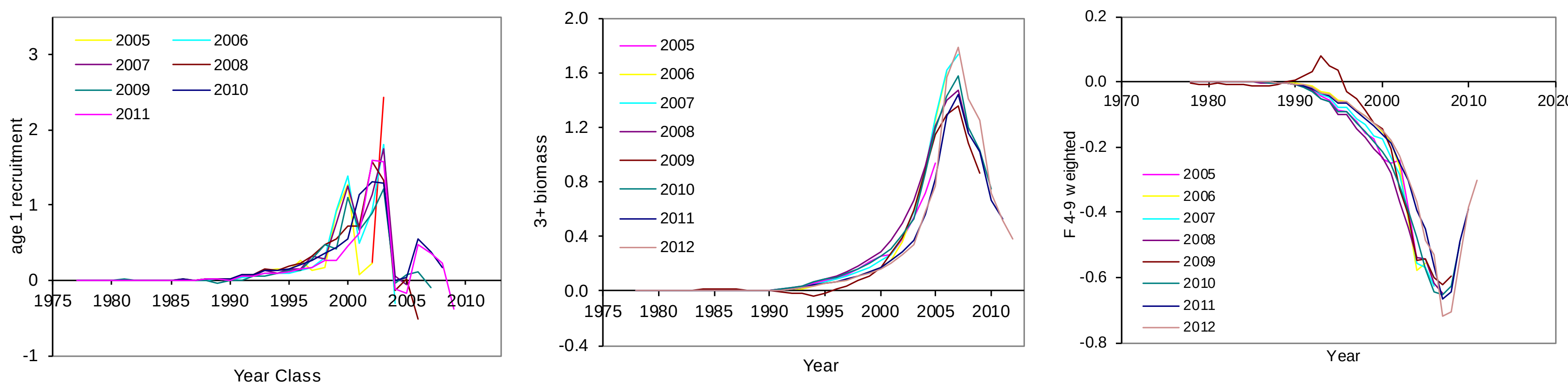


Figure 31. Relative retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the "M 0.8" model in 2013 assessment.

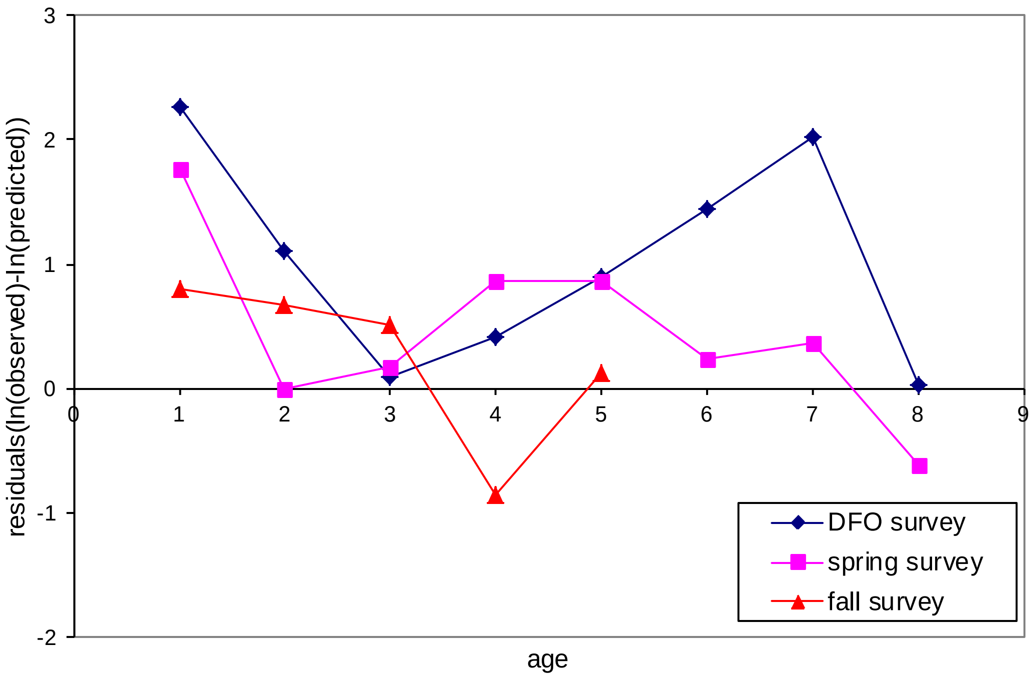


Figure 32. Residuals of the predicted survey values of the 2003 year class for the "M 0.8" model in 2013 assessment.

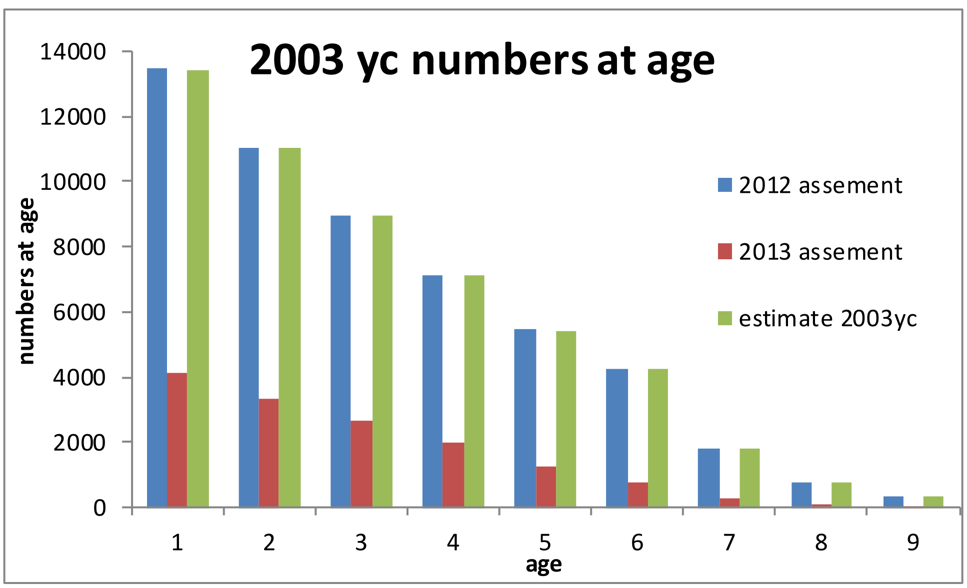


Figure 33. The estimated population abundance at age of the 2003 year class from different model formulations of eastern Georges Bank cod.

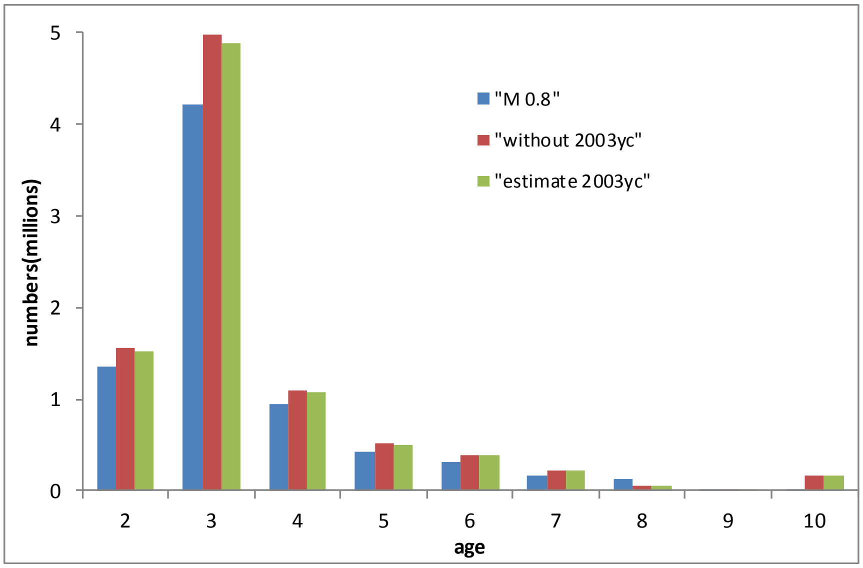


Figure 34. The estimated beginning of year 2013 population abundance at age from different model formulations of eastern Georges Bank cod.

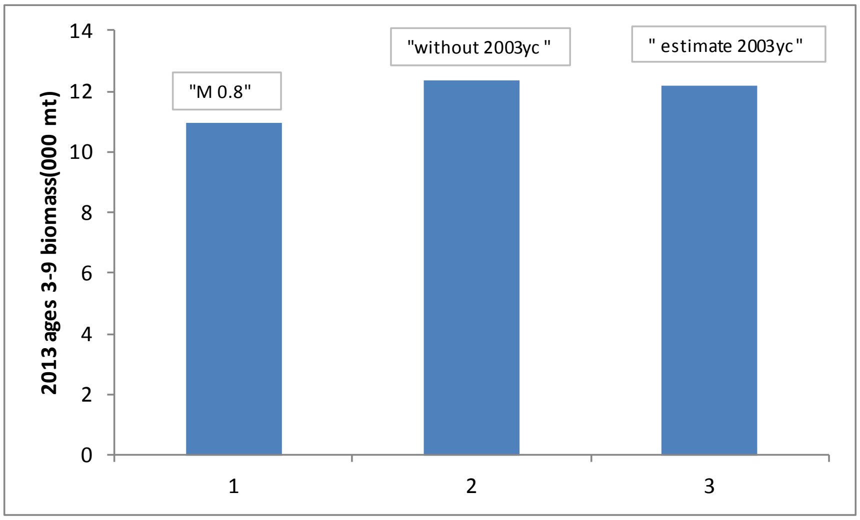


Figure 35. The estimated beginning of year 2013 ages 3-9 population biomassfrom different model formulations of eastern Georges Bank cod.

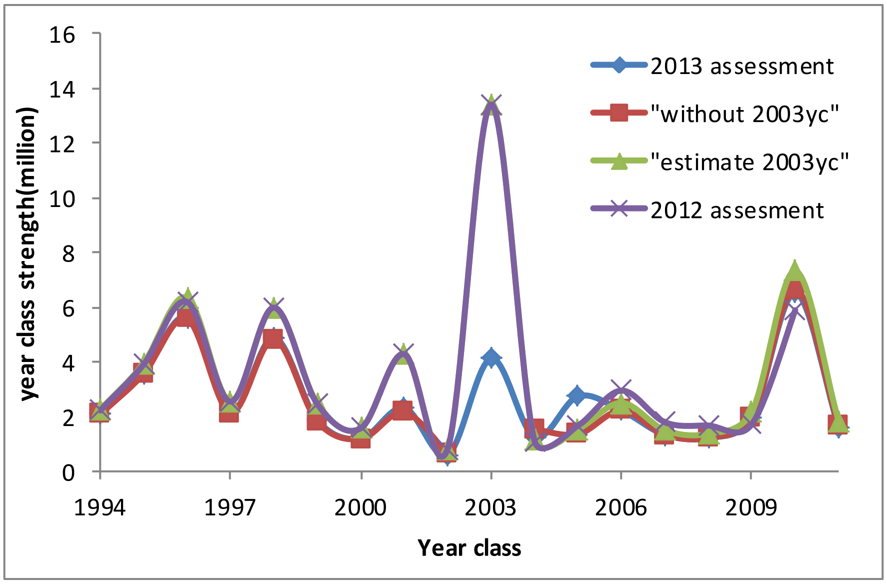


Figure 36. The estimated recruitment from different model formulations of eastern Georges Bank cod.

