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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 of 600 mt, which was the lowest catch since 1978. Catches from the 2014 Fisheries and Oceans Canada (DFO) and National Marine Fisheries Service (NMFS) spring surveys decreased from 2012, and both indices were among the lowest in the time series. Both the fishery and the survey catches showed truncated age structure in recent years.

The Virtual Population Analysis (VPA) “M 0.8” model from the 2013 benchmark assessment was used to provide catch advice. In 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 = 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.

For the VPA “M 0.8” model, Transboundary Resources Assessment Committee (TRAC) agreed that F = 0.11 was an appropriate fishing mortality reference point. A 50% probability of not exceeding an F = 0.11 implies catches less than 1,150 mt. However, given the extremely low Spawning Stock Biomass (SSB), stock rebuilding should be promoted. Even with no fishing in 2015, there would be a higher than 50% risk that 3+ biomass will decrease between 2015 and 2016.

For the consequence analysis, a catch of 1,150 mt at F = 0.11 would result in a decrease in biomass of 10% in the VPA “M 0.8” model and a decrease of 5% in the ASAP “M 0.2” model. A catch of 489 mt at F_{ref} = 0.18 would result in at least a minimum 10% increase in the 2016 biomass based on the ASAP “M 0.2” model; however, the biomass in 2016 would decrease by 5% based on the VPA “M 0.8” model.

RÉSUMÉ

En 2013, les prises de morues franches combinées du Canada et des États-Unis se sont chiffrées à 463 tm, sur un quota de 600 tm, soit le total le plus bas depuis 1978. Les prises des relevés de printemps de 2014 effectués par Pêches et Océans Canada (MPO) et le National Marine Fisheries Service (NMFS) ont diminué par rapport à 2012, et les deux indices étaient parmi les plus faibles de la série chronologique. Au cours des dernières années, les prises de la pêche et des relevés ont montré une structure selon l'âge tronquée.

Le modèle d'analyse de population virtuelle (APV) « M = 0,8 » de l'évaluation de référence de 2013 a été utilisé pour faire des recommandations en matière de prises. Dans ce modèle, la mortalité naturelle (M) est estimée à 0,2, sauf pour les individus de 6 ans et plus, où M = 0,8 depuis 1994. Dans la projection et l'analyse des risques, on a examiné les résultats d'une analyse des conséquences, afin de comprendre les risques associés aux hypothèses du modèle d'APV « M = 0,8 » et du modèle du Programme d'évaluation selon la structure d'âge (PESA) « M = 0,2 » (avec la constante M = 0,2).

Quoique les mesures de gestion aient eu pour effet de faire baisser le taux d'exploitation depuis 1995, la mortalité totale est demeurée élevée et la biomasse des adultes a fluctué tout en restant faible. La biomasse de la population adulte était estimée à 11 719 tm au début de 2014, ce qui correspondait à environ 20 % de la biomasse des adultes de 1978. La mortalité par pêche était élevée avant 1994 et elle a été estimée à 0,04 en 2013, soit le niveau le plus faible jamais enregistré. Le recrutement à l'âge 1 a été faible ces dernières années. On estime que la classe d'âge de 2003 représente le plus fort recrutement depuis 2000. En fonction de l'évaluation de 2014, on a initialement estimé que la classe d'âge de 2010 était plus abondante que la classe d'âge de 2003. Au cours des dernières années, les plus faibles poids selon l'âge au sein de la population et le faible recrutement ont nui au rétablissement du stock.

Pour le modèle d'APV « M = 0,8 », le Comité d'évaluation des ressources transfrontalières (CERT) a convenu que F = 0,11 était un point de référence relatif à la mortalité par pêche approprié. Une probabilité de 50 % que le taux de mortalité par pêche ne dépasse pas F = 0,11 suppose des prises inférieures à 1 150 tm. Cependant, étant donné le niveau extrêmement faible de la biomasse du stock reproducteur (BSR), on devrait favoriser le rétablissement du stock. Même en l'absence de pêche en 2015, il y aurait un risque supérieur à 50 % que la biomasse des individus de 3 ans et plus diminue entre 2015 et 2016.

Pour l'analyse des conséquences, une prise de 1,150 tm à F = 0,11 entraînerait une diminution de 10 % de la biomasse selon le modèle d'APV « M = 0,8 », ainsi qu'une diminution de 5 % selon le modèle du PESA « M = 0,2 ». Des prises de 489 tm à $F_{réf}$ = 0,18 donneraient lieu à une augmentation d'au moins 10 % de la biomasse en 2016, selon le modèle du PESA « M = 0,2 ». Toutefois, la biomasse en 2016 diminuerait de 5 %, selon le modèle d'APV « M = 0,8 ».

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.

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 patterns. 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 formulations that were agreed upon were documented in the proceedings (Claytor and O'Brien**,** 2013).

The current assessment applied the 2013 benchmark formulations using Canadian and USA fishery information updated to 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, was 424 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 78% by weight of the mobile gear fleet landings, 29% by weight of the fixed gear landings and 19% 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 from otter trawl vessels 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) (Table 1). Cod discards from the 2013 Canadian groundfish fishery were estimated at 11 mt from the mobile gear and 10 mt from the fixed gear fishery (Table 1).

Since 1996, the Canadian scallop fishery has not been permitted to land cod. Landings until 1995 included those catches reported by the scallop fishery. The 3-month moving average observed discards rate has been applied to scallop effort to estimate discards from scallop fishery since 2005 (Gavaris *et al*., 2007b). Estimated discards of cod by the Canadian scallop fishery ranged between 29 mt to 200 mt annually since 1978 (Van Eeckhaute *et al.,* 2005). In 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, and 2002. Quotas were introduced in May 2004. Limits on sea days, as well as trip limits, have also been implemented (Table 2). With the implementation of a catch share system in 2010, most of the fleets are now managed by quotas. USA catches during 1994-2000 ranged between 544 mt and 1,204 mt and increased to 1,935 mt in 2003, then subsequently declined. Total USA catch (landings and discards combined) was 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 Northeast Fisheries Science Center (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 Northeast Regional Stock Assessment Workshop (SAW) 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 (19 in) (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). By weight, the 2010 year class dominated the 2013 fishery (44%) followed by the 2009 (31%) and 2008 year classes (9%) (Figure 11). 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, Figures 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 spring (April) since 1968 and each fall (October) since 1963. All surveys use a stratified random design (Figures 14 and 15). Most of the DFO surveys have been conducted by the *CCGS Alfred Needler* using a Western IIA trawl. A sister ship, the *CCGS Wilfred Templeman*, conducted the survey in 1993, 2004, 2007, and 2008. In 2006, another vessel, the *CCGS Teleost*, conducted 6 of the sets. Using data from a comparative paired trawl fishing experiment conducted in the southern Gulf of St. Lawrence, the analysis showed no significant difference in the catchability of cod between *Alfred Needler* and *Teleost* (Benoît, 2006). 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 *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 2013 NMFS fall, 2014 DFO and 2014 NMFS spring 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 2013, among the lowest 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 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 2013 NMFS fall survey 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 (totaling 72% by number), and 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 remains low. In 2014, both the DFO and NMFS spring survey biomasses 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, 4 and 9.

