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Assessment of Eastern Georges Bank Atlantic Cod for 2014

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Abstract

The combined 2013 Canada/USA Atlantic cod catches were 463 mt with a quota 600 mt, which was the lowest catch since 1978. Catches from the 2014 DFO and NMFS spring surveys decreased from 2012, and both were among the lowest level in the time series. 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 2014 was estimated at 11,719 mt, which was about 20% of the adult biomass in 1978. Fishing mortality was high prior to 1994 and was estimated to be 0.04 in 2013, the lowest on record. Recruitment at age 1 has been low in recent years. The 2003 year class was estimated to be the highest recruitment since 2000. The initial estimate of the 2010 year class was stronger than the 2003 year class based on the 2014 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 1,150 mt. However, given the extremely low SSB, stock rebuilding should be promoted. Even no fishing in 2015, there would be higher than 50% risk that 3+ biomass will decrease between 2015 and 2016.

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.

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). In the 2013 assessment, the VPA "M 0.8" model from the 2013 benchmark assessment was used to provide catch advice; A consequence analysis to understand the risks associated with assumptions of the VPA "M 0.8" and ASAP "M 0.2" model was examined in the projection and risk analysis(Wang and O'Brien, 2013).

The current assessment applied the 2013 benchmark formulations using Canadian and USA fishery information updated to 2013 including commercial landings and discards, the Fisheries and Oceans Canada (DFO) survey updated to 2014, the National Marine Fisheries Services (NMFS) spring survey updated to 2014 and the NMFS fall survey updated to 2013.

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 2013 were 463 mt, including 54 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 1995-2012, Canadian catches fluctuated between 468 mt and 3,405 mt (Table 1). In 2013, total catch (extracted landings on May. 26, 2013, 395 mt) including discards were 468 mt against a quota of 513 mt, taken primarily between June and December by otter trawl and longline (Table 3, Figure 4 and 5). All 2013 landings were subject to dockside monitoring and at sea observers monitored close to ##% by weight of the mobile gear fleet landings, ##% by weight of the fixed gear landings and ##% 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 2013, 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 2013 Canadian groundfish fishery were estimated at 21 mt from the mobile gear and 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 2013, estimated discards of cod by the Canadian scallop fishery were 18 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, 2002 and 2013. 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 39 mt for calendar year 2013. 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 gillnet gear about 8% of the landings during 2013.

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 1989-2013. 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 15 mt in 2013, a 71% decrease from 52 mt discarded in 2012 (Table 1, Figure 3).

SIZE AND AGE COMPOSITION

The size and age compositions of the 2013 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. 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 67 cm (26 in) for longliners. Gillnetters caught fewer cod but these fish were larger, peaking at 70 cm (28 in) (Figure 7). The combined landings for all gears peaked at 52 cm (20 in) (Figure 8).The size composition of cod discards from the 2013 Canadian scallop fishery was derived from at-sea sampling. Cod discards from the scallop fishery peaked at 34 cm (13 in) (Figure 7). The discards from the groundfish fishery were assumed to have the same size composition as the groundfish landings. The Canadian combined cod discards in 2013 from the groundfish and scallop fisheries peaked at 34 to 49 cm (13 to 19 in) (Figure 8).

The size and age compositions of the 2013 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 2013 peaked at 56 cm (22 in) and discards peaked at 47 cm (19in) (Figure 9).

The total catch composition of combined landings and discards for Canada and the USA is shown in Figure 10. Canadian catches peaked at 52 cm (20 in); and USA catches peaked at 59 cm (22 in).

Canadian catch-at-age composition was obtained by applying quarterly fishery age-length keys to the size composition. The age-length key from the 2013 DFO survey was used to augment the first quarter key.

The age composition of the 2013 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 2013 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 (1989-2013), the Canadian groundfish fishery (1997-2013) and the Canadian scallop fishery (1978-2013) were all included in the assessment.

The 2013 combined Canada/USA fishery age composition, by number, was dominated by the 2010 year class at age 3 (52%), followed by the 2009 year class at age 4 (24%) and the 2011 year class at age 2 (15%) (Table 5, Figure 11). The 2003 year class at age 9 made little contribution to the 2013 catch (0.04%). By weight, the 2010 year class dominated the 2013 fishery (44%) followed by the 2009 (31%) and 2008 year classes (9%) (Figure11). The contribution of age 7 and older fish continued to be small in recent years, 1% by number and 3% by weight in 2013 (Table 5, Figure 11 and 12).

Fishery weights at age showed a declining trend starting in the early 1990s (Table 6, Figure 15). Compared to 2012, the weights at age in 2013 improved but still at lower levels.

ABUNDANCE INDICES

RESEARCH SURVEYS

Surveys of Georges Bank have been conducted by DFO each year (February/March) since 1986 and by NMFS each fall (October) since 1963 and each spring (April) since 1968. All surveys use a stratified random design (Figures 14 and 15). 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 7) have been applied to the survey results to make the series consistent (Forrester *et al.* 1997). Additionally, two different trawl nets have been used on the NMFS spring survey, a modified Yankee 41 from 1973-81 and a Yankee 36 in other years, but no net conversion factors were available for cod. A new net and vessel (NOAA ship *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 *Henry B. Bigelow* to make the data equivalent to previous surveys conducted by former NOAA ship *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 8).

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 16-18).

The catch in numbers from the 2014 DFO survey was lower than 2012, among the lowest level in the time series (1986-2014) (Table 9). The 2010 year class at age 4 was dominant (44% by number), followed by the 2011 year class at age 3 (30% by number). There was no catch of the 2007 year class at age 7 and no catch of fish older than 8 (Table 9, Figure 19).

Similar to the DFO survey, the 2014 NMFS spring survey catch decreased from 2013 and was among the lowest level in the time series (Table 10). The 2010 year class at age 4 was dominant (52% by number), followed by the 2011 year class at age 3 (32% in number). There were no fish caught older than age 6 (Table 10, Figure 19).

The catch from the NMFS 2013 fall increased from 2012, but was below the average of the time series. The 2010 year class at age 3 and 2011 year class at age 2 were dominant (totally 72% by number), the 2013 year class accounted for 10% by number. There were no catches of fish older than age 4 (Table 11, Figure 19).

The coefficient of variation (CV) of stratified mean catch number/tow for the three surveys is shown in Tables 12-14 and Figure 20. Median CV values indicated the most variable catch of ages 1 and 8 for DFO survey, ages 7 and 8 for the NMFS spring survey, 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 and 2003 year classes and potentially the 2010 year class (all of which were below the time series average), the survey abundance at age (Tables 9-11, Figure 19) 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. 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 (Tables 9-11, Figure 19).

For the survey swept area biomass, the 2013 NMFS fall survey biomass increased from the 2012, but still at lower level. In 2014, both the DFO and NMFS spring survey biomass decreased from 2013 and were among the lowest in the time series (Table 15, Figure 21).

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 22). Weights at age in 2014 are higher than in 2013 except for ages 2 and 4.

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 11), and the trend from those samples was not clear (Figure 23). All the three surveys show that fish conditions are improved in 2014.

The total mortality (Z) was calculated by two age groups (ages 4 and 5, and ages 6 to 8) using DFO and NMFS spring survey abundance indices, separately. It showed that Z of ages 4 and 5 has been lower than the older age group (Figure 24). Z has been high throughout assessment time period for both age groups (Figure 24), although relative F (fishery catch at age/survey abundance indices) declined significantly since mid-1990s (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 2013 (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 2013, 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… 2013.17, 2014.00
$I_{2,a,t}$ = 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… 2013.28, 2014.00
$I_{4,a,t}$ = NMFS fall survey, ages a = 1 to 5 and time t = 1978.69, 1979.69… 2012.69, 2013.69

The population was calculated to the beginning of 2014; therefore the DFO and NMFS spring survey indices for 2014 were designated as occurring at the beginning of the year, i.e. 2014.00. 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 2013 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:
$v_{a,t} = lnN_{a,t} = ln$ population abundance for a = 2 to 9 at beginning of 2014
$K_{1,a}$ = *ln* DFO survey catchability for ages a = 1 to 8 at time t=1986 to 2014
$K_{2,a}$ = *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 2014
$K_{4,a}$ = *ln* NMFS fall survey catchability for ages a = 1 to 5 at time t= 1978 to 2013

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 2012 year classes at age 2 at beginning of 2014 exhibited the largest relative bias of 22% and relative error of 76%. The relative bias for other ages ranged between 3% and 5%, and the relative error ranged between 40% and 23% (Table 17). 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, 1994-2008 and the recent 5 years (2009-2013) was 0.48, 0.27 and 0.09, 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 compared with 13.5 million with one less year of data (Figures 30 and 31). The estimate was 4.4 million in the 2014 assessment, close to the 2013 assessment. Residuals of the 2003 year class from the three surveys were predominantly positive, which means that the 2003 year class was underestimated in both the 2013 and 2014 assessment (Figure 32). The 2014 assessment results were very close with the 2013 assessment, there was no consistent pattern.

Possible reasons for the appearance of a retrospective bias after adding one more year of data were explored. At the benchmark model review in 2012, with catch data through 2011 as described above, the age 9 in 2012 (2003 year class) was estimated directly as a model parameter. While in the 2013 and 2014 assessment, the determination of the 2003 year class relied on the 2012 fishery age 9 (2003 year class) catch and the assumption that F9 (2003 year class) is equal to the population weighted average F on ages 7 and 8 of adjacent year classes. And there is no age 9 survey abundance indices applied to calibrate the catch-at-age matrix.

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.

One possible reason for the low value of age 9 (2003 year class) catch in 2012 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 and 7). Sensitivity runs were conducted to explore the uncertainties in estimation of the 2003 year class. The impacts on the estimate of recruitment of other year classes, terminal year (2014) population abundance as well as the implication for the projection were 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 2014 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 abundance indices entirely from the data input (‘without 2003yc’ model). In this sensitivity run, the abundance of the 2003 year class at age 9 was arbitrarily fixed at a value of 100 thousands. Since no 2003 year class survey abundance indices were used in the calibration and objective function, this fixed value has no impact on estimation of the other year classes.

The estimated 2003 year class numbers at age from run 1 were compared with the 2012 and 2014 assessments. The 2003 year class at age 1 from the “estimate 2003yc” model was very close to the 2012 assessment at about 13.5 million fish at age 1, well above 4.1 million from the 2013 and 4.5 million from the 2014 assessment (Table 18, Figure 33). For recruitment in other years, the “estimate 2003yc” model had almost the identical results with the 2012 assessment; while the estimate from the ‘without 2003yc’ model was closer to the 2014 VPA “M 0.8” model. The 2014 assessment with “M 0.8” model estimated the 2010 year class at 5.6 million, while about 5.9 and 5.4 million from the 2 sensitivity runs (Table 18, Figure 34). Although the 2014 VPA

“M 0.8” model tended to underestimate the size of pre-2003 year classes, the estimate for the most recent 3 year classes was very similar among all models (Table 18 and Figure 34).

For the terminal year population abundance estimate, the “estimate 2003yc” model had higher estimate for most age groups compared to the 2014 VPA “M 0.8” model. There was very minor difference between ‘without 2003yc’ model and 2014 VPA “M 0.8” model (Table 18 and Figure 35).

For the terminal year biomass, the “estimate 2003 yc” model had the highest estimate of ages 10+ biomass at 915 mt with deeply dome-shaped PR compared with 162 mt from the 2014 VPA “M 0.8” model. However, the difference in the terminal year ages 3-9 biomasses was minor between the VPA “M 0.8” model and ‘without 2003yc’ model (Table 18 and Figure 36).

The above sensitivity analyses suggested that the low estimate of the 2003 year class may be an outlier which then caused a retrospective bias in the 2013 and 2014 assessment. Removing the 2003 year class abundance indices (“without 2003yc” model) showed that it had little impact on the estimation of other year classes in the terminal year (Table 18, Figure 35 and 36) or recruitments in other years (Table 18, Figure 34) compared with the 2014 assessment using the VPA “M 0.8” model.

STATE OF RESOURCE

Fixing the retrospective bias could be done by the “est 2003yc” model. However, the adult biomass, recruitment, and fishing mortality estimates were different from the VPA “M 0.8” model (Figure 30). The estimates (Tables 19-21) presented below were from the 2012 benchmark 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 19, Figure 37). Biomass has subsequently fluctuated between 5,900 mt and 18,800 mt. The estimate of 3+ biomass was 11,179 mt (80% confidence interval: 1,0461 mt – 14,750 mt) at the beginning of 2014 (Table 19). The increase of 3+ biomass during 2005-2009 was largely due to the recruitment and growth of the 2003 year class, and since 2011 was largely due to the recruitment and growth of the 2010 year class (Figure 38). High natural mortality, lower weights at age in the population in recent years, and generally poor recruitment have contributed to the lack of sustained rebuilding. Survey biomass indices have been lower since the mid-1990s (Figure 21). The estimated adult population biomass at the beginning of 2014 from the VPA was about one fifth of the 1978 biomass (Figure 37).

Recruitment at age 1 has been low in recent years (Table 20, Figure 37). Since 2000, the 2003 year class at 4.4 million fish at age 1 (13.5 million fish at age 1 from the 2012 assessment), had been the highest recruitment estimated. However, the initial estimate of the 2010 year class at 5.4 million age 1 fish is stronger than the 2003 year class based on the 2014 assessment. Both the 2003 and 2010 year classes are around half of the average (about 11 million age 1 fish) during 1978-1990, when the productivity was considered to be higher (Table 21, Figure 37). Recruitment for the 2002 and 2008 year classes are the lowest on record. The current biomass is well below 30,000 mt, above which there is expected to be a better chance for higher recruitment (Figure 39).

Fishing mortality (population number weighted average of ages 4-9) was high prior to 1994 (Table 21, Figure 37). F declined in 1995 to F=0.11 due to restrictive management measures and then fluctuated between 0.04 and 0.38. F in 2013 was estimated to be 0.04 (80% confidence interval: 0.036-0.051). The assessment showed recent reductions in F, and the 2013 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 41). 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 (Figure 38). 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 2012 and 2013, 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 30,000 mt; when biomass is above this threshold, there is a better chance for higher recruitment (Figure 39). 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 2013 fishery remains low (Table 16). The research survey spatial distribution patterns of adult (age 3+) cod have not changed over the past decade (Figures 16-18). 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 and 2014 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 2015 to 2016. 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.

For projections, the average of the most recent three years of fishery and survey weights at age is used for fishery and beginning year population biomass for 2015 and 2016. The 2014 and 2015 partial recruitment pattern iss based on the most recent five years of estimated partial recruitment (Table 22). The 2009-2013 geometric mean of recruitment at age 1 is used for 2014-2016 projections, the uncertainties for this estimate is not reflected in the projection. Catch in 2014 is assumed to be equal to the 700 mt quota, and F=0.18 or F=0.11 in 2015.

Projection based on F_{ref}=0.18

Table 23 shows the deterministic projection results, where the projected catch at F_{ref}=0.18 would be 1,959 mt in 2015. The stochastic projection indicates a combined Canada/USA catch of 1,850 mt in 2015 will result at neutral risk of F exceeding F_{ref}=0.18 (Table 24, Figure 42). Because F_{ref}=0.18 is not consistent with the “M 0.8” assessment model, it is inappropriate for catch advice.

Projection based on F=0.11

Both deterministic (Table 25) and stochastic (Table 24, 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 1,150 mt (Table 24, Figure 42). Even no fishing in 2015, there is higher than 50% risk that 2016 adult biomass will be lower than 2015. Catches of 225 mt will result in a higher risk (75%) that 2016 adult biomass will not increase (Figure 42).

Sensitivity analysis

To examine the effect of the uncertainties in the estimation of the 2003 year class, the “estimate 2003yc” model is used as a sensitivity analysis for projections. The strong dome-shaped partial recruitment for ages 10+ from the model results is applied in the projection (Table 22). Deterministic (Table 25) and stochastic (Table 24, Figure 43) projections are provided. A 50% probability of not exceeding F_{ref} =0.18 implies a combined Canada/USA catch less than 1,900 mt, and less than 1,200mt for F =0.11. Even no fishing in 2015, there is higher than 50% risk that 2016 adult biomass will be lower than 2015. Catches of 175 mt will result in a higher risk (75%) that 2016 adult biomass will not increase (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 promote stock biomass rebuilding, catches must not exceed 175 mt based on above analysis (Table 24, Figure 42 and 43).

Consequence Analysis (to be updated)

The risks associated with management actions taken during 2015 are 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 2014 in this assessment and will be reviewed at the June 2014 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 2015, and do not account for any longer-term consequences.

The column headers in Table 26 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 (2015) 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 601mt 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

The table 27 summarizes the performance of the management system. It reports the TRAC advice, TMGC quota decision, actual catch, and realized stock conditions for this stock. Fishing mortality and trajectory of age 3+ biomass from the assessment following the catch year are compared to results from this assessment. These comparisons were kindly provided in 2011 by Tom Nies (staff member of the New England Fishery Management Council (NEFMC)) and updated for this assessment. The inconsistency of TRAC advice in the past with the realized stock conditions from the recent assessment was mainly due to 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 is 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 benchmark meeting that projections would be run at the current F_{ref} of 0.18 and at a value less than 0.18. A value of F=0.11 was used to provide catch advice for 2015. 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 to 2013.

	Canada				USA			Combined
Year	Landings	Discards - Scallop	Discards - Groundfish	Total	Landings	Discards	Total	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	6,343
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	96	52	148	616
2013	385	18	21	424	24	15	39	463
Minimum	385	18	13	424	24	0	39	463
Maximum	17,827	200	428	17,898	10,550	279	10,550	26,463
Average	5,453	79	153	5,579	3,342	70	3,391	8,970

Table 2. Canadian (a) and USA (b) fishery management history of cod on eastern Georges Bank, 1978 to 2013.

2a)

Year	Canadian Management History
1978	Foreign fleets were excluded from the 200 mile exclusive economic zones of Canada and USA.
1984	October implementation of the maritime boundary between the USA and Canada in the Gulf of Maine Area.
1985	5Z cod assessment started in Canada; Set TAC; TAC=25,000mt
1986	TAC=11,000mt
1987	TAC=12,500mt
1988	TAC=12,500mt
1989	TAC=8,000mt; 5Zjm cod assessment.
1990	Changes to larger and square mesh size; Changes from TAC to individual and equal boat quotas of 280,000lb with bycatch restrictions; Temporary Vessel Replacement Program was introduced.
1991	TAC=15,000mt; Dockside monitoring; Maximum individual quota holdings increased to 2% or 600t (whichever was less).
1992	TAC=15,000mt Introduction of ITQs for the OTB fleet.
1993	TAC=15,000mt, ITQ for the OTB fleet not based on recommended catch quotas; OTB <65 fleet was allowed to fish during the spawning season (Mar.–May. 31).
1994	TAC=6,000mt, Spawning closures January to May 31; Mesh size was 130mm square for cod, haddock an Pollock for ITQ fleet; Minimum mesh size of 6" was required for gillnets; Minimum fish size is 43cm (small fish protocols) for cod, haddock an Pollock for ITQ fleet; OT> 65' could not begin fishing until July 1; Fixed gear must choose to fish either 5Z or 4X during June 1 to September 30.
1995	TAC=1,000mt as a bycatch fishery; January 1 to June 18 was closed to all groundfish fishery; 130mm square mesh size for all mobile fleets; Small fish protocols continued; 100% dock side monitoring; Fixed gear vessels with a history since 1990 of 25mt or more for 3 years of cod, Haddock, Pollock, hake or Cusk combined can participate in 5Z fishery.
1996	TAC=2,000mt; 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=3,000mt
1998	TAC=1,900mt
1999	TAC=1,800mt; Mandatory cod separator panel when no observer on board; Jan. and Feb. mobile gear winter Pollock fishery.
2000	TAC=1,600mt; Jan. and Feb. mobile gear winter Pollock fishery.
2001	TAC=2,100mt
2002	TAC=1,192mt

2003	TAC=1,301mt
2004	TAC=1,000mt; Canada-USA resource sharing agreement on Georges Bank.
2005	TAC=740mt; Exploratory winter fishery Jan. to Feb. 18, 2005; Spawning protocol: 25% of maturity stages at 5 and 6.
2006	TAC=1,326mt; Exploratory winter fishery Jan. to Feb.6, 2006; Spawning protocol: 30% of maturity stages at 5 to 7.
2007	TAC=1,406mt; Exploratory winter fishery Jan. to Feb. 15, 2007; High mobile gear observer coverage (99%); Spawning protocol: 30% of maturity stages at 5 to 7.
2008	TAC=1,633mt; Winter fishery from Jan.1 to Feb. 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=1,173mt; Winter fishery from Jan. 1 to Feb. 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=1,350mt; Winter fishery from Jan. 1 to Feb. 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=1,050mt; Winter fishery from Jan. 1 to Feb. 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=513mt; Winter fishery from Jan. 1 to Feb. 6, 2012; At sea observer coverage 42% by weight of the mobile gear fleet landings, 26 % by weight of the fixed gear landings and 35% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2013	TAC=504mt; Winter fishery from Jan. 1 to Feb. 3, 2013; At sea observer coverage ##% by weight of the mobile gear fleet landings, ##%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)

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

Table 2b. cont.

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, 2004-2013.

Year	Gear	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2004	Mobile	-	-	-	-	-	78	82	50	47	56	42	16	371
2004	Gillnet	-	-	-	-	-	4	2	14	21	-	11	-	52
2004	Longline	-	-	-	-	-	6	85	231	168	89	97	14	689
2004	Total	-	-	-	-	-	88	169	294	236	145	150	30	1,112
2005	Mobile	12	22	-	-	3	50	49	31	27	28	31	30	283
2005	Gillnet	-	-	-	-	-	11	18	-	6	-	-	-	36
2005	Longline	1	-	-	-	-	9	44	101	71	52	29	4	311
2005	Total	13	22	-	-	3	70	111	133	105	80	60	34	630
2006	Mobile	41	16	-	-	-	88	73	74	63	39	24	39	458
2006	Gillnet	-	-	-	-	-	-	27	15	-	-	-	-	43
2006	Longline	3	-	-	-	-	7	126	173	147	91	34	14	595
2006	Total	44	16	-	-	-	96	226	262	211	130	58	53	1,096
2007	Mobile	68	18	-	-	-	44	84	55	31	49	14	28	393
2007	Gillnet	-	-	-	-	-	-	4	41	13	-	-	-	58
2007	Longline	-	-	-	-	-	7	116	173	219	102	39	-	657
2007	Total	68	18	-	-	-	51	205	268	263	152	53	28	1,108
2008	Mobile	40	21	-	-	-	69	100	55	67	46	43	28	468
2008	Gillnet	-	-	-	-	-	1	22	50	22	-	-	-	94
2008	Longline	-	-	-	-	-	7	190	280	177	136	38	-	827
2008	Total	40	21	-	-	-	77	312	384	265	182	81	28	1,390
2009	Mobile	23	7	-	-	-	51	32	17	10	59	46	25	271
2009	Gillnet	-	-	-	-	-	4	29	61	36	12	-	-	142
2009	Longline	-	-	-	-	-	-	68	135	198	124	53	13	590
2009	Total	23	7	-	-	-	55	129	213	244	195	99	38	1,003
2010	Mobile	26	8	-	-	-	56	56	26	31	51	54	36	345
2010	Gillnet	-	-	-	-	-	5	17	13	19	-	-	-	54
2010	Longline	-	-	-	-	-	1	21	100	107	72	47	-	349
2010	Total	26	8	-	-	-	62	95	139	158	123	102	36	748
2011	Mobile	33	7	-	-	-	18	35	33	42	38	27	45	279
2011	Gillnet	-	-	-	-	-	4	15	24	15	7	-	-	65
2011	Longline	-	-	-	-	-	14	56	109	79	65	34	-	358
2011	Total	33	7	-	-	-	36	107	165	136	111	61	45	702
2012	Mobile	10	8	-	-	-	15	29	32	17	15	5	19	151
2012	Gillnet	-	-	-	-	-	0.5	1	4	0.4	1	3	-	11
2012	Longline	-	-	-	-	-	-	39	44	44	90	15	-	233
2012	Total	10	8	-	-	-	16	70	81	62	105	24	19	395
2013	Mobile	23	7	-	-	-	23	3	14	23	18	15	20	147
2013	Gillnet	-	-	-	-	-	3	1	4	7	-	-	-	15
2013	Longline	-	-	-	-	-	-	16	74	72	61	-	-	223
2013	Total	23	7	-	-	-	25	20	92	102	79	15	20	384

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 1987-2013; 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)
2013			75,275	1,334(319)

Table 5. Annual catch at age numbers (thousands) for eastern Georges Bank cod for 1978-2013.

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
2013	1	0	31	109	51	11	7	2	0	0	0	0	0	0	0	0	0	211

Table 6. 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	0.62	1.27	1.96	3.35	4.89	6.02	6.79	9.80	10.70	12.77
1990	0.69	1.55	2.38	3.22	4.59	6.04	7.80	9.81	11.19	12.82
1991	0.75	1.52	2.42	3.14	4.24	5.53	7.45	9.46	9.18	13.28
1992	0.86	1.41	2.28	3.32	4.24	5.66	6.80	8.66	11.22	14.85
1993	0.60	1.40	2.11	2.84	4.29	5.40	6.76	8.29	9.14	11.13
1994	0.60	1.33	2.14	3.44	4.39	6.42	7.19	8.15	7.97	11.40
1995	0.32	1.32	2.12	3.35	4.94	6.38	10.10	10.01	10.44	15.35
1996	0.51	1.42	2.17	3.05	4.70	5.83	6.42	8.96	10.35	10.38
1997	0.68	1.42	2.06	2.93	3.86	5.36	7.26	8.31	11.48	9.88
1998	0.71	1.35	2.15	2.98	3.97	5.33	6.59	7.82	10.23	12.88
1999	0.54	1.30	1.97	3.10	3.91	5.48	6.27	7.54	9.38	13.52
2000	0.61	1.32	1.96	2.90	4.02	4.70	5.72	6.77	8.35	14.05
2001	0.21	0.93	1.84	2.74	3.58	4.87	5.22	7.27	8.65	11.07
2002	0.33	1.20	1.96	2.84	4.01	4.88	6.41	8.23	7.98	10.11
2003	-	1.24	2.12	2.71	3.53	4.24	5.47	6.84	7.63	8.13
2004	0.24	1.23	1.84	2.77	3.46	4.56	5.24	7.24	8.54	8.64
2005	0.17	0.81	1.56	2.34	3.49	4.46	4.86	6.81	8.05	8.94
2006	0.25	0.65	1.75	2.32	3.30	4.29	6.10	5.79	6.89	7.20
2007	0.46	1.05	1.62	2.32	3.00	3.91	6.10	6.84	6.90	9.32
2008	0.29	1.26	2.22	2.79	3.65	5.03	5.82	7.92	7.97	8.73
2009	0.66	1.13	1.91	3.03	3.70	4.51	5.73	6.72	10.00	10.26
2010	0.48	1.32	2.06	2.53	3.38	3.43	5.10	6.08	8.80	10.86
2011	0.29	1.05	1.73	2.56	3.52	4.28	4.23	6.06	9.85	9.37
2012	0.29	0.94	1.67	2.63	3.69	4.11	4.64	5.70	5.33	5.23
2013	0.57	0.94	1.88	2.83	3.77	4.78	5.37	6.28	9.04	7.22
Min	0.17	0.65	1.52	2.32	3.00	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.	0.46	1.08	1.85	2.72	3.61	4.22	5.01	6.17	8.61	8.59

[1]for 2009-2013

Table 7. 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 8. 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 *Henry B. 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 9. 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
2014	0	76	9	360	538	169	35	0	27	0	0	0	0	0	0	0	0	1213

Table 10. 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	3	3	450	749	834	209	127	13	0	0	0	0	0	0	0	0	0	2389
2013	0	0	653	3864	1202	129	64	15	0	0	0	0	0	0	0	0	0	5926
2014	0	55	64	568	922	109	27	0	0	0	0	0	0	0	0	0	0	1746

Table 11. 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	58	323	362	248	177	110	32	0	0	0	0	0	0	0	0	0	0	1309
2012	0	14	188	90	13	20	0	0	0	0	0	0	0	0	0	0	0	324
2013	162	51	565	554	226	0	0	0	0	0	0	0	0	0	0	0	0	1559

Table 12. 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
2014	0.58	0.54	0.21	0.24	0.30	0.36	0.00	0.49	0.22	2.9
Median	0.57	0.34	0.24	0.26	0.30	0.33	0.34	0.41	0.25	12.0

Table 13. 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	0.36	3.42
2010	0.72	0.41	0.19	0.17	0.31	0.30	0.35	0.00	0.20	2.57
2011	0.38	0.40	0.29	0.36	0.37	0.41	0.49	0.77	0.29	2.11
2012	1.07	0.37	0.33	0.20	0.28	0.30	0.34	0.00	0.30	4.57
2013	0.00	0.52	0.67	0.58	0.42	0.70	1.00	0.00	0.62	11.18
2014	0.46	0.38	0.40	0.31	0.35	0.81	0.00	0.00	0.32	3.29
Median	**0.40**	**0.40**	**0.34**	**0.35**	**0.31**	**0.36**	**0.48**	**0.49**	**0.28**	**5.50**

Table 14. 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	0.45	1.23
2010	0.41	0.60	0.43	0.34	0.75	0.77	2.81
2011	0.49	0.56	0.60	0.68	0.89	0.52	3.27
2012	0.62	0.51	0.39	0.44	0.89	0.46	0.70
2013	0.85	0.67	0.72	0.58	0.00	0.58	3.47
Median	**0.59**	**0.45**	**0.50**	**0.51**	**0.74**	**0.44**	**2.81**

Table 15. Swept area biomass (mt) for eastern Georges Bank cod from the DFO, NMFS spring and fall surveys. Conversion factors to account for vessel and trawl door changes have been applied, the biomass conversion factor used for the Henry B. Bigelow since 2009 is 1.58, the numbers in brackets show the unconverted values.