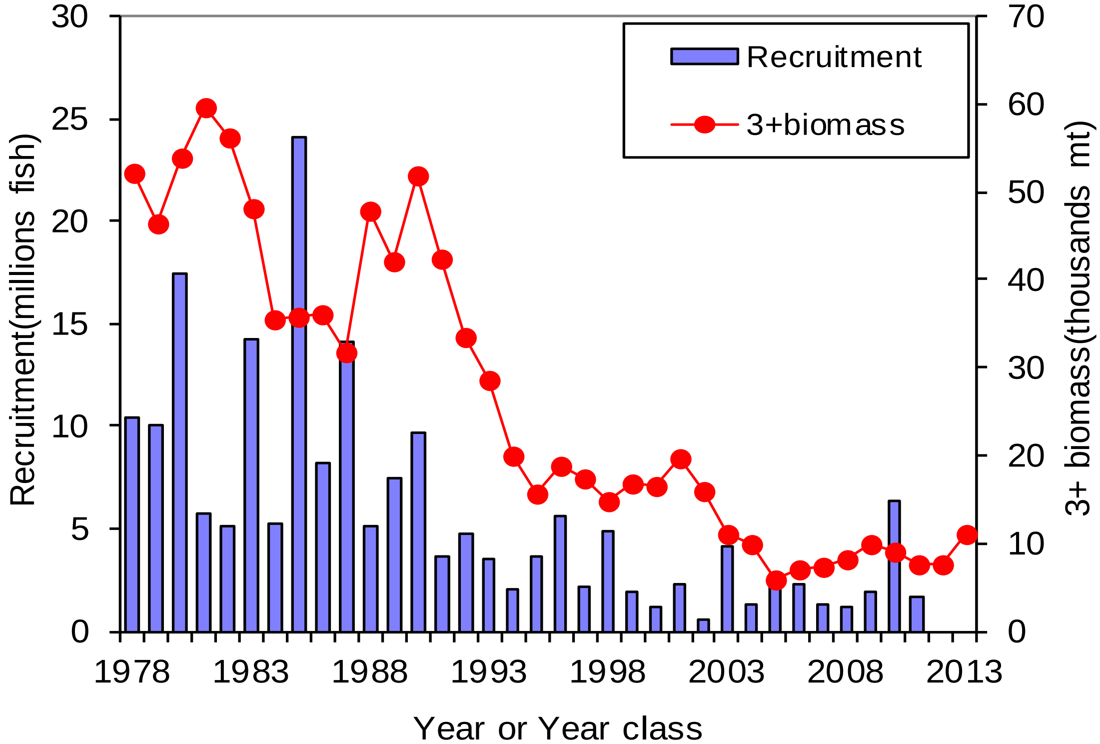


Figure 37. Adult biomass (ages 3+) and year class abundance at age 1 for eastern Georges Bank cod.

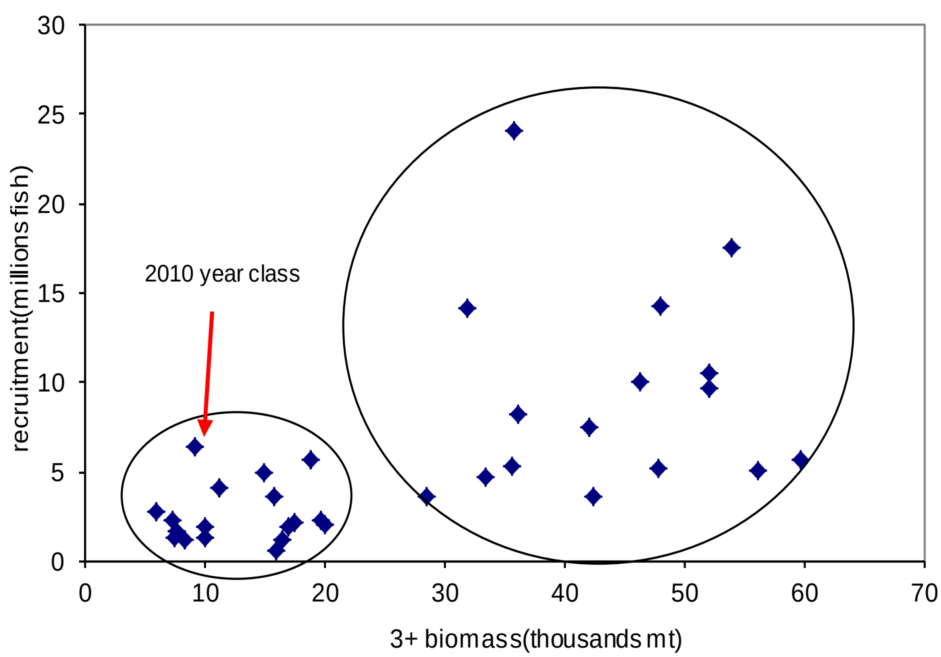


Figure 38. Relationship between adult biomass (ages 3+) and recruits at age 1 for eastern Georges Bank cod. The red arrow indicate the 2010 year class at age 1.

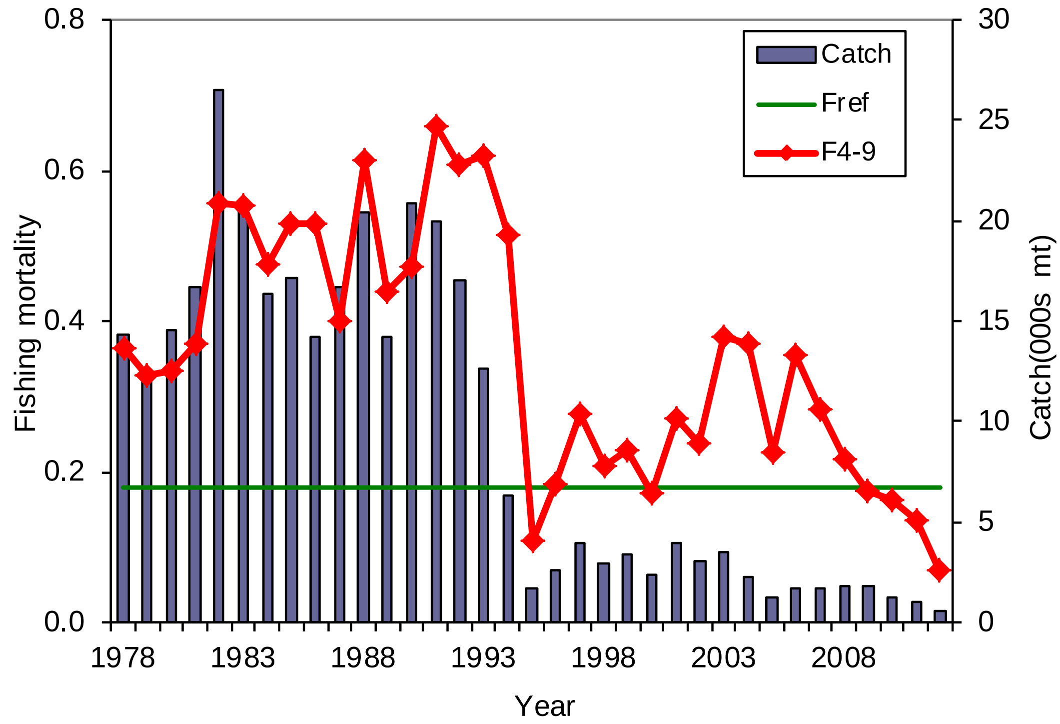


Figure 39. Average fishing mortality rate at ages 4 to 9 and catches for eastern Georges Bank cod. The established fishing mortality threshold reference, F_{ref}=0.18.

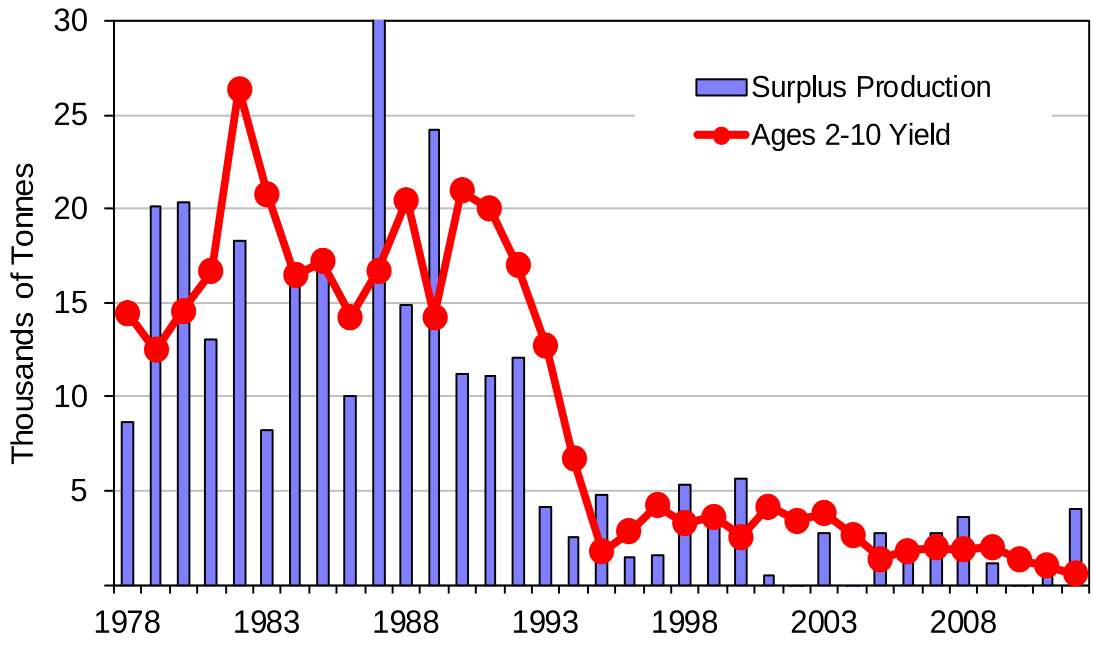


Figure 40. Surplus production of eastern Georges Bank cod compared to harvested yield.

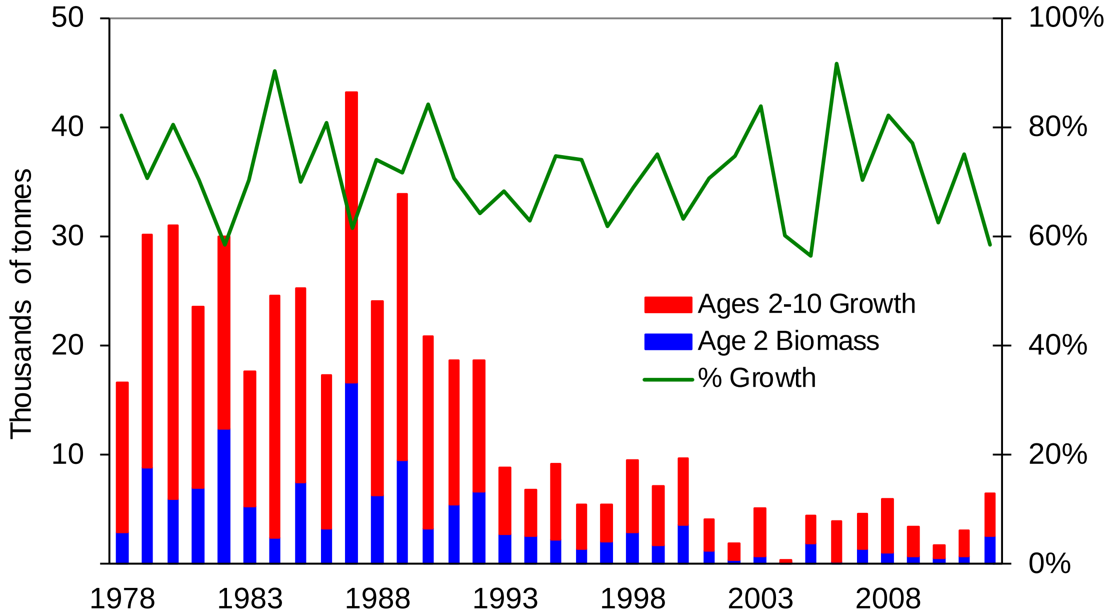


Figure 41. Components of annual production for eastern Georges Bank cod attributable to growth of ages 2 to 10 and to the amount contributed by incoming year classes at age 2.