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 (Figure 23), although the NMFS spring survey does show an increasing trend since 2011. 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 the assessment time period for both age groups (Figure 24) and increasing in recent years 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 VIRTUAL 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) "M 0.8" 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: DFO, NMFS spring and NMFS fall. 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; and

$I_{4,a,t}$ = 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; and

$K_{4,a}$ = *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, or recruitment, relative to the terminal year estimates. At the 2013 benchmark meeting, the VPA “M 0.8” model with catch data through 2011 did not show any retrospective pattern (Claytor and O’Brien, 2013), suggesting that model assumptions on natural mortality were appropriate and that the fishery catch at age was consistent with the survey indices. However, in the 2013 assessment with catch data through 2012 (Wang and O’Brien, 2013), the 2003 year class was estimated to be substantially smaller than the estimate from the 2013 benchmark model formulation with one less year of data. In the 2013 assessment, the 2003 year class was estimated at 4.1 million at age 1 compared to the benchmark estimate of 13.5 million, with one less year of data (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 2013, 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 assessments, 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.

The low catch of age 9 (2003 year class) in 2012 could be due to error in the fishery catch. Another possible reason might be the actual M experienced by the 2003 year class between ages 8 and 9 was higher than that assumed M = 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 (yc) 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 thousand. 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 the 2 sensitivity runs estimated the year class at about 5.9 and 5.4 million (Table 18, Figure 34). Although the 2014 VPA “M 0.8” model tended to underestimate the size of year classes prior to 2003, 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 estimates for most age groups compared to the 2014 VPA “M 0.8” model. There were very minor differences between ‘without 2003yc’ model and 2014 VPA “M 0.8” model, except for age 9 (Table 18 and Figure 35).

For the terminal year biomass, the “estimate 2003yc” model had the highest estimate of age 10+ biomass at 915 mt with a 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.

Applying the retrospective adjustment was not appropriate and was not conducted in this assessment.

1) There is no consistent pattern in the retrospective analysis. As shown in the sensitivity analysis, the retrospective bias might be caused by natural mortality changes (Z>>1 from surveys using catch curve analysis) or bias in fishery catch on older fish of the 2003 year class.
2) With dominant positive residuals, the residual plot (Figures 28 and 32) showed that the 2003 year class were underestimated in the 2013 and 2014 assessment from the “M 0.8” model. Retrospective adjustment would further underestimate the biomass.
3) The sensitivity analysis (“without 2003yc”) showed that the 2014 assessment with the “M 0.8” model gets very similar result with the “without 2003 yc” run (Table 18, Figures 34-36) when the effect of the 2003 year class was removed from the objective function. It illustrated the 2014 assessment with the VPA “M 0.8” model is robust to the uncertainties in the estimate of the 2003yc.

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 40). 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), the consensus was 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, and a lower value for F_{ref} would be more appropriate. At the 2014 TRAC meeting, it was agreed that F = 0.11 was an appropriate fishing reference point for the VPA “M 0.8” model based on the analyses presented (O’Brien and Worcester, 2014). This value was derived from an age-disaggregated Sissenwine-Shepherd production model using M = 0.8 (Wang and O’Brien, 2013). TRAC recommends basing catch advice on F = 0.11.

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, or the possibility that the model may not reflect stock dynamics closely enough.

For projections, the average of the most recent three years of fishery and survey weights at age is used for fishery and beginning year population biomass for 2015 and 2016. The 2014 and 2015 partial recruitment pattern is 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 are 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 with 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 1,200 mt for F = 0.11. Even with 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 (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 2014 for 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 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 1,150 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 1st ages 3+ biomass, and the projected percent increase in biomass from 2015 to 2016.

A catch of 1,150 mt at F = 0.11, would result in a decrease in biomass of 10% in the VPA “M 0.8” model and 5% in the ASAP “M 0.2” model. A catch of 489 mt at F_{ref} = 0.18 would result in at least a minimum 10% increase in the 2016 biomass based on the ASAP “M 0.2” model; however, the biomass in 2016 would decrease by 5% based on the VPA “M 0.8” 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.

SPECIAL CONSIDERATIONS

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.

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. In the ASAP model, the retrospective bias was not adjusted for 2014 and projected catches would be lower if the adjustments were done.

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

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TABLES

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 = 25,000 mt.
1986	TAC = 11,000 mt
1987	TAC = 12,500 mt
1988	TAC = 12,500 mt
1989	TAC = 8,000 mt; 5Zjm cod assessment.
1990	Changes to larger and square mesh size; Changes from TAC to individual and equal boat quotas of 280,000 lbs with bycatch restrictions; Temporary Vessel Replacement Program was introduced.
1991	TAC = 15,000 mt; Dockside monitoring; Maximum individual quota holdings increased to 2% or 600t (whichever was less).
1992	TAC = 15,000 mt; Introduction of ITQs for the OTB fleet.
1993	TAC = 15,000 mt, ITQ for the OTB fleet not based on recommended catch quotas; OTB <65 fleet was allowed to fish during the spawning season (March–May 31st).
1994	TAC = 6,000 mt, Spawning closures January to May 31st; Mesh size was 130 mm square for cod, haddock an Pollock for ITQ fleet; Minimum mesh size of 6" was required for gillnets; Minimum fish size is 43 cm (small fish protocols) for cod, haddock an Pollock for ITQ fleet; OT> 65’ could not begin fishing until July 1; Fixed gear must choose to fish either 5Z or 4X during June 1st to September 30th.
1995	TAC = 1,000 mt as a bycatch fishery; January 1st to June 18th was closed to all groundfish fishery; 130mm square mesh size for all mobile fleets; Small fish protocols continued; 100% dock side monitoring; Fixed gear vessels with a history since 1990 of 25mt or more for 3 years of cod, Haddock, Pollock, hake or Cusk combined can participate in 5Z fishery.
1996	TAC = 2,000 mt; Prohibition of the landing of groundfish (except monkfish) by the scallop fishery; ITQ vessel require minimum 130 mm square mesh for directed cod, Haddock and Pollock trips; Small fish protocols continued; For community management, quota allocation of each fixed gear based on catch history using the years 1986-1993; 100% mandatory dockside monitoring and weighout.
1997	TAC = 3,000 mt
1998	TAC = 1,900 mt
1999	TAC = 1,800 mt; Mandatory cod separator panel when no observer on board; January and February mobile gear winter Pollock fishery.
2000	TAC = 1,600 mt; January and February mobile gear winter Pollock fishery.
2001	TAC = 2,100 mt
2002	TAC = 1,192 mt
2003	TAC = 1,301 mt

Year	Canadian Management History
2004	TAC = 1,000 mt; Canada-USA resource sharing agreement on Georges Bank.
2005	TAC = 740 mt; Exploratory winter fishery January to February 18, 2005; Spawning protocol: 25% of maturity stages at 5 and 6.
2006	TAC = 1,326 mt; Exploratory winter fishery January to February 6, 2006; Spawning protocol: 30% of maturity stages at 5 to 7.
2007	TAC = 1,406 mt; Exploratory winter fishery January to February 15, 2007; High mobile gear observer coverage (99%); Spawning protocol: 30% of maturity stages at 5 to 7.
2008	TAC = 1,633 mt; Winter fishery from January1st to February 8, 2009; At-sea observer coverage 38% by weight of the mobile gear fleet landings and 21% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2009	TAC = 1,173 mt; Winter fishery from January 1 to February 21, 2009; At-sea observer coverage 23% by weight of the mobile gear fleet landings and 15% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2010	TAC = 1,350 mt; Winter fishery from January 1 to February 8, 2010; At-sea observer coverage 18% by weight of the mobile gear fleet landings and 6% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2011	TAC = 1,050 mt; Winter fishery from January 1 to Februay 5, 2011; At-sea observer coverage 19% by weight of the mobile gear fleet landings, 20% by weight of the fixed gear landings and 3% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2012	TAC = 513 mt; Winter fishery from January 1 to February 6, 2012; At-sea observer coverage 42% by weight of the mobile gear fleet landings, 26 % by weight of the fixed gear landings and 35% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2013	TAC = 504 mt; Winter fishery from January 1 to February 3, 2013; At-sea observer coverage 78% by weight of the mobile gear fleet landings, 29%by weight of the fixed gear landings and 19% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.