Year	NMFS Fall		NMFS spring		DFO
1970	5,054		7,801		-
1971	5,287		10,435		-
1972	3,947		13,779		-
1973	11,697		82,311		-
1974	2,741		27,269		-
1975	5,246		23,503		-
1976	5,082		10,354		-
1977	9,509		9,335		-
1978	12,213		22,731		-
1979	13,050		12,831		-
1980	4,494		20,520		-
1981	7,256		18,568		-
1982	2,216		172,300		-
1983	2,449		20,376		-
1984	7,018		4,808		-
1985	2,390		23,190		-
1986	2,174		12,532		18,633
1987	2,634		7,615		8,824
1988	6,764		9,294		19,452
1989	5,145		12,104		14,547
1990	5,121		10,828		56,665
1991	435		9,391		25,068
1992	1,734		6,113		14,581
1993	606		6,598		16,545
1994	1,734		1,294		13,140
1995	1,220		10,113		8,118
1996	1,790		6,613		32,173
1997	1,875		4,051		11,004
1998	2,970		12,267		5,006
1999	1,044		5,308		9,178
2000	895		7,374		32,298
2001	1,159		3,721		18,037
2002	11,525		4,432		20,333
2003	608		6,405		6,218
2004	8,347		21,080		5,661
2005	1,446		4,407		26,200
2006	2,165		7,331		12,546
2007	424		6,066		11,228
2008	792		5,327		13,657
2009	1,203	(1,900)	4,343	(6,862)	23,180
2010	732	(1,157)	3,587	(5,668)	26,352
2011	2,304	(3,640)	1,724	(2,725)	8,437
2012	609	(962)	4,864	(7,686)	2,449
2013	2,566	(4,054)	9,616	(15,193)	11,113
2014	-	-	3,254	(5,141)	2,409

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	0.020	0.508	1.189	2.158	2.907	3.760	5.106	6.329	5.300	11.653
2013	0.029	0.685	1.216	2.016	2.785	3.557	4.343	5.350	6.628	11.653
2014	0.079	0.565	1.243	1.821	3.116	4.745	4.724	6.580	5.633	11.653
Average	0.100	0.746	1.643	2.561	3.768	5.089	6.525	7.912	9.635	13.707
Minimum	0.010	0.288	1.073	1.574	2.504	3.182	3.670	4.484	5.080	11.653
Maximum	0.276	1.132	2.354	3.564	6.182	7.487	9.629	12.712	14.114	14.635

Table 17. Statistical properties of estimates for population abundance (numbers in thousands) at beginning of year 2014 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[2014 2]	374	284	76%	84	22%
N[2014 3]	1089	431	40%	53	5%
N[2014 4]	2927	914	31%	111	4%
N[2014 5]	689	215	31%	28	4%
N[2014 6]	269	85	32%	13	5%
N[2014 7]	150	49	33%	6	4%
N[2014 8]	95	30	32%	3	3%
N[2014 9]	90	20	23%	3	3%
DFO age 1	0.01	0.002	21%	<0.001	3%
DFO age 2	0.10	0.02	19%	0.001	1%
DFO age 3	0.51	0.10	19%	0.007	1%
DFO age 4	0.83	0.17	21%	0.024	3%
DFO age 5	0.93	0.18	20%	0.010	1%
DFO age 6	0.83	0.15	18%	0.008	1%
DFO age 7	0.89	0.18	21%	0.007	1%
DFO age 8	1.08	0.21	19%	0.017	2%
NMFS Spring Y41 age 1	0.02	0.00	56%	0.002	13%
NMFS Spring Y41 age 2	0.19	0.02	72%	0.040	20%
NMFS Spring Y41 age 3	0.22	0.06	61%	0.034	16%
NMFS Spring Y41 age 4	0.21	0.09	58%	0.028	13%
NMFS Spring Y41 age 5	0.31	0.09	62%	0.038	12%
NMFS Spring Y41 age 6	0.30	0.07	58%	0.038	13%
NMFS Spring Y41 age 7	0.38	0.18	63%	0.053	14%
NMFS Spring Y41 age 8	0.33	0.16	58%	0.038	11%
NMFS Spring Y36 age 1	0.02	0.01	22%	0.001	3%
NMFS Spring Y36 age 2	0.11	0.04	19%	0.001	1%
NMFS Spring Y36 age 3	0.31	0.07	18%	0.006	2%
NMFS Spring Y36 age 4	0.48	0.08	18%	0.009	2%
NMFS Spring Y36 age 5	0.46	0.10	19%	0.005	1%
NMFS Spring Y36 age 6	0.36	0.11	18%	0.005	1%
NMFS Spring Y36 age 7	0.38	0.09	18%	0.008	2%
NMFS Spring Y36 age 8	0.44	0.10	22%	0.009	2%
NMFS Fall age 1	0.05	0.01	17%	0.001	2%
NMFS Fall age 2	0.08	0.03	17%	0.001	1%
NMFS Fall age 3	0.12	0.05	17%	0.002	2%
NMFS Fall age 4	0.08	0.05	18%	0.002	2%
NMFS Fall age 5	0.07	0.05	19%	0.001	1%

Table 18. Model results comparison for VPA “M 0.8” model and sensitivity runs for eastern Georges Bank cod.

Model runs	2014 assessment (VPA "M 0.8")	"without 2003yc"	"estimate 2003yc"	2012 assessment (VPA "M 0.8)
terminal year(2014) population number(thousands)				
age 2	374	310	347	NA
age 3	1089	1037	1132	NA
age 4	2927	2832	3116	NA
age 5	689	668	752	NA
age 6	269	262	303	NA
age 7	150	146	170	NA
age 8	95	105	137	NA
age 9	90	49	24	NA
age 10+	14	NA	78	NA
terminal year(2014) ages 3-9 biomass(thousands mt)	11.4	11.2	12.7	NA
recruitment(thousands)				
1994 year class	2096	2090	2254	2257
1995 year class	3600	3582	3945	3952
1996 year class	5642	5612	6342	6360
1997 year class	2189	2167	2557	2563
1998 year class	4917	4875	5963	5991
1999 year class	1896	1854	2477	2480
2000 year class	1213	1208	1564	1579
2001 year class	2398	2251	4306	4312
2002 year class	583	634	797	836
2003 year class	4475	NA	13486	13491
2004 year class	777	738	747	1132
2005 year class	3613	2392	1634	1680
2006 year class	2504	2639	3068	2984
2007 year class	1417	1392	1540	1811
2008 year class	1015	997	1109	1751
2009 year class	1886	1841	2027	1810
2010 year class	5602	5428	5946	5776
2011 year class	1669	1592	1733	NA
2012 year class	458	379	425	NA

Table 19. Beginning of year population biomass (mt) for eastern Georges Bank cod during 1978-2014 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2014.

Year/Age	1	2	3	4	5	6	7	8	9	10+	1+	3+
1978	1391	2962	17458	14216	7106	4461	5335	946	1135	1463	56474	52120
1979	1174	8843	4591	16585	10125	3742	4220	4264	729	2098	56372	46354
1980	2778	6032	14275	4181	16615	8341	2526	2623	3132	2289	62791	53981
1981	1654	7011	11170	15681	4761	11839	6296	3330	2431	4181	68356	59691
1982	524	12411	13223	10171	10866	3433	7952	4124	1382	4906	68993	56058
1983	1144	5256	15969	7040	4992	7152	2137	3897	2561	4256	54403	48003
1984	719	2420	6058	11564	3744	3299	3635	981	2117	4143	38681	35542
1985	460	7539	6160	5816	10057	3773	2802	2528	774	3778	43685	35687
1986	3159	3319	12155	4375	4397	7369	2139	1462	1188	2994	42558	36080
1987	1237	16627	5312	9886	3333	3178	4867	1161	912	3244	49756	31892
1988	2155	6262	22150	5426	8270	2095	1932	3283	1311	3270	56155	47738
1989	730	9624	8950	17664	3711	5529	1198	654	1648	2771	52479	42126
1990	1600	3302	16309	10340	15104	3006	3178	746	444	2889	56917	52016
1991	849	5464	5420	14117	8435	7859	2109	1672	530	2204	48657	42345
1992	461	6657	8368	3828	8012	5026	4524	1154	775	1811	40615	33497
1993	332	2795	7587	6144	3193	4606	2734	1844	654	1774	31661	28534
1994	510	2536	2794	4396	3629	2326	2342	1738	1084	1705	23061	20015
1995	383	2314	4755	2609	2311	2390	746	827	841	1321	18499	15802
1996	315	1437	3625	5815	3387	2751	1183	547	528	1024	20613	18861
1997	1071	2108	2316	3700	4748	3956	1013	868	184	720	20686	17507
1998	171	2997	3143	2112	3245	4002	1359	386	257	393	18065	14897
1999	544	1789	4970	3534	1845	3399	2032	743	119	325	19300	16968
2000	114	3596	2207	5999	3202	1828	1888	853	363	207	20256	16546
2001	12	1194	4579	2683	6368	3435	1106	876	390	213	20856	19650
2002	38	489	1434	4928	2339	4776	1382	435	410	239	16469	15943
2003	9	862	914	1608	4192	1491	1994	581	134	256	12041	11170
2004	96	137	2294	1265	1650	3115	634	748	267	164	10370	10137
2005	44	2124	444	2061	852	855	999	334	220	150	8082	5913
2006	108	193	3330	426	2014	603	434	425	74	194	7802	7500
2007	132	1807	534	3822	397	1853	319	211	236	122	9434	7495
2008	63	1162	3372	718	3475	320	618	137	94	157	10117	8891
2009	112	818	2371	4401	630	3215	143	254	42	97	12083	11153
2010	145	527	1405	2506	4233	521	1271	45	90	55	10799	10127
2011	206	720	756	1290	1987	3647	211	546	10	82	9455	8529
2012	32	2263	1397	958	1256	1874	2249	114	265	44	10453	8158
2013	10	891	4328	1741	904	1174	900	1037	50	275	11312	10410
2014		164	1288	5130	2061	1216	680	606	575	162	11883	11719

Table 20. Beginning of year population abundance (numbers in thousands) for eastern Georges Bank cod during 1978-2014 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2014.

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	39679
1987	8244	19676	3122	3681	588	424	651	174	90	222	36872
1988	14155	6730	12407	1797	1984	334	229	376	106	223	38342
1989	5130	11569	5249	6403	862	860	157	84	146	189	30648
1990	7454	4193	8849	3567	3462	501	370	78	33	197	28705
1991	9669	6093	2777	4457	1988	1605	280	166	53	151	27240
1992	3630	7867	4091	1370	1925	820	648	135	74	124	20685
1993	4725	2928	4113	2113	708	782	391	250	70	121	16201
1994	3565	3861	1950	1672	918	312	320	201	118	117	13032
1995	2096	2914	2996	1162	665	509	112	104	71	90	10720
1996	3598	1715	2334	2240	867	450	217	46	44	70	11580
1997	5638	2941	1368	1700	1476	638	163	89	18	49	14080
1998	2187	4610	2275	935	1070	886	233	50	31	27	12303
1999	4911	1787	3682	1579	621	733	312	90	14	22	13752
2000	1893	4015	1391	2579	990	410	290	104	31	14	11718
2001	1211	1548	3230	1039	1768	675	160	116	39	18	9804
2002	2388	988	1182	2172	661	1089	236	52	41	21	8830
2003	582	1955	800	854	1376	444	389	87	18	22	6527
2004	4429	476	1578	517	478	762	147	118	27	14	8547
2005	770	3608	380	1164	287	259	254	44	34	13	6812
2006	3531	629	2893	271	768	190	94	91	13	17	8496
2007	2462	2889	498	2167	151	452	55	31	30	10	8745
2008	1381	2015	2326	352	1388	92	148	17	9	13	7742
2009	981	1130	1613	1773	233	912	32	45	5	8	6732
2010	1825	802	892	1132	1326	149	321	8	14	5	6473
2011	5401	1493	634	634	733	1018	57	122	2	7	10101
2012	1590	4418	1183	450	435	497	441	18	50	4	9085
2013	355	1300	3560	864	325	330	207	194	8	24	7167
2014		290	1036	2817	661	256	144	92	87	14	5398

Table 21. Annual fishing mortality rate 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 2014.

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	0.16	0.21	0.18	0.24	0.15	0.47	0.21	0.12	0.21
1999	0.00	0.05	0.16	0.27	0.21	0.13	0.30	0.25	0.29	0.05	0.23
2000	0.00	0.02	0.09	0.18	0.18	0.14	0.12	0.19	0.14	0.07	0.17
2001	0.00	0.07	0.20	0.25	0.28	0.25	0.33	0.24	0.29	0.08	0.27
2002	0.00	0.01	0.12	0.26	0.20	0.23	0.20	0.28	0.22	0.26	0.24
2003	0.00	0.01	0.24	0.38	0.39	0.30	0.39	0.37	0.39	0.12	0.38
2004	0.01	0.02	0.10	0.39	0.41	0.30	0.41	0.45	0.43	0.25	0.37
2005	0.00	0.02	0.14	0.22	0.21	0.21	0.23	0.42	0.26	0.18	0.22
2006	0.00	0.04	0.09	0.38	0.33	0.44	0.31	0.32	0.31	0.19	0.35
2007	0.00	0.02	0.15	0.24	0.30	0.31	0.36	0.40	0.37	0.08	0.26
2008	0.00	0.02	0.07	0.21	0.22	0.26	0.38	0.42	0.38	0.11	0.23
2009	0.00	0.04	0.15	0.09	0.25	0.24	0.53	0.39	0.45	0.12	0.16
2010	0.00	0.03	0.14	0.22	0.06	0.15	0.16	0.61	0.18	0.11	0.14
2011	0.00	0.03	0.13	0.16	0.18	0.04	0.35	0.09	0.17	0.05	0.12
2012	0.00	0.01	0.11	0.12	0.07	0.07	0.02	0.07	0.02	0.01	0.07
2013	0.00	0.02	0.03	0.06	0.03	0.03	0.01	0.01	0.01	0.005	0.04

Table 22. Projection inputs for eastern Georges Bank cod.

	Age Group									
	1	2	3	4	5	6	7	8	9	10+
Natural Mortality										
2014-2015	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)										
2014-2015	0.01	0.3	0.8	1	1	1	1	1	1	0.3
Fishery Partial Recruitment("estimate 2003 yc" model)										
2014-2015	0.01	0.2	0.7	1	1	1	1	0.7	0.4	0.1
Fishery Weight at Age										
2014	0.35	1.11	1.82	2.57	3.53	3.94	4.66	5.95	7.99	11.65
2015	0.35	1.11	1.82	2.57	3.53	3.94	4.66	5.95	7.99	11.65
Population Beginning of Year Weight at Age										
2015	0.04	0.59	1.21	1.99	2.93	4.02	4.72	6.09	6.63	11.65
2016	0.04	0.59	1.21	1.99	2.93	4.02	4.72	6.09	6.63	11.65

Table 23. 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												
2014	0.001	0.018	0.047	0.059	0.059	0.059	0.059	0.059	0.059	0.018		
2015	0.002	0.054	0.144	0.18	0.18	0.18	0.18	0.18	0.18	0.054		
Projected Population Numbers												
2014	1408	290	1036	2817	661	256	144	92	87	14		
2015	1408	1152	233	809	2174	510	109	61	39	43		
2016	1408	1151	894	166	553	1487	192	41	23	33		
Projected Population Biomass												
2014	113	163	1285	5127	2063	1215	680	606	575	162	11989	11713
2015	56	680	283	1611	6370	2052	512	371	259	500	12693	11957
2016	56	679	1081	329	1622	5977	904	248	152	383	11432	10696
Projected Catch Numbers												
2014	1	5	43	147	34	10	6	4	3	0		
2015	2	55	28	121	326	59	12	7	4	2		
Projected Catch Biomass												
2014	0	5	79	377	121	40	27	22	27	2	700	695
2015	1	61	52	311	1149	231	58	42	36	18	1959	1897

Table 24. 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 Fref.

Probability of exceeding F_{ref} in 2015	**0.25**	**0.5**	**0.75**
“M 0.8”(F =0.11)	1,000 mt	1,150 mt	1,350mt
“estimate 2003 yc”(F =0.11)	1,050 mt	1,200mt	1,350 mt
“M 0.8”(F_{ref}=0.18)	1,625 mt	1,850 mt	2,150 mt

b. Changes in adult biomass from 2015 to 2016.

Risk (75%) that biomass will not increase by:	**0%**
“M 0.8”	225 mt
“estimate 2003 yc”	175 mt

Table 25. 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												
2014	0.001	0.018	0.047	0.059	0.059	0.059	0.059	0.059	0.059	0.018		
2015	0.001	0.033	0.088	0.11	0.11	0.11	0.11	0.11	0.11	0.033		
Projected Population Numbers												
2014	1408	290	1036	2817	661	256	144	92	87	14		
2015	1408	1152	233	809	2174	510	109	61	39	43		
2016	1408	1152	913	175	594	1594	205	44	25	34		
Projected Population Biomass												
2014	113	163	1285	5127	2063	1215	680	606	575	162	11989	11713
2015	56	680	283	1611	6370	2052	512	371	259	500	12693	11957
2016	56	679	1104	348	1739	6410	970	266	163	400	12136	11401
Projected Catch Numbers												
2014	1	5	43	147	34	10	6	4	3	0		
2015	1	34	18	77	206	37	8	4	3	1		
Projected Catch Biomass												
2014	0	5	79	377	121	40	27	22	27	2	700	695
2015	0	38	32	197	726	145	37	26	23	11	1235	1197

b. “estimate 2003 yc” model

	Age Group											
	1	2	3	4	5	6	7	8	9	10+	1+	3+
Fishing Mortality												
2014	0	0.011	0.039	0.055	0.055	0.055	0.055	0.039	0.022	0.006		
2015	0	0.022	0.077	0.11	0.11	0.11	0.11	0.077	0.044	0.011		
Projected Population Numbers												
2014	1579	324	1117	3142	748	305	172	138	23	78		
2015	1579	1293	262	880	2434	580	130	73	60	45		
2016	1579	1293	1035	199	645	1785	233	52	30	46		
Projected Population Biomass												
2014	126	181	1385	5718	2334	1446	814	909	154	912	13981	13673
2015	63	763	317	1750	7131	2330	612	446	396	527	14336	13510
2016	63	763	1253	396	1890	7176	1101	318	202	533	13695	12869
Projected Catch Numbers												
2014	0	3	39	154	37	11	6	4	0	0		
2015	0	26	18	83	230	42	9	4	2	0		
Projected Catch Biomass												
2014	0	4	70	395	129	45	30	22	3	3	700	696
2015	0	28	32	214	813	165	44	22	14	4	1336	1308

Table 26. 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). To be updated

		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<=Fref & 10% biomass increase in 2015		
(light blue)	F< =Fref & biomass increase < 10% in 2015		
(red)	F>Fref and biomass increase < 10% in 2015		
(dark grey)	not feasible projection		

Table 28. 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 Fref. 20% chance of decrease in biomass from 2004-2005.	1,300 mt	Neutral risk of exceeding Fref. 20% chance of decrease in biomass from 2004-2005.	2,332 mt Exceed Fref 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 Fref. 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 = 0.22 Biomass decreased 4% 05 - 06
2005	2006	2,200 mt	Neutral risk of exceeding Fref. Low risk of less than 10% biomass increase from 2006 - 2007.	1,700 mt	Low risk of exceeding Fref, 75% probability of stock increase of 10%	1,705 mt Approx 25% risk of exceeding Fref; biomass increase not likely to be 20%	*F=0.15* *Biomass stabled* Now F = 0.35 Biomass increased 19% 06 - 07
2006[4]	2007	(1) 2,900 mt (2) 1,500 mt	(1) Neutral risk of exceeding Fref. (2) Neutral risk of biomass decline from 2007 – 2008.	1,900 mt	Low risk of exceeding Fref, nominal decline in stock size	1,811mt No risk of exceeding Fref; neutral risk of biomass decline	*F=0.13* *Biomass stabled* Now F = 0.26; Biomass decreased 5% 07-08
2007[4]	2008	2,700 mt	Neutral risk of exceeding Fref and a neutral risk of stock decline	2,300 mt	Low risk of exceeding Fref, nominal stock size increase	1,780 mt No risk of exceeding Fref; biomass not expected to increase	*F = 0.25 or 0.17* *Biomass increased 16%/19%*

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch[1] /Compared to Risk Analysis	Actual F Result[2]
			from 2008 - 2009			10%	Now 0.23; Biomass increased 16% 08-09;
2008[4]	2009	(1) 2,100 mt (2) 1,300 mt	(1) Neutral risk of exceeding Fref (2) neutral risk of stock decline from 2009 - 2010	1,700 mt	Low risk of exceeding Fref, high risk biomass will not increase	1,837 mt Slightly less than neutral risk of exceeding Fref; biomass almost certain not to increase	*F = 0.33 or 0.20 Biomass stable or declined 7%* Now F=0.16; Biomass decreased 10% 09-10;
2009[4]	2010	(1) 1,300 – 1,700 mt (2) 1,800 – 900 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock decline from 2010 - 2011	1,350 mt	Neutral risk of biomass decline	1,326 mt	*F = 0.41 or 0.25 Biomass decreased 15%/ 17%* Now F=0.14; Biomass decreased 14% 10-11;
2010[4]	2011	(1) 1,000 – 1,400 mt (2) 1,850 – 1,350 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock decline from 2011 - 2012	1,050 mt	Low risk of exceeding Fref, and biomass growth of up to 10%.	1,037 mt	*F = 0.49 or 0.28 Biomass increased 6%/stable* Now F= 0.12; Biomass increased 22% 11-12
2011	2012	(1) 600 – 925 mt (2) 1,350 – 900 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock decline from 2012 – 2013	675 mt	Low risk of exceeding Fref, and low to neutral risk of biomass decline	614mt	*F=0.07; Biomass increased 16%* Now F= 0.07; Biomass increased 27% 12-13
2012	2013	(1) 400 – 775 mt (2) 400 – 575 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock not increase by 20% from 2013 – 2014	600mt	Neutrual risk of exceeding Fref, and stock biomass increase more than 10%	463mt	*F=0.04; Biomass increased 13%*
2013	2014	600mt	(1) low risk of exceeding Fref	700mt	Low risk of exceeding Fref, and stock		

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch[1] /Compared to Risk Analysis	Actual F Result[2]
			(2) Neutral risk of stock not increase by10% from 2014 – 2015		biomass increase close to 10%		

[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

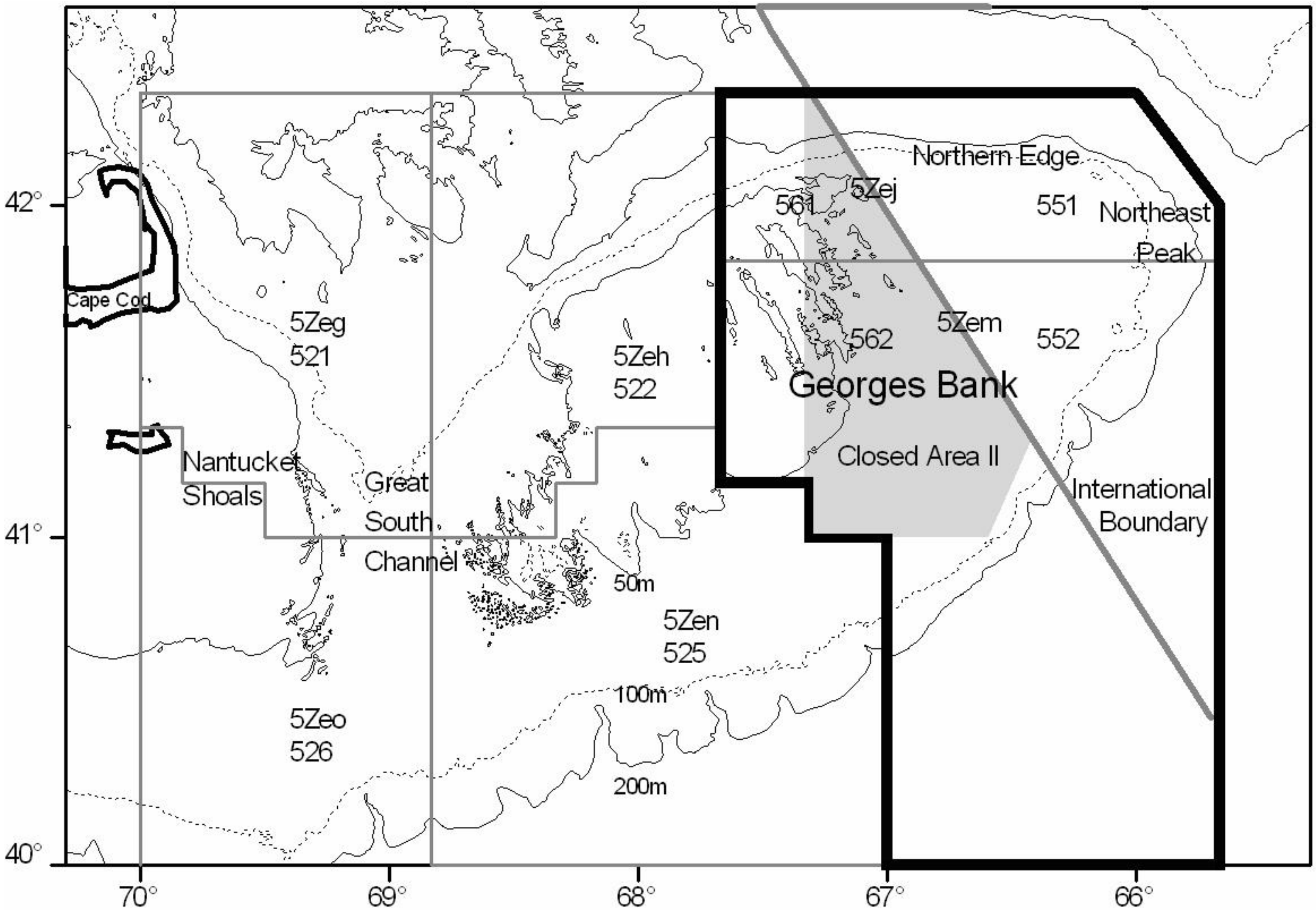


Figure 1. Fisheries statistical unit areas (CANADA and USA) in NAFO Subdivision 5Ze. The eastern Georges Bank management unit is outlined by a heavy black line.

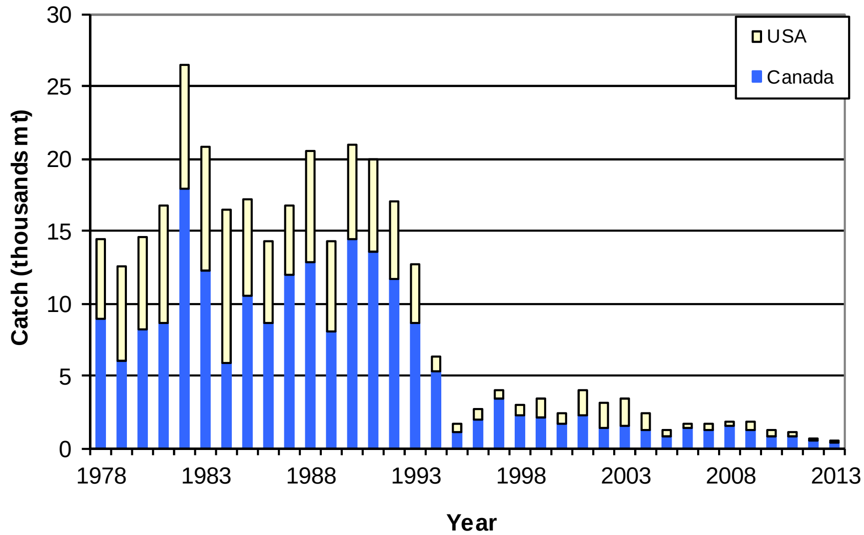
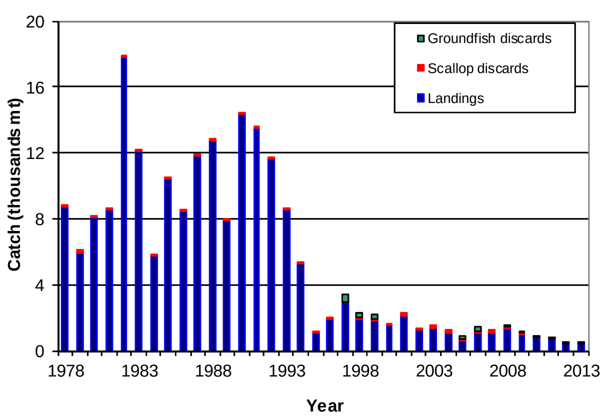


Figure 2. Catches of cod from eastern Georges Bank, 1978 to 2013.



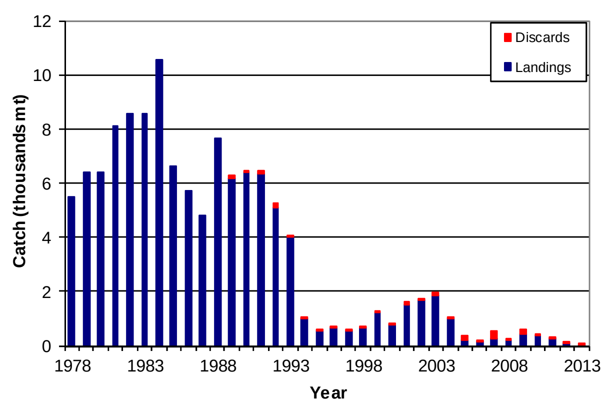


Figure 3. Canadian and USA landings and discards of cod from eastern Georges Bank, 1978 to 2013.