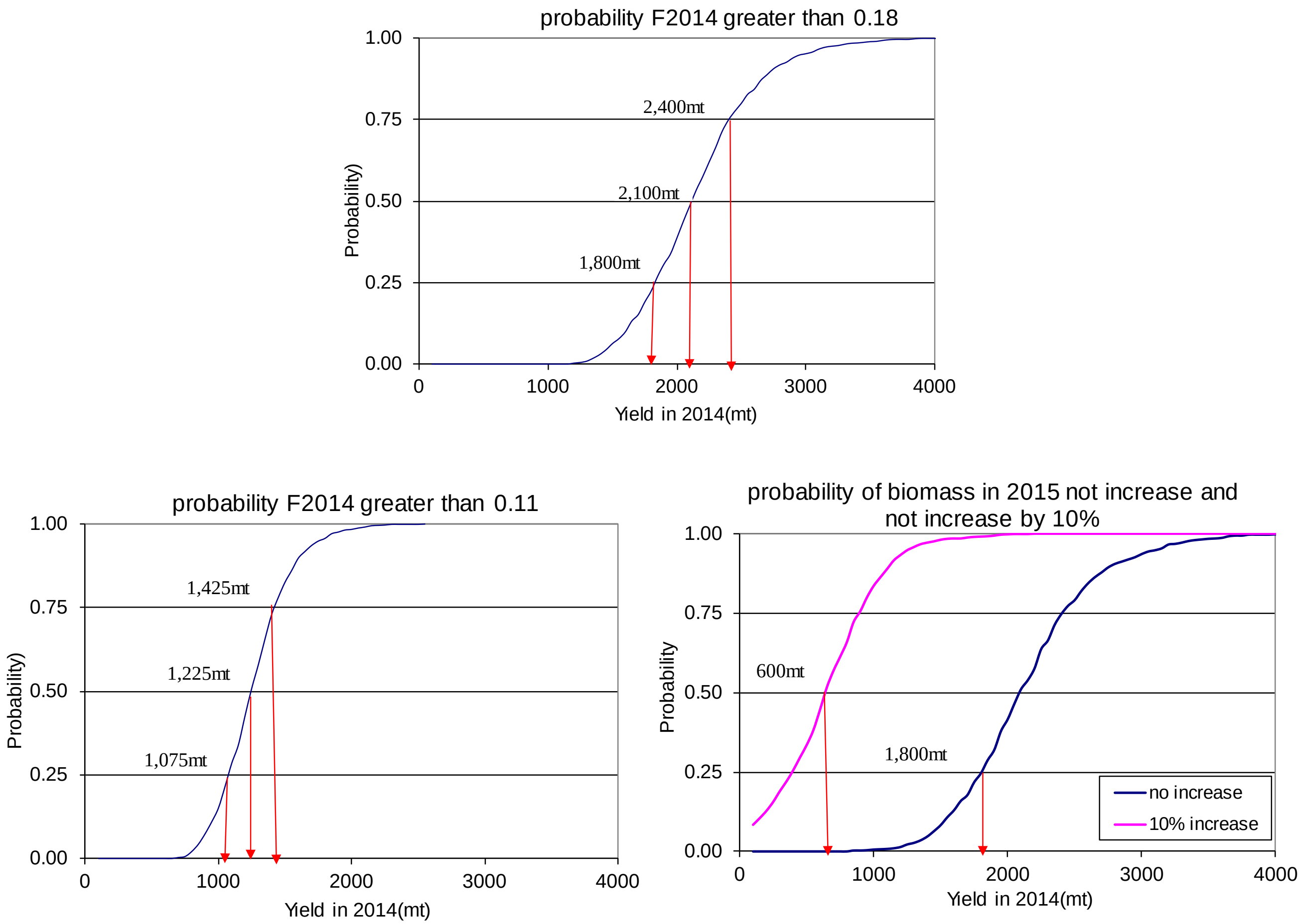


Figure 42. Risk of 2014 fishing mortality exceeding proposed F_{ref} = 0.11 and 2015 biomass not increasing, and 2015 biomass not increasing by 10% from 2014 for alternative total yields of eastern Georges Bank cod from the "M 0.8" model formulation.

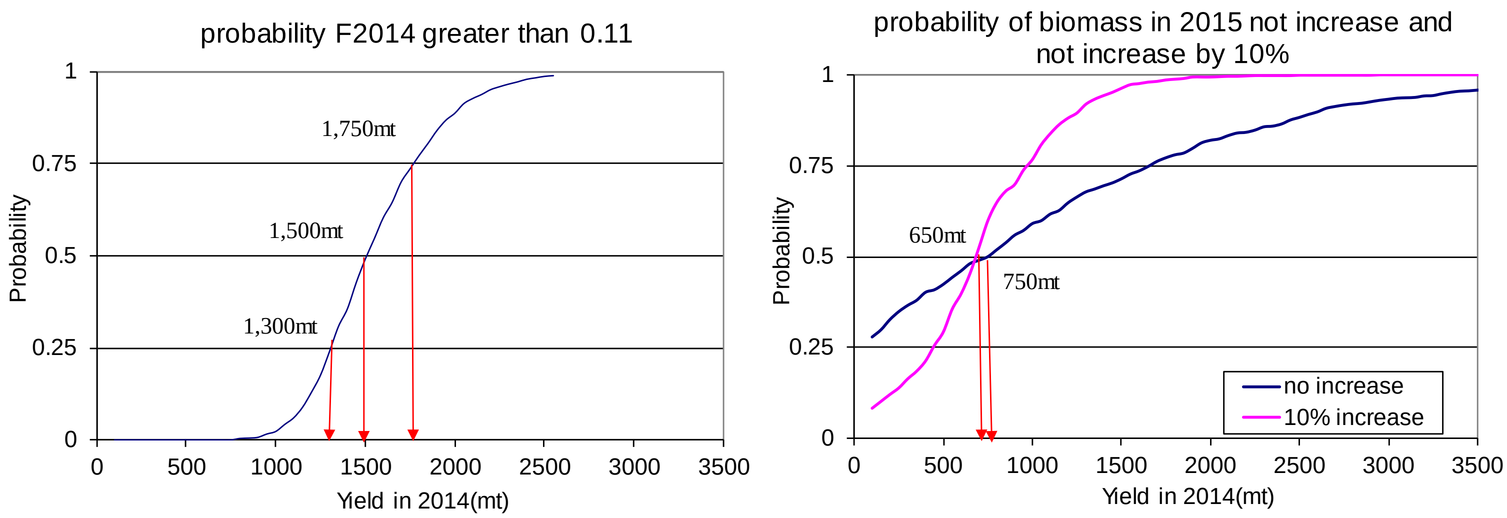


Figure 433. Risk of 2014 fishing mortality exceeding proposed F_{ref} = 0.11 and 2015 biomass not increasing, and 2015 biomass not increasing by 10% from 2014 for alternative total yields of eastern Georges Bank cod from the "estimate 2003yc" formulation.

APPENDIX A. 2013 STATISTICAL CATCH AT AGE (ASAP) MODEL UPDATE FOR EASTERN GEORGES BANK ATLANTIC

INTRODUCTION

This assessment presents an update of the statistical catch at age model 'Age Structured Assessment Program' (ASAP) reviewed at the 2012 April Eastern Georges Bank cod benchmark model meeting. The ASAP model was not chosen by then TRAC as a benchmark model for stock status or catch advice; however, the TRAC agreed to apply the ASAP model results in a consequence analysis of projection results.

The ASAP model was chosen to explore as an alternative model to the virtual population model (VPA) during the EGB cod benchmark in part because ASAP had recently been accepted as the new benchmark model for the US GB cod assessment, replacing the VPA that had historically been applied since 1978 (NEFSC, 2013). Prior to 2004, both the EGB and GB cod assessments had been conducted with VPA and had similar formulations. After the 2002 EGB cod benchmark review (O'Boyle and Overholtz, 2002) the assessments started to diverge. While it is not mandatory that the two assessments be similarly formulated, given that EGB cod data is in both assessments, it would be appropriate to have the populations on the same scale. Also, given that part or all of the Georges Bank cod stock is managed by both the TMGC and the NEFMC, respectively, similarly scaled populations would allow for compatibility in management decisions.

ASAP was used to derive estimates of instantaneous fishing mortality in 2012 and stock size in 2012. A retrospective analysis was performed for terminal year fishing mortality, spawning stock biomass, and age 1 recruitment. Stochastic projections from model result were performed to provide estimated landings and spawning stock biomass (SSB) in 2014-2015.

ASSESSMENT MODEL FORMULATION

Model Description

ASAP, a forward projecting statistical catch at age model (Legault and Restrepo, 1998) can be downloaded from the NOAA Fisheries Toolbox (NFT, http://nft.nefsc.noaa.gov/). As described at the NFT software website, ASAP is an age-structured model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch-at-age, and indices of abundance. Discards can be treated explicitly. The separability assumption is partially relaxed by allowing for fleet-specific computations and by allowing the selectivity at age to change in blocks of years. Weights are input for different components of the objective function which allows for configurations ranging from relatively simple age-structured production models to fully parameterized statistical catch at age models.

The objective function is the sum of the negative log-likelihood of the fit to various model components. Catch at age composition is modeled assuming a multinomial distribution. Surveys can be treated as either "west coast style" in the same manner as the catch data with a total survey time series and survey catch at age composition modeled assuming a multinomial distribution, or "east coast style" with the survey indices at age entered as separate series. Most other model components are assumed to have lognormal error. Specifically, lognormal error is assumed for: total catch in weight by fleet, survey indices, stock recruit relationship, and annual deviations in fishing mortality. Recruitment deviations are also assumed to follow a lognormal distribution, with annual deviations estimated as a bounded vector to force them to sum to zero (this centers the predictions on the expected stock recruit relationship). For further details, the reader is referred to the technical manual (Legault, 2008).

Data Input

Input to the ASAP model is the same as the VPA and includes the total catch (mt) for the combined landings and discards of USA and Canadian fleets (Table 1[1], Figure 2[1]), and the catch-at-age (Table 6[1] Figure 14[1]) and weight-at-age (Table 7[1], Figure 15[1]) for ages 1-10+ during 1978-2012. Beginning year weight-at-age is back-calculated from the mid-year catch weight-at-age (Table A1) and also estimated from an average of the DFO and NEFSC spring research survey weight-at-age (Table 16[1]). Swept-area population estimates derived from indices of abundance include the Canadian DFO 1986-2012 estimates for ages 1- 10+ (Table 10[1], Figure 21[1]), the NEFSC 1978-2012 standardized spring estimates for ages 1- 10+ (Table 11[1], Figure 21[1]), and the NEFSC 1978-2012 standardized autumn estimates for ages 1-6 (Table 12[1], Figure 21[1]). The NEFSC spring survey was dis-aggregated into two series based on the use of the Yankee #41 otter trawl from 1978-1981 and the Yankee #36 otter trawl after that time. Maturity was age and time invariant and knife edge maturity was assumed at age 3 as in previous EGB cod assessments. Natural mortality was age and time invariant and was assumed to be 0.2 as in previous assessments (Wang and O'Brien 2012).

Model Formulation

The ASAP model was updated using the model run3f.1 formulation presented and reviewed at the April 2013 benchmark. A multinomial distribution was assumed for both fishery catch at age and survey age compositions. The survey time series were not split between 1994/1995 as had been done in previous EGB cod VPA formulations (Wang and O'Brien, 2012). 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 1994-2012.

The effective samples size (ESS) of the catch and surveys were adjusted based on interpretation of the so-called '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.

The catch ESS was set at 75 for 1978-1995 and 125 for 1996-2012, and the ESS for each survey was set at 50.

At the 2012 benchmark the CV for each survey was initially set at the value generated from the survey estimate of stratified mean number per tow (DFO STRANAL). For the DFO survey the CVs averaged 0.31, with a range of 0.15-0.66, for the NEFSC spring the CVs averaged 0.32, with a range of 0.13-0.83, and for the NEFSC autumn survey the CVs averaged 0.47, with a range of 0.24-0.88. 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 (NEFSC spring #36), and 0.2 (NEFSC autumn), except the NEFSC spring #4, which was not adjusted. These same values were added during this 2013 update.

Model Results

Model results, including the objective function (OF), number of parameters, components to the OF, the root mean square error (RMSE), computed from standardized residuals, and SSB and fishing mortality (F) estimates are summarized in Table A2 for all model runs conducted.

[1] The tables and figures referenced in this paragraph refer to the tables and figures in the main document.

A bridge ASAP run was conducted to include corrected coefficient of variation (CV) estimates for the NMFS 2009-2011 survey abundance estimates. Comparing the differences between the benchmark ASAP model formulation and the corrected CV model, both with terminal year =2011, shows little differences in the OF or the RMSE. The updated CV run resulted in slightly higher F and SSB in 2011.

BASE 2013 ASAP

The bridge run was updated with 2012 catch and survey and results described below.

Catch

The model fit to the observed catch is almost exact with the CV of 0.05 assigned to the commercial catch (Figure A1). The catch age composition exhibits larger residuals in the early time period, with a pattern of negative residuals for age 3 (Figure A2). The magnitude of the input ESS appears appropriate given that the predicted ESS generally bisects the observed ESS (Figure A3).

Indices

The fit of the predicted indices through the observed DFO survey indices was better during the period 1995-2000 than before or after that period; in recent years the model fit does not bisect the survey confidence bounds for all years (Figure A4). A pattern of negative residuals in the older age groups during 1986-1995 and in the younger ages during 2000-2011 is apparent in the age composition (Figure A5). The final DFO survey ESS was set at 50 and appears appropriate given that the predicted ESS generally bisects the observed ESS (Figure A6).

The fit of the predicted indices through the NEFSC autumn survey indices did not show any strong patterning, although in recent years the model fit does not bisect the survey confidence bounds for all years (Figure A7). The maximum residual of the age composition is the largest of the 4 surveys at 0.36 (Figure A8). The age 1 residuals are large and have a positive values in the early years and a negative pattern in the later years , however the older ages do not exhibit this pattern (Figure A8). The final input ESS was set = 50 and appears appropriate given that the predicted ESS generally bisects the observed ESS (Figure A9).

The model fit diagnostics for the NEFSC spring (Yankee #41) are presented in Figures A10-A12. With only 4 years of survey indices, no patterns are easily described or evaluated.