2b)

Year	USA Management History
	Regulatory Actions
1953	ICNAF era
1973-1986	TAC implemented for Div. 5Z cod; 35,000/year
1977	Groundfish Fishery Management Plan (FMP Magnuson-Steveson Conservation management Act (MSCMA)
1982	Interim FMP
1984	Hague Line implemented
1985	Multi-species FMP
1989	Amendment 2
1994	Emergency Rule – December year-round closures in effect
1994	Amendment 5; Days at Sea (DAS) monitoring; Mandatory reporting; Vessel Trip Reports (VTR) Amendment 6
1996	Amendment 7; accelerated DSA reduction Sustainable Fisheries Act (SFA)
1999	Amendment 9
2002	Interim rule; 20% reduction in DAS
2004	Amendment 13; further reduction in DAS; hard TAC on eastern Georges Bank haddock and cod Eastern US/CAN Area haddock Special Access Program (SAP) Pilot Program
2005	DAS vessels limited to one trip/month in eastern US/CAN Area until April 30th Limited access DAS vessles required to use separator panel trawl in the area
2006	Haddock separator trawl or flounder net required in eastern US/CAN Area
2008	Eastern US/CAN Area access delayed until August 1st, except longline gear September – Ruhle trawl (eliminator trawl) allowed in eastern US/CAN Area
2009	November – Eastern US/CAN Area, trawl vessels required to use separator/Ruhle south 41-40N
2010	Amendment 16, Framework 44 implemented; Secotr management; Prohibition on discarding legal size fish US/CAN 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) commercial and recreational
1997	21 inches (53.3) recreational
2002	22 inches (55.9 cm) commercial; 23 inches (58.4 cm) recreational
2003	21 inches (53.3 cm) recreational
2013	19 inches (48.3 cm) commercial
	Trip Limits
2004	Georges Bank cod: 2,000 lbs/day; 10,000 lbs/trip; eastern Georges Bank: hard TAC on cod 500 lbs/day; 5,000 lbs/trip in eastern US/CAN Area
2005	500 lbs/day; 5,000 lbs/trip in eastern UC/CAN Area Starting July, one trip/month in eastern US/CAN Area until April 30, 2006
2006	500 lbs/day, 5,000 lbs/trip in eastern US/CAN Area
2007	1,000 lbs/trip of cod in eastern US/CAN Area or Haddock SAP

Year	USA Management History
2008	1,000lbs/trip of cod in eastern US/CAN Area, fishing eastern Geoges Bank exclusively
2009	March – 500 lbs/trip of cod in eastern US/CAN Area; back to 1,000 in April April 16th – eastern US/CAN Area closed until May 1st
2010	Georges Bank cod: 2,000 lbs/day; 20,000/trip; eastern Georges Bank cod: 500 lbs/day, 5,000 lbs/trip
2011	March – 3,000 lbs/day during April 500 lbs/day after April in eastern Georges Bank area
	Closures
1970	Area 1(A) and 2(B) March-April
1972-1974	Area 1(A) and 2(B) March-May
1977	Seasonal spawning closure
1987	Modify Closed Area I to overlap with haddock spawning area
1994	January Closed Area II expanded, closed January –May, Closed Area I closed to all vessels except sink gillnet December Closed Area I and II closed year-round to all vessels
1999	Scallopers allowed limited access to Closed Area II
2004	May to December access to northern corner of Closed Area II and adjacent area to target haddock with separator trawl October – eastern Georges Bank closed to multi-species DAS permits
2005	January – eastern US/CAN Area reopened April – eastern US/CAN Area closed until April 30th August – eastern US/CAN area closed (Georges Bank cod TAC projected near 90%)
2006	Eastern US/CAN haddock SAP delayed opening until August 1st
2007	April 25th – eastern US/CAN Area closed until April 30th June – eastern US/CAN Area closed to limited access multi-species TAC (due to cod catch) October – eastern US/CAN Area open to limited access multi-species TAC November – eastern US/CAN Area closes
2008	May – eastern US/CAN Area delayed opening until August 1st; June – eastern US/CAN Area delayed opening until August 1st for all gear (prevent catching 1st quarter cod TAC)
2009	May – eastern US/CAN Area closed until August 1st for trawl vessels
2010	April – eastern US/CAN Area closed; May 1st opening delayed untl 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	2,951	842	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.[1]	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 NOAA research vessels Henry B. Bigelow and 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, 1986-2014.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1986	0	770	3,538	3,204	331	692	445	219	35	66	0	10	0	0	0	0	0	9,311
1987	0	48	1,791	642	753	162	89	181	89	13	13	0	13	16	0	0	0	3,812
1988	0	148	450	5,337	565	838	95	79	179	18	12	4	0	16	0	0	0	7,741
1989	0	350	2,169	764	1,706	258	332	42	85	112	5	32	8	5	0	0	0	5,868
1990	20	106	795	3,471	1,953	4,402	535	1,094	144	157	289	65	52	37	0	0	5	13,125
1991	0	1,198	1,019	1,408	1,639	882	1,195	148	249	38	45	30	12	5	8	0	0	7,876
1992	0	48	2,049	1,221	409	643	451	300	93	38	0	3	3	18	0	0	0	5,276
1993	0	31	355	1,723	622	370	754	274	268	51	31	0	20	6	0	0	0	4,504
1994	0	13	629	691	1,289	477	182	363	84	119	12	0	0	0	8	5	0	3,871
1995	0	32	187	1,240	757	520	186	44	67	28	18	8	6	0	0	0	0	3,093
1996	0	90	203	1,744	4,337	1,432	1,034	445	107	149	39	4	0	0	5	0	0	9,590
1997	0	30	376	568	1,325	1,262	216	50	35	23	17	0	3	0	0	0	0	3,905
1998	0	6	582	831	322	317	238	56	29	7	8	3	4	0	0	0	0	2,402
1999	0	3	156	1,298	1,090	449	317	190	10	28	5	9	0	3	0	0	0	3,561
2000	0	0	423	1,294	4,967	2,157	1,031	510	317	20	23	12	0	0	0	0	0	10,754
2001	0	3	37	802	519	1,391	645	334	224	225	36	24	7	0	0	0	0	4,248
2002	0	0	118	477	2,097	694	1,283	458	188	63	76	7	0	0	0	0	0	5,462
2003	0	0	8	200	510	867	194	219	69	12	0	0	0	0	0	0	0	2,078
2004	0	427	40	246	381	422	353	59	108	25	5	0	3	0	0	0	0	2,069
2005	0	25	1,025	1,398	7,149	1,766	816	743	60	87	8	4	0	0	0	0	0	13,082
2006	0	0	41	1,500	673	1,779	757	217	216	83	34	10	15	0	0	0	0	5,325
2007	0	18	130	549	2,606	379	653	119	81	53	0	4	0	0	0	0	0	4,591
2008	0	12	147	1,027	755	2,978	194	392	41	4	20	0	0	0	0	0	0	5,569
2009	0	11	51	2,487	2,261	519	2,955	0	82	0	0	0	18	0	0	0	0	8,384
2010	0	5	92	956	4,105	1,781	703	1,828	65	84	5	0	0	0	0	0	0	9,623
2011	0	193	271	766	952	1,324	256	67	112	14	8	2	0	0	0	0	0	3,965
2012	0	9	149	327	315	195	158	7	18	4	0	0	0	0	0	0	0	1,182
2013	0	0	431	3,754	2,173	285	81	52	10	0	0	0	0	0	0	0	0	6,786
2014	0	76	9	360	538	169	35	0	27	0	0	0	0	0	0	0	0	1,213