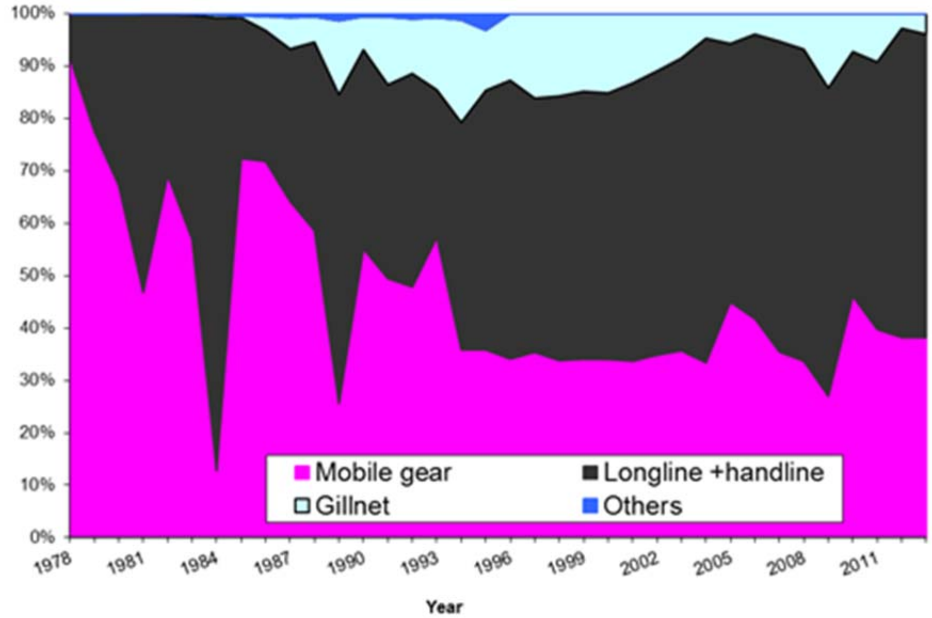
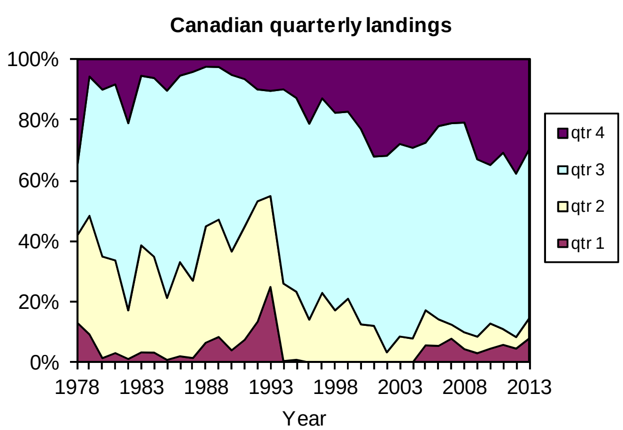


Figure 4. Proportion of Canadian gear specific landings of cod from eastern Georges Bank for 1978 to 2012.



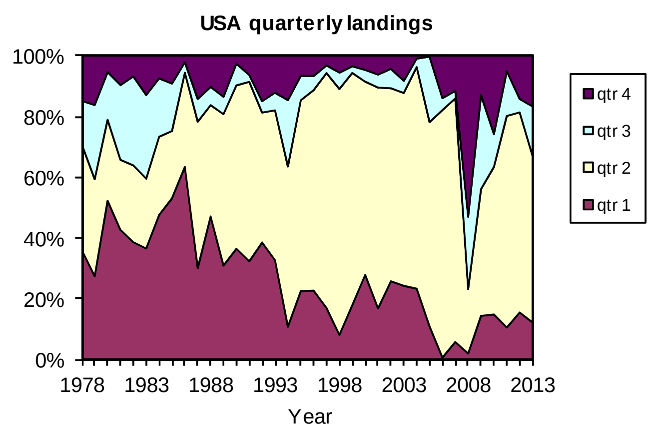


Figure 5. Proportion of Canadian and USA quarterly landings of cod from eastern Georges Bank, 1978 to 2012.

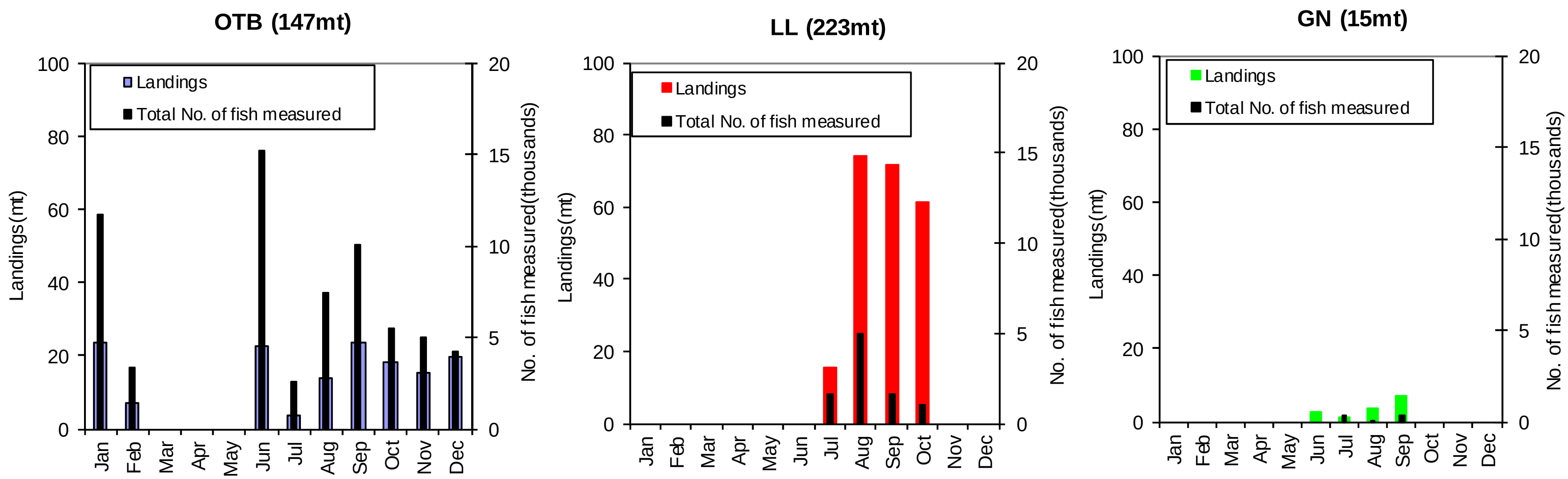


Figure 6. Landings (wide bars) and sampling (narrow dark bars) of cod by gear and month from the 2013 Canadian bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on eastern Georges Bank.

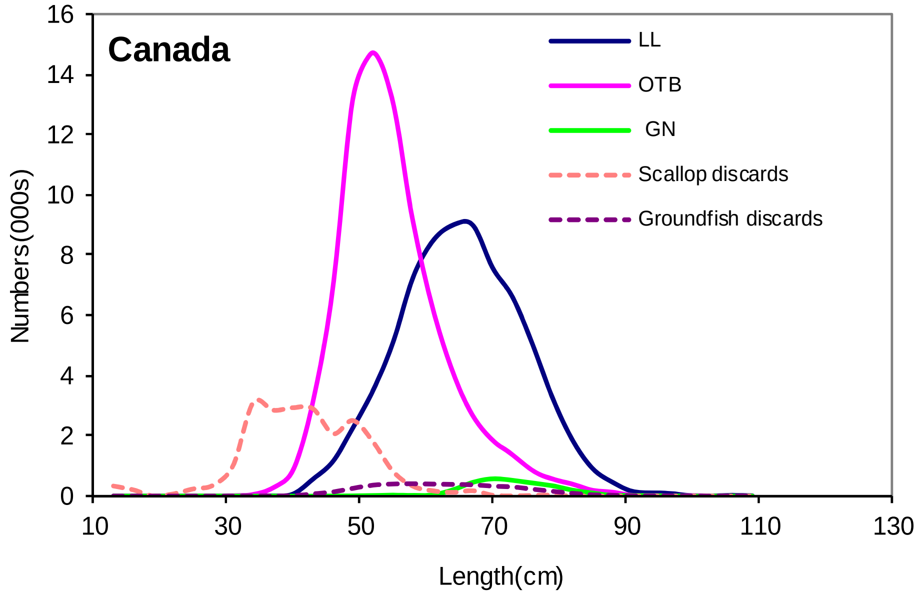


Figure 7. Cod catches at length by gear from the 2013 Canadian fisheries on eastern Georges Bank.

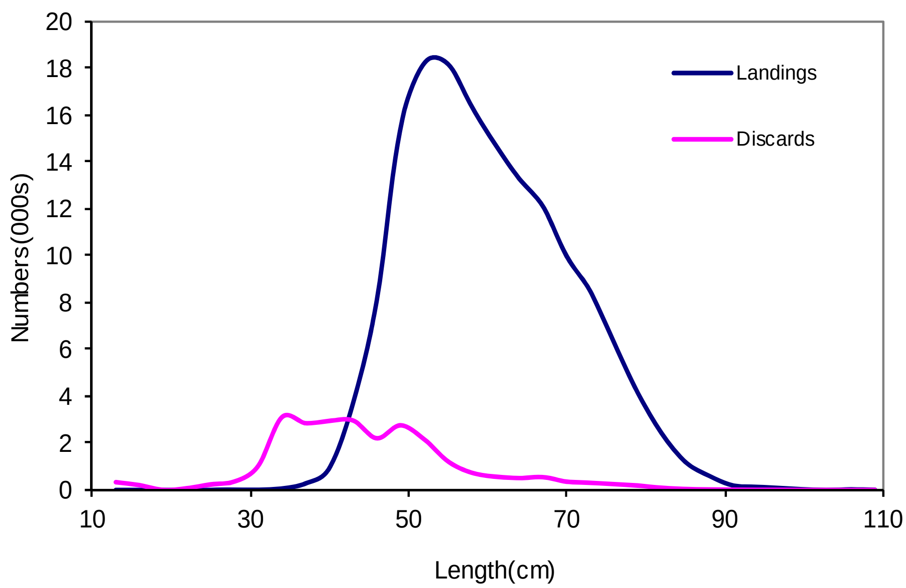


Figure 8. Cod landings and discards at length from the 2013 Canadian fisheries on eastern Georges Bank.

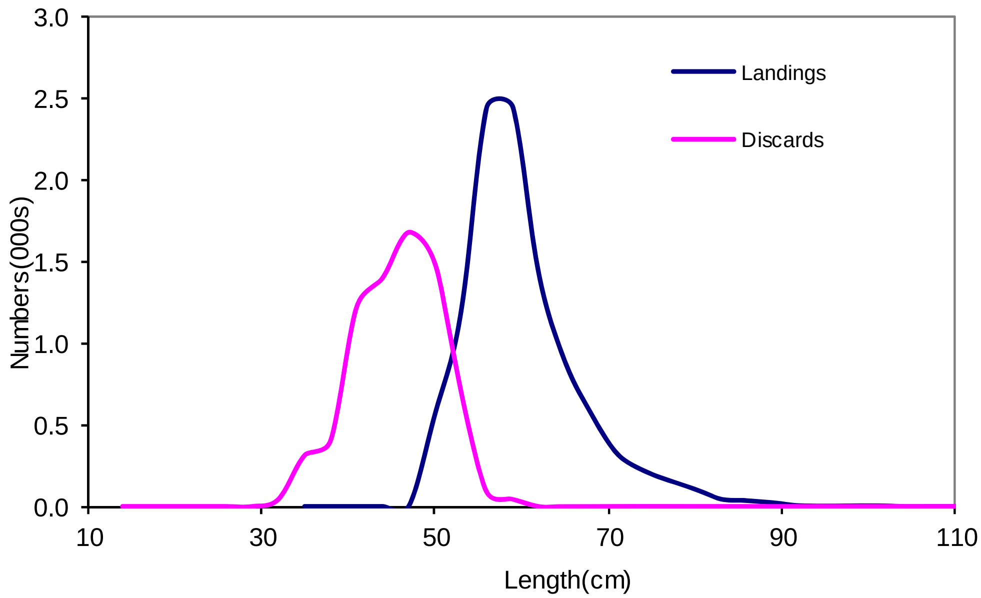


Figure 9. Cod landings and discards at length from the 2013 USA fisheries on eastern Georges Bank.

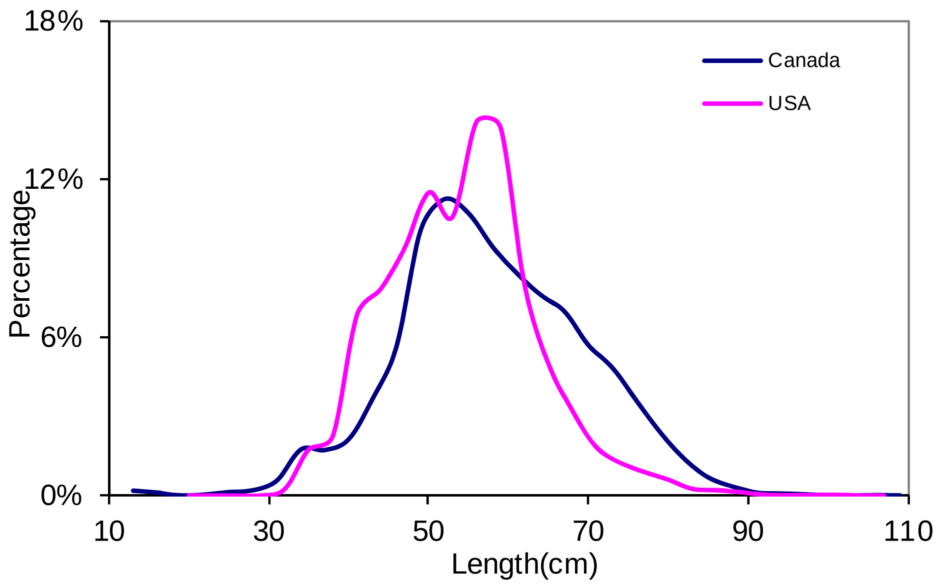
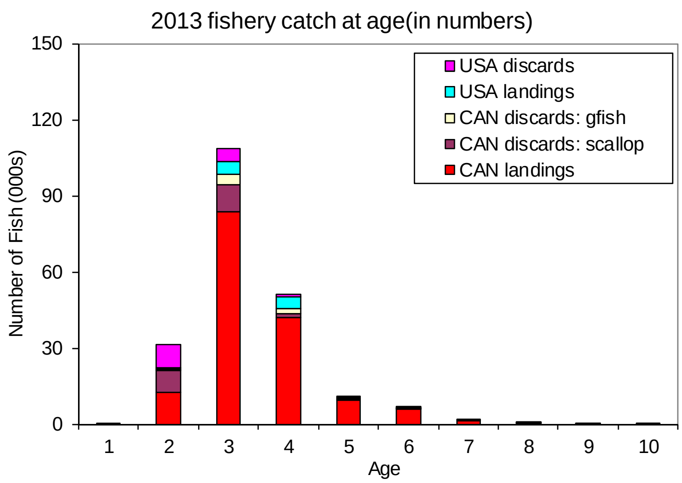


Figure 10. Cod length frequency from the 2013 Canadian and USA fisheries on Eastern Georges Bank.



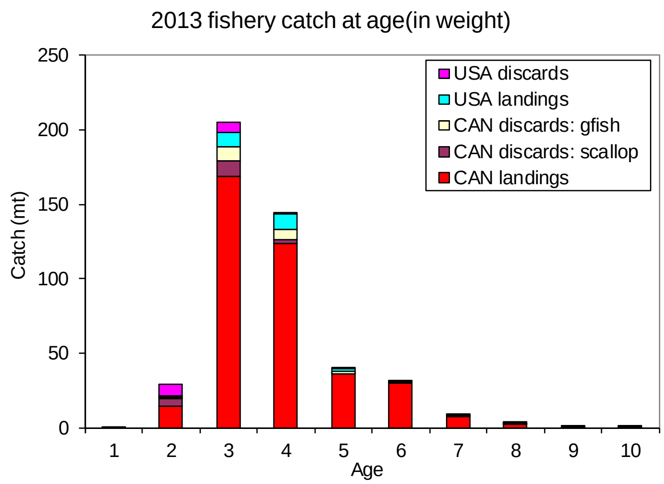
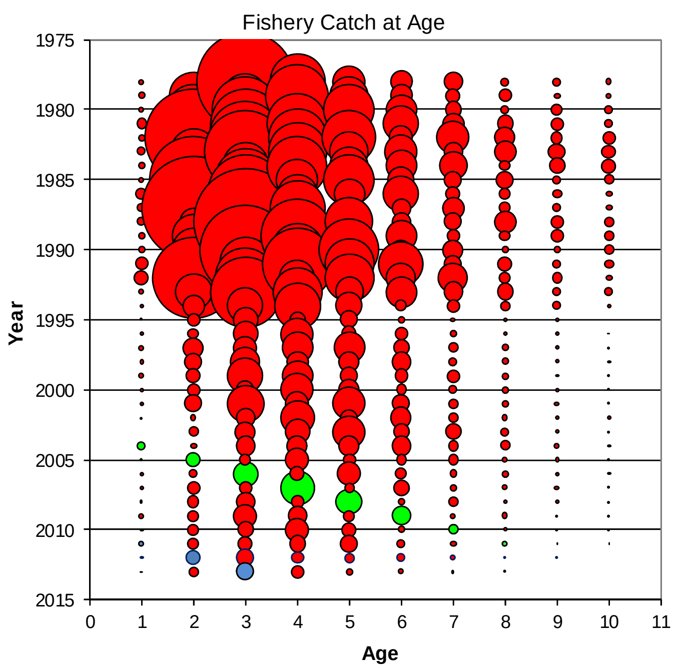


Figure 11. Catch at age in numbers (left) and weight (right) for landings and discards of cod from the 2013 eastern Georges Bank fisheries.



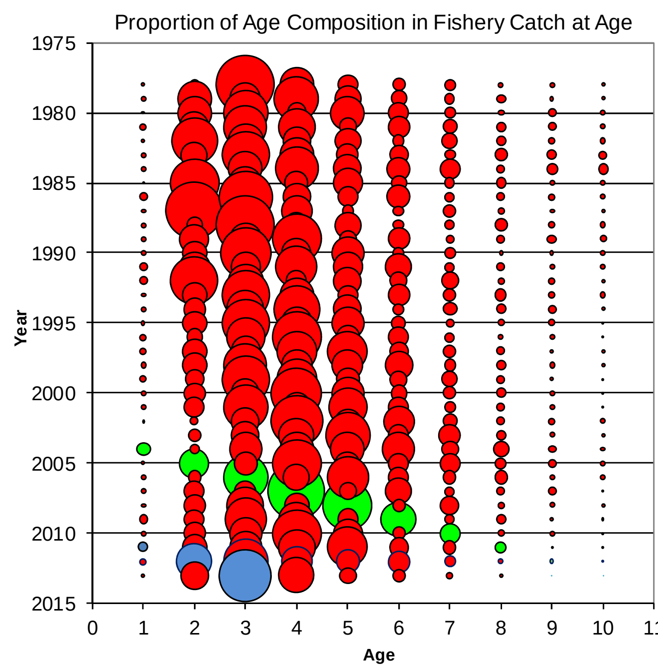


Figure 12. Total catch at age (numbers) of cod (left) and proportion of catch at age from eastern Georges Bank for 1978 to 2013. The bubble area is proportional to the magnitude. The light green circles are the 2003 year class and the light blue circles are the 2010 year class.

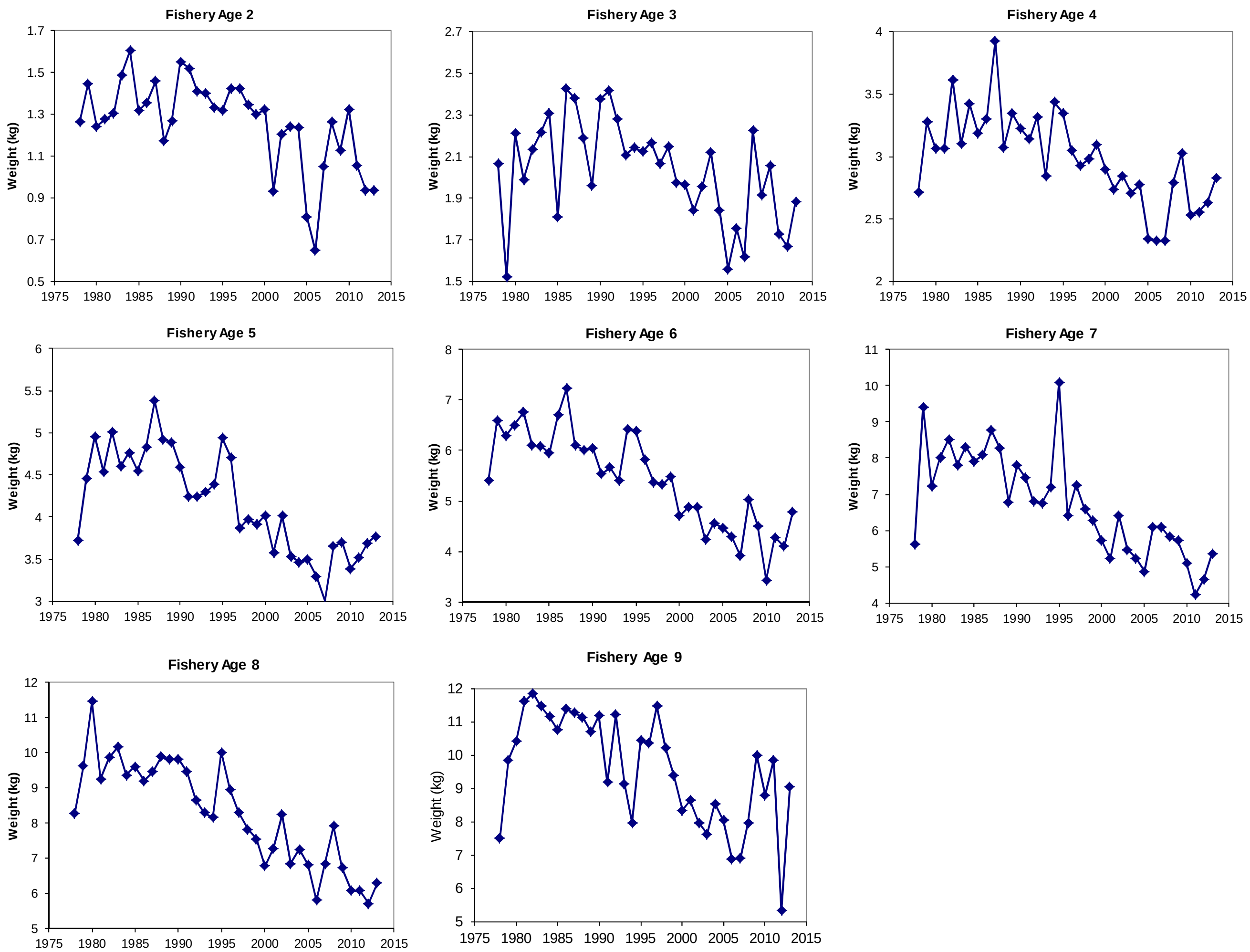


Figure 13. Average weight at age for ages 2 to 9 of cod from the eastern Georges Bank fishery, 1978 to 2013.

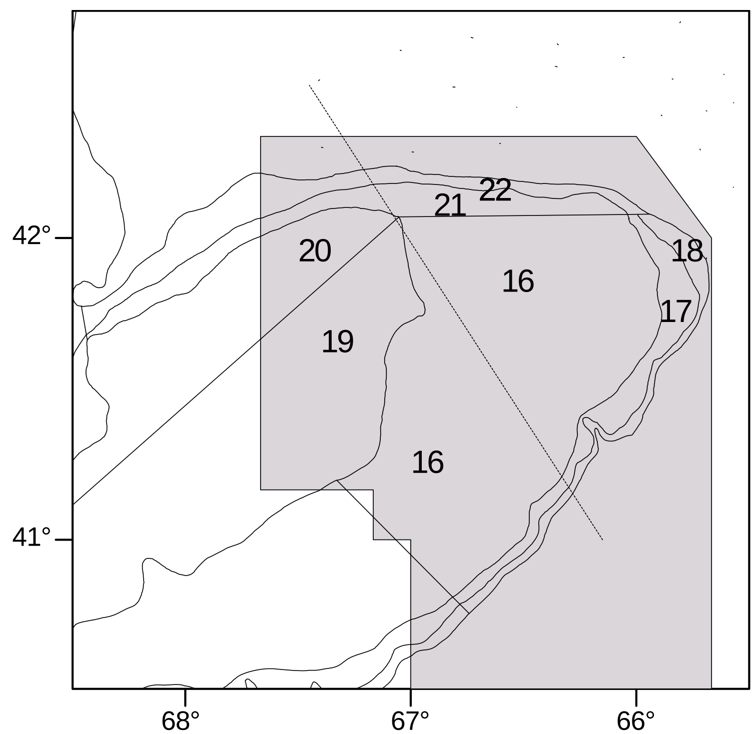


Figure 14. Stratification used for the NMFS surveys. The eastern Georges Bank management unit is indicated by shading.

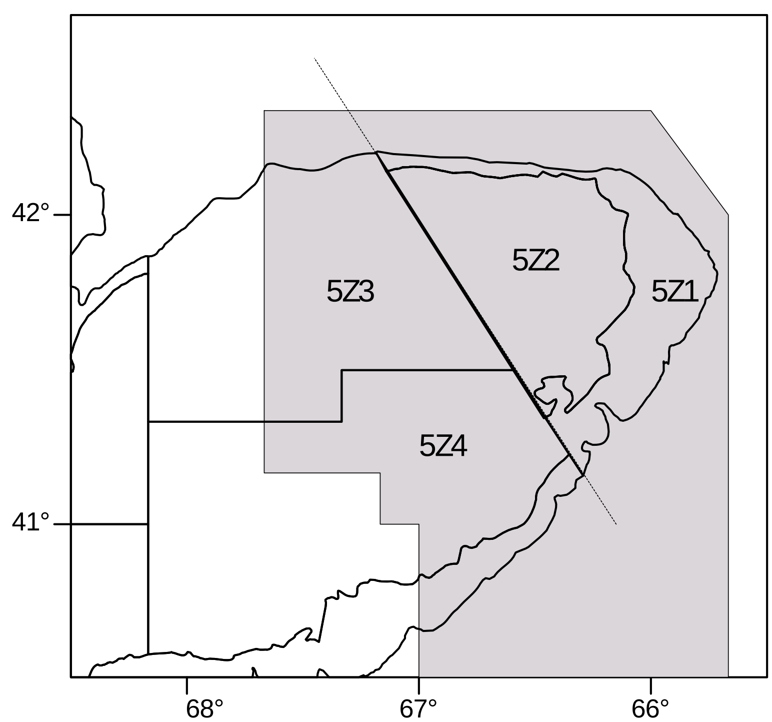


Figure 15. Stratification used for the DFO survey. The eastern Georges Bank management unit is indicated by shading.

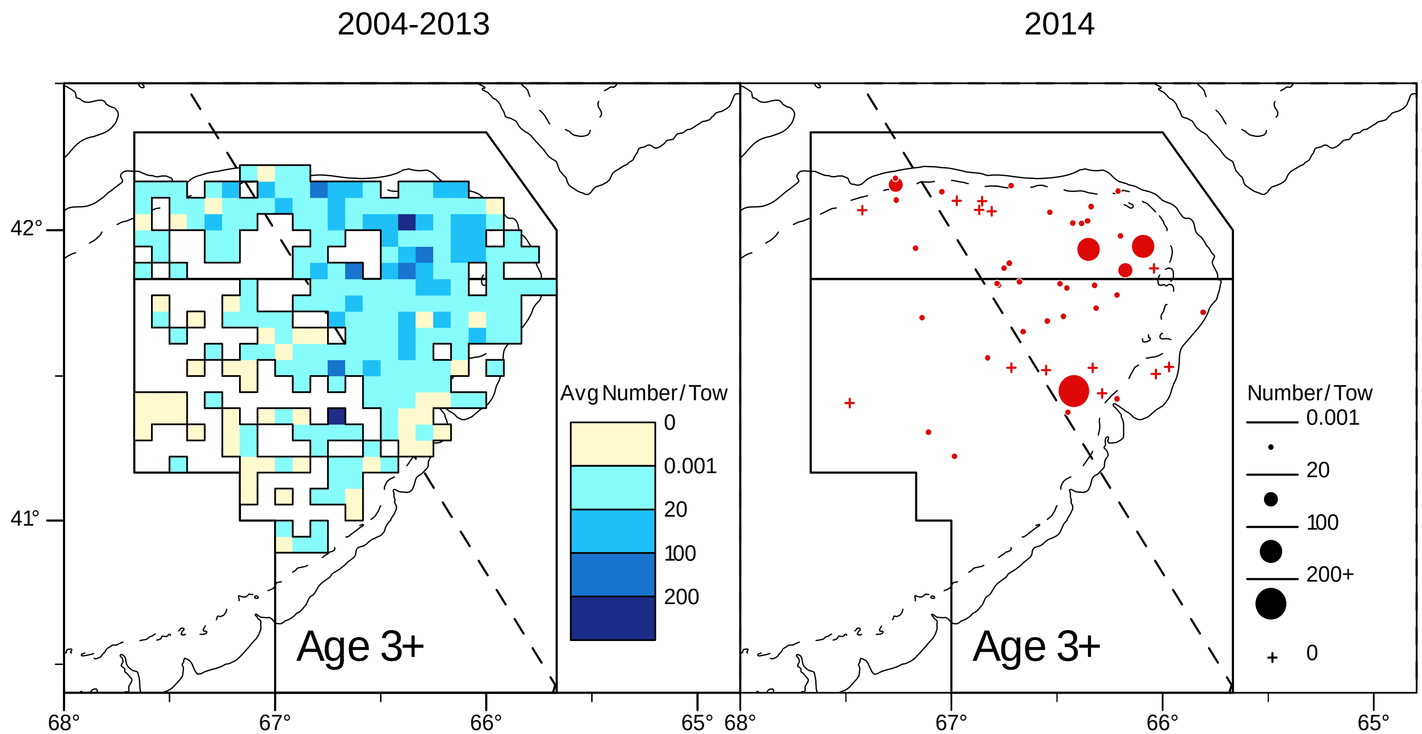


Figure 16. Spatial distribution of age 3+ cod on eastern Georges Bank from the DFO survey for 2014 (right panel) compared to the average for 2004 to 2013 (left panel).