The fit of the predicted indices through the NEFSC spring (Yankee #36) survey indices indicated, similar to the DFO survey, a series of negative residuals in the late 1980s to 1994 and a series of positive residuals since the mid-2000s (Figure A13). The residuals of the age composition show a pattern of positive residuals in age 2 and negative in age 4 in the early years and the opposite in the later years (Figure A14). The input ESS was set = 50 and appears appropriate given that the predicted ESS generally bisects the observed ESS (Figure A15).

Fishing Mortality, SSB, and Recruitment

Fully recruited F (unweighted, ages 5+) was estimated at 0.44 in 2012 (Table A3, Figure A16), a 44% decrease from 2011. SSB in 2012 was estimated at 1,922 mt, a 4% increase from 2011 (Table A3, Figure A16). Recruitment (millions of age 1 fish) of the 2003 year class (2.5 million) is now estimated to be smaller than the 1998 year class (3.4 million), the 2010 year class is estimated at 2.1 million,and the 2011 year class is the 3rd smallest year class estimated at 0.5 million (Table A3, Figures A16-A17).

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 (2005-2011) prior to the terminal year,

2012. The pattern of overestimating SSB and underestimating F relative to the terminal year, as observed in the VPA (Wang and O'Brien, 2012), is not very strong in this model for F and SSB, but there is a pattern of underestimating recruitment relative to the terminal year estimate (Figure A18). The retrospective rho values, the average of the last 7 years of the relative retrospective peels, were 0.23 for SSB, -0.17 for F5+, and -0.35 for recruitment. Applying a retrospective adjustment ((1/(1+rho)) * estimate) results in 2012 estimates of F=0.53, SSB=1,567 mt, age 1 recruitment =0.69 million fish.

Model Uncertainty - MCMC

A Monte Carlo Markov chain (MCMC) simulation was performed to estimate uncertainty in the model estimates. The MCMC provides posterior probability distributions of the SSB and average F5+ time series. 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 good mixing for both SSB and F (Figure A19). The lagged autocorrelations showed decreased correlation with increased lag with correlations ≤ 0.1 beyond lag 0 for SSB and F (Figure A20). From the MCMC distributions, a 90% probability interval (PI) was calculated to provide a measure of uncertainty for the model point estimates for SSB and average F5+. Time series plots of the 90% PIs as well as plots of the posterior probability distributions for SSB2012 and average F5+ are shown in Figures A21-A22.

The 2012 SSB MCMC estimate of 1,910 mt has a 90% PI of 1,317 mt – 2,832 mt and the 2012 MCMC average F5+ = 0.45 has a 90% PI of 0.28- 0.71.

SENSITIVITY RUN

The base ASAP model was run using Jan.1 back-calculated mean weight at age based on the Rivard method (Rivard, 1982). A sensitivity run was done using January1st weight at age based on an average of the DFO and NMFS spring survey data. The results (Table A2) indicate minimal differences when applying these two weight-at-age matrices.

BIOLOGICAL REFERENCE POINTS

Yield per Recruit Analysis

For the 2013 cod model benchmark, a yield per recruit (YPR) analysis was conducted using the methods of Thompson and Bell (1934). Input data for catch and stock weights (ages 1-10+) were derived from an average of the most recent five years (2007-2011). The partial recruitment (PR) was based on a normalized arithmetic mean of 2007-2011 total fishing mortality from the ASAP model run3f.1. The maturity ogive was knife-edge at age 3. Results of YPR analysis are presented below. The current negotiated EGB cod F reference point is F_{ref} =0.18 (TMGC meeting December 2002). (The current GB cod F_{MSY} proxy= $F_{40\%}$ = 0.18).

	F
F0.1	0.19
fmax	0.43
F30%	0.29
F40%	0.19
Fcurrent	0.45

EGB cod is not managed by biomass reference points, however, for background purposes, non-parametric estimates of MSY and SSB_{MSY} based on $F_{40\%}$ were estimated 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 , SSB_{msy} = 39,353 mt.

The yield per recruit analysis was not updated with the 2013 June ASAP results.

MSY Biological Reference Points

Long-term Stochastic Projection

For the 2013 cod model benchmark, 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 2013), 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 A17), when SSB is <15,000 mt recruitment is drawn from the low recruitment CDF, and when SSB >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 mt - 14,180 mt),
SSB_{MSY} = 30,622 mt (80% CI: 25,450 mt - 84,346 mt).

PROJECTIONS

Short term stochastic projections under $F_{40\%}$ were performed from the updated 2013 ASAP model results to estimate landings and SSB during 2014. The input values for mean catch and stock weights, partial recruitment (PR), and maturity were estimated as 3-year averages from 2010-2012. Recruitment was estimated using the 2-stage CDF described above and associated with a SSB breakpoint of 15,000 mt. Catch in 2013 was estimated based on assumption that the 2012 quota would be caught.

The results of the short term projections indicate under the F_{ref} = 0.18 catch is projected to increase each year through 2015, and SSB is also projected to increase in each year through 2015.

Year	SSB	F	Catch
2013	3476	0.27	600
2014	3937	0.18	601
2015	4520	0.18	710

SUMMARY DISCUSSION

Productivity of EGB 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. Lack of large numbers of older repeat spawners in the EGB 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 3 or more times would contribute to higher productivity (Trippel 1998). 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 update model formulation exhibits minimal retrospective bias in F and SSB that had been prevalent in previous assessments, however, additional variability was added to the survey abundance estimates, thus placing more emphasis on the catch data.

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Table A1. Mid-year catch weight at age (kg) of Eastern Georges Bank cod for ages 1-10+, 1978-2012.

	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	0.437	0.825	1.787	2.705	4.393	5.725	7.731	9.308	10.266	13.719
1989	0.190	0.886	1.515	2.705	3.877	5.437	6.434	9.003	10.286	13.839
1990	0.446	0.771	1.732	2.512	3.921	5.435	6.849	8.163	10.475	13.416
1991	0.524	1.008	1.935	2.731	3.694	5.041	6.711	8.587	9.494	13.813
1992	0.715	1.011	1.858	2.826	3.649	4.898	6.130	8.033	10.299	15.042
1993	0.449	1.118	1.720	2.544	3.766	4.787	6.186	7.504	8.896	12.002
1994	0.394	0.926	1.731	2.689	3.532	5.249	6.232	7.420	8.124	12.629
1995	0.153	0.881	1.680	2.679	4.119	5.294	8.051	8.482	9.223	17.374
1996	0.302	0.676	1.690	2.543	3.970	5.365	6.399	9.511	10.178	10.964
1997	0.485	0.846	1.712	2.518	3.430	5.022	6.505	7.303	10.140	11.130
1998	0.506	0.953	1.744	2.480	3.408	4.536	5.944	7.535	9.220	13.567
1999	0.373	0.942	1.623	2.578	3.413	4.666	5.780	7.050	8.566	13.926
2000	0.470	0.866	1.587	2.390	3.527	4.288	5.599	6.517	7.936	13.056
2001	0.087	0.728	1.551	2.318	3.218	4.423	4.954	6.449	7.654	10.674
2002	0.187	0.499	1.332	2.277	3.317	4.180	5.588	6.554	7.616	11.169
2003	0.138	0.629	1.581	2.295	3.167	4.114	5.168	6.622	7.924	8.729
2004	0.118	0.590	1.451	2.405	3.052	4.010	4.698	6.294	7.643	9.942
2005	0.104	0.437	1.332	2.048	3.113	3.911	4.691	5.971	7.637	9.364
2006	0.026	0.331	1.213	1.830	2.746	3.875	5.195	5.287	6.850	7.384
2007	0.146	0.287	0.963	2.002	2.629	3.569	5.097	6.459	6.320	9.431
2008	0.047	0.605	1.453	2.087	2.888	3.870	4.759	6.922	7.382	9.086
2009	0.067	0.362	1.517	2.577	3.198	4.045	5.351	6.240	8.897	10.910
2010	0.269	0.445	1.409	2.167	3.197	3.556	4.789	5.897	7.671	11.265
2011	0.132	0.653	1.406	2.244	2.971	3.805	3.809	5.561	7.737	9.627
2012	0.176	0.470	1.272	2.125	3.068	3.797	4.458	4.909	5.685	5.230

Table A2. ASAP model diagnostics and results for four model formulations: number of parameters, 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).

		TY=2011	TY=2011	TY=2012	TY=2012
Model		benchmark	bridge_cv	base_rivard	base_sv_wts
number of parameters		94			
objective function		2967.13	2968.37	3017.29	3017.29
components of					
obj. function	**catch total**	225.948	225.94	230.458	230.458
			0		0.00
	index fit total	842.41	841.993	873.41	873.41
	catch age composition	551.534	551.823	567.608	567.61
			0		0.00
	Index age composition	1347.24	1348.62	1345.81	1345.81
	Recruit deviations	0		0	
RMSE	**Catch fleet**	0.28	0.28	0.29	0.29
	total catch	0.28	0.28	0.29	0.29
	discards	0.00	0.00	0.00	0.00
	total discards	0.00	0.00	0.00	0.00
	DFO	1.34	1.32	1.41	1.41
	Autumn	1.27	1.29	1.35	1.35
	Spring 41	0.76	0.76	0.76	0.76
	Spring 36	1.32	1.31	1.35	1.35
	Index total	1.29	1.29	1.35	1.35
CV	**catch**	0.05	0.05	0.05	0.05
	dfo	0.25+	0.25+	0.25+	0.25+
	fall	0.2+	0.2+	0.2+	0.2+
	spring #41	1x	1x	1x	1x
	spring #36	0.3+	0.3+	0.3+	0.3+
ESS	**catch**	75/125('96)	75/125('96)	75/125('96)	75/125('96)
	dfo	50	50	50	50
	fall	50	50	50	50
	41	50	50	50	50
	36	50	50	50	50
Jan 1 biomass		4140	4549	2989	2945
SSB TY mt		3002	3296	1922	1875
SSB TY retro bias adj		2930	3310	1567	1528
F TY (age 5+)		0.45	0.40	0.44	0.442
F TY retro bias adj.		0.48	0.41	0.53	0.53
TY age 1 (millions)		2.41	2.80	0.446	0.446
TY age 1 retro bias adj.		5.12	6.24	0.69	0.69
rho F		-0.05	-0.02	-0.17	-0.17
rho SSB	`	0.02	0.00	0.23	0.23
rho rct		-0.53	-0.55	-0.35	-0.35

Table A3. ASAP model results for January 1 biomass (mt), spawning stock biomass (SSB (mt), age 3+), fishing mortality (F) and recruitment (age 1, 000s fish), 1978-2012.

Year	Jan.1 Biomass	SSB	F	Recruitment
1978	38572	30411.7	0.45	10955
1979	43676.9	27754	0.37	10588
1980	47237.6	33590	0.39	9149
1981	50124.2	34473	0.46	19410
1982	52739.5	31782	0.73	7456
1983	45339	32598	0.62	3636
1984	41400	27227	0.60	13811
1985	35188.2	19074	0.85	5432
1986	35169.4	19760	0.66	26295
1987	42134.1	17890	0.60	6509
1988	48321.7	32869	0.64	14061
1989	39831.3	25565	0.47	5784
1990	41664.4	30361	0.65	6864
1991	38792.1	22535	0.91	11523
1992	29183.5	14588	1.03	2506
1993	19537.6	12694	1.15	3056
1994	10979.4	6334	1.53	1962
1995	8123.84	6055	0.42	1230
1996	9539.66	7339	0.51	2610
1997	11099.5	6555	0.85	3511
1998	10498.8	6404	0.68	1231
1999	11078.3	7949	0.68	3439
2000	10928.3	7105	0.43	1546
2001	10451.2	8358	0.74	1070
2002	8487.87	6990	0.55	1511
2003	7694.24	5924	0.82	397
2004	5681.66	4570	0.74	2490
2005	4451.34	3181	0.48	436
2006	4518.63	3937	0.64	912
2007	4191.41	3333	0.68	1295
2008	4117.78	3029	0.72	658
2009	3935.64	3221	0.90	517
2010	3185.89	2376	0.81	1017
2011	2948.81	1854	0.78	2146
2012	2989.11	1922	0.44	445