Table 10. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS spring survey, 1970-2014. 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	1,115	302	610	73	263	48	0	71	24	0	48	0	0	0	0	2,907
1971	0	185	716	503	119	326	124	257	227	40	40	79	0	0	0	0	0	2,615
1972	56	1,578	1,856	2,480	393	114	136	60	88	73	18	14	0	0	14	0	0	6,879
1973	0	665	37,880	5,474	6,109	567	467	413	0	163	231	0	0	0	95	0	0	52,064
1974	0	461	5,877	4,030	759	2,001	360	91	267	45	48	54	0	0	0	0	0	13,991
1975	0	0	467	3,061	4,348	446	960	79	0	122	0	0	0	0	0	0	0	9,483
1976	84	1,733	1,111	620	444	759	0	167	35	0	0	0	0	48	0	0	0	5,001
1977	0	0	2,358	736	354	307	334	22	35	0	0	0	0	0	0	0	0	4,145
1978	373	187	0	2,825	615	916	153	787	62	43	40	0	0	0	0	0	0	6,001
1979	71	339	1,332	122	1,430	543	176	91	130	0	0	0	0	0	0	0	0	4,234
1980	0	11	2,251	2,168	169	1,984	410	78	48	31	0	47	0	0	0	0	0	7,197
1981	283	1,956	1,311	2,006	1,093	43	453	197	59	0	0	0	0	0	0	0	0	7,399
1982	44	455	6,642	13,614	12,667	9,406	0	3,088	992	120	0	0	0	0	0	0	0	47,027
1983	0	389	2,017	3781	779	608	315	106	98	0	70	0	0	0	0	0	35	8,197
1984	0	103	117	344	483	92	182	74	18	105	0	0	0	0	0	0	0	1,518
1985	58	36	2,032	633	1,061	1,518	328	217	213	83	116	34	23	0	0	0	0	6,352
1986	97	619	339	1,132	298	427	536	20	109	142	0	0	0	0	0	0	0	3,719
1987	0	0	1,194	247	568	0	152	148	30	54	0	0	0	0	0	0	0	2,394
1988	138	320	243	2,795	274	461	51	5	67	0	0	10	0	0	0	0	0	4,364
1989	0	174	1,238	338	1,685	234	396	99	12	36	48	24	0	0	0	0	0	4,284
1990	24	45	360	1,687	586	634	152	164	19	0	0	24	0	0	0	0	0	3,696
1991	217	725	620	514	903	460	382	44	17	0	24	53	0	0	0	0	0	3,957
1992	0	81	666	349	103	261	152	159	27	52	0	0	0	0	0	0	0	1,850
1993	0	0	462	1,284	262	46	182	46	43	46	12	0	0	0	0	0	0	2,382
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	3,614
1996	0	139	300	990	1,343	121	94	28	0	0	0	0	0	0	0	0	0	3,016
1997	271	54	218	48	402	519	53	126	57	0	0	0	0	0	0	0	0	1,747
1998	54	0	1,040	1,985	995	983	609	30	31	0	0	0	0	0	0	0	0	5,729
1999	22	22	145	673	624	370	172	107	34	8	0	0	0	0	0	0	0	2,176
2000	36	0	304	643	1,348	492	138	52	20	0	0	0	0	0	0	0	0	3,032
2001	0	0	64	889	96	350	109	0	12	10	0	0	0	0	0	0	0	1,530
2002	36	0	121	470	1,081	175	214	61	0	0	0	0	0	0	0	0	0	2,158
2003	0	0	125	287	812	1,154	135	78	9	0	0	0	0	0	0	0	0	2,599
2004	0	549	10	838	2,091	2,105	1,351	239	382	29	0	0	0	0	0	0	0	7,595
2005	36	15	345	70	747	287	190	131	34	0	0	0	0	0	0	0	0	1,855
2006	0	37	73	952	411	1,007	340	151	79	0	0	0	0	0	0	0	0	3,050
2007	0	0	369	308	2,258	239	291	47	28	0	0	0	0	0	0	0	0	3,540
2008	43	37	112	675	372	1,385	51	66	0	0	0	0	0	0	0	0	0	2,741
2009	0	61	86	875	408	219	377	24	12	15	0	0	0	0	0	0	0	2,078
2010	0	25	126	367	667	168	44	147	0	12	0	0	0	0	0	0	0	1,556
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	2,389
2013	0	0	653	3,864	1,202	129	64	15	0	0	0	0	0	0	0	0	0	5,926
2014	0	55	64	568	922	109	27	0	0	0	0	0	0	0	0	0	0	1,746

Table 11. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS fall survey, 1970-2013. 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	1,391	2,962	17,458	14,216	7,106	4,461	5,335	946	1,135	1,463	56,474	52,120
1979	1,174	8,843	4,591	16,585	10,125	3,742	4,220	4,264	729	2,098	56,372	46,354
1980	2,778	6,032	14,275	4,181	16,615	8,341	2,526	2,623	3,132	2,289	62,791	53,981
1981	1,654	7,011	11,170	15,681	4,761	11,839	6,296	3,330	2,431	4,181	68,356	59,691
1982	524	12,411	13,223	10,171	10,866	3,433	7,952	4,124	1,382	4,906	68,993	56,058
1983	1,144	5,256	15,969	7,040	4,992	7,152	2,137	3,897	2,561	4,256	54,403	48,003
1984	719	2,420	6,058	11,564	3,744	3,299	3,635	981	2,117	4,143	38,681	35,542
1985	460	7,539	6,160	5,816	10,057	3,773	2,802	2,528	774	3,778	43,685	35,687
1986	3,159	3,319	12,155	4,375	4,397	7,369	2,139	1,462	1,188	2,994	42,558	36,080
1987	1,237	16,627	5,312	9,886	3,333	3,178	4,867	1,161	912	3,244	49,756	31,892
1988	2,155	6,262	22,150	5,426	8,270	2,095	1,932	3,283	1,311	3,270	56,155	47,738
1989	730	9,624	8,950	17,664	3,711	5,529	1,198	654	1,648	2,771	52,479	42,126
1990	1,600	3,302	16,309	10,340	15,104	3,006	3,178	746	444	2,889	56,917	52,016
1991	849	5,464	5,420	14,117	8,435	7,859	2,109	1,672	530	2,204	48,657	42,345
1992	461	6,657	8,368	3,828	8,012	5,026	4,524	1,154	775	1,811	40,615	33,497
1993	332	2,795	7,587	6,144	3,193	4,606	2,734	1,844	654	1,774	31,661	28,534
1994	510	2,536	2,794	4,396	3,629	2,326	2,342	1,738	1,084	1,705	23,061	20,015
1995	383	2,314	4,755	2,609	2,311	2,390	746	827	841	1,321	18,499	15,802
1996	315	1,437	3,625	5,815	3,387	2,751	1,183	547	528	1,024	20,613	18,861
1997	1,071	2,108	2,316	3,700	4,748	3,956	1,013	868	184	720	20,686	17,507
1998	171	2,997	3,143	2,112	3,245	4,002	1,359	386	257	393	18,065	14,897
1999	544	1,789	4,970	3,534	1,845	3,399	2,032	743	119	325	19,300	16,968
2000	114	3,596	2,207	5,999	3,202	1,828	1,888	853	363	207	20,256	16,546
2001	12	1,194	4,579	2,683	6,368	3,435	1,106	876	390	213	20,856	19,650
2002	38	489	1,434	4,928	2,339	4,776	1,382	435	410	239	16,469	15,943
2003	9	862	914	1,608	4,192	1,491	1,994	581	134	256	12,041	11,170
2004	96	137	2,294	1,265	1,650	3,115	634	748	267	164	10,370	10,137
2005	44	2,124	444	2,061	852	855	999	334	220	150	8,082	5,913
2006	108	193	3,330	426	2,014	603	434	425	74	194	7,802	7,500
2007	132	1,807	534	3,822	397	1,853	319	211	236	122	9,434	7,495
2008	63	1,162	3,372	718	3,475	320	618	137	94	157	10,117	8,891
2009	112	818	2,371	4,401	630	3,215	143	254	42	97	12,083	11,153
2010	145	527	1,405	2,506	4,233	521	1,271	45	90	55	10,799	10,127
2011	206	720	756	1,290	1,987	3,647	211	546	10	82	9,455	8,529
2012	32	2,263	1,397	958	1,256	1,874	2,249	114	265	44	10,453	8,158
2013	10	891	4,328	1,741	904	1,174	900	1,037	50	275	11,312	10,410
2014		164	1,288	5,130	2,061	1,216	680	606	575	162	11,883	11,719