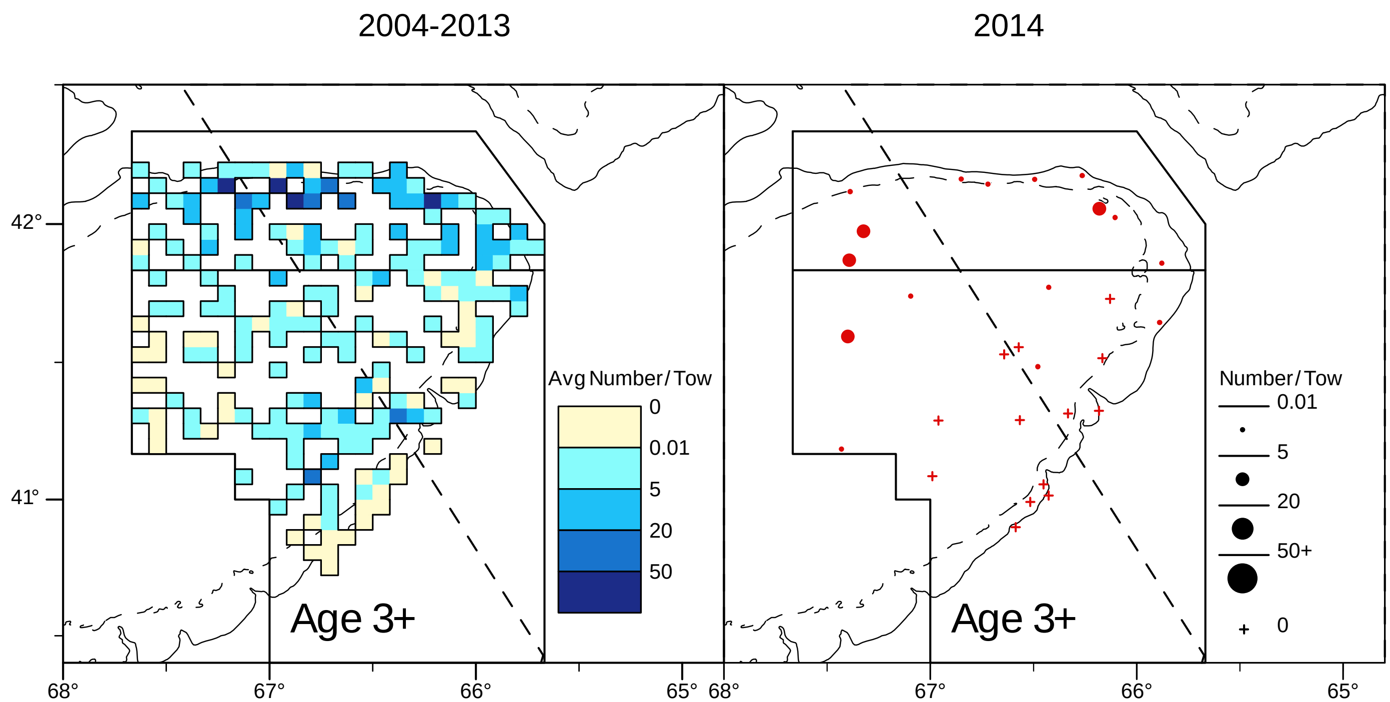


Figure 17. Spatial distribution of age 3+ cod on eastern Georges Bank from the NMFS spring survey for 2014 (right panel) compared to the average for 2004-2013(left panel).

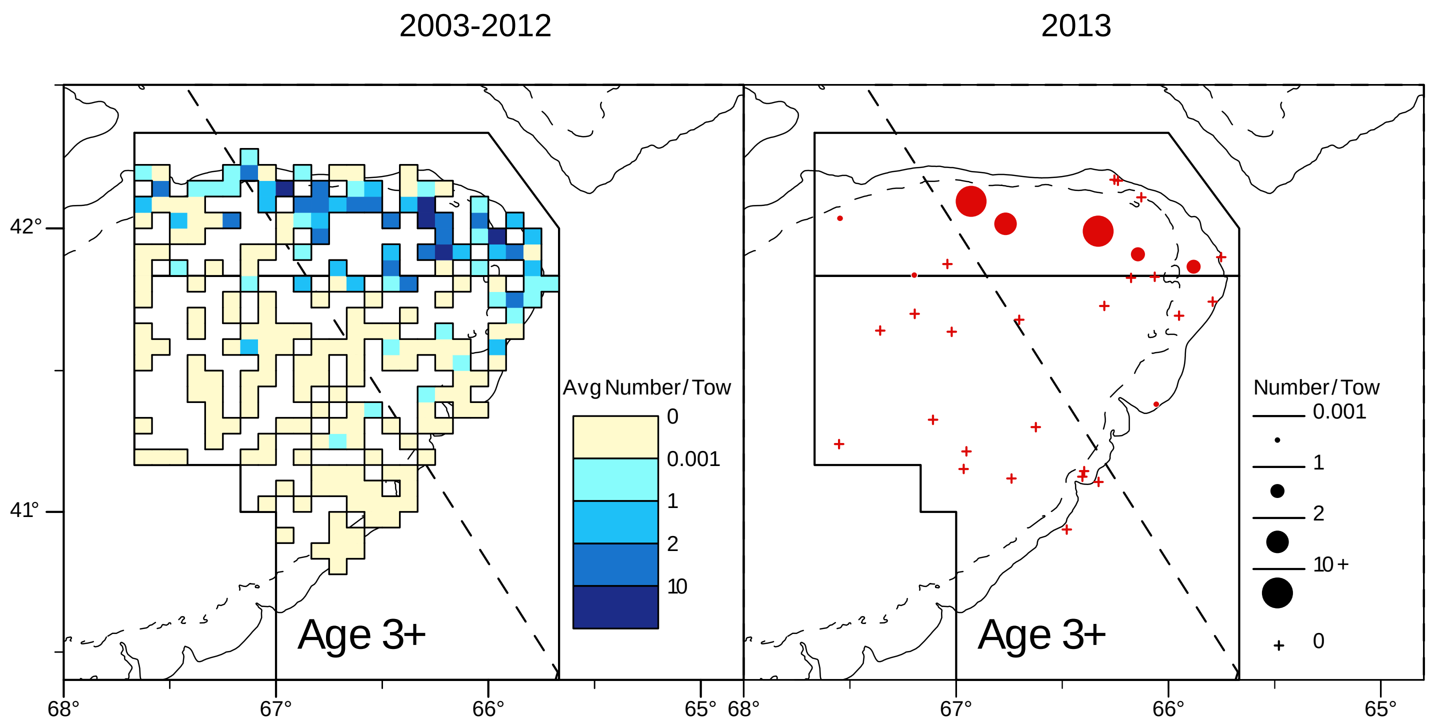


Figure 18. Spatial distribution of age 3+ cod on eastern Georges Bank from the NMFS fall survey for 2013 (right panel) compared to the average for 2003-2012 (left panel).

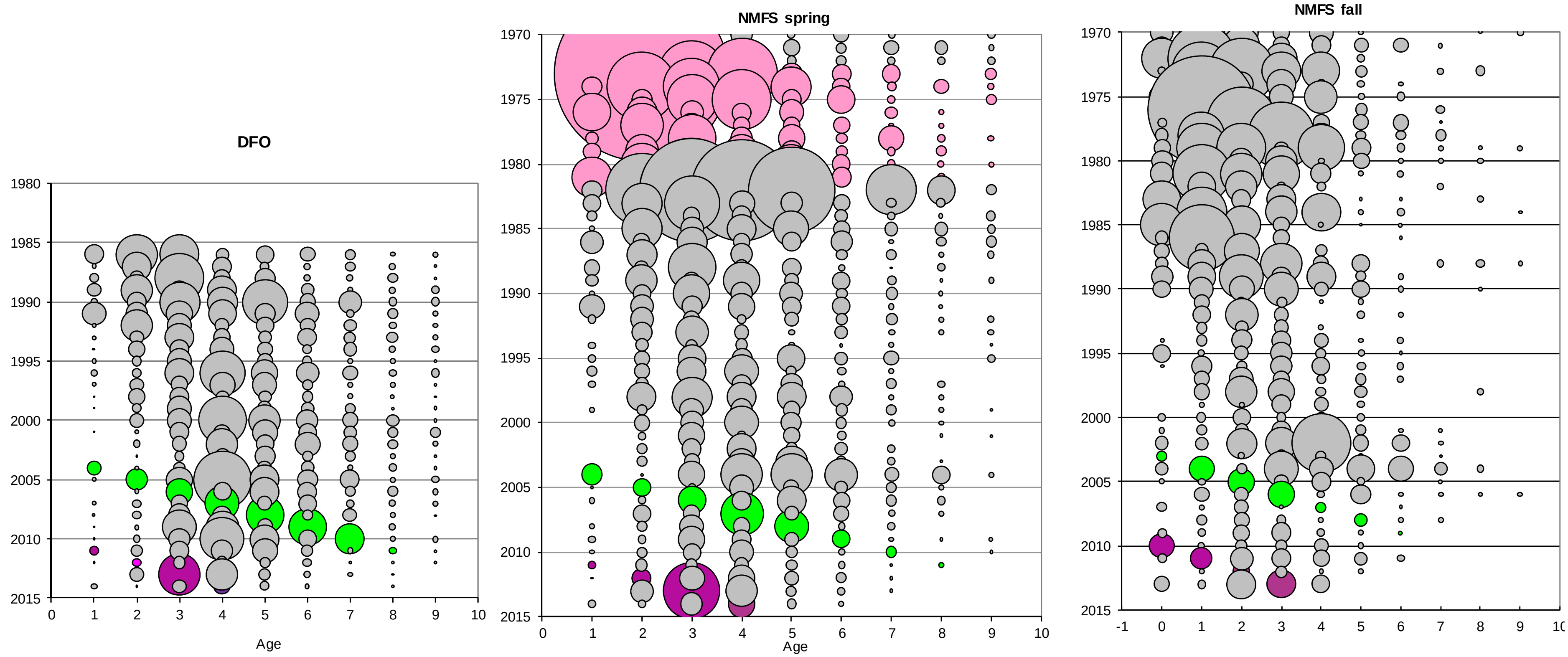


Figure 19. Survey abundance at age (numbers) of eastern Georges Bank cod. The bubble area is proportional to magnitude within each survey. Conversion factors to account for changes in door type, net and survey vessel were applied to the NMFS surveys. The NMFS spring survey was conducted using a modified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

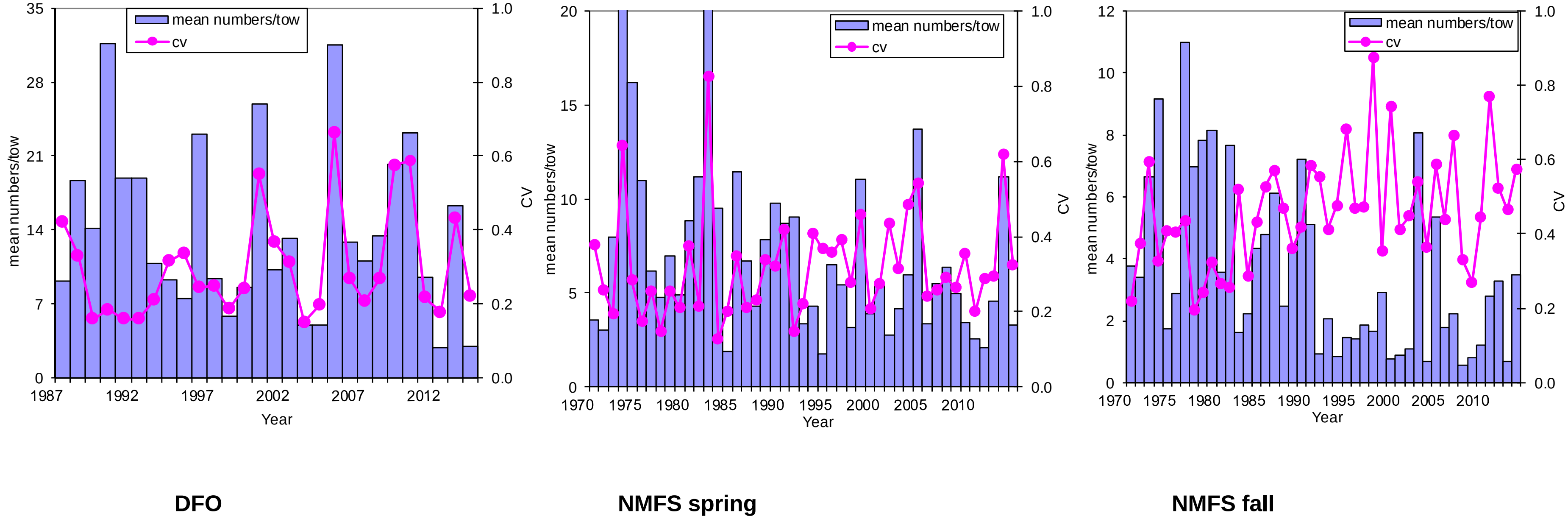


Figure 20. Stratified mean number/tow and coefficient of variation (CV) for DFO, NMFS spring and fall survey catch of EGB cod.

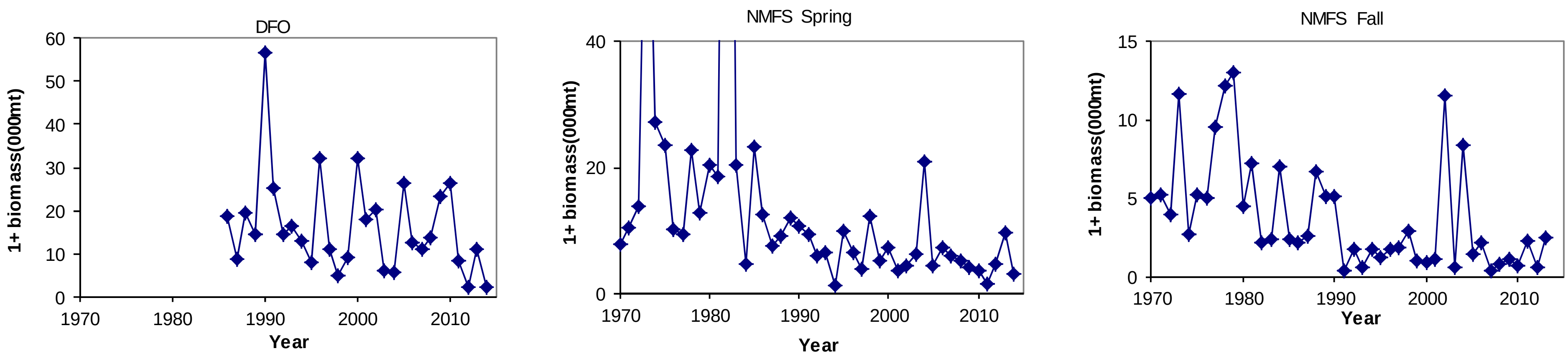


Figure 21. Survey biomass indices (ages 1+) for eastern Georges Bank cod from the DFO spring and NMFS spring and fall surveys, 1978-2014.

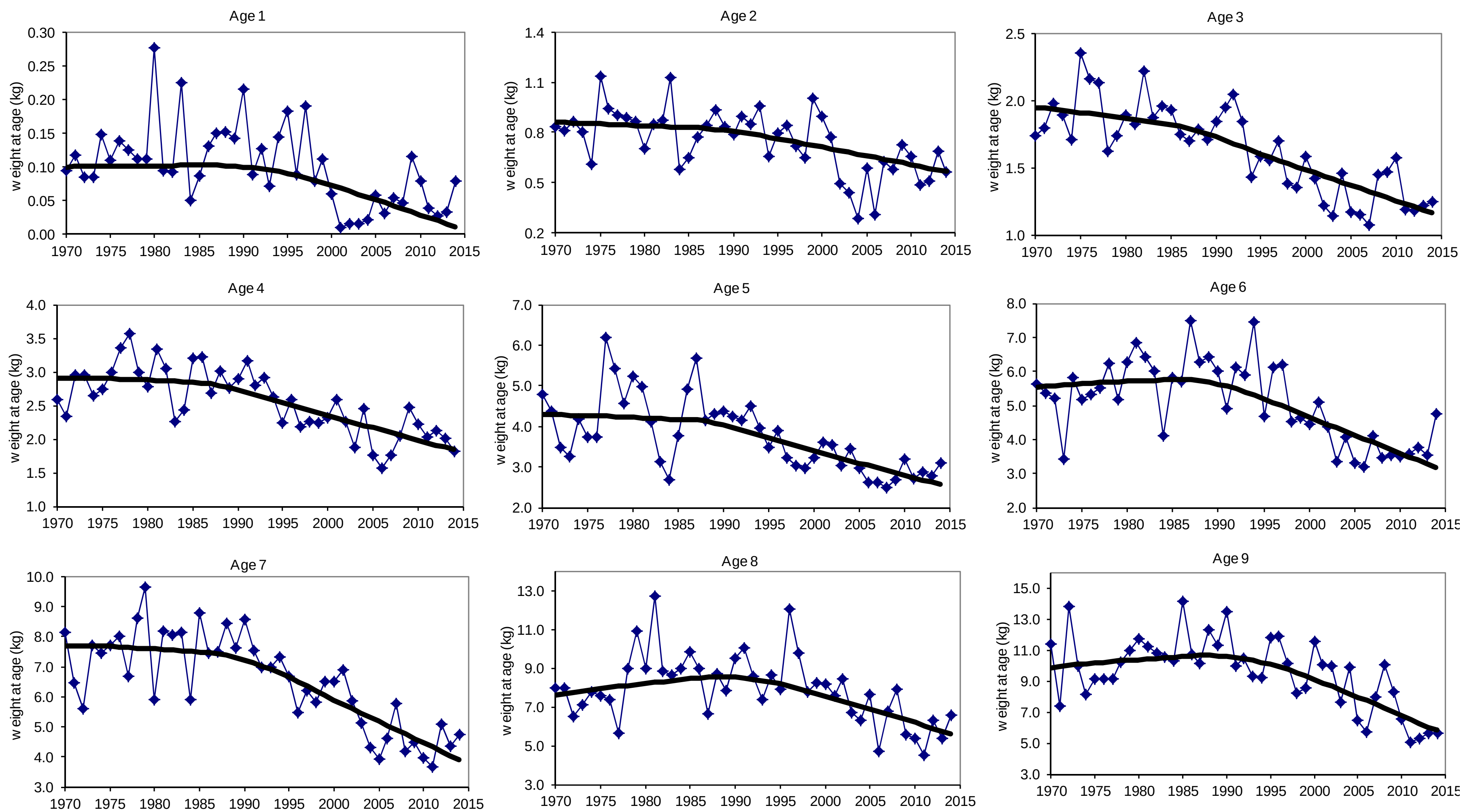


Figure 22. Beginning of year weight at age of eastern Georges Bank cod from DFO and NMFS spring surveys. The lines show the smoothed values using the LOESS method.

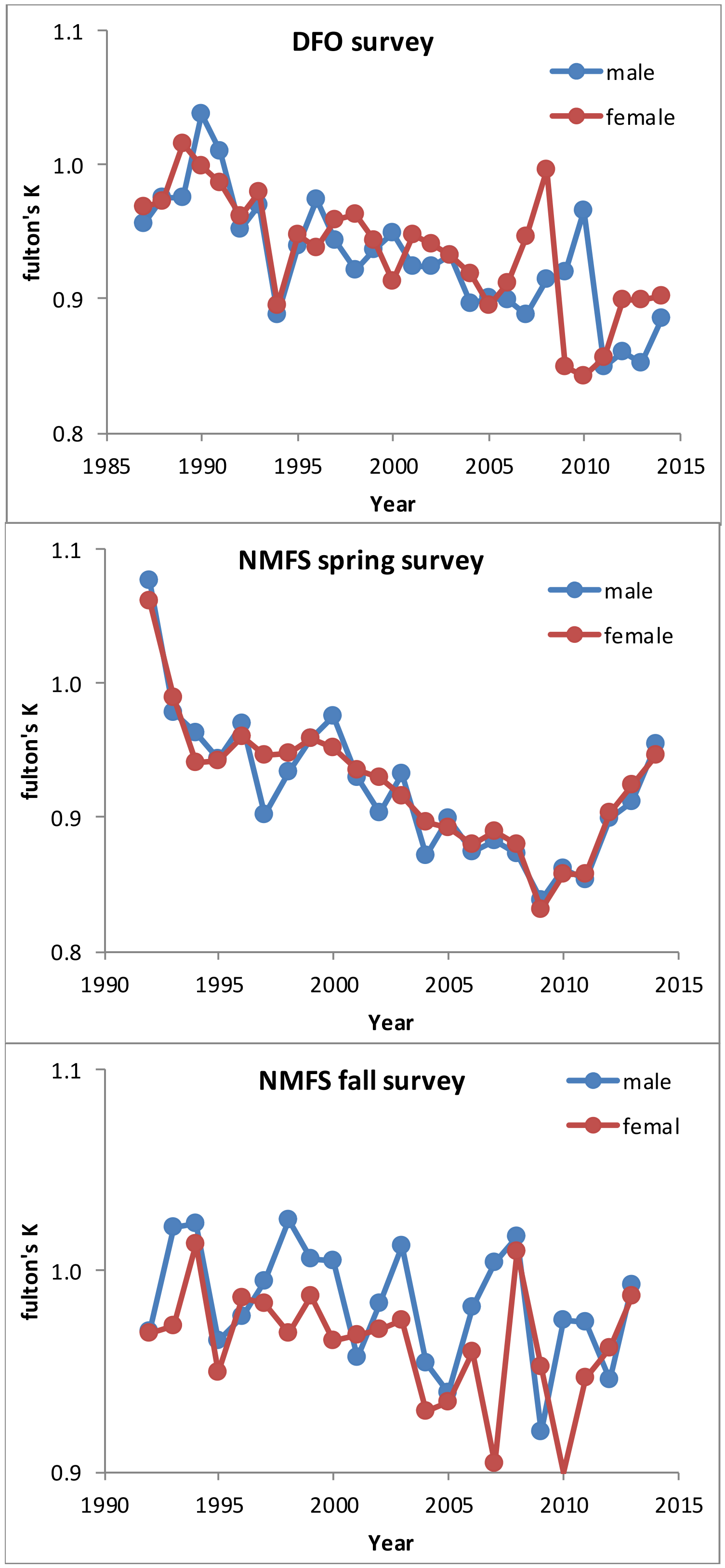


Figure 23. Fish condition (Fulton's K) for eastern Georges Bank cod.

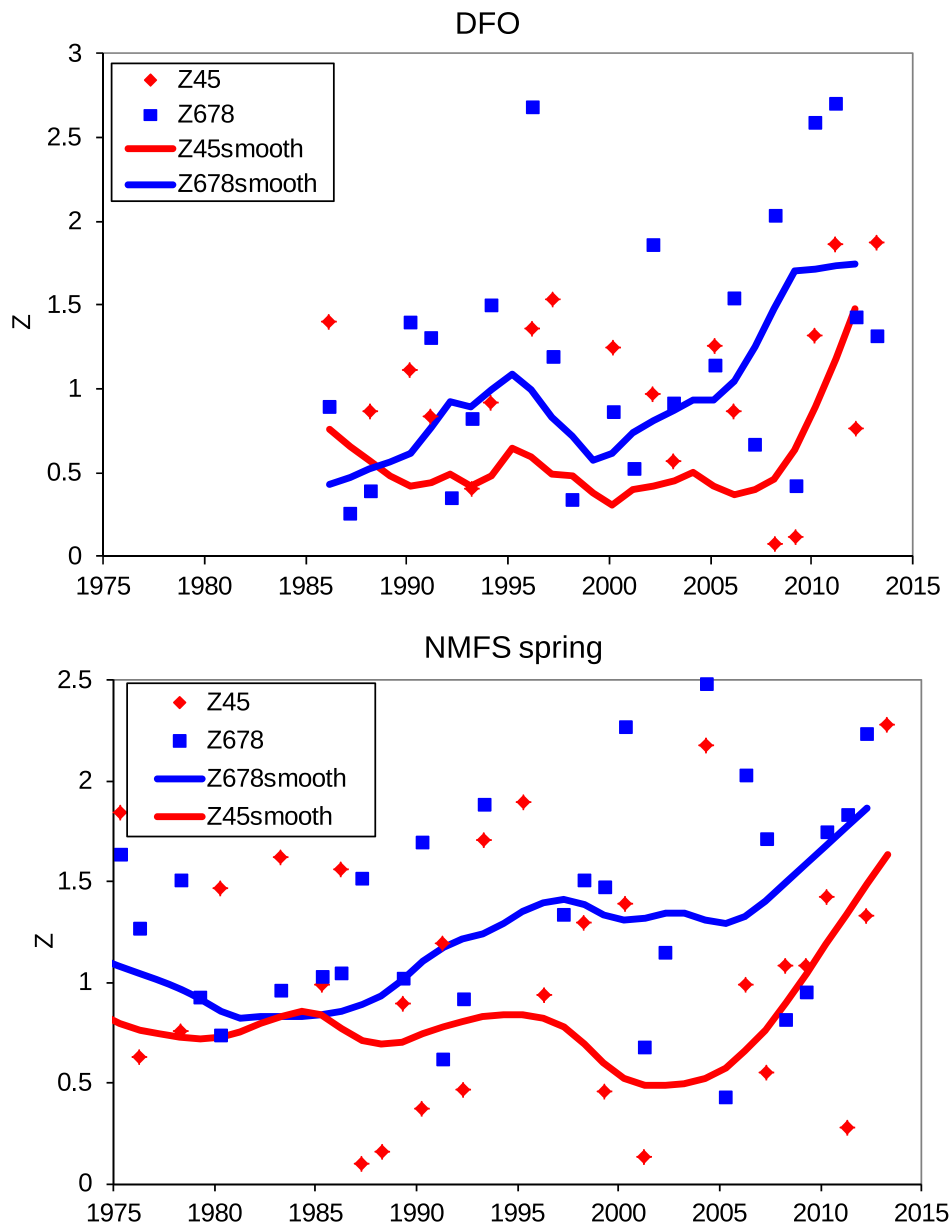


Figure 24. Total mortality(Z) calculated using the DFO and NMFS spring surveys data for eastern Georges Bank cod.