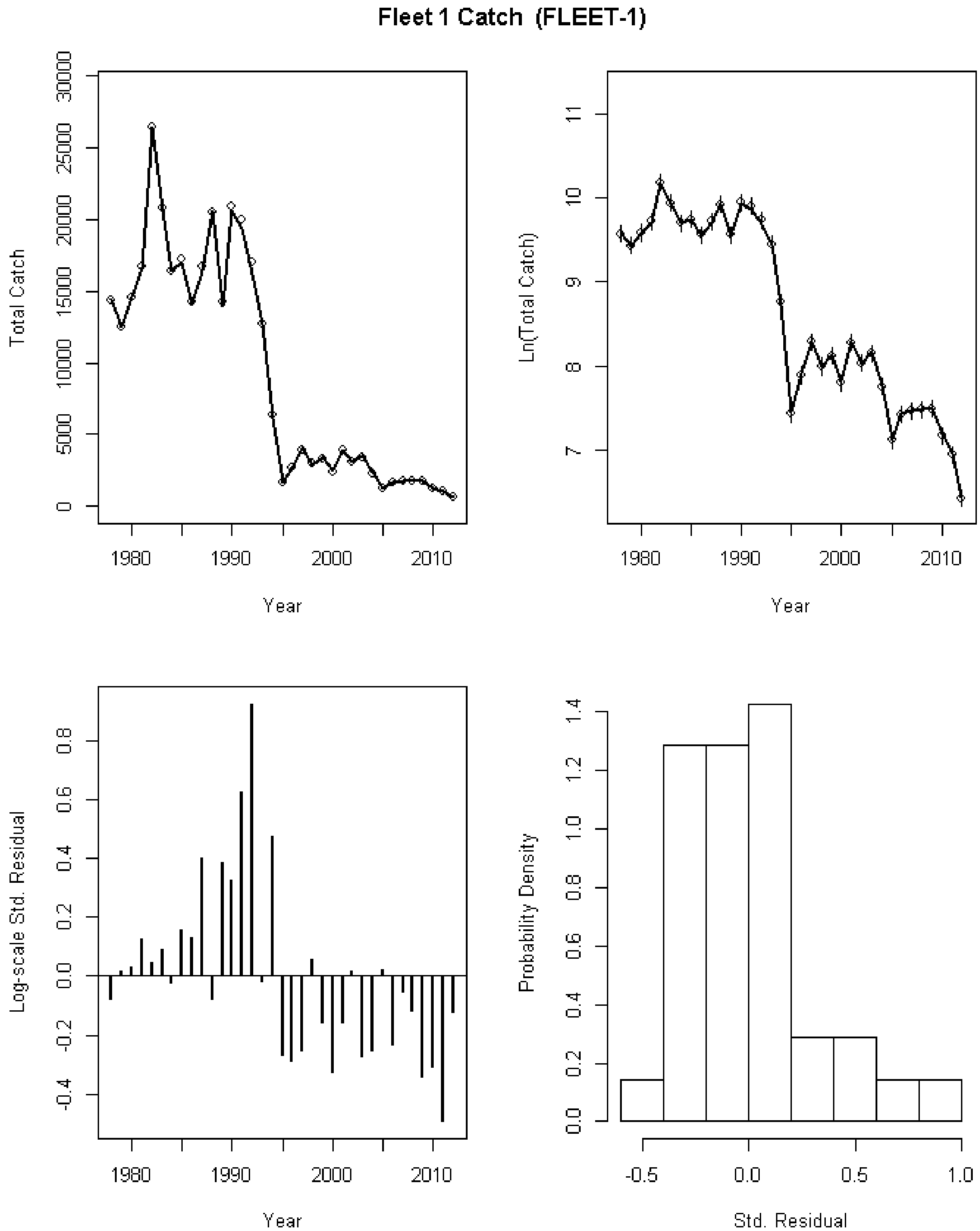


Figure A1. ASAP model fit to total catch of Eastern Georges Bank cod, 1978-2012.

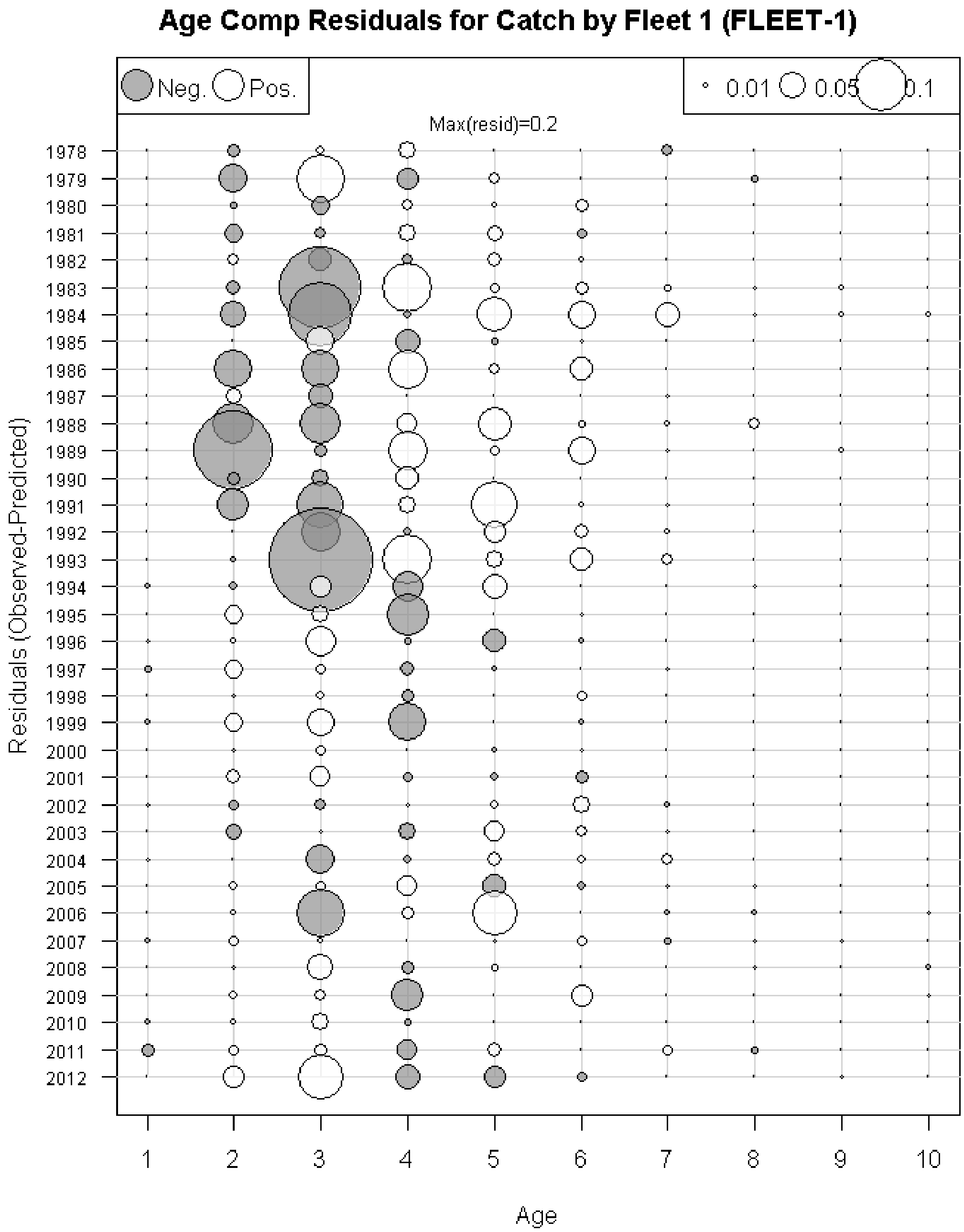


Figure A2. ASAP model residuals for the commercial catch age composition of Eastern Georges Bank cod, 1978-2012.

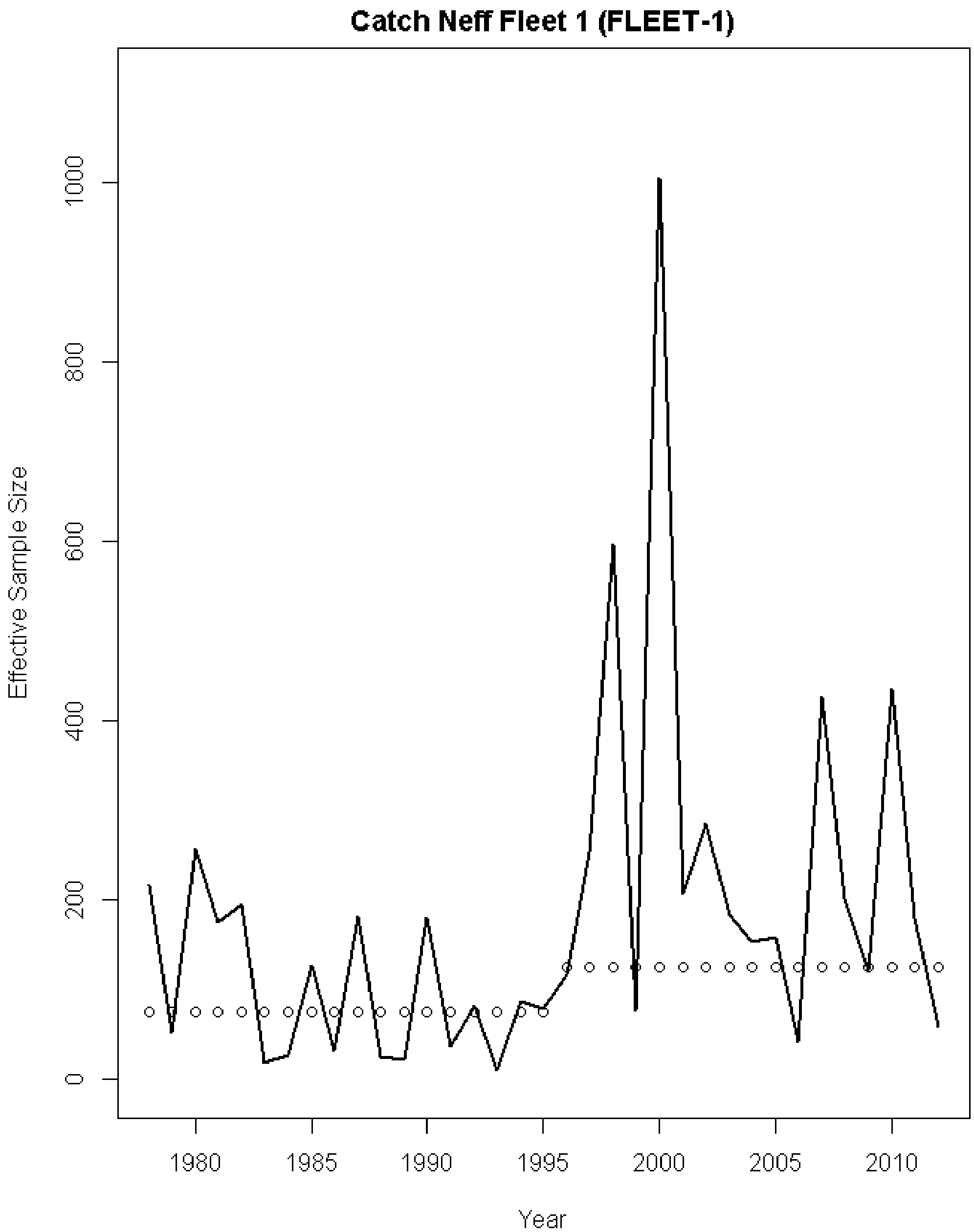


Figure A3. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the total catch, 1978-2012.

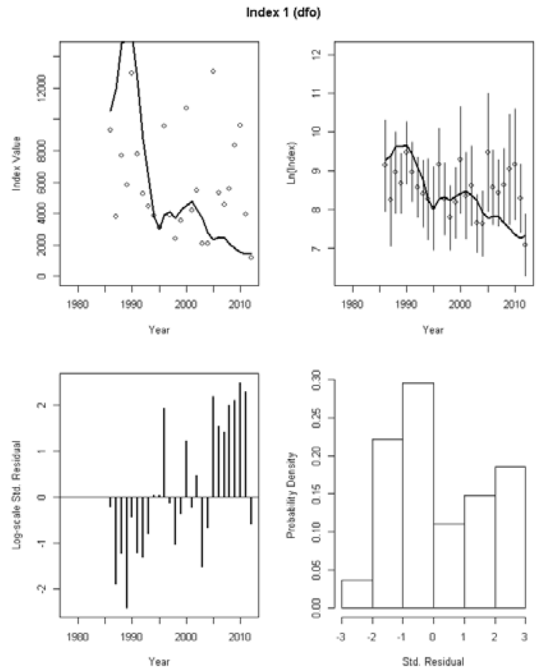


Figure A4. ASAP model fit to DFO survey indices of Eastern Georges Bank cod, 1978-2012.