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	12,459	3,342	10,752	3,989	1,312	714	618	105	111	100	33,504
1979	10,450	10,193	2,639	5,537	2,218	721	438	392	66	143	32,798
1980	10,052	8,542	7,543	1,501	3,169	1,328	427	292	266	156	33,276
1981	17,481	8,224	6,117	4,692	958	1,725	769	262	216	286	40,731
1982	5,693	14,281	5,958	3,334	2,641	534	986	467	128	335	34,359
1983	5,107	4,648	8,533	3,111	1,594	1,190	262	450	243	291	25,428
1984	14,264	4,161	3,100	4,733	1,387	801	617	109	206	283	29,662
1985	5,273	11,663	3,199	1,815	2,660	647	319	256	55	258	26,145
1986	24,078	4,309	6,978	1,360	894	1,293	288	163	111	205	39,679
1987	8,244	19,676	3,122	3,681	588	424	651	174	90	222	36,872
1988	14,155	6,730	12,407	1,797	1,984	334	229	376	106	223	38,342
1989	5,130	11,569	5,249	6,403	862	860	157	84	146	189	30,648
1990	7,454	4,193	8,849	3,567	3,462	501	370	78	33	197	28,705
1991	9,669	6,093	2,777	4,457	1,988	1,605	280	166	53	151	27,240
1992	3,630	7,867	4,091	1,370	1,925	820	648	135	74	124	20,685
1993	4,725	2,928	4,113	2,113	708	782	391	250	70	121	16,201
1994	3,565	3,861	1,950	1,672	918	312	320	201	118	117	13,032
1995	2,096	2,914	2,996	1,162	665	509	112	104	71	90	10,720
1996	3,598	1,715	2,334	2,240	867	450	217	46	44	70	11,580
1997	5,638	2,941	1,368	1,700	1,476	638	163	89	18	49	14,080
1998	2,187	4,610	2,275	935	1,070	886	233	50	31	27	12,303
1999	4,911	1,787	3,682	1,579	621	733	312	90	14	22	13,752
2000	1,893	4,015	1,391	2,579	990	410	290	104	31	14	11,718
2001	1,211	1,548	3,230	1,039	1,768	675	160	116	39	18	9,804
2002	2,388	988	1,182	2,172	661	1,089	236	52	41	21	8,830
2003	582	1,955	800	854	1,376	444	389	87	18	22	6,527
2004	4,429	476	1,578	517	478	762	147	118	27	14	8,547
2005	770	3,608	380	1,164	287	259	254	44	34	13	6,812
2006	3,531	629	2,893	271	768	190	94	91	13	17	8,496
2007	2,462	2,889	498	2,167	151	452	55	31	30	10	8,745
2008	1,381	2,015	2,326	352	1,388	92	148	17	9	13	7,742
2009	981	1,130	1,613	1,773	233	912	32	45	5	8	6,732
2010	1,825	802	892	1,132	1,326	149	321	8	14	5	6,473
2011	5,401	1,493	634	634	733	1,018	57	122	2	7	10,101
2012	1,590	4,418	1,183	450	435	497	441	18	50	4	9,085
2013	355	1,300	3,560	864	325	330	207	194	8	24	7,167
2014		290	1,036	2,817	661	256	144	92	87	14	5,398

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 F_{ref} = 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 2003yc" model formulations. Considering F_{ref} = 0.18 is not consistent with the assessment VPA "M 0.8" model, it is inappropriate for the catch advice (shown in grey font).

a. The probability of exceeding F_{re}f.

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 2003yc” 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 2003yc” 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 2015 fishing mortality (F), 2016 January 1st stock biomass (ages 3+), and percent increase in biomass from 2015 to 2016, based on 2015 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).

CONSEQUENCE ANALYSIS

		VPA 0.8	**ASAP**
Catch 2013		463 mt	463 mt
Quota 2014		700 mt	700 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(mt)	10,802	2,169
	% inc B from 2015	-15%	-28%
1,150	2015 F	0.11	0.48
(VPA F=0.11)	2016 Biomass(mt)	11,484	2,843
	% inc B from 2015	-10%	-5%
489	2015 F	0.04	0.18
(ASAP F=0.18)	2016 Biomass(mt)	12,129	3,481
	% inc B from 2015	-5%	16%
308	2015 F	0.03	0.11
(ASAP F=0.11)	2016 Biomass(mt)	12,307	3,660
	% inc B from 2015	-4%	22%

🟩	F<=Fref & 10% biomass increase in 2016
🟦	F< =Fref & biomass increase < 10% in 2016
🟥	F>Fref and biomass increase < 10% in 2016
⬜	not feasible projection