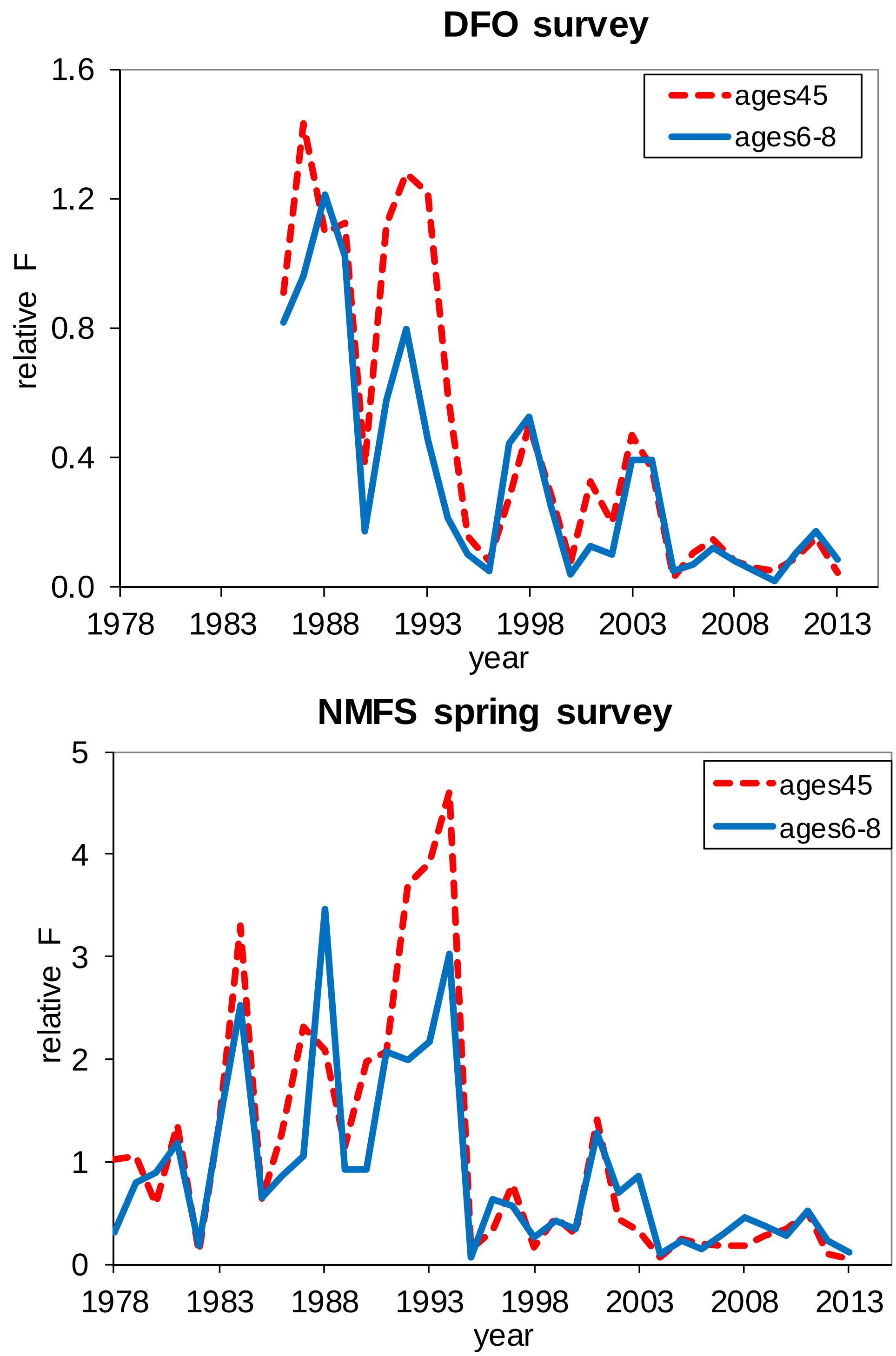


Figure 25. Relative F for eastern Georges Bank cod.

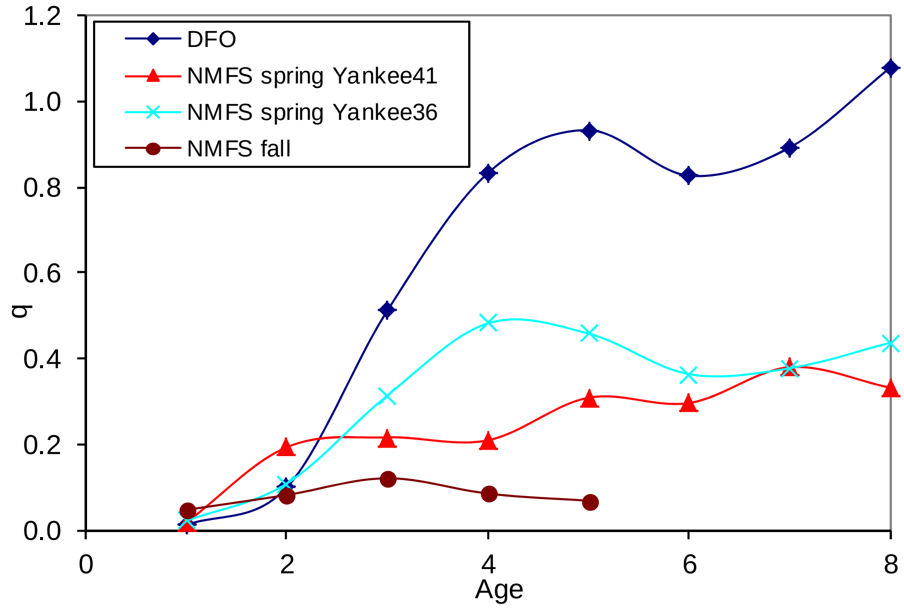


Figure 26. Survey catchability (*q*) for the DFO, NMFS spring and NMFS fall surveys for eastern Georges Bank cod.

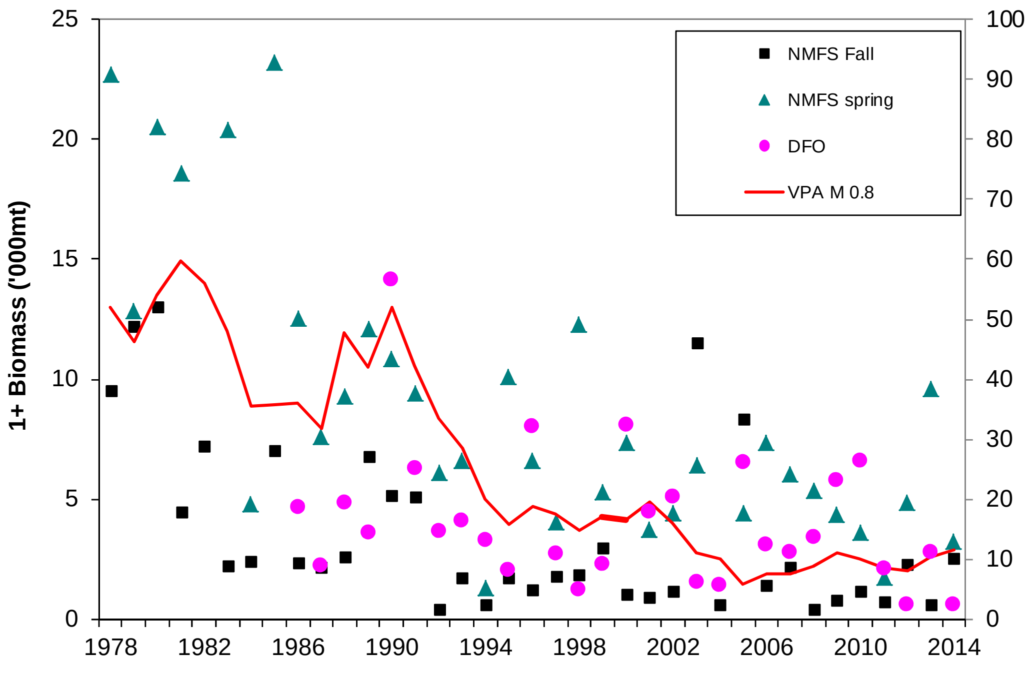


Figure 27. Age 1+ biomass from survey and VPA estimation.

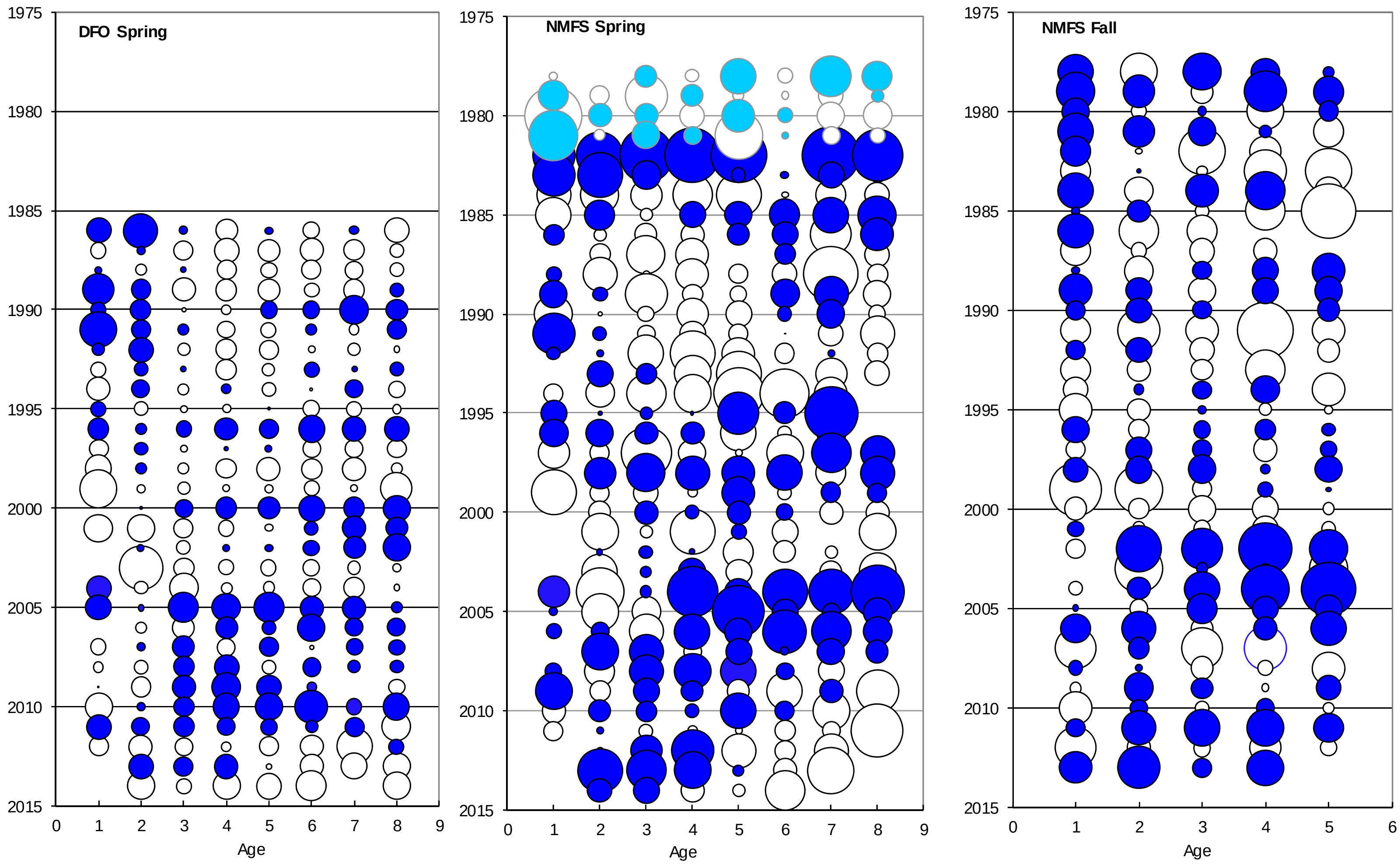


Figure 28. Residuals by year and age group from survey indices for eastern Georges Bank cod. Solid bubbles indicate positive values, open bubbles indicate negative values and the bubble area is proportional to magnitude. The NMFS spring survey was conducted using a modified Yankee 41 from 1978 to 1981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

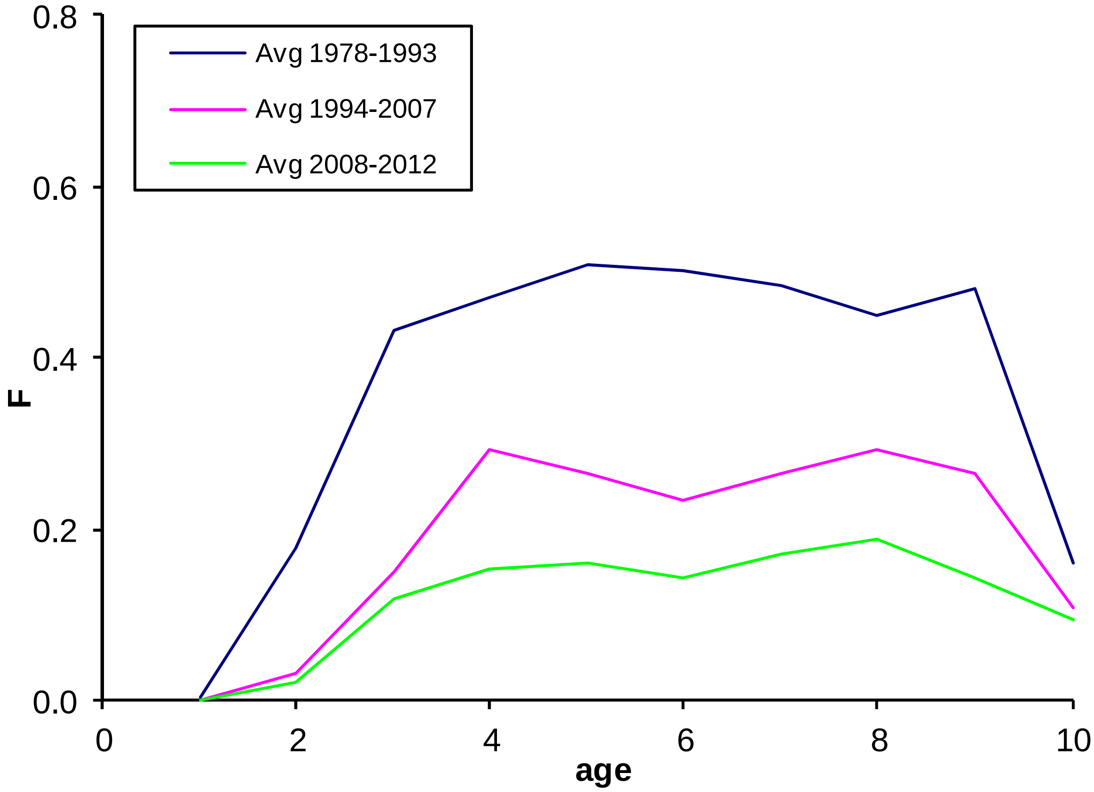


Figure 29. Average fishing mortality (F) for eastern Georges Bank cod in three time series blocks (1978-1993, 1994-2007, 2008-2012).

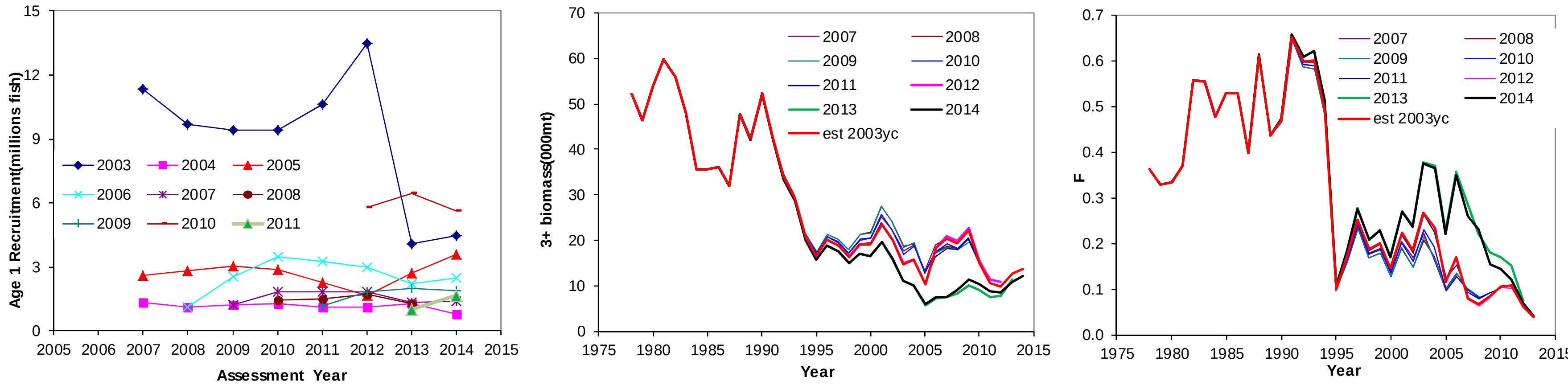


Figure 30. Retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the “M 0.8” model in 2013 assessment. ‘estimate 2003yc’ is the sensitivity run in 2014.

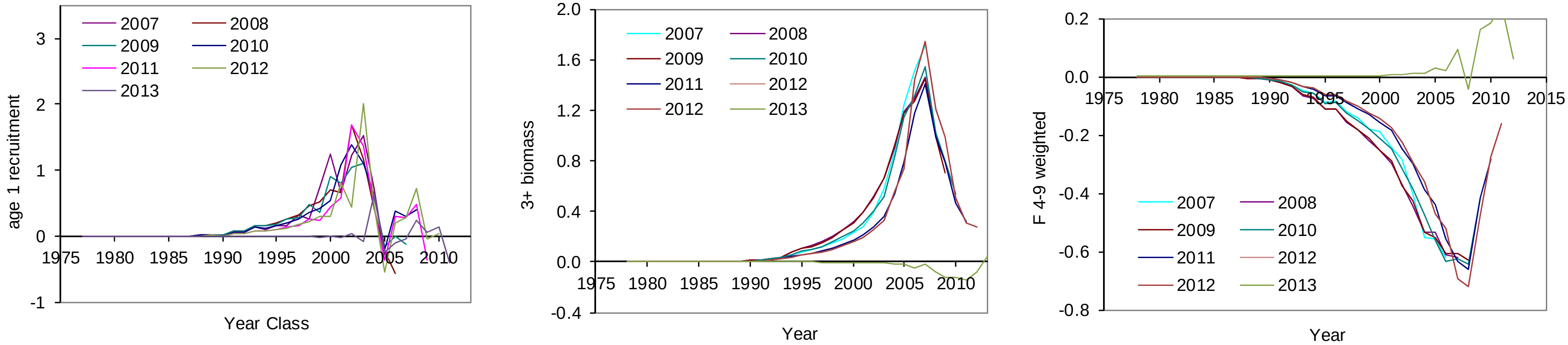
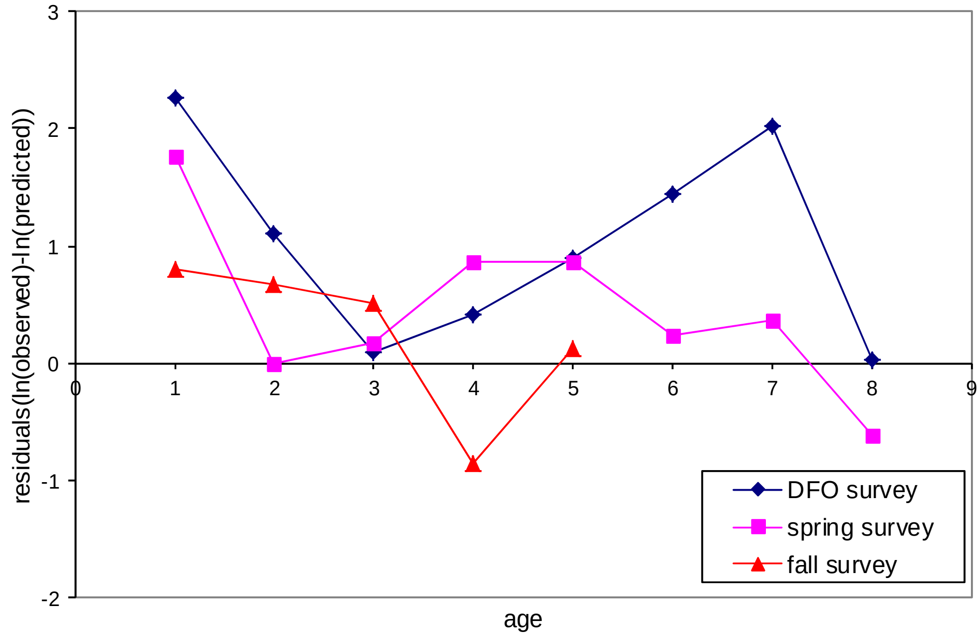
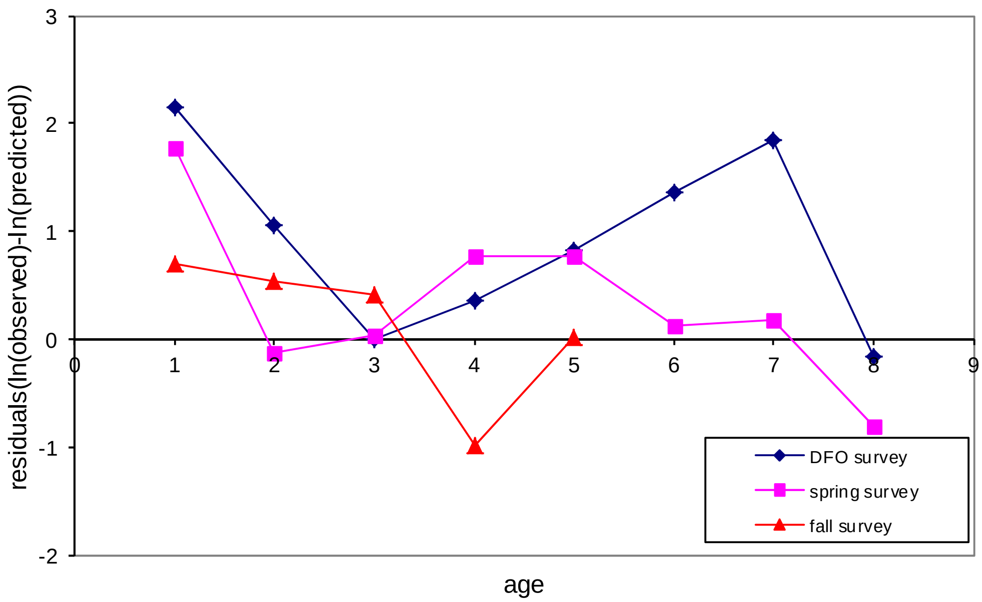


Figure 31. Relative retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the “M 0.8” model in 2014 assessment.



2013 assessment



2014 assessment

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

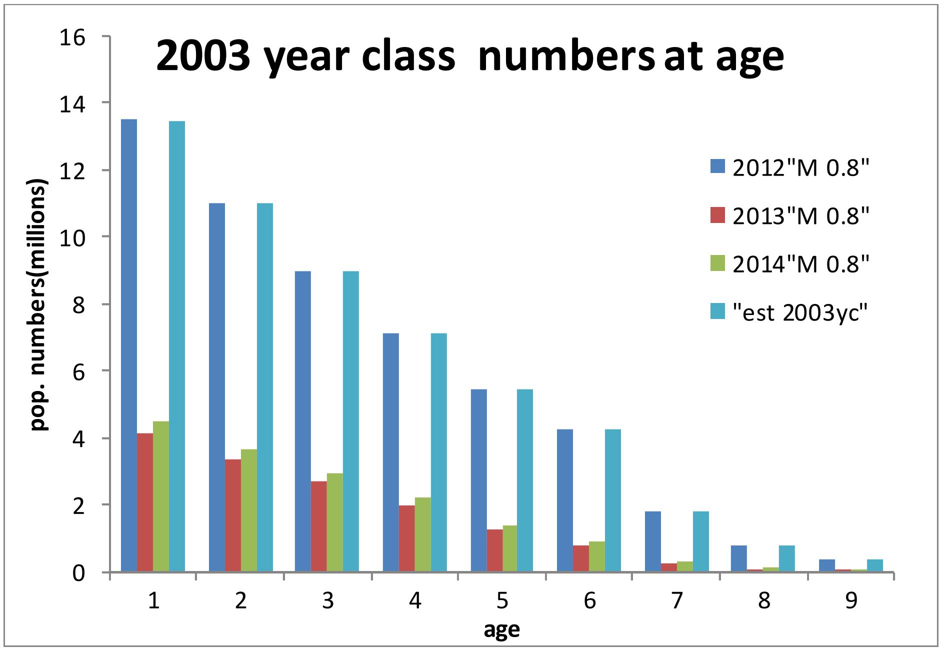


Figure 33. The estimated population abundance at age of the 2003 year class from different model formulations of eastern Georges Bank cod.

Figure 34. The estimated recruitment from different model formulations of eastern Georges Bank cod.

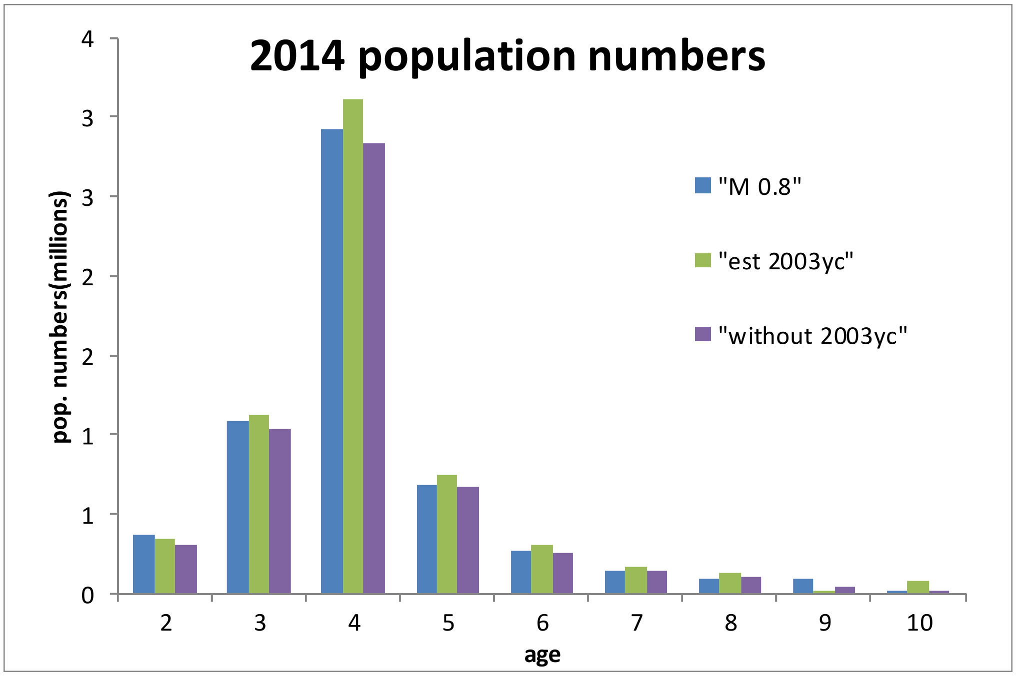


Figure 35. The estimated beginning of year 2014 population abundance at age from different model formulations of eastern Georges Bank cod.

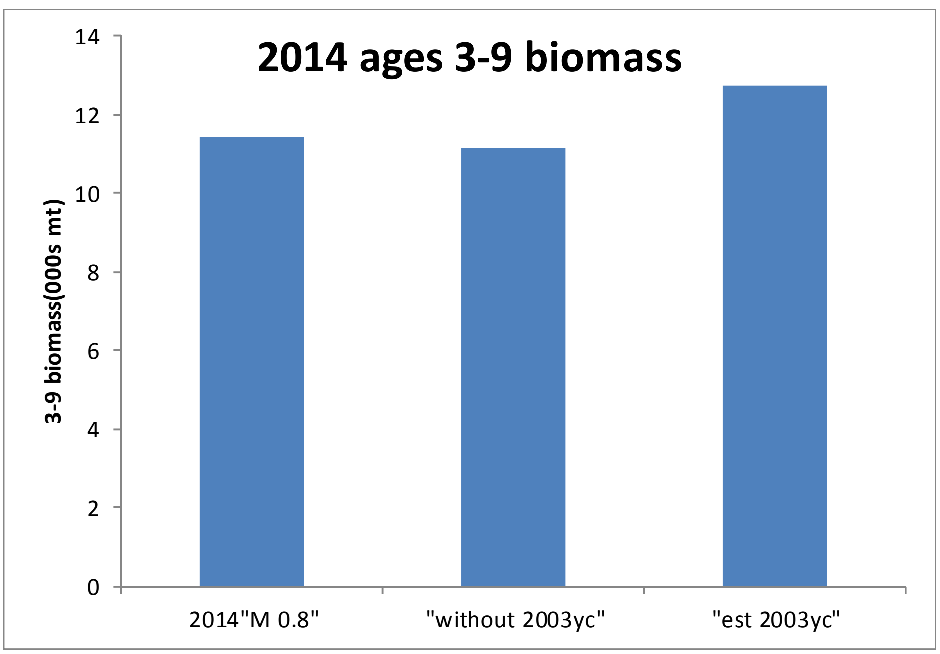


Figure 36. The estimated beginning of year 2014 ages 3-9 population biomassfrom different model formulations of eastern Georges Bank cod.

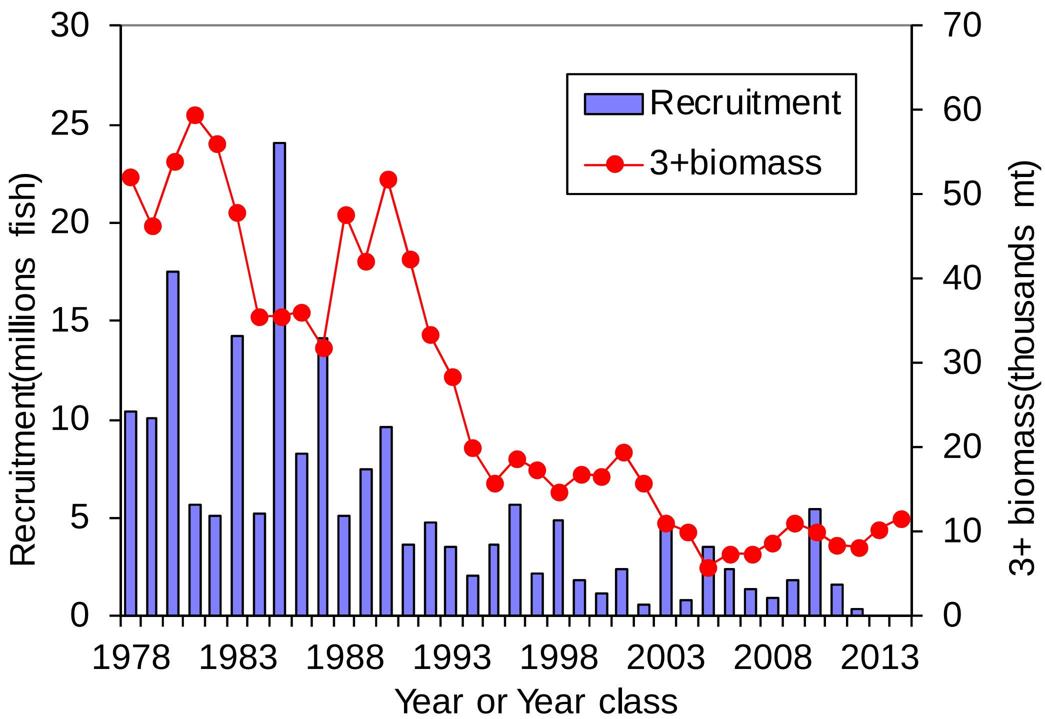


Figure 37. Adult biomass (ages 3+) and year class abundance at age 1 for eastern Georges Bank cod.