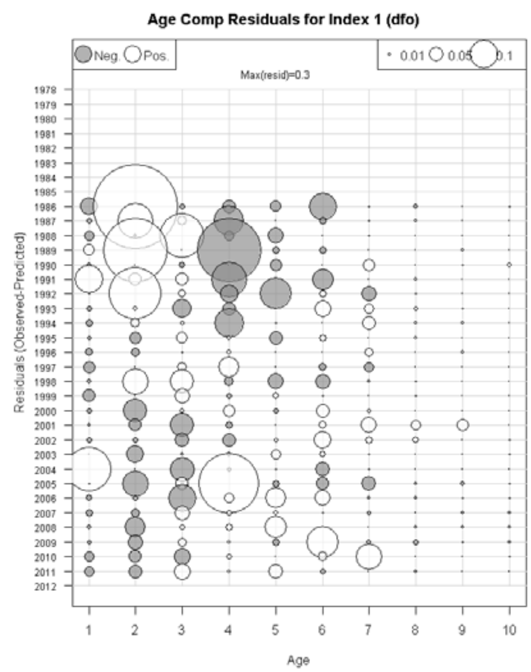


Figure A5. ASAP model run age composition residuals for DFO survey index of Eastern Georges Bank cod, 1978-2012.

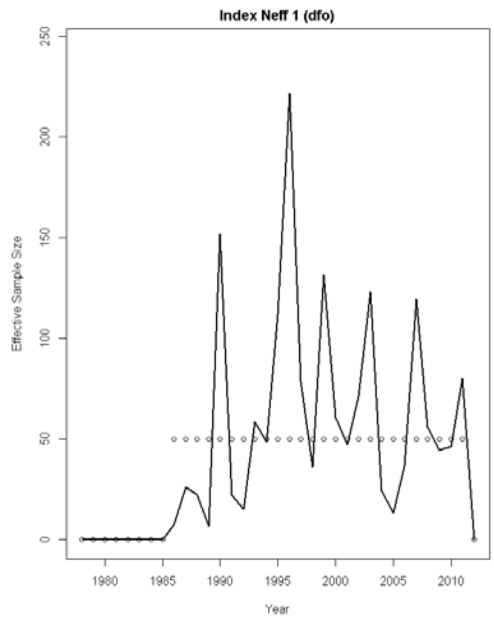


Figure A6. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the DFO survey, 1978-2012.

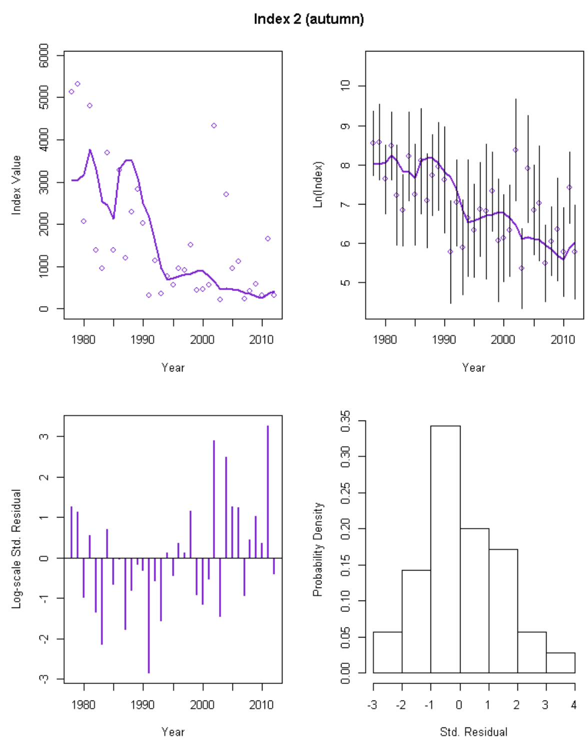


Figure A7. ASAP model fit to NEFSC autumn survey indices of Eastern Georges Bank cod, 1978-2012.

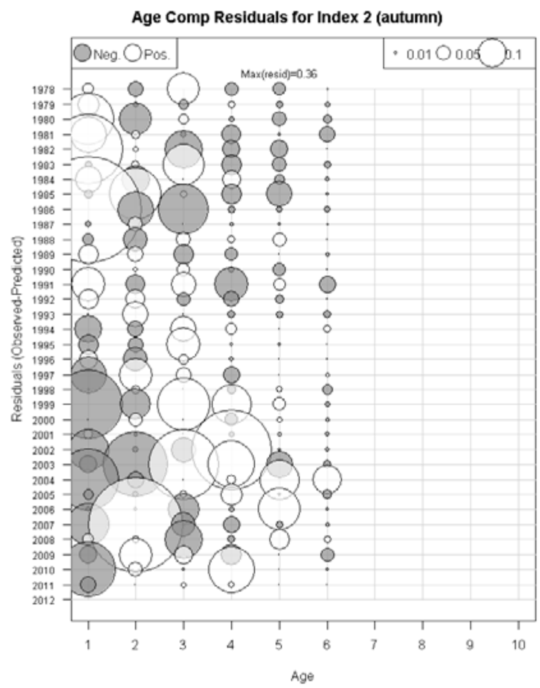


Figure A8. ASAP model age composition residuals for NEFSC autumn survey index of Eastern Georges Bank cod, 1978-2012.

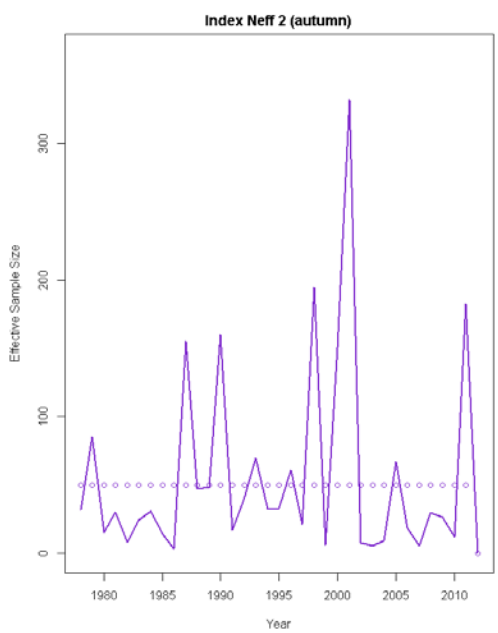


Figure A9. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the NEFSC autumn survey, 1978-2012.

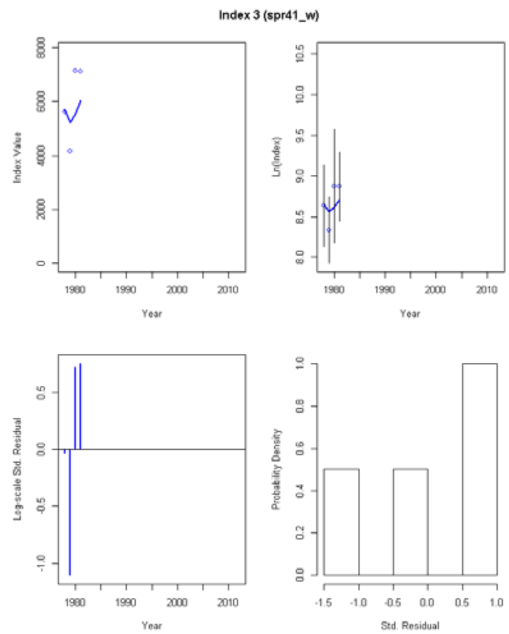


Figure A10. ASAP model fit to NEFSC spring Yankee #41 trawl survey indices of Eastern Georges Bank cod, 1978-2012

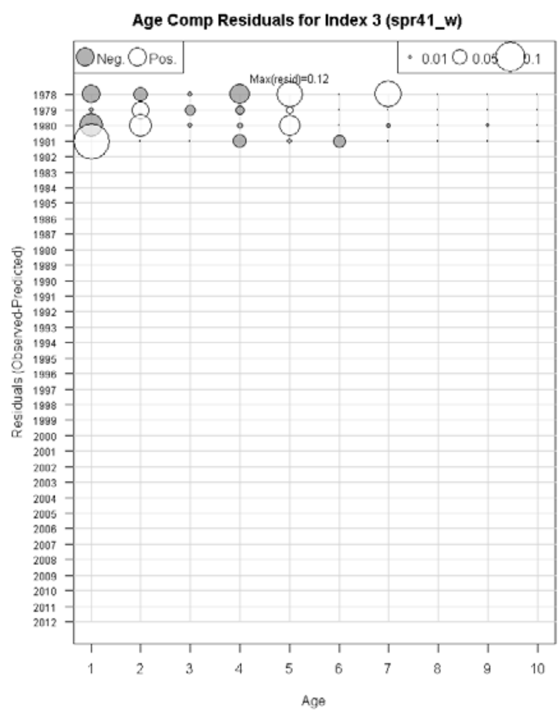


Figure A11. ASAP model age composition residuals for NEFSC spring Yankee #41 trawl survey index of Eastern Georges Bank cod, 1978-1981.

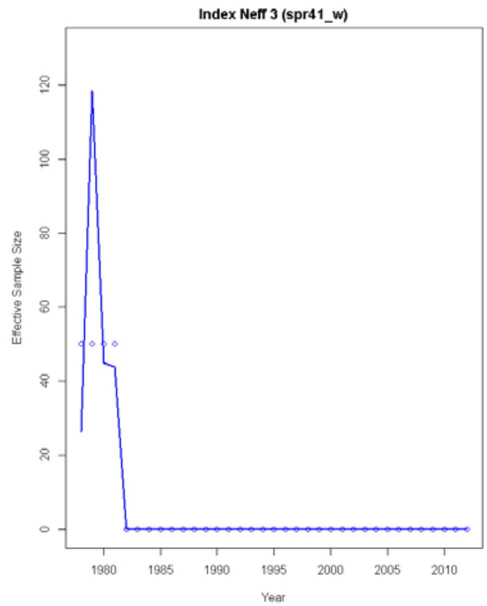


Figure A12. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the NEFSC spring Yankee #41 trawl survey, 1978-2012.

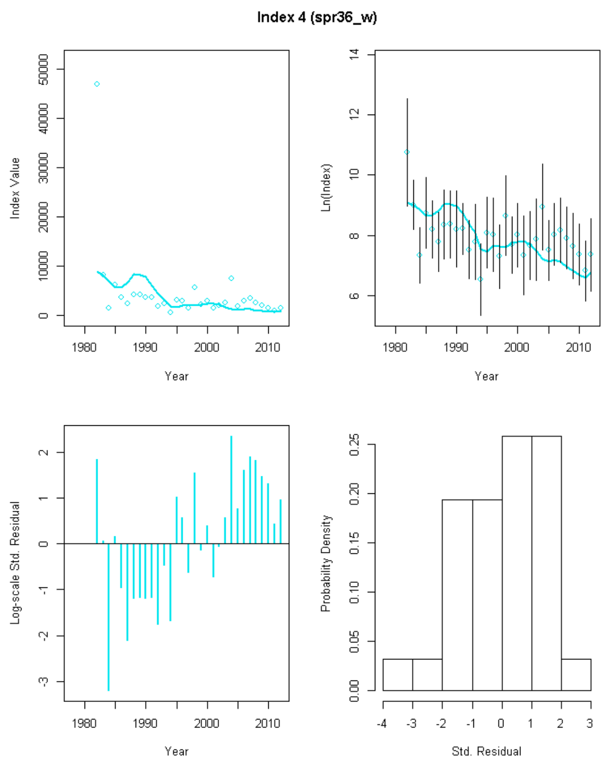


Figure A13. ASAP model fit to NEFSC spring Yankee #36 trawl survey indices of Eastern Georges Bank cod, 1982-2012.

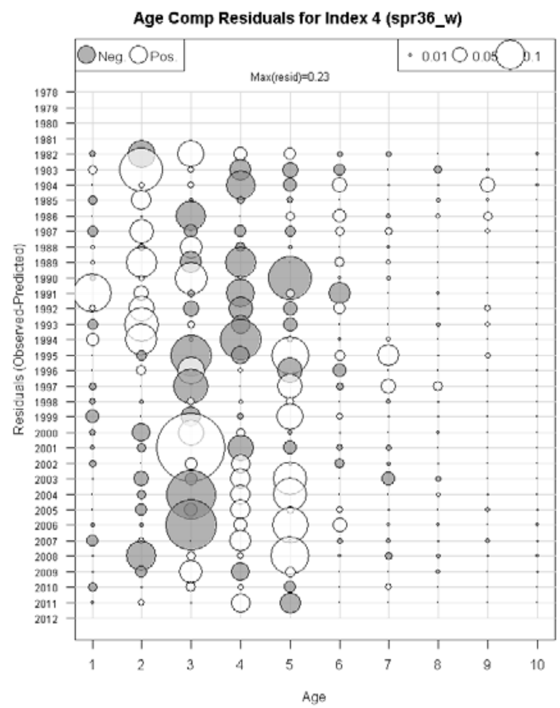


Figure A14. ASAP model age composition residuals for NEFSC spring Yankee #36 trawl survey index of Eastern Georges Bank cod, 1982-2012.