Table 27. 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 F_{ref}. 20% chance of decrease in biomass from 2004-2005.	2,332 mt Exceed F_{ref} and biomass to decline.	*F = 0.16* *Biomass decreased 23%* Now F = 0.37 Biomass decreased 23% 04 - 05
2004	2005	1,100 mt	Neutral risk of exceeding F_{ref}. Greater than 50% risk of decline in biomass from 2005 - 2006.	1,000 mt	Low risk of exceeding F_{ref}, neutral risk of stock decline.	1,287 mt Greater than neutral risk of exceeding $F_{0.1}$; biomass expected to decline 10%.	*F = 0.10* *Biomass stabled* Now F = 0.22 Biomass decreased 4% 05 - 06
2005	2006	2,200 mt	Neutral risk of exceeding F_{ref}.Low risk of less than 10% biomass increase from 2006 - 2007.	1,700 mt	Low risk of exceeding F_{ref}, 75% probability of stock increase of 10%.	1,705 mt Approx 25% risk of exceeding F_{ref}; biomass increase not likely to be 20%.	*F = 0.15* *Biomass stabled* Now F = 0.35 Biomass increased 19% 06 - 07
2006(4)	2007	(1) 2,900 m (2) 1,500 mt	(1) Neutral risk of exceeding F_{ref}. (2) Neutral risk of biomass decline from 2007 – 2008.	1,900 mt	Low risk of exceeding F_{ref}, nominal decline in stock size.	1,811 mt No risk of exceeding F_{ref}; neutral risk of biomass decline.	*F = 0.13* *Biomass stabled* Now F = 0.26 Biomass decreased 5% 07-08
2007(4)	2008	2,700 mt	Neutral risk of exceeding F_{ref} and a neutral risk of stock decline from	2,300 mt	Low risk of exceeding F_{ref}, nominal stock size increase.	1,780 mt No risk of exceeding F_{ref}; biomass not expected to increase	*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$^{(2)}$**
			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 F_{ref}. (2) neutral risk of stock decline from 2009 – 2010.	1,700 mt	Low risk of exceeding F_{ref}, high risk biomass will not increase.	1,837 mt Slightly less than neutral risk of exceeding F_{ref}; biomass almost certain not to increase.	*F = 0.33 or 0.20* *Biomass stable or declined 7%* Now F=0.16 Biomass decreased 10% 09-10
2009$^{(4)}$	2010	(1) 1,300 – 1,700 mt (2) 1,800 – 900 mt	(1) Neutral risk of exceeding F_{ref}. (2) Neutral risk of stock decline from 2010 – 2011.	1,350 mt	Neutral risk of biomass decline.	1,326 mt	*F = 0.41 or 0.25* *Biomass decreased 15% / 17%* Now F=0.14 Biomass decreased 14% 10-11
2010$^{(4)}$	2011	(1) 1,000 – 1,400 mt (2) 1,850 – 1,350 mt	(1) Neutral risk of exceeding F_{ref}. (2) Neutral risk of stock decline from 2011 – 2012.	1,050 mt	Low risk of exceeding F_{ref}, and biomass growth of up to 10%.	1,037 mt	*F = 0.49 or 0.28* *Biomass increased 6%/stable* Now F= 0.12 Biomass increased 22% 11-12
2011	2012	(1) 600 – 925 mt (2) 1,350 – 900 mt	(1) Neutral risk of exceeding F_{ref}. (2) Neutral risk of stock decline from 2012 – 2013.	675 mt	Low risk of exceeding F_{ref}, and low to neutral risk of biomass decline.	614 mt	*F = 0.07* *Biomass increased 16%* Now F= 0.07 Biomass increased 27% 12-13
2012	2013	(1) 400 – 775 mt (2) 400 – 575 mt	(1) Neutral risk of exceeding F_{ref}. (2) Neutral risk of stock not increase by 20% from 2013 – 2014.	600 mt	Neutral risk of exceeding F_{ref}, and stock biomass increase more than 10%.	463 mt	*F = 0.04* *Biomass increased 13%*
2013	2014	600 mt	(1) Low risk of exceeding F_{ref}.	700 mt	Low risk of exceeding F_{ref}, 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%.		
2014	2015			650 mt			

(1) All catches are calendar year catches.
(2) Values in italics are assessment results in year immediately following the catch year; values in normal font are results from this assessment.
(3) Prior to implementation of US/CA Understanding.
(4) Advice and results reported for two assessment models.

FIGURES

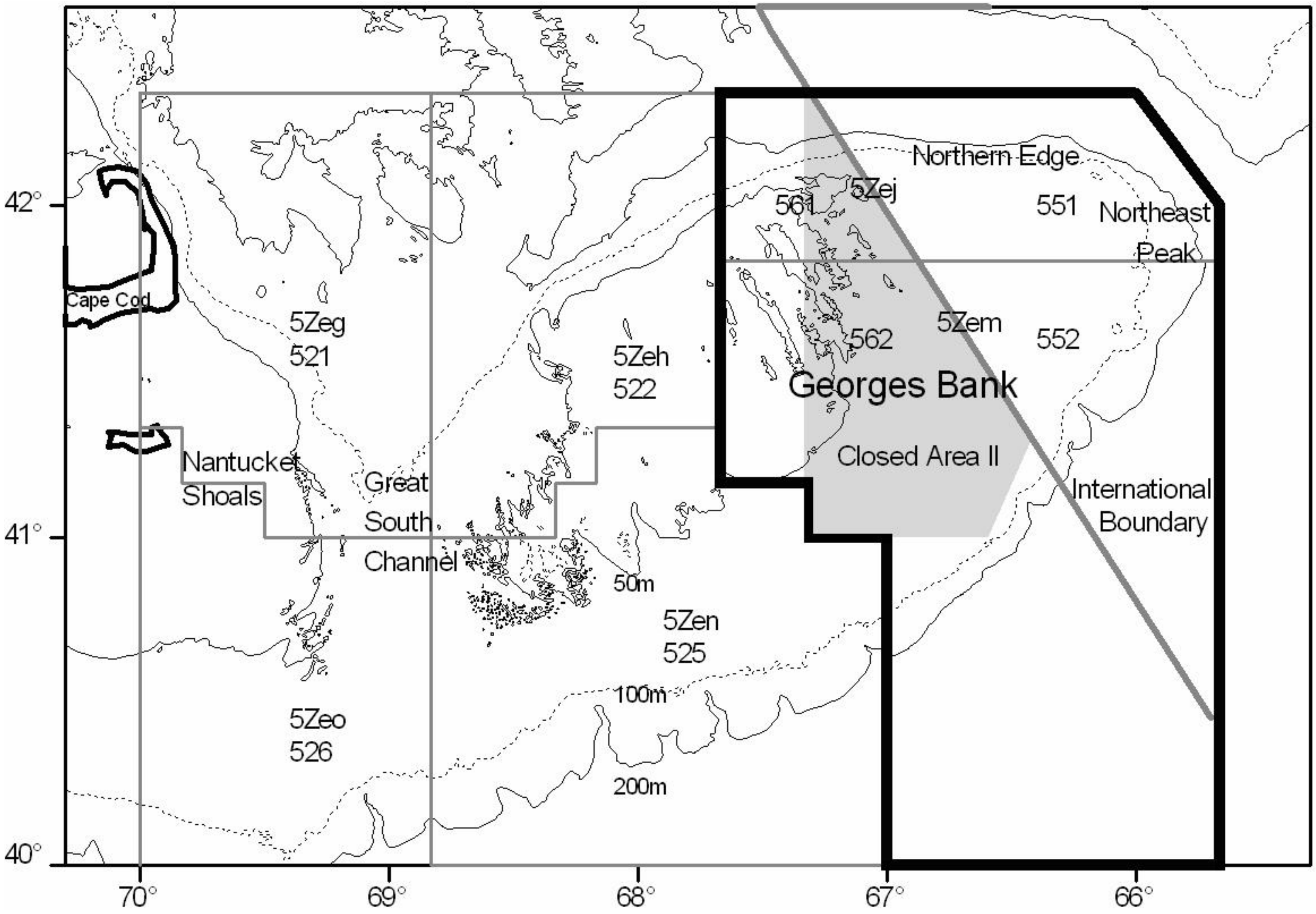


Figure 1. Fisheries statistical areas (CANADA and USA) in NAFO Subdivision 5Ze. The eastern Georges Bank Atlantic Cod management unit is outlined by a heavy black line.