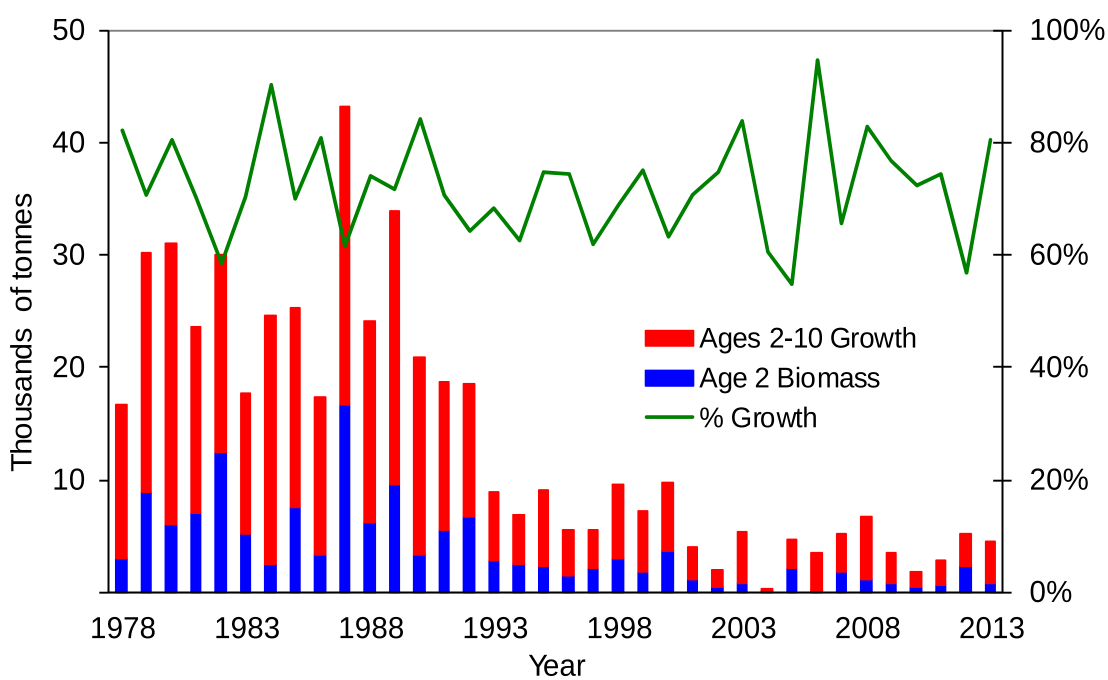


Figure 38. Components of annual production for eastern Georges Bank cod attributable to growth of ages 2 to 10 and to the amount contributed by incoming year classes at age 2.

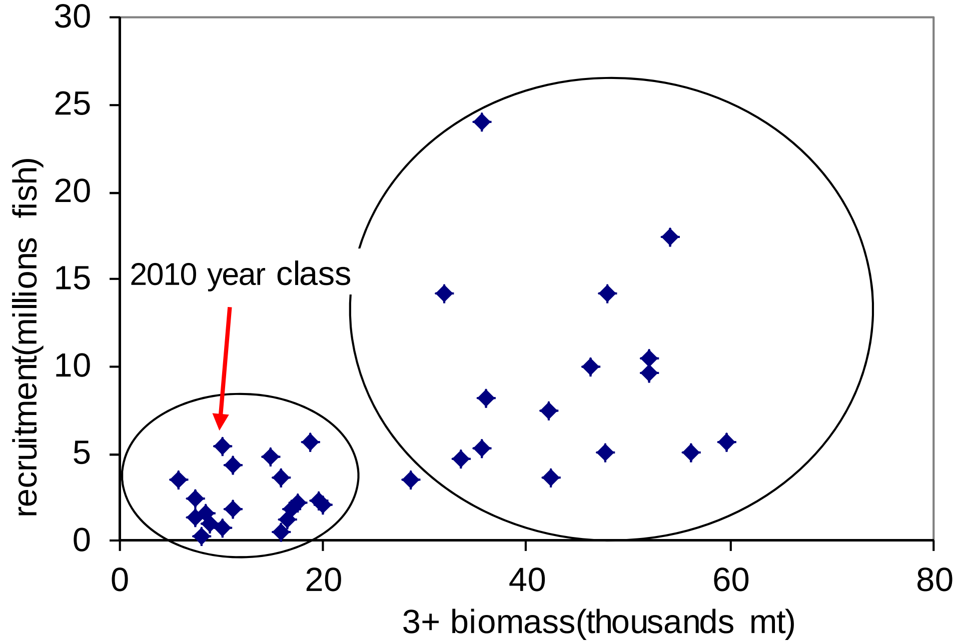


Figure 39.. Relationship between adult biomass (ages 3+) and recruits at age 1 for eastern Georges Bank cod. The red arrow indicate the 2010 year class at age 1.

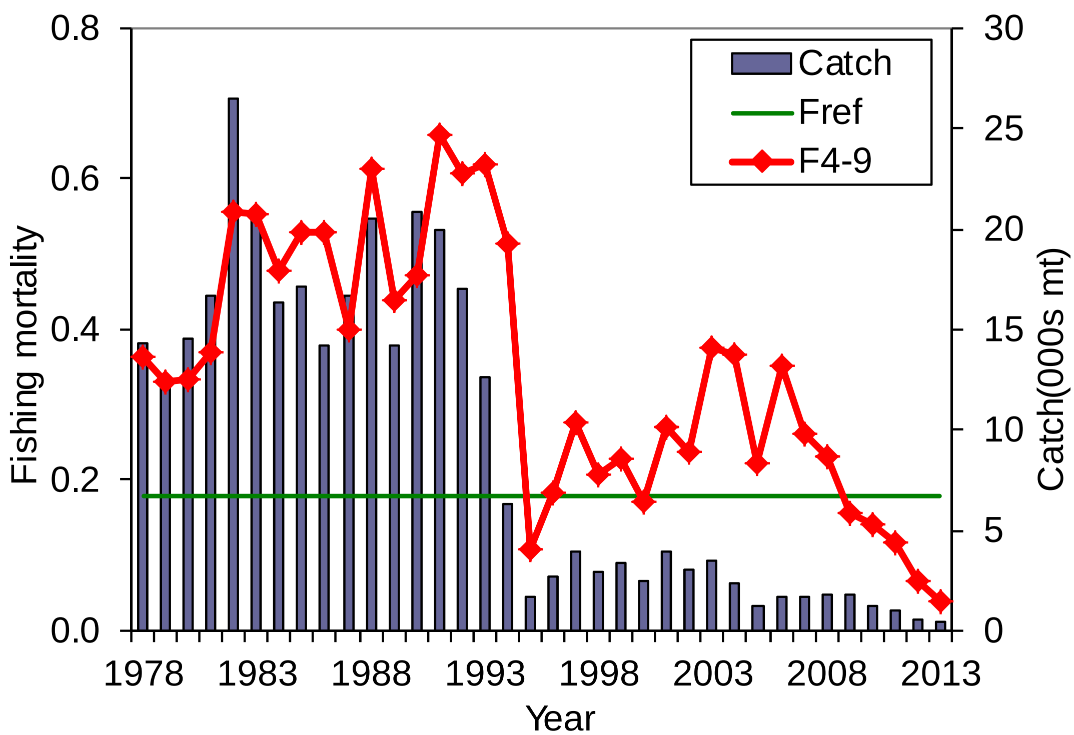


Figure 40. Average fishing mortality rate at ages 4 to 9 and catches for eastern Georges Bank cod. The established fishing mortality threshold reference, F_{ref}=0.18.

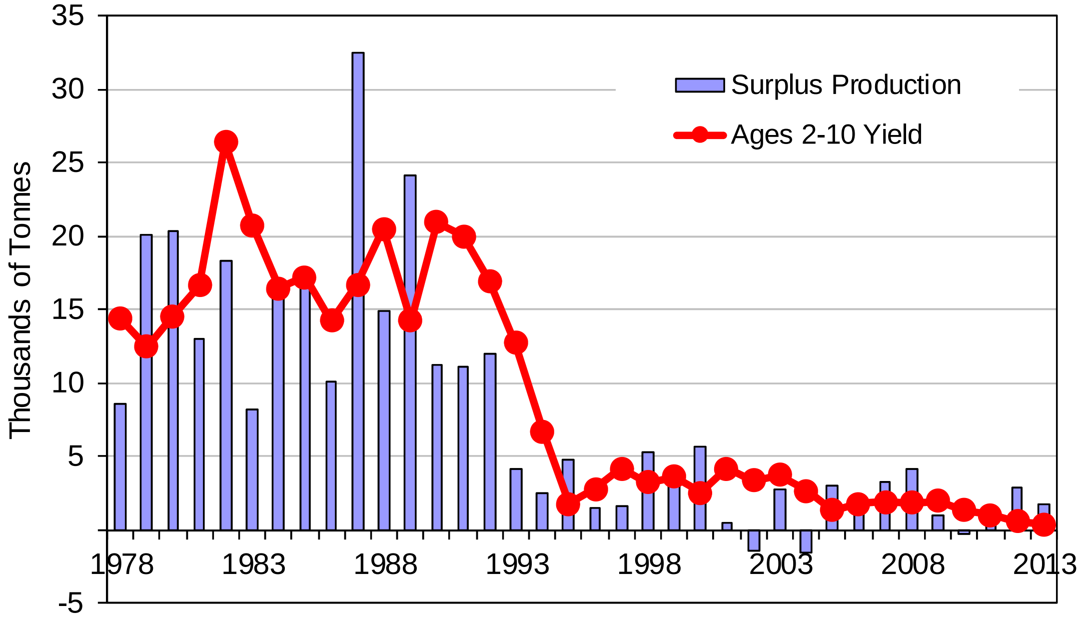


Figure 41. Surplus production of eastern Georges Bank cod compared to harvested yield.

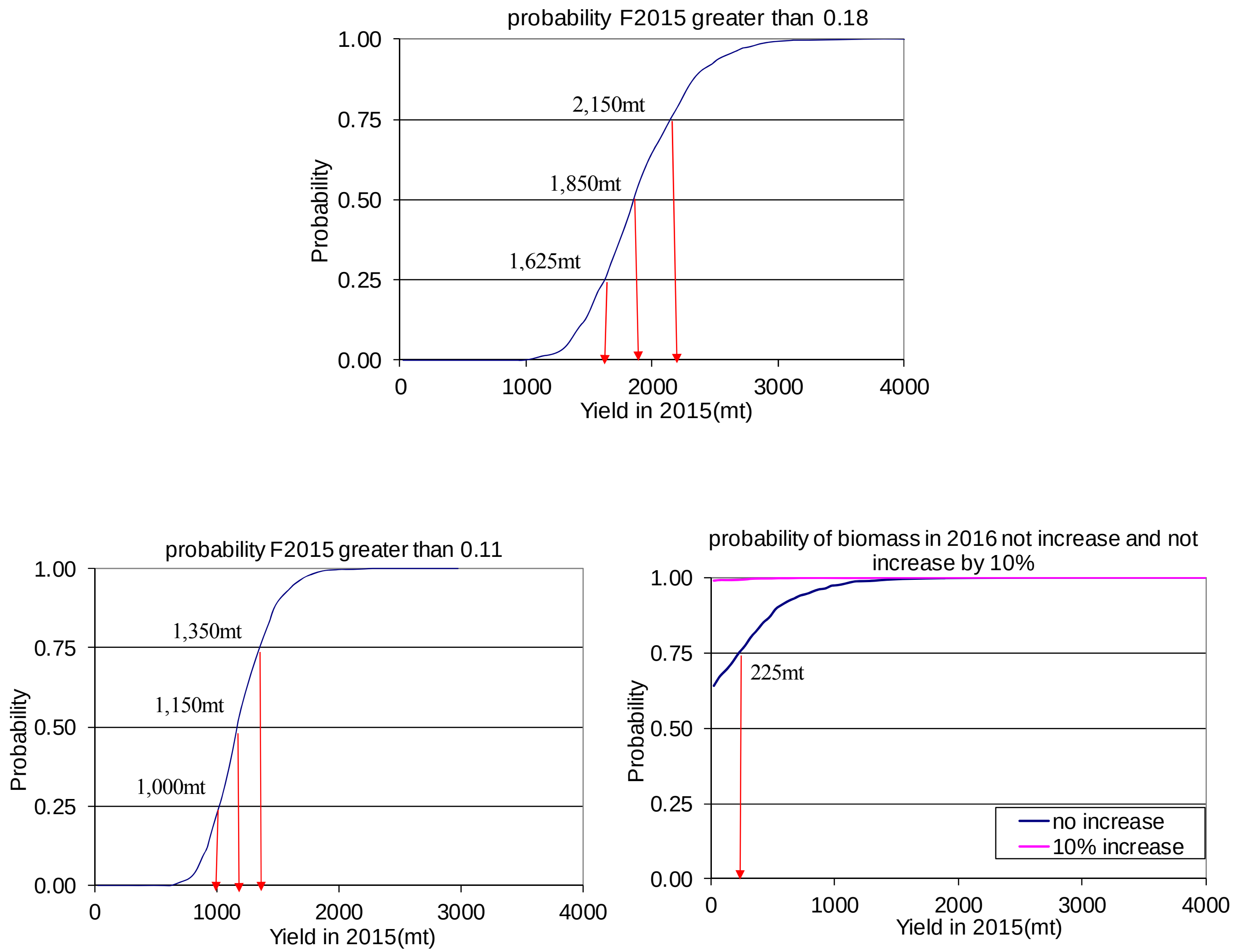


Figure 42. Risk of 2015 fishing mortality exceeding proposed F_{ref} = 0.11 and 2016 biomass not increasing, and 2016 biomass not increasing by 10% from 2015 for alternative total yields of eastern Georges Bank cod from the “M 0.8” model formulation.

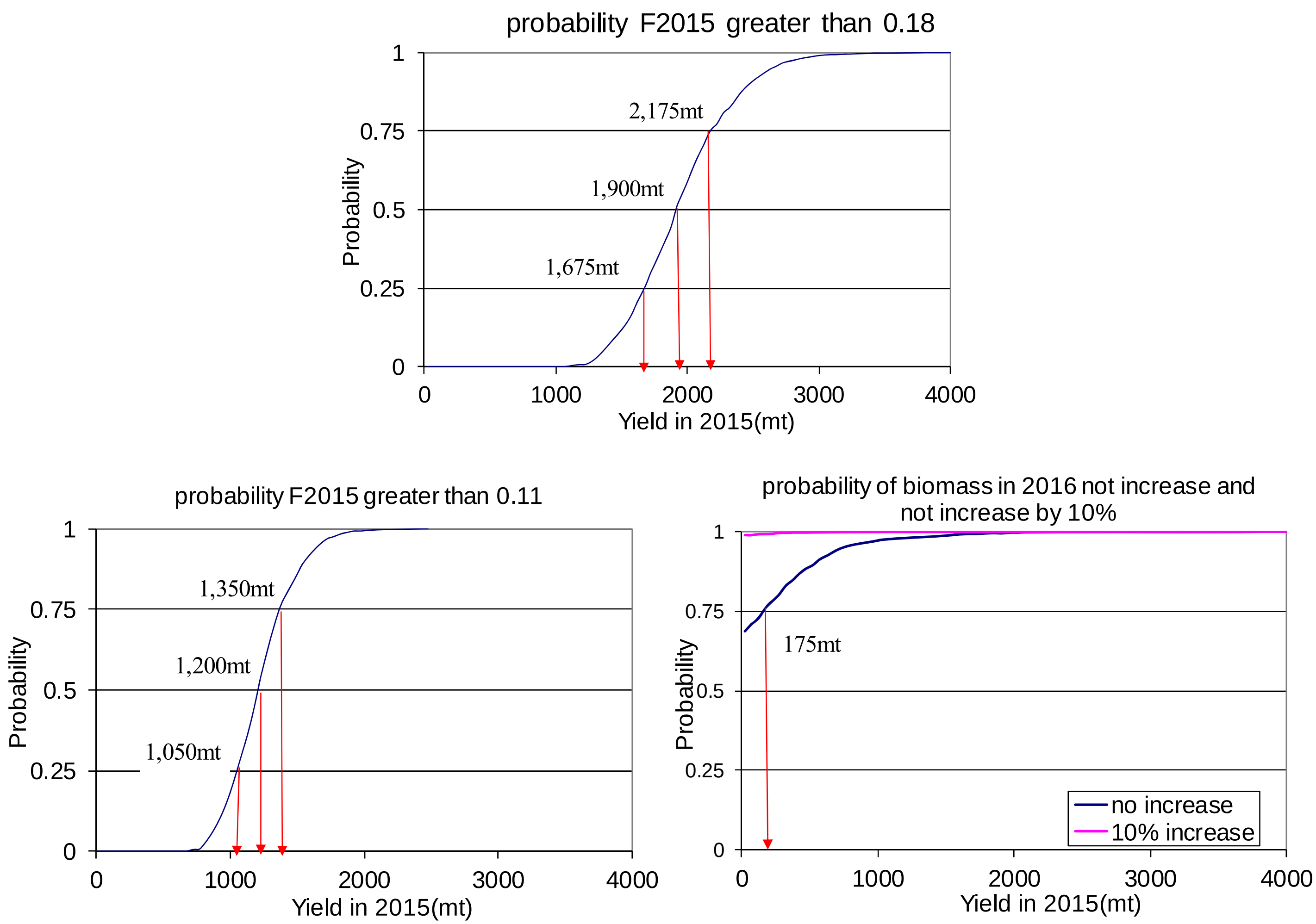


Figure 43. Risk of 2015 fishing mortality exceeding proposed F_{ref} = 0.11 and 2016 biomass not increasing, and 2016biomass not increasing by 10% from 2015 for alternative total yields of eastern Georges Bank cod from the “estimate 2003yc” formulation.

APPENDIX A. 2014 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 the 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 (Appendix B) 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 NEFSC 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 2013 and stock size in 2013. A retrospective analysis was performed for terminal year fishing mortality, spawning stock biomass, and age1 recruitment. Stochastic projections from model results were performed to provide estimated landings and spawning stock biomass (SSB) in 2015-2016.

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 on the NFT 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, Figure 2), and the catch-at-age (Table 5, Figure 12) and weight-at-age (Table 6, Figure 13) for ages 1-10+ during 1978-2013. Beginning year weight-at-age is back-calculated from the mid-year catch weight-at-age (Appendix A.Table 1) and also estimated from an average of the DFO and NEFSC spring research survey weight-at-age (Table 16). Swept-area population estimates derived from indices of abundance include the Canadian DFO 1986-2013 estimates for ages 1- 10+ (Table 9, Figure 19), the NEFSC 1978-2013 standardized spring estimates for ages 1- 10+ (Table 10, Figure 19), and the NEFSC 1978-2013 standardized autumn estimates for ages 1-6 (Table 11, Figure 19). 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 from 1982-2008.The NEFSC spring survey has been conducted by the NOAA Ship Henry B. Bigelow since 2009 and these indices have been calibrated to Albatross IV units ((Table 8). 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 earlier assessments (Wang and O'Brien 2012).

Model formulation

The 2013 ASAP model formulation (base_rivard) presented and reviewed at the June 2013 TRAC (Wang and O'Brien 2014) was updated for the 2014 assessment. 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 1994-2013.

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

The catch ESS was set at 75 for 1978-1995 and 125 for 1996-2013, and the ESS for each survey was set at 50.

At the 2012 benchmark (WP 2013/08) 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 2014 update.

Model Results

Model results, including the objective function (OF), components to the OF, the root mean square error (RMSE), computed from standardized residuals, SSB, fishing mortality (F), recruitment estimates at age 1, and the Mohn's rho retrospective bias adjustments are summarized in Appendix A.Table 2 for all model runs conducted.

A bridge ASAP run was conducted to include several corrections to the input data. A correction was made to the US catch at age (CAA) due to the misapplication of discard length frequencies. Last year, the January-June length frequency was erroneously applied to the July-December data. Also, an adjustment was made to the DFO and NEFSC spring survey CAA due to the incorrect summation of the 10+ age group. And the 2012 NEFSC spring and 2011 autumn survey indices were re-estimated due to missing station data when first estimated using preliminary data in 2013.

A comparison of the differences between the 2013 ASAP model results (2013 run2) and the bridge run (2014 run1) resulted in an increase in the objective function (OF), and minor changes in age composition and root mean square errors (RMSE). There was a decline in estimates of recruitment and SSB, and an increase in fishing mortality (F) and the retrospective Mohn's rho estimate for SSB and F increased, whereas the recruitment rho estimate declined (Appendix Table 2).

BASE 2014 ASAP

The bridge run was updated with 2013 catch estimates and survey data and the results are described below.

Catch

The model fit to the observed catch is almost exact with the CV of 0.05 assigned to the commercial catch (Appendix A.Figure 1). The catch age composition exhibits larger residuals tearly in the time period, with a pattern of negative residuals for age 3 (Appendix A.Figure 2). The magnitude of the input ESS appears appropriate given that the predicted ESS generally bisects the observed ESS (Appendix A. Figure 3).

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 (Appendix A. Figure 4). A pattern of negative residuals in the older age groups during 1986-1995 and in the younger ages during 2000-2013 is apparent in the age composition (Appendix A.Figure 5). The final DFO survey ESS was set at 50 and appears appropriate given that the predicted ESS generally bisects the observed ESS (Appendix A. Figure 6).

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 (Appendix A.Figure 7). The maximum residual of the age composition is the largest of the 4 surveys at 0.36 (Appendix A.Figure 8). 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 (Appendix A.Figure 8). The final input ESS was set = 50 and appears appropriate given that the predicted ESS generally bisects the observed ESS (Appendix A.Figure 9).

The model fit diagnostics for the NEFSC spring (Yankee #41) are presented in Appendix A. Figures 10-12. 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 (Appendix A.Figure 13). 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 (Appendix A.Figure 14). The input ESS was set =50 and appears appropriate given that the predicted ESS generally bisects the observed ESS (Appendix A.Figure 15).

Fishing mortality, SSB, and recruitment
Fully recruited F (unweighted, ages 5+) was estimated at 0.33 in 2013 (Appendix A.Table 3, Appendix A.Figure 16), a 59% decrease from 2012. SSB in 2013 was estimated at 2,142 mt, a 80% increase from 2012 (Appendix A.Table 3, Appendix A.Figure 16). Recruitment (millions of age 1 fish) of the 2003 year class (2.4 million) is now estimated to be smaller than the 1998 year class (3.4 million), the 2010 year class is estimated at 1.5 million, and the 2012 year class is the smallest year class estimated at 0.125 million (Appendix A.Table 3, Appendix A.Figures 16-17).

Retrospective analysis
A retrospective analysis was performed to evaluate how well the ASAP calibration would have estimated F, SSB, and recruits at age 1 for seven years (2006-2012) prior to the terminal year, 2013. The pattern of overestimating SSB and underestimating F relative to the terminal year, is stronger than last year in last years' ASAP run, and there is a pattern of underestimating recruitment relative to the terminal year estimate (Appendix A.Figure 18). The retrospective rho values, the average of the last 7 years of the relative retrospective peels, were 0.46 for SSB, -0.32

for F_{5+}, and -0.25 for recruitment. Applying a retrospective adjustment ((1/(1+rho)) * estimate) results in 2013 estimates of F = 0.49, SSB=1,470 mt, age 1 recruitment =0.17 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 F_{5+} 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 (Appendix A.Figure 19). The lagged autocorrelations showed variable correlation with increased lag, with correlations ≤ 0.1 beyond lag 0 for SSB and F (Appendix A.Figure 20). 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 F_{5+}. Time series plots of the 90% PIs as well as plots of the posterior probability distributions for SSB_{2012} and average F_{5+} are shown in Appendix A. Figures 21-22.

The 2013 SSB MCMC estimate of 2,134 mt has a 90% PI of 1,384 mt – 3,345 mt and the 2013 MCMC average F_{5+} = 0.33 has a 90% PI of 0.20- 0.56.

Sensitivity Runs

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 Jan.1 weight at age based on an average of the DFO and NMFS spring survey data as applied in the VPA. The results (Appendix A.Table 2) indicate minimal differences when applying these two weight-at-age matrices. The base run with rivard weights will be used in projections, as this follows the weight at age used for the GB cod assessement (NEFSC 2013b).

Various other sensitivity runs were conducted, but none showed substantial improvements in model diagnostics.

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 ,
SSBmsy = 39,353 mt.

The yield per recruit analysis was not updated with the 2014 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 (Appendix A.Figure 17), 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 2014 ASAP model results to estimate landings and SSB during 2015-2016. The input values for mean catch and stock weights, partial recruitment (PR), and maturity were estimated as 3-year averages from 2011-2013. Recruitment was estimated using the 2-stage CDF described above and associated with a SSB breakpoint of 15,000 mt. Catch in 2014 was estimated based on assumption that the 2013 quota of 700 mt would be caught.

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

Year	SSB	F	Catch
2014	2914	0.32	700
2015	2820	0.18	489
2016	3283	0.18	525

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 (Miller WP 2). 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 1st and 2nd time spawners (13% and 62%) until the 3rd 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 updated model formulation exhibits an increase in the retrospective bias in F and SSB compared to the 2013 ASAP model results . In the is ASAP formulation additional variability is added to the survey abundance estimates, thus placing more emphasis on the reported catch data.

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Appendix A. Table 1. January 1 catch weight at age (kg) for ages 1-10+, for Eastern Georges Bank cod,1978-2013.

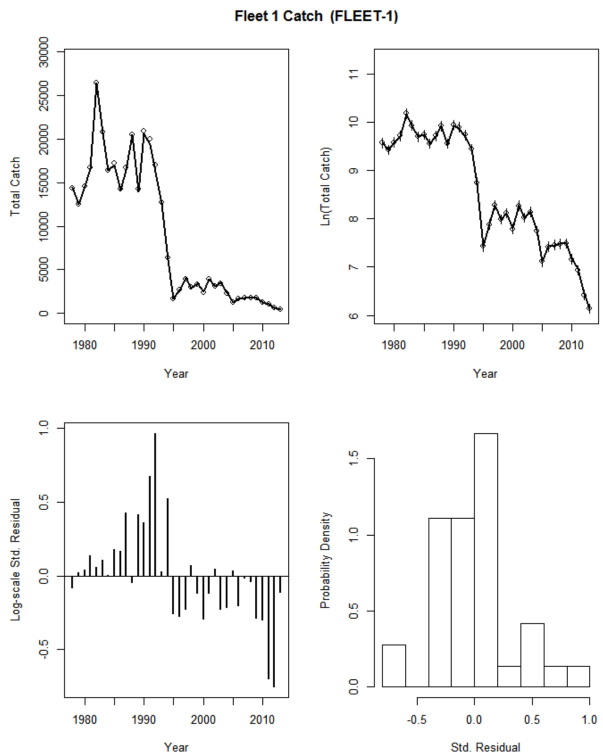
					AGE					
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1978	0.245	1.149	1.639	2.121	2.799	4.103	4.285	7.587	7.881	13.216
1979	0.564	0.800	1.386	2.601	3.477	4.954	7.137	7.347	9.036	14.362
1980	0.207	0.955	1.789	2.161	4.030	5.289	6.898	10.385	10.008	13.455
1981	0.331	0.697	1.572	2.603	3.731	5.675	7.101	8.170	11.537	15.920
1982	0.340	0.825	1.651	2.681	3.919	5.537	7.438	8.895	10.471	16.018
1983	0.674	0.909	1.699	2.572	4.077	5.529	7.262	9.298	10.635	15.056
1984	0.486	1.202	1.853	2.753	3.843	5.290	7.116	8.545	10.646	13.731
1985	0.337	0.945	1.705	2.712	3.946	5.322	6.938	8.930	10.030	13.758
1986	0.326	0.853	1.787	2.446	3.922	5.522	6.933	8.529	10.454	12.262
1987	0.410	0.886	1.797	3.086	4.215	5.908	7.662	8.744	10.183	13.811
1988	0.435	0.826	1.787	2.705	4.393	5.725	7.730	9.308	10.266	13.719
1989	0.391	0.889	1.516	2.706	3.877	5.437	6.434	9.003	10.286	13.839
1990	0.469	0.981	1.738	2.513	3.921	5.435	6.849	8.163	10.475	13.417
1991	0.544	1.027	1.937	2.732	3.695	5.041	6.711	8.587	9.494	13.813
1992	0.675	1.026	1.861	2.831	3.650	4.898	6.130	8.033	10.299	15.042
1993	0.404	1.097	1.723	2.544	3.773	4.787	6.186	7.504	8.896	12.002
1994	0.410	0.895	1.731	2.691	3.532	5.249	6.232	7.421	8.125	12.629
1995	0.153	0.893	1.683	2.680	4.119	5.293	8.052	8.482	9.223	17.374
1996	0.306	0.677	1.690	2.543	3.970	5.365	6.399	9.510	10.178	10.964
1997	0.483	0.853	1.715	2.519	3.430	5.023	6.505	7.303	10.139	11.130
1998	0.524	0.956	1.749	2.480	3.409	4.536	5.945	7.536	9.220	13.567
1999	0.343	0.959	1.630	2.579	3.413	4.666	5.780	7.050	8.566	13.926
2000	0.487	0.844	1.597	2.392	3.527	4.288	5.599	6.517	7.936	13.056
2001	0.087	0.751	1.562	2.319	3.220	4.423	4.954	6.449	7.654	10.674
2002	0.169	0.501	1.351	2.289	3.316	4.180	5.589	6.554	7.617	11.169
2003	0.138	0.639	1.598	2.303	3.169	4.123	5.167	6.622	7.924	8.729
2004	0.135	0.595	1.512	2.425	3.063	4.013	4.709	6.293	7.643	10.017
2005	0.085	0.445	1.388	2.077	3.112	3.930	4.710	5.971	7.637	9.364
2006	0.123	0.328	1.192	1.904	2.779	3.871	5.217	5.308	6.850	7.384
2007	0.278	0.514	1.023	2.019	2.639	3.589	5.116	6.459	6.320	9.541
2008	0.148	0.763	1.530	2.124	2.911	3.885	4.771	6.949	7.382	9.086
2009	0.467	0.572	1.556	2.595	3.215	4.055	5.368	6.258	8.897	10.910
2010	0.326	0.936	1.521	2.203	3.201	3.565	4.795	5.898	7.693	11.265
2011	0.163	0.712	1.513	2.293	2.985	3.804	3.809	5.561	7.737	9.627
2012	0.162	0.523	1.326	2.133	3.072	3.799	4.458	4.909	5.685	5.230
2013	0.623	0.522	1.329	2.174	3.150	4.199	4.694	5.401	7.180	7.220

Appendix A.Table 2. ASAP model diagnostics and results for four model formulations: total objective function (OF) value, contribution to the OF by components, root mean square error (RMSE) of the standardized residuals, catch and survey coefficient of variation (CV) and effective sample size (ESS) and the spawning stock biomass and fishing mortality of unweighted ages 5+ for the terminal year (TY), and the Mohn's rho retrospective bias adjustments.