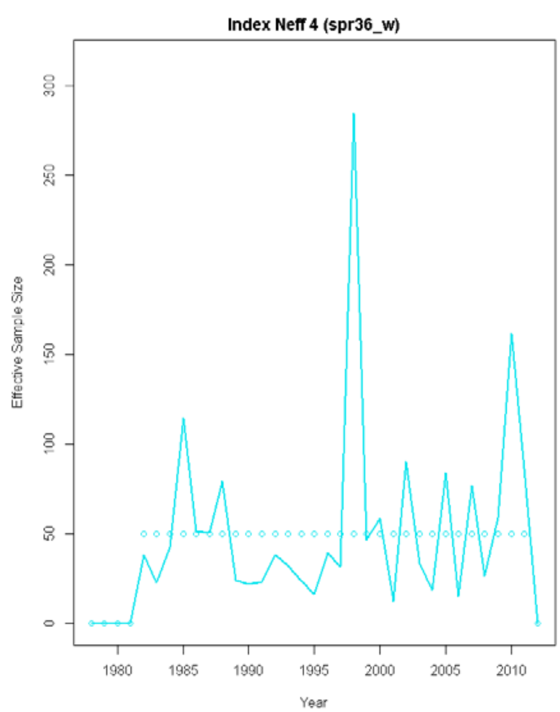


Figure A15. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the NEFSC spring Yankee #36 trawl survey, 1982-2012.

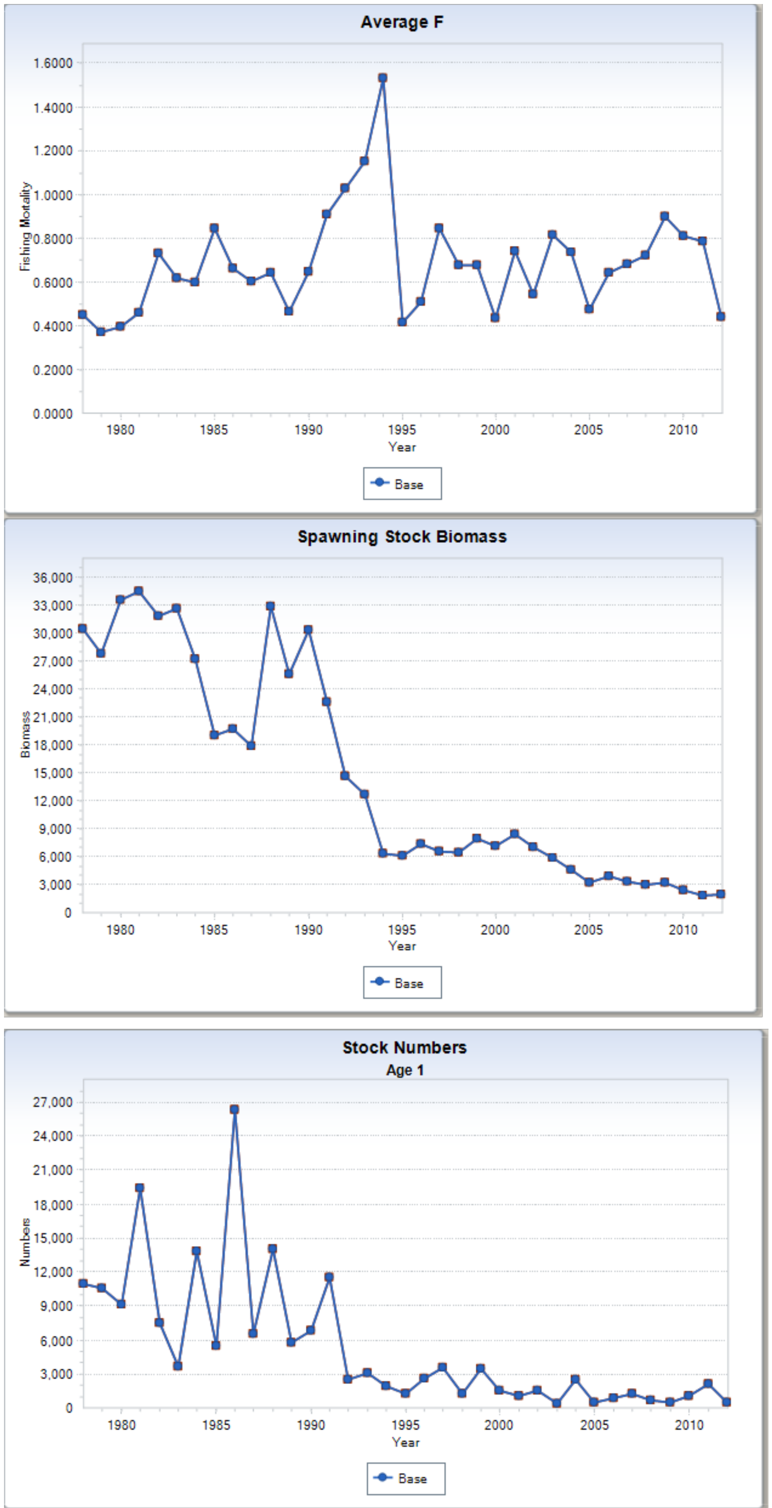


Figure A16. ASAP model results for fishing mortality (ages 5+), spawning stock biomass, and recruitment (age1, 000s fish), 1978-2012.

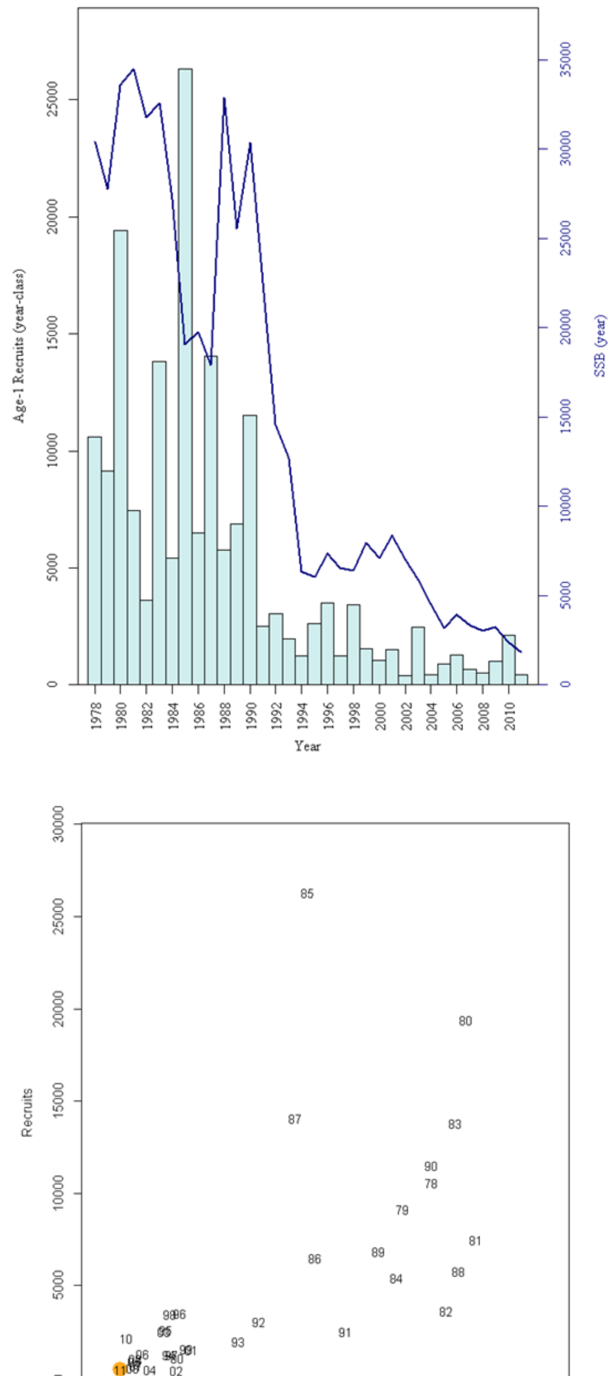


Figure 17A. ASAP model results for spawning stock biomass (mt, line) and recruitment (age1, 000s fish, bars) in the upper panel, and the stock – recruitment plot in the lower panel with year-class designation, 1978-2012.

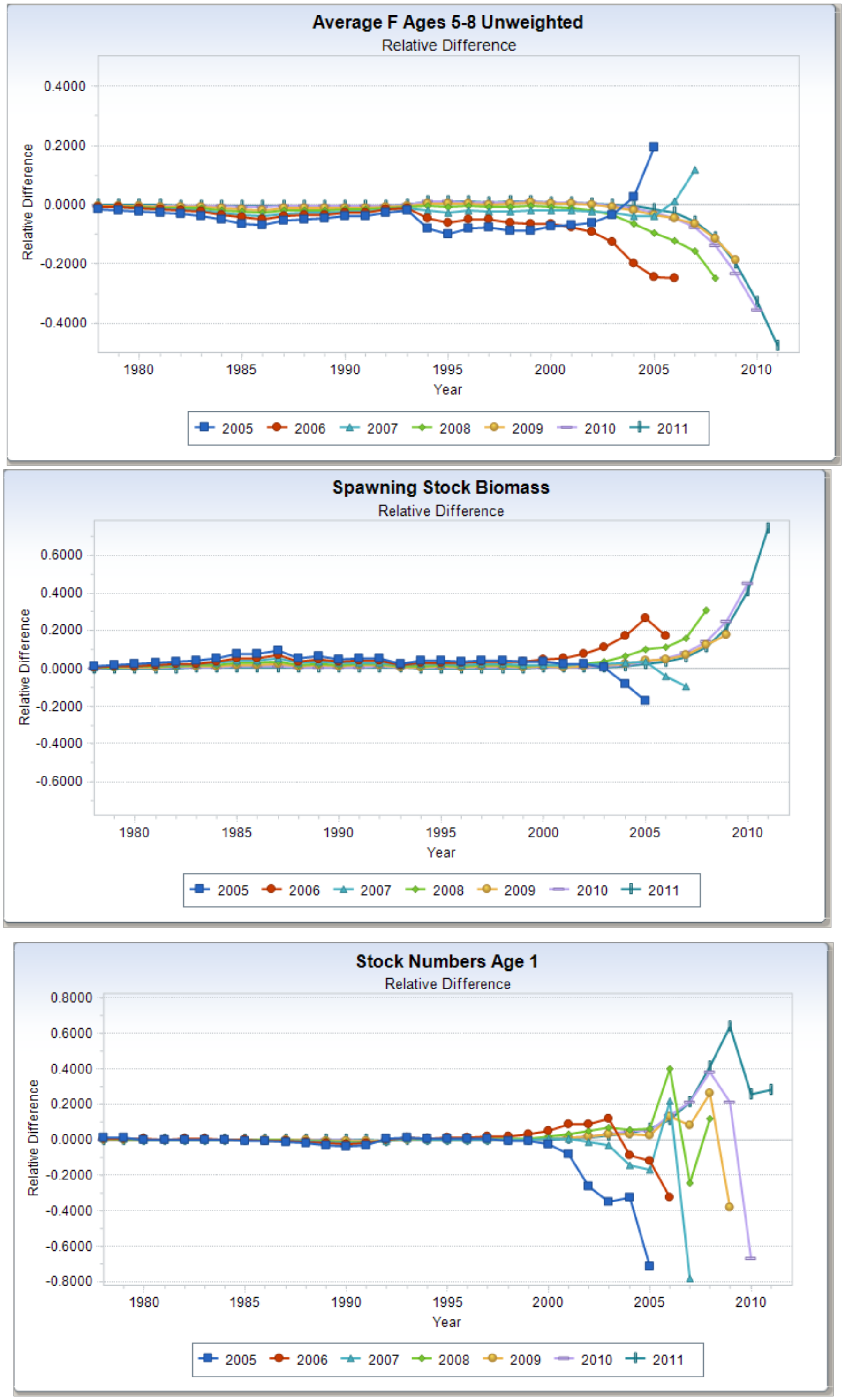
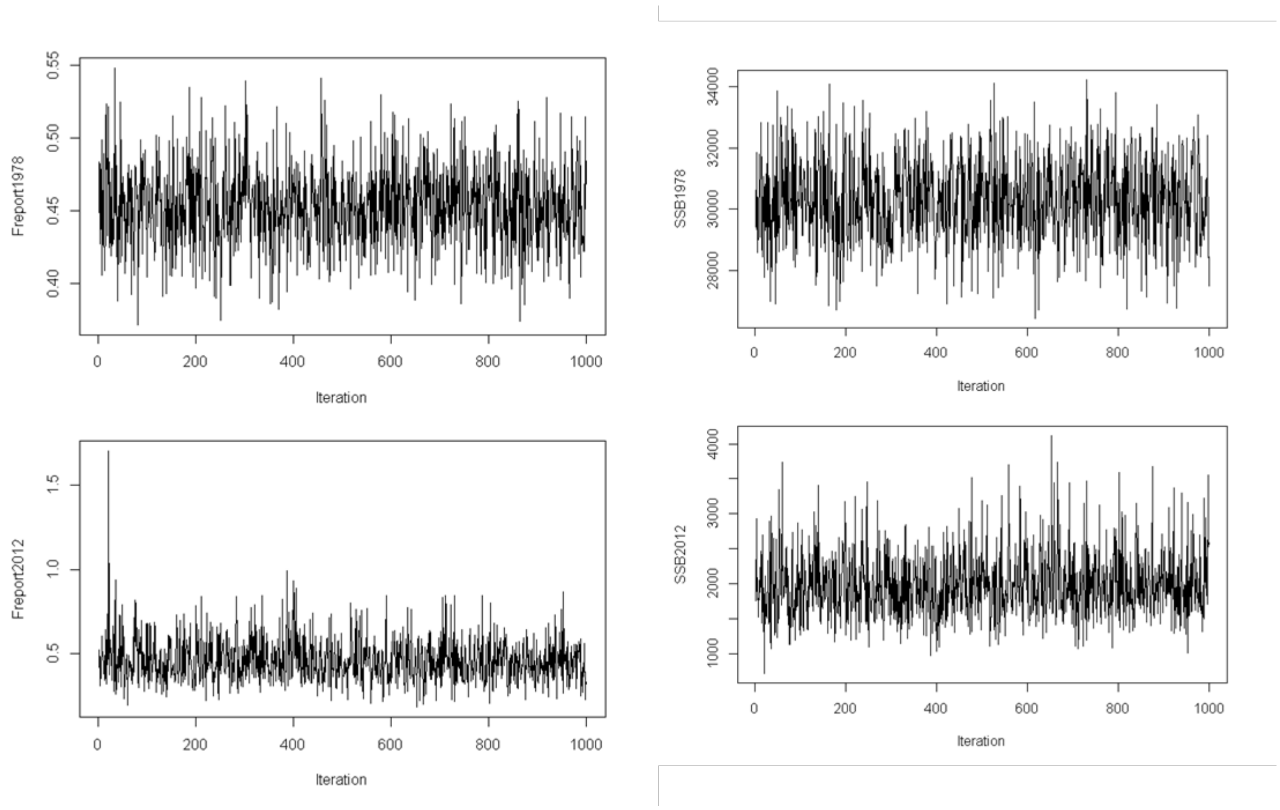