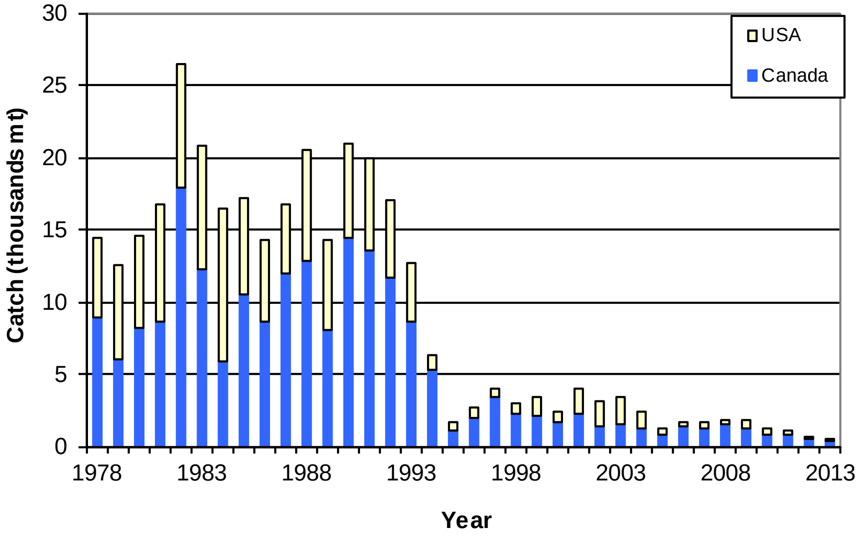


Figure 2. Catches of cod from eastern Georges Bank, 1978 to 2013.

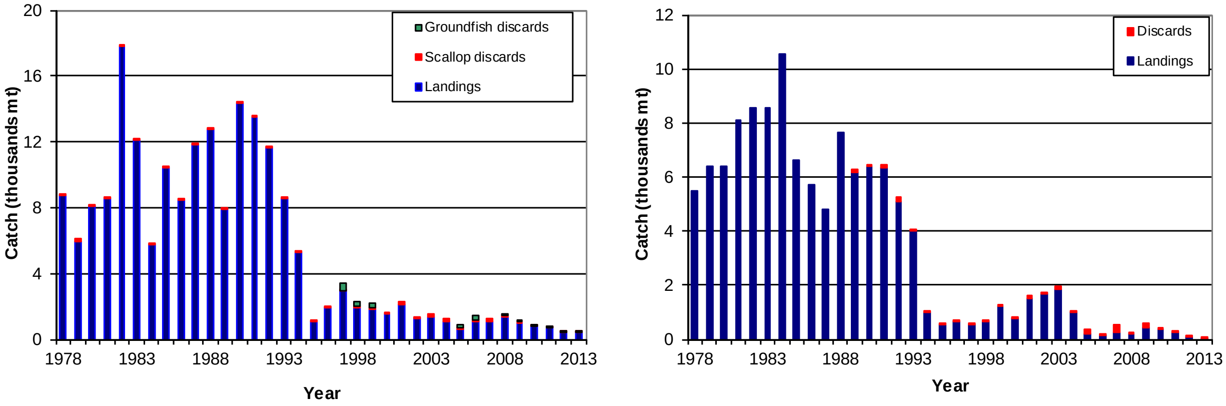


Figure 3. Canadian (left panel) and USA (right panel)landings and discards of cod from eastern Georges Bank, 1978 to 2013.

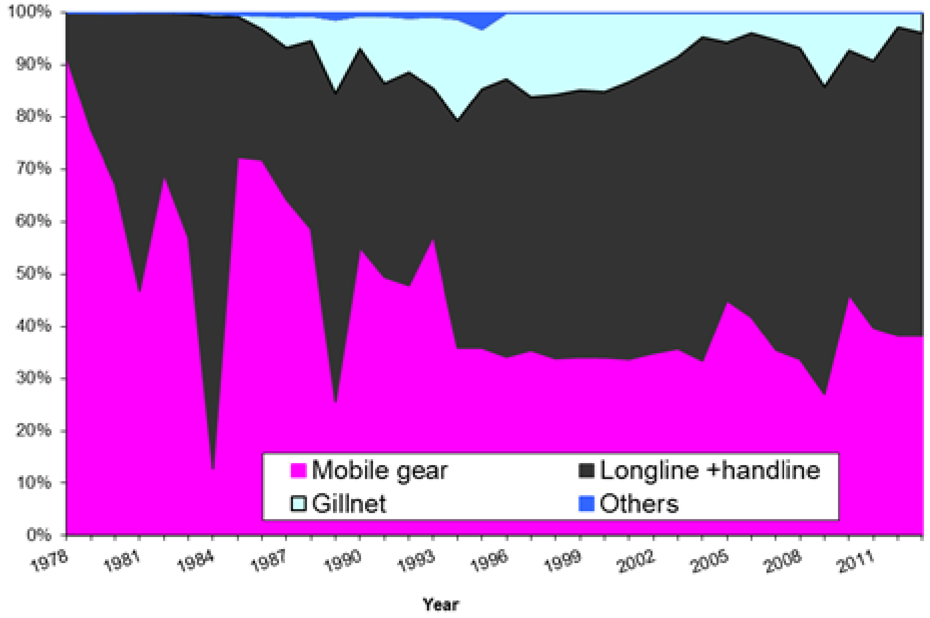


Figure 4. Proportion of Canadian gear specific landings of cod from eastern Georges Bank for 1978 to 2012.

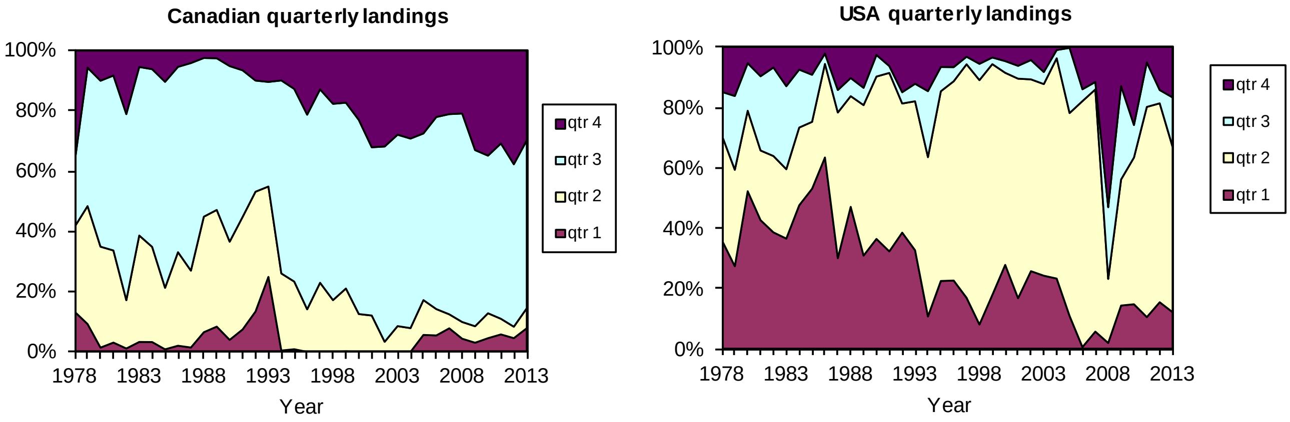


Figure 5. Proportion of Canadian and USA quarterly landings of cod from eastern Georges Bank, 1978 to 2012.