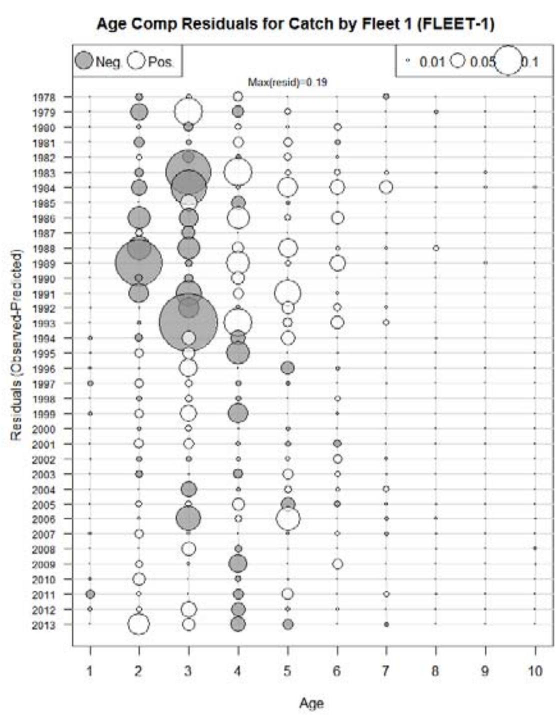
		2013 run2	2014 run1	run 2	run2b
		TY=2012	TY=2012	TY=2013	TY=2013
Model		base_rivard	bridge	base_rivard	base_sv_wts
objective function		3017.29	3057.51	3163.31	3163.31
components of					
obj. function	**catch total**	230.458	230.526	234.975	234.975
			0.00	0.00	0.00
	index fit total	873.41	875.14	914.99	914.99
	catch age composition	567.608	570.91	588.49	588.49
			0.00	0.00	0.00
	Index age composition	1345.81	1380.94	1424.86	1424.86
	Recruit deviations	0	0		
RMSE	**Catch fleet**	0.29	0.30	0.33	0.33
	total catch	0.29	0.30	0.33	0.33
	discards	0.00	0.00	0.00	0.00
	total discards	0.00	0.00	0.00	0.00
	DFO	1.41	1.44	1.53	1.53
	Autumn	1.35	1.28	1.34	1.34
	Spring 41	0.76	0.78	0.78	0.78
	Spring 36	1.35	1.42	1.50	1.50
	Index total	1.35	1.35	1.43	1.43
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		2989	2546	2729	2581
SSB TY mt		1922	1695	2142	1965
SSB TY retro bias adj		1567	1330	1470	1345
F TY (age 5+)		0.44	0.53	0.33	0.33
F TY retro bias adj.		0.53	0.67	0.49	0.49
TY age 1 (millions)		0.446	0.190	0.125	0.125
TY age 1 retro bias adj.		0.689	0.276	0.166	0.166
rho F		-0.17	-0.22	-0.32	-0.32
rho SSB	`	0.23	0.27	0.46	0.46
rho rct		-0.35	-0.31	-0.25	-0.25

Appendix A.Table 3. ASAP model results for January 1 biomass (mt), spawning stock biomass (SSB (mt), age 3+), fishing mortality (F) and recruitment (age 1, 000s fish), 1978-2013.

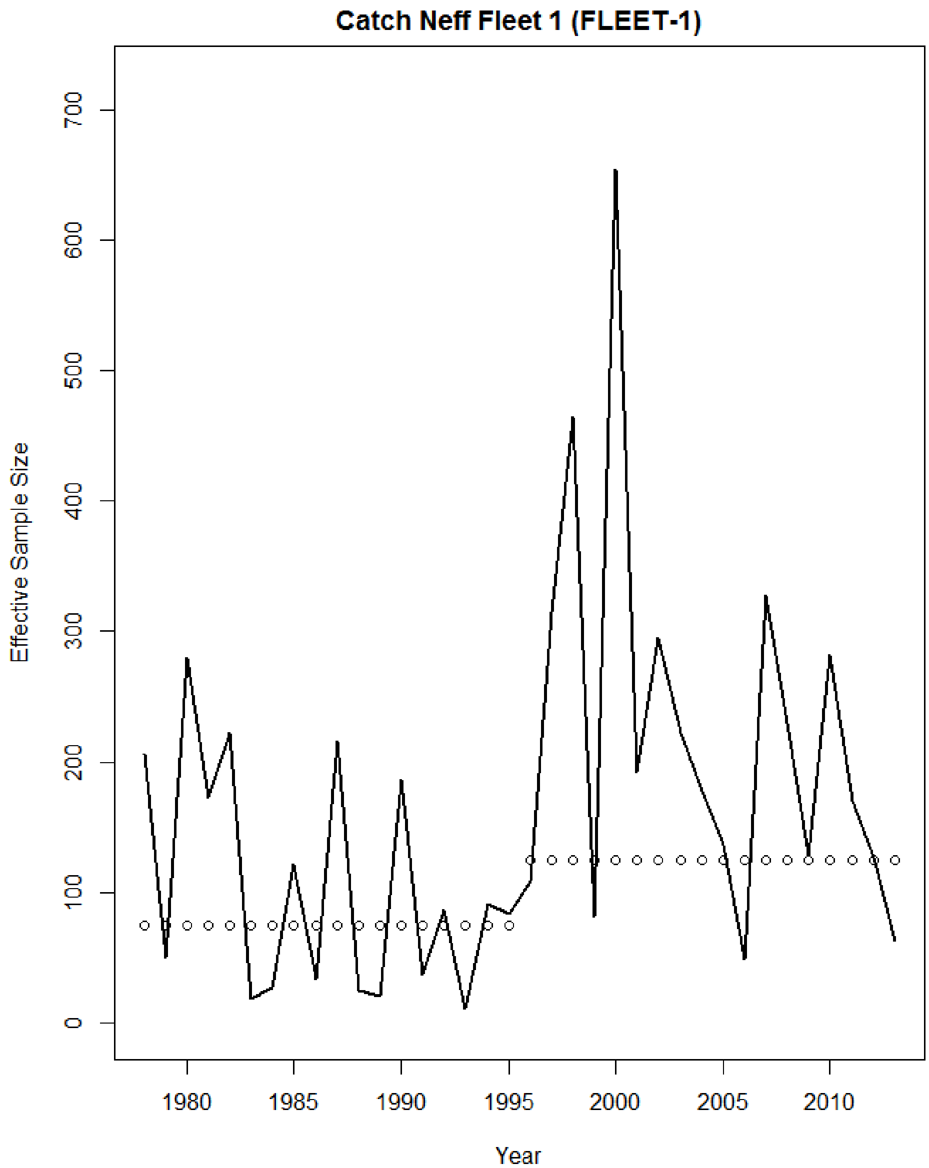
Year	Jan. 1 Biomass	SSB	F	Recruitment
1978	38869	30710	0.44	10936
1979	43986	28098	0.37	10554
1980	47567	33947	0.39	9111
1981	50438	34824	0.46	19351
1982	52993	32109	0.72	7430
1983	45547	32853	0.61	3606
1984	41530	27444	0.59	13723
1985	35308	19278	0.83	5418
1986	35224	19869	0.65	26261
1987	42203	17998	0.60	6499
1988	48307	32932	0.64	13978
1989	41023	25640	0.46	5762
1990	42813	30396	0.65	6838
1991	39049	22523	0.91	11483
1992	29176	14592	1.02	2519
1993	19341	12673	1.15	3074
1994	10932	6332	1.55	1961
1995	8157	6075	0.42	1226
1996	9555	7348	0.52	2606
1997	11108	6567	0.85	3508
1998	10532	6418	0.68	1226
1999	10989	7964	0.69	3406
2000	10868	7113	0.44	1535
2001	10458	8347	0.75	1053
2002	8445	6983	0.56	1493
2003	7651	5885	0.83	391
2004	5720	4573	0.75	2434
2005	4408	3154	0.49	424
2006	4490	3832	0.66	867
2007	4400	3257	0.71	1179
2008	4171	2936	0.77	563
2009	3919	2970	1.00	433
2010	2964	2056	1.00	699
2011	2349	1414	1.18	1534
2012	2134	1192	0.81	866
2013	2729	2142	0.33	125



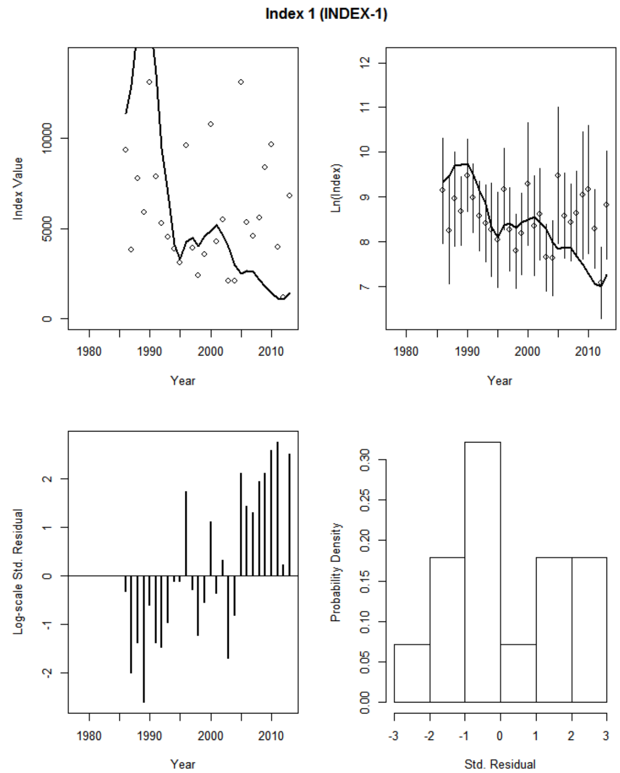
Appendix A.Figure 1. ASAP model fit to total catch of Eastern Georges Bank cod, 1978-2013.



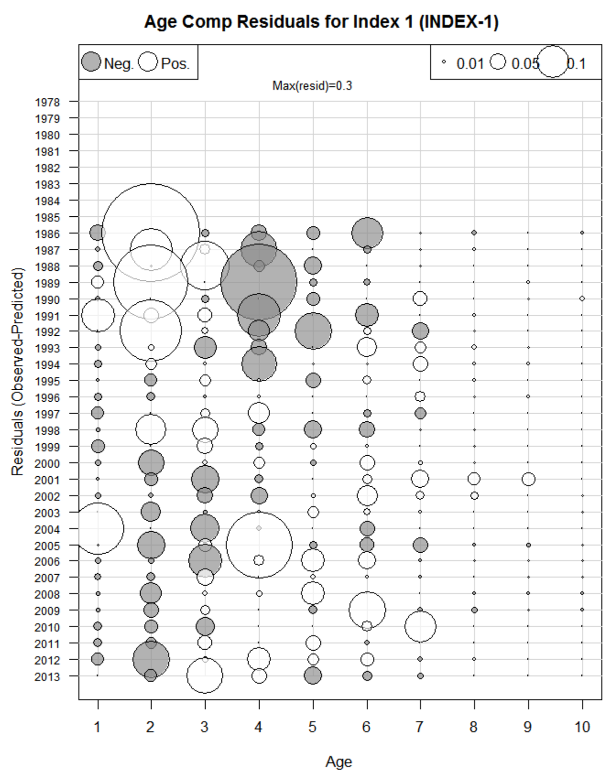
Appendix A.Figure 2. ASAP model residuals for the commercial catch age composition of Eastern Georges Bank cod, 1978-2013.



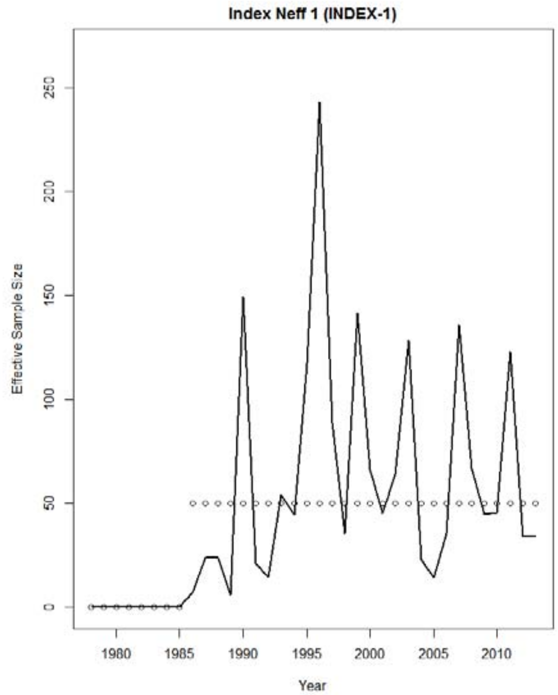
Appendix A.Figure 3. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the total catch, 1978-2013.



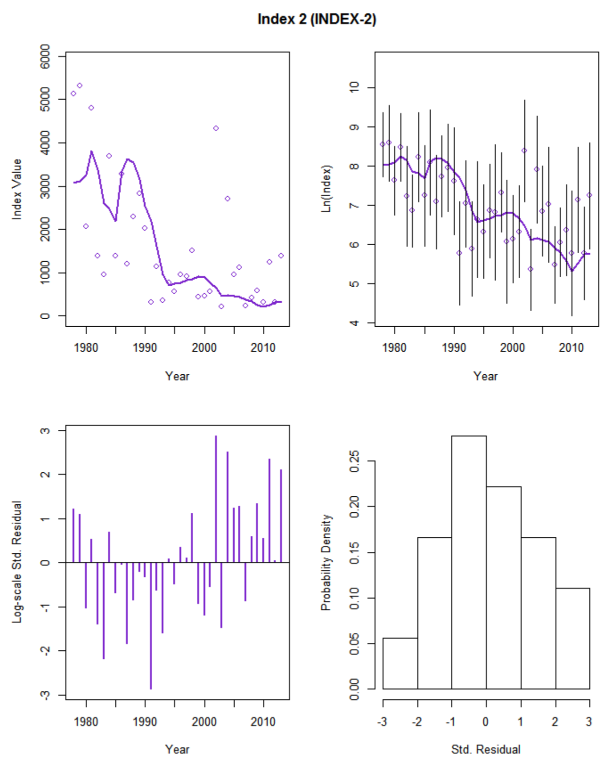
Appendix A.Figure 4. ASAP model fit to DFO survey indices of Eastern Georges Bank cod, 1978-2013.



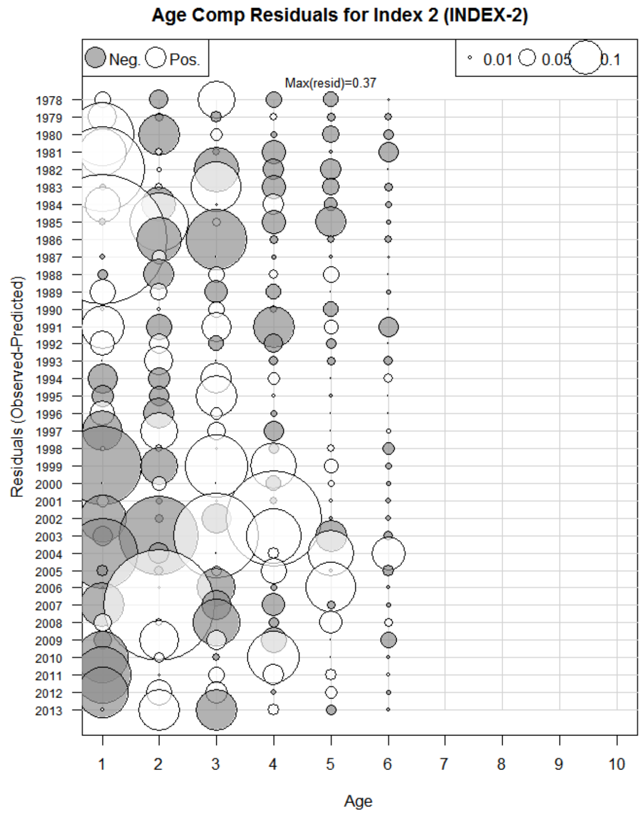
Appendix A.Figure 5. ASAP model run age composition residuals for DFO survey index of Eastern Georges Bank cod, 1978-2013.



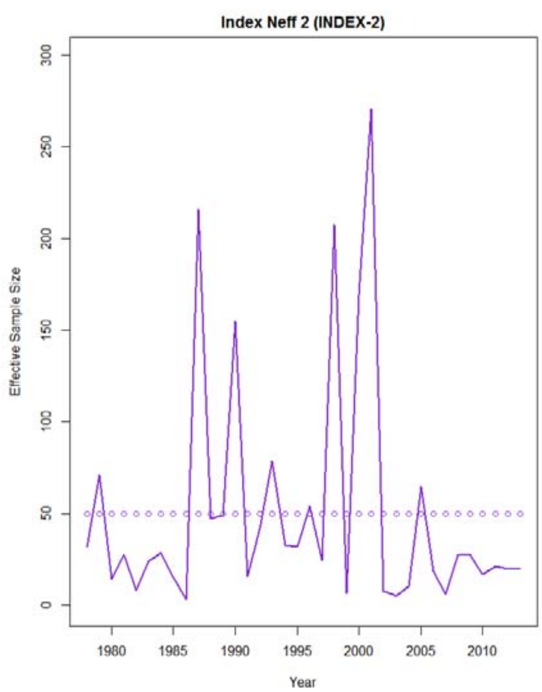
Appendix A,Figure 6. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the DFO survey, 1978-2013.



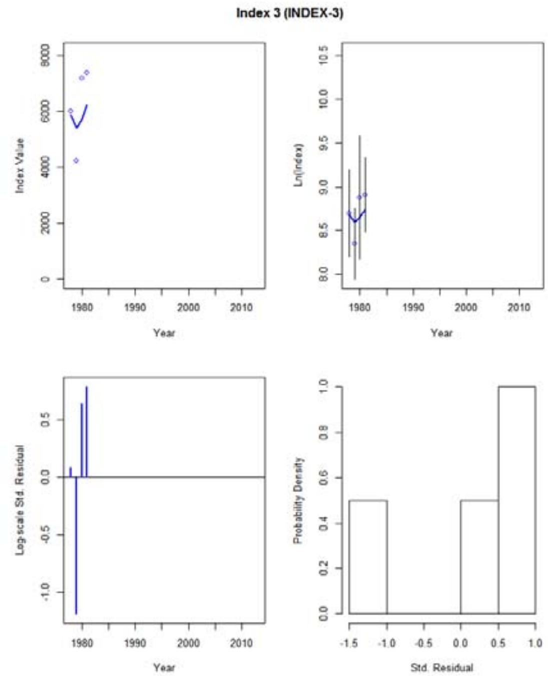
Appendix A.Figure 7. ASAP model fit to NEFSC autumn survey indices of Eastern Georges Bank cod, 1978-2013.



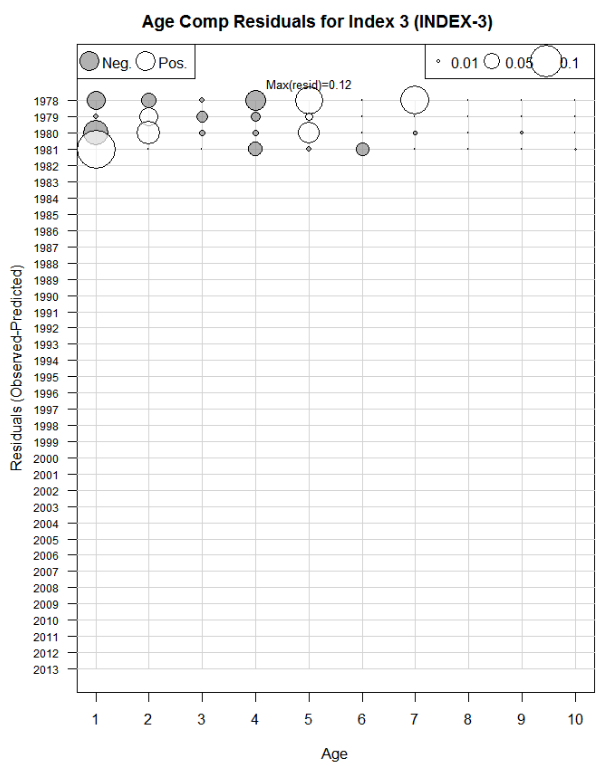
Appendix A.Figure 8. ASAP model age composition residuals for NEFSC autumn survey index of Eastern Georges Bank cod, 1978-2013.



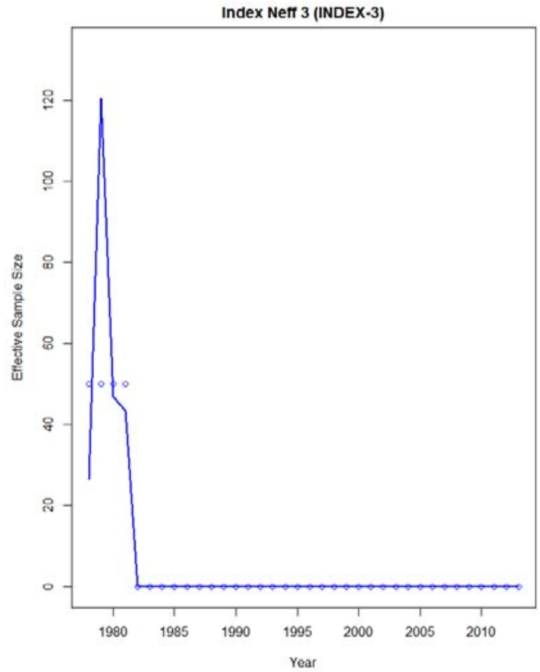
Appendix A.Figure 9. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the NEFSC autumn survey, 1978-2013.



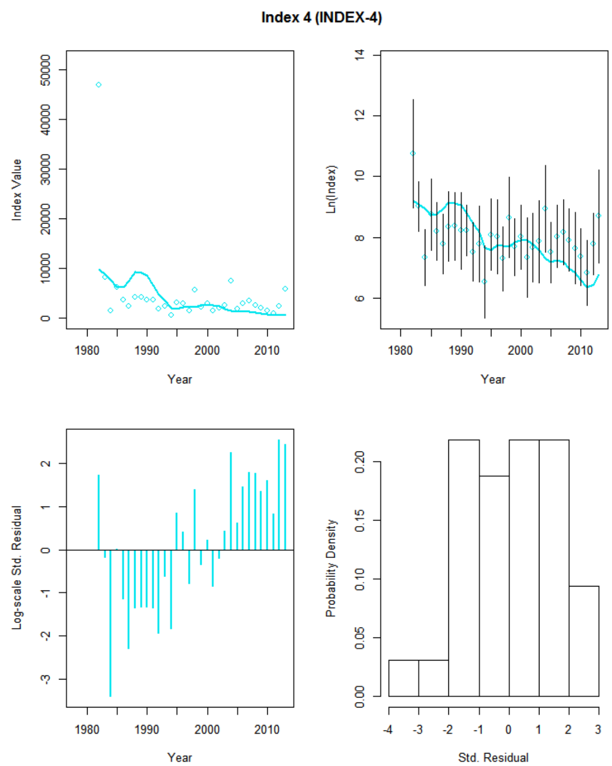
Appendix A.Figure 10. ASAP model fit to NEFSC spring Yankee #41 trawl survey indices of Eastern Georges Bank cod, 1978-1981.



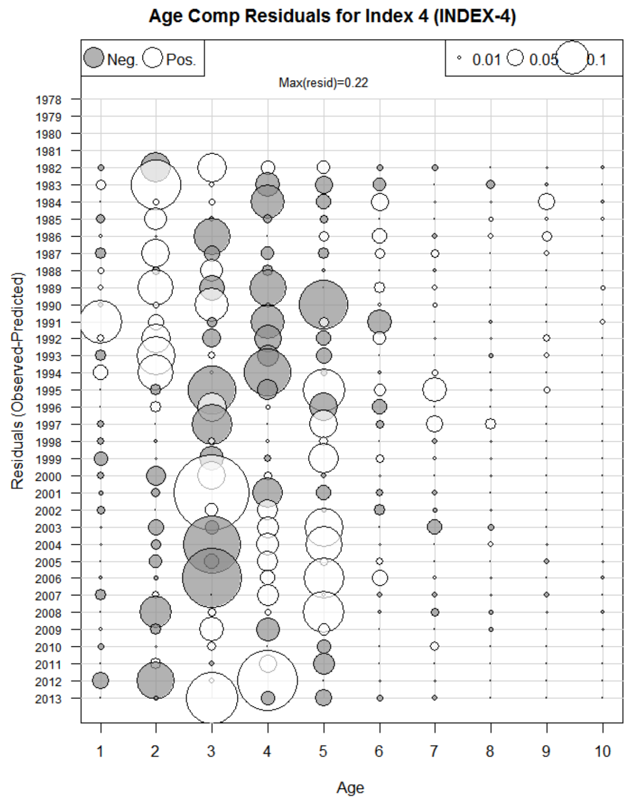
Appendix A.Figure 11. ASAP model age composition residuals for NEFSC spring Yankee #41 trawl survey index of Eastern Georges Bank cod, 1978-1981.



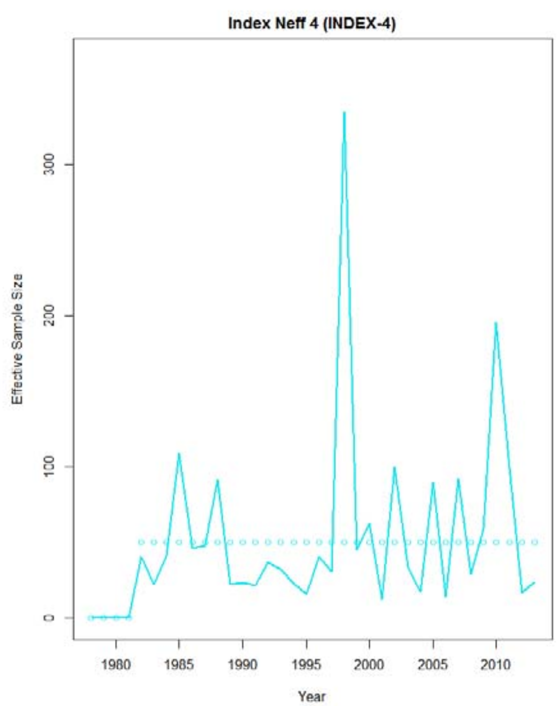
Appendix A.Figure 12. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the NEFSC spring Yankee #41 trawl survey, 1978-1981.