Figure 18A. ASAP model results of retrospective bias of fishing mortality (F), spawning stock biomass (SSB), and age1 recruitment. Retrospective bias adjustment for



F = -0.17, SSB = 0.23, and age 1 recruitment = -0.35.

Figure A19. ASAP model results of trace of MCMC chains for Eastern Georges Bank cod fishing mortality (left) and spawning stock biomass (right) for 1978 and 2012. 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.

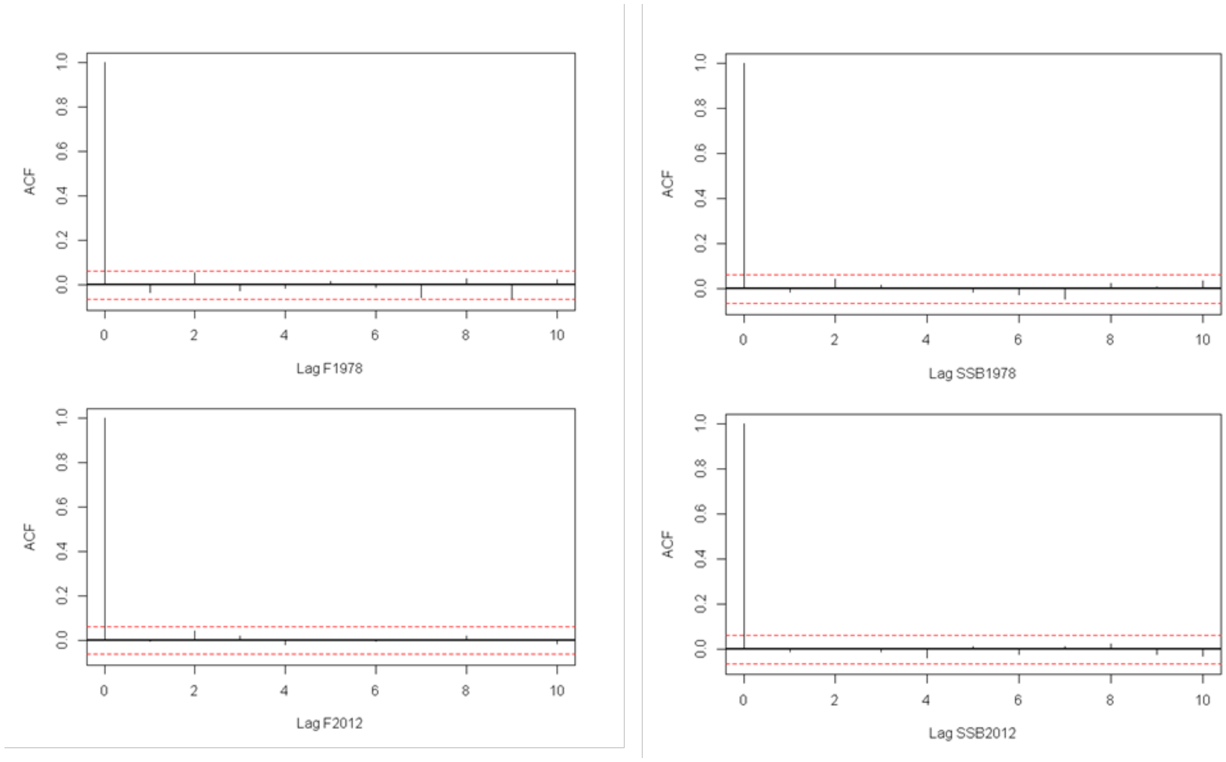


Figure A20. ASAP model auto correction within the 1978 and 2012 MCMC chains for fishing mortality (F, left panel) and spawning stock biomass (SSB, right panel) for Eastern Georges Bank cod.

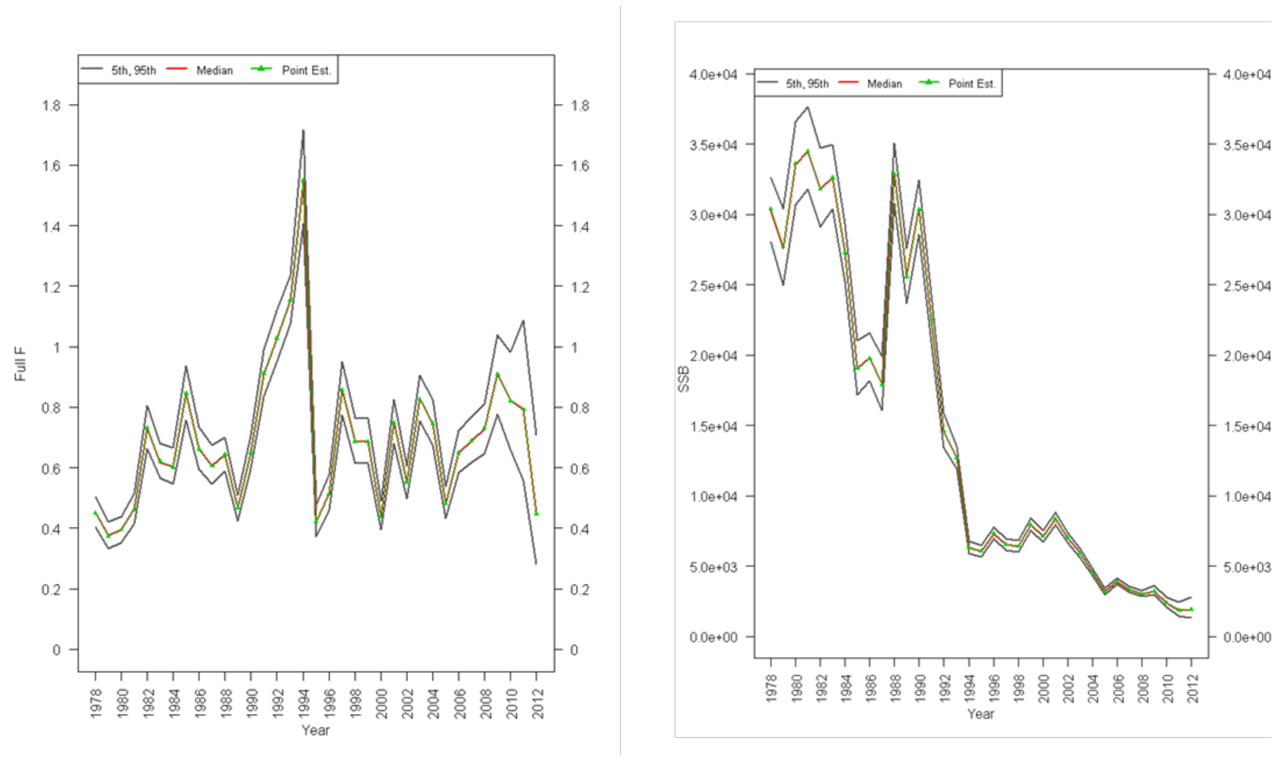


Figure A21. ASAP model 90% probability interval for Eastern Georges Bank fishing mortality (left) and cod spawning stock biomass (SSB). The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the model (joint posterior modes) is shown in the thin green line with filled triangles.

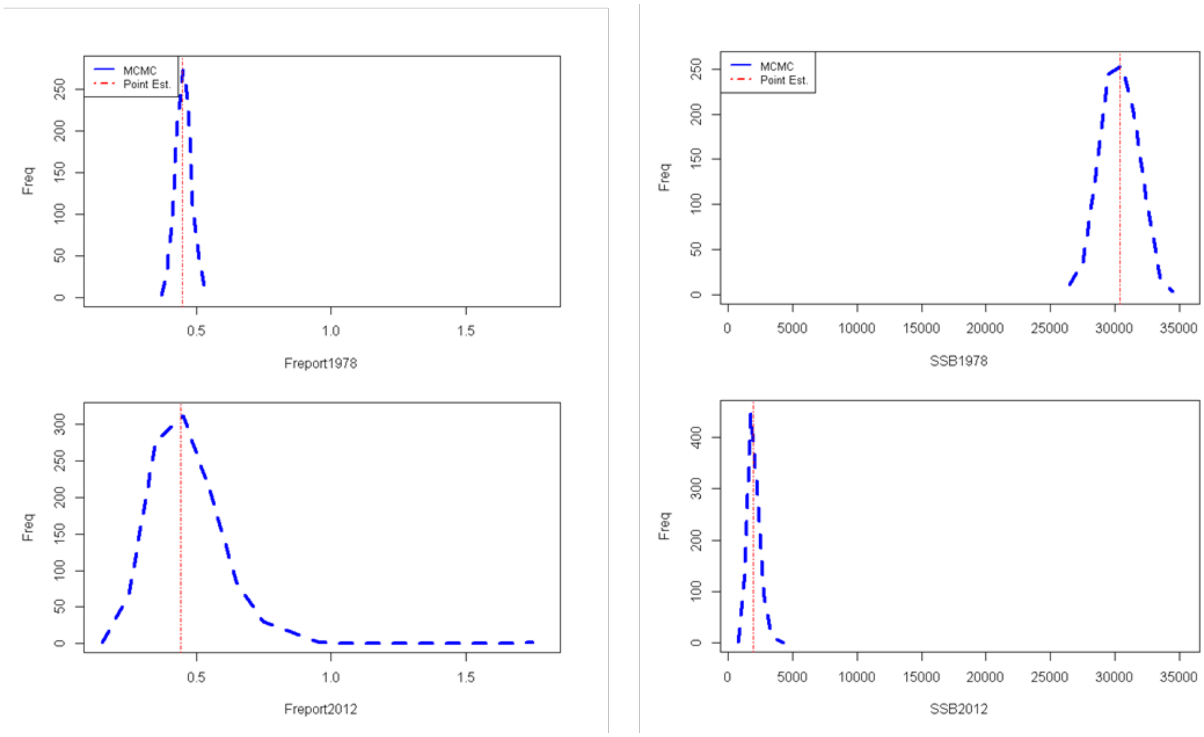


Figure A22. ASAP model MCMC distribution of Eastern Georges Bank and fishing mortality (F, left panel) and cod spawning stock biomass (SSB, right panel) in 1978 and 2012. The model point estimate is indicated by the dashed red line.