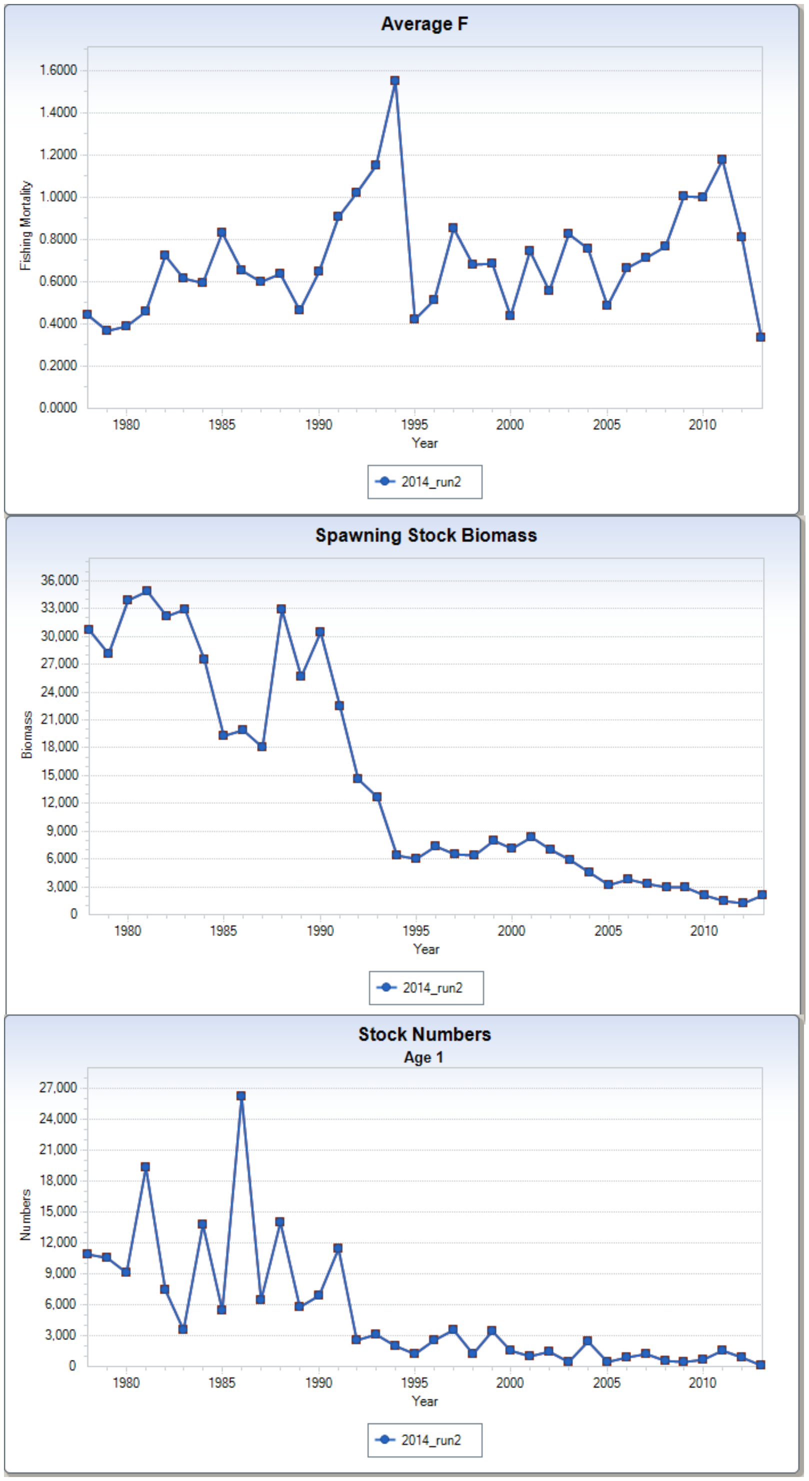
Appendix A.Figure 13. ASAP model fit to NEFSC spring Yankee #36 trawl survey indices of Eastern Georges Bank cod, 1982-2013.



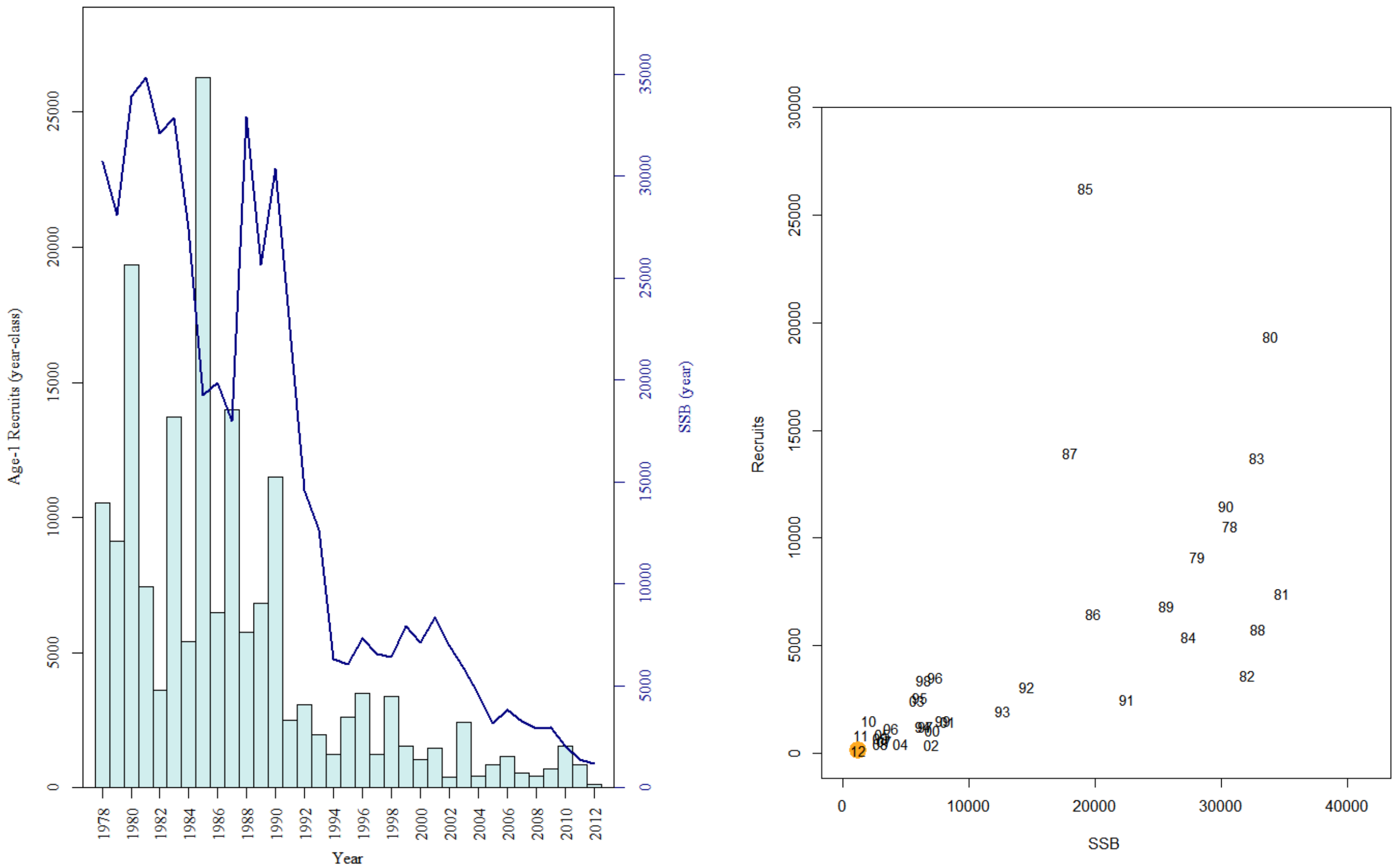
Appendix A.Figure 14. ASAP model age composition residuals for NEFSC spring Yankee #36 trawl survey index of Eastern Georges Bank cod, 1982-2013.



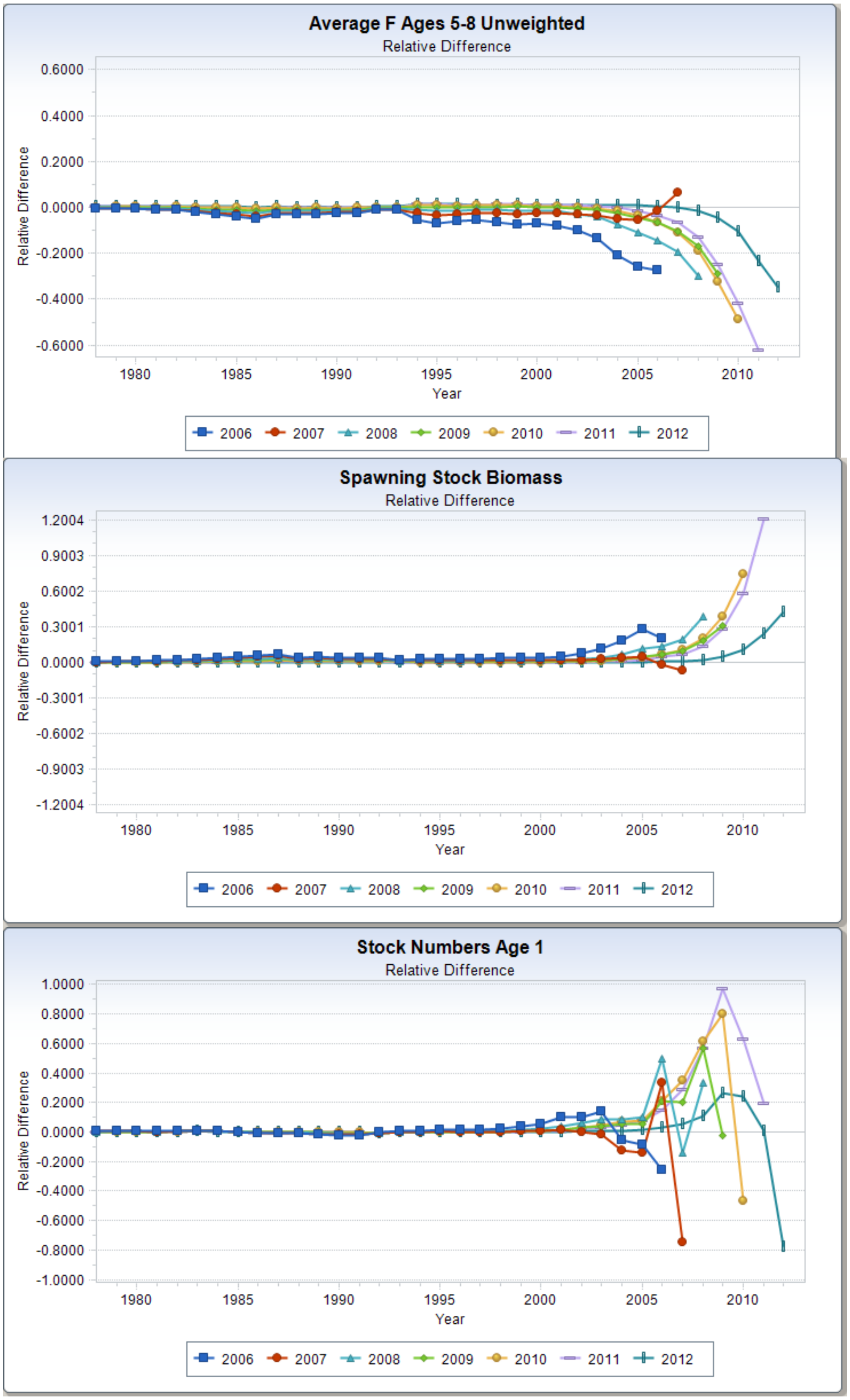
Appendix A.Figure 15. ASAP model observed (line) and predicted (circles) effective sample size of Eastern Georges Bank cod in the NEFSC spring Yankee #36 trawl survey, 1982-2013.



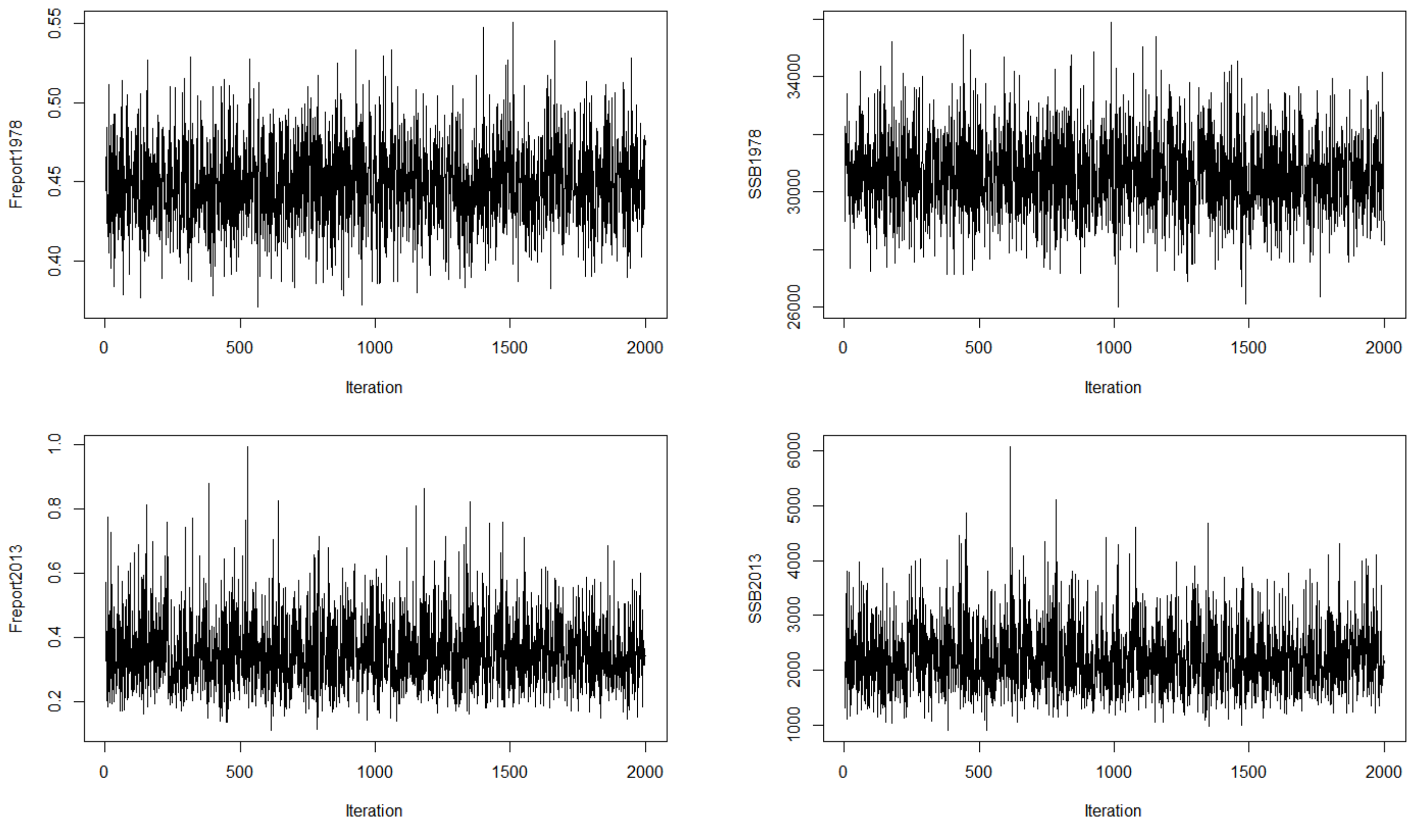
Appendix A.Figure 16. ASAP model results for fishing mortality (ages 5+), spawning stock biomass, and recruitment (age1, 000s fish), 1978-2013.



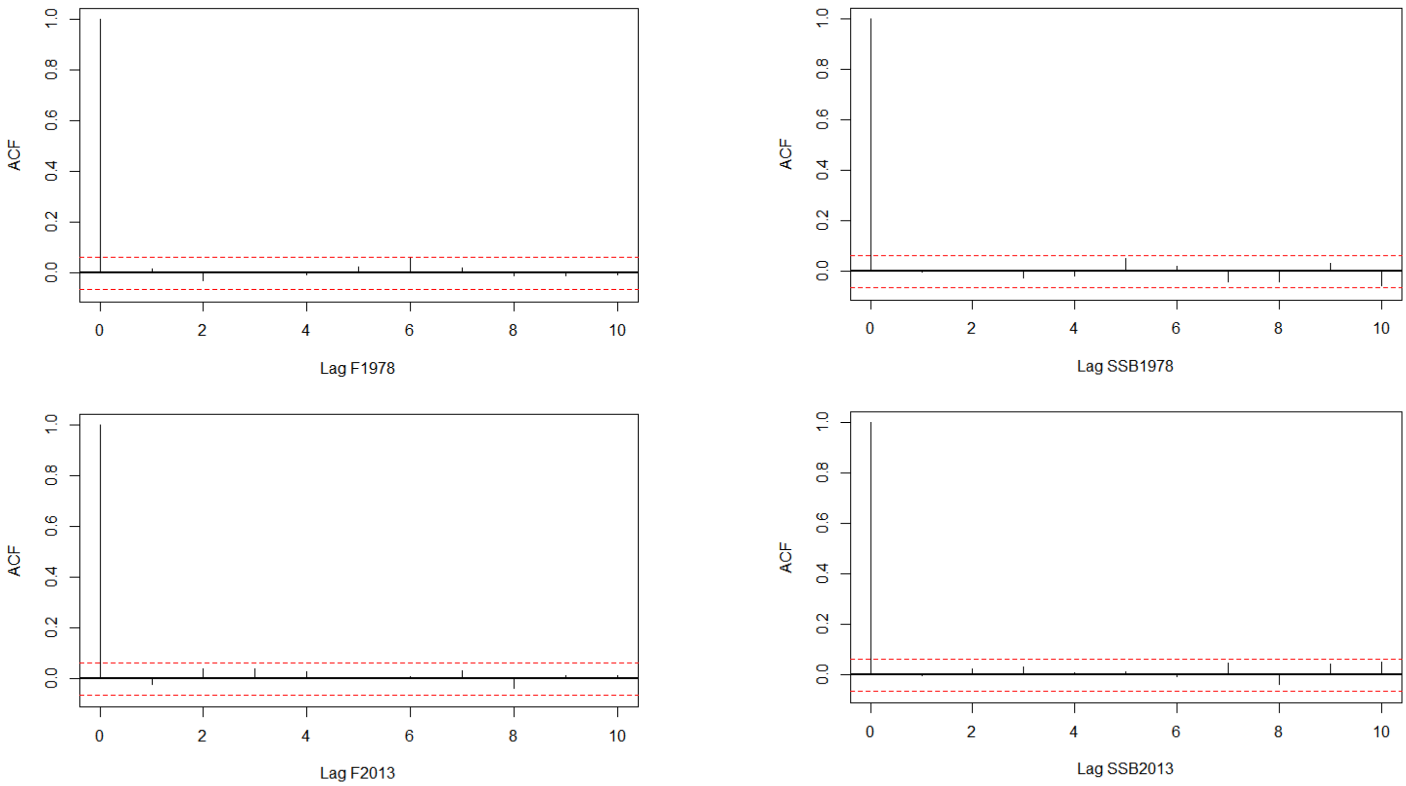
Appendix A.Figure 17. ASAP model results (left panel) for spawning stock biomass (mt, line) and recruitment (age1, 000s fish, bars) and the stock – recruitment plot (right panel) with year-class designation, 1978-2013.



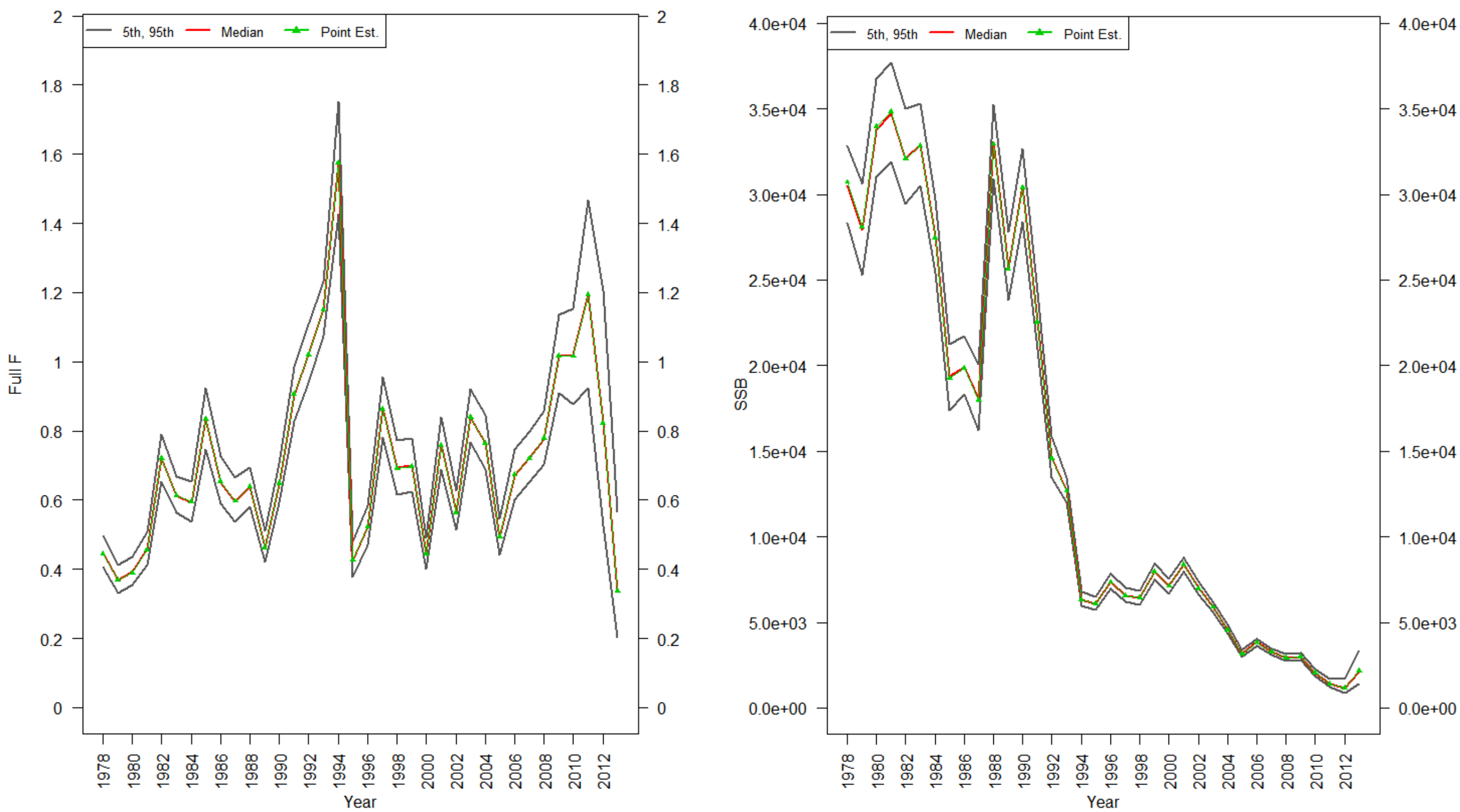
Appendix A.Figure 18. ASAP model results of retrospective bias of fishing mortality (F), spawning stock biomass (SSB), and age1 recruitment. Retrospective bias adjustment for F= -0.32, SSB=0.46, and age 1 recruitment = -0.25.



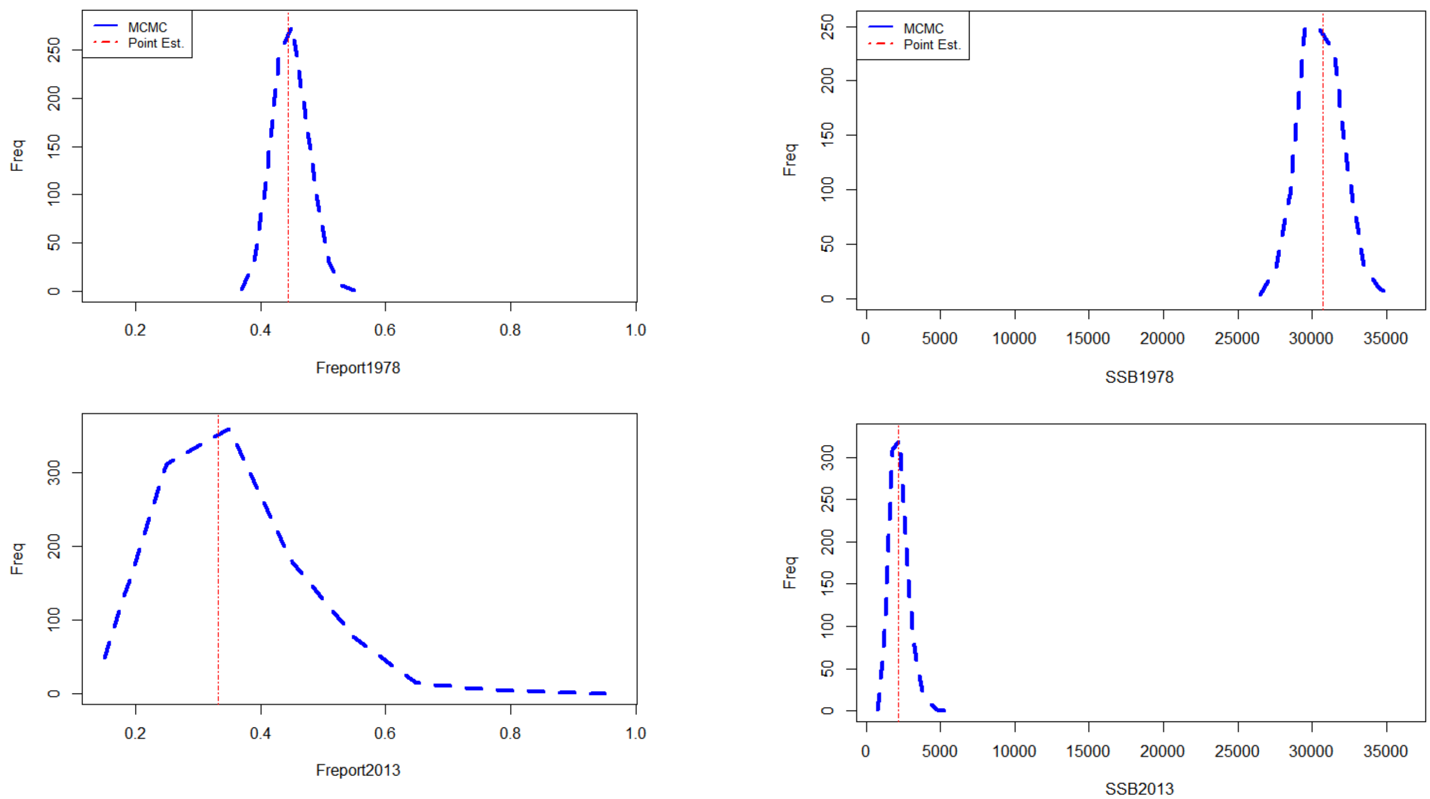
Appendix A.Figure 19. ASAP model results of trace of MCMC chains for Eastern Georges Bank cod fishing mortality (left) and spawning stock biomass (right) for 1978 and 2013. Each chain had an initial length of 5.0 million and was thinned at a rate of one out of every 2,500th resulting in a final chain length of 2000.



Appendix A.Figure 20. ASAP model autocorrection within the 1978 and 2013 MCMC chains for fishing mortality (F, left panel) and spawning stock biomass (SSB, right panel) for Eastern Georges Bank cod.



Appendix A.Figure 21. 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.



Appendix A.Figure 22. 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 2013. The model point estimate is indicated by the dashed red line.

APPENDIX B. Consequence Analysis: Risks Associated with 2015 Projected Catch

The risks associated with potential management actions taken during 2015 are 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 2014for this 2014 assessment. 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 on older ages since 1994 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 2016, and do not account for any longer-term consequences.

The column headers in the text table below 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 (2015) for four different catches. The notation in parentheses indicates where that catch was derived, e.g., the row with a 1,150 mt catch was projected from the VPA "M 0.8" model at F=0.11. The cells of the table indicate the projected 2015 fully recruited F and 2016 January 1 ages 3+ biomass, and the projected percent increase in biomass from 2015 to 2016.

If the VPA "M 0.8" model assumptions are the 'true state of nature', fishing at projected catch of 1,850 mt at F_{ref} = 0.18 or at catch of 1,150 would not allow for a biomass increase in 2016, and fishing at the projected catch of 489 mt or 308 mt from the ASAP model would not allow for biomass increase in 2016 either.

If the ASAP M=0.2 model assumptions are the 'true state of nature', implementing the VPA 0.8 projected catch of 1,850 results in high F in 2015 and loss of biomass in 2016 as would the projected catch of 1,235 mt. At projected catches of 489 mt or 308 mt, biomass would increase more than 10%.

In summary, considering both model projections, 2015 catches at or below 489 mt would allow for low exploitation of the stock but not necessarily a minimum 10% increase in the 2016 biomass. Even with no fishing, the 3+ biomass in 2016 would decrease from 2015 based on the

VPA M 0.8 model, while a catch of 489 mt would result in at least a minimum 10% increase in the 2016 biomass based on the ASAP 0.2 model.

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.

Appendix B. Table 1. Projection of 2015 fishing mortality (F), 2016 January 1 stock biomass (ages 3+), and percent increase in biomass from 2015 to 2016 of Eastern Georges Bank Atlantic cod at F_{ref}=0.18 and alternative F=0.11 for each of two 'true state of nature' management models: VPA M=0.8 and ASAP M=0.2 and the consequence analysis of the projections of the alternative management action.

CONSEQUENCE ANALYSIS			
		VPA 0.8	**ASAP**
Catch 2013		463 mt	463 mt
quota 2014		7,600 mt	7,600 mt
2013 biomass (3+)		10,410 mt	2,285 mt
2014 biomass (3+)		11,719 mt	NA
Projected 2015 Catch (mt)			
1,850	2015 F	0.18	0.89
(VPA F=0.18)	2016 Biomass	10,802	2,169
	% inc B from 2015	-15%	-28%
1,150	2015 F	0.11	0.48
(VPA F=0.11)	2016 Biomass	11,484	2,843
	% inc B from 2015	-10%	-5%
489	2015 F	0.04	0.18
(ASAP F=0.18)	2016 Biomass	12,129	3,481
	% inc B from 2015	-5%	16%
308	2015 F	0.03	0.11
(ASAP F=0.11)	2016 Biomass	12,307	3,660
	% inc B from 2015	-4%	22%
	F<=Fref & 10% biomass increase in 2015		
	F< =Fref & biomass increase < 10% in 2015		
	F>Fref and biomass increase < 10% in 2015		
	not feasible projection		