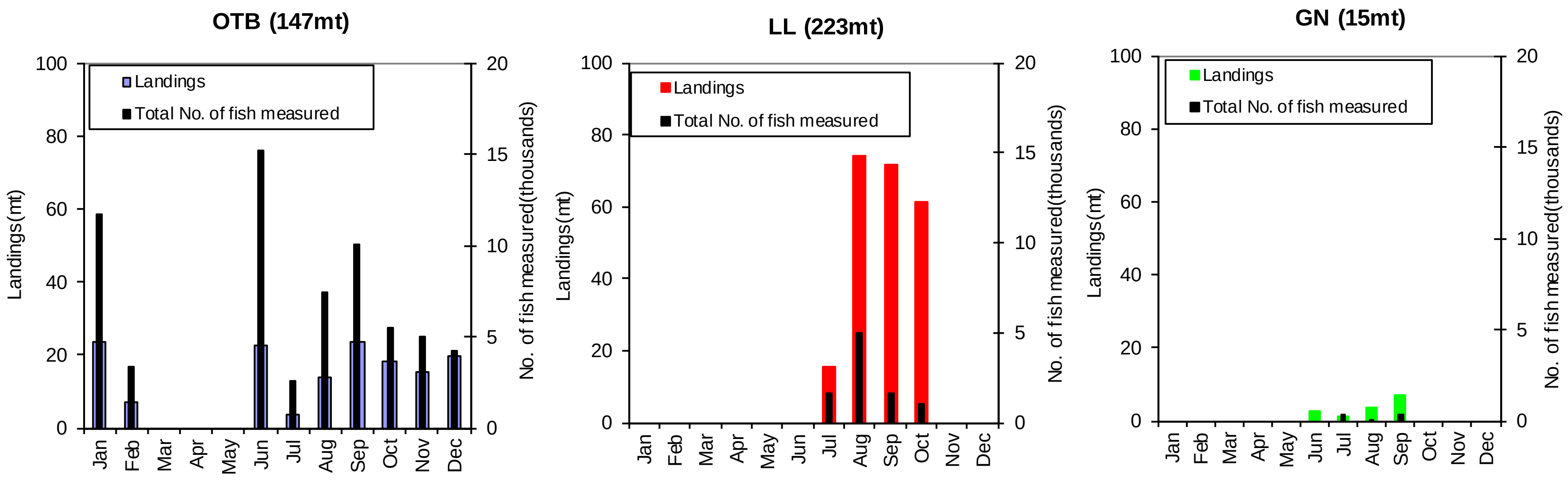


Figure 6. Landings (wide bars) and sampling (narrow dark bars) of cod by gear and month from the 2013 Canadian bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on eastern Georges Bank.

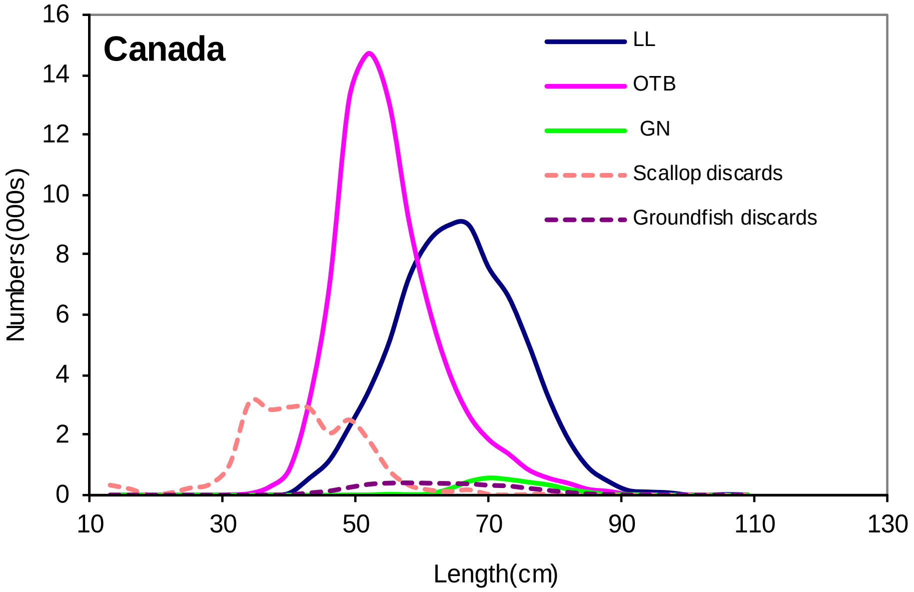


Figure 7. Cod catches at length by gear from the 2013 Canadian fisheries on eastern Georges Bank.

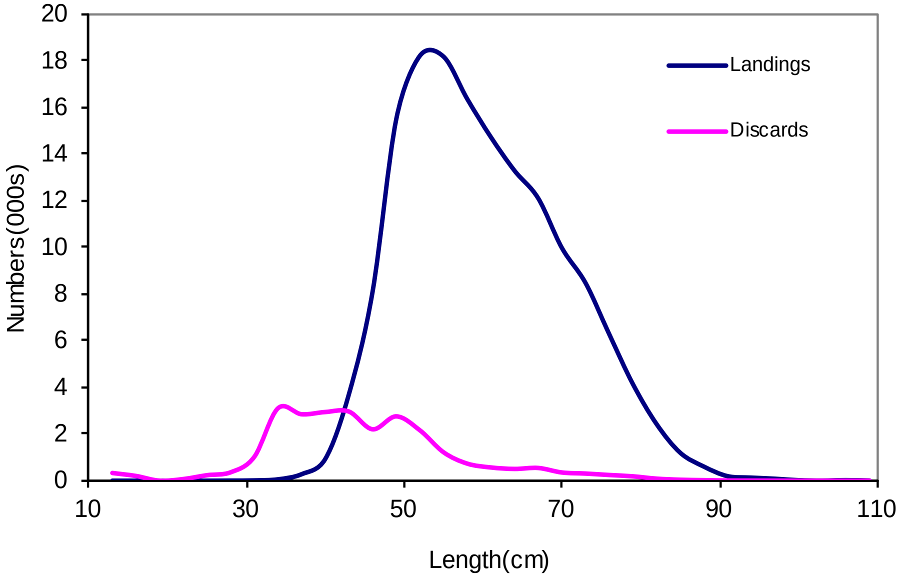


Figure 8. Cod landings and discards at length from the 2013 Canadian fisheries on eastern Georges Bank.

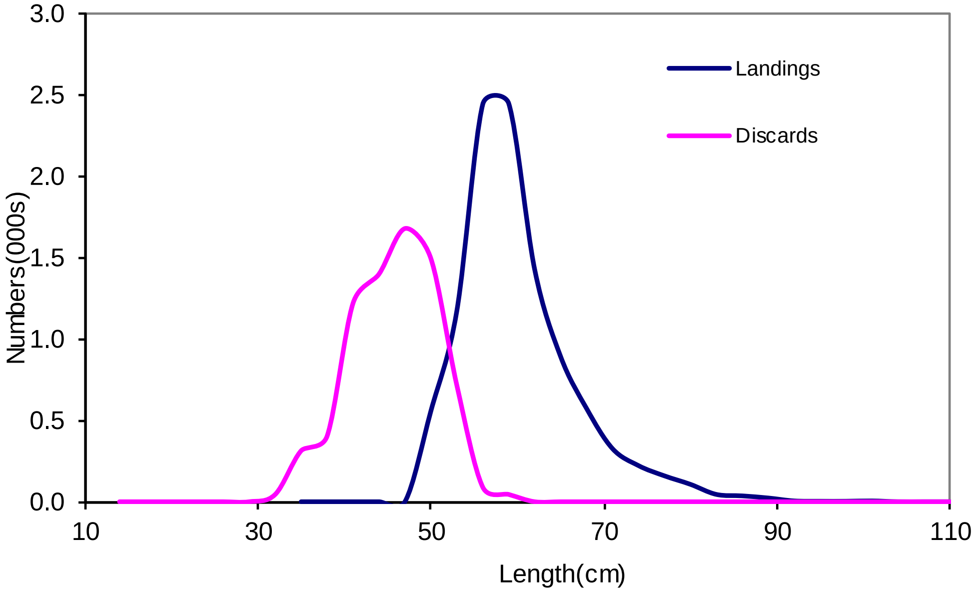


Figure 9. Cod landings and discards at length from the 2013 USA fisheries on eastern Georges Bank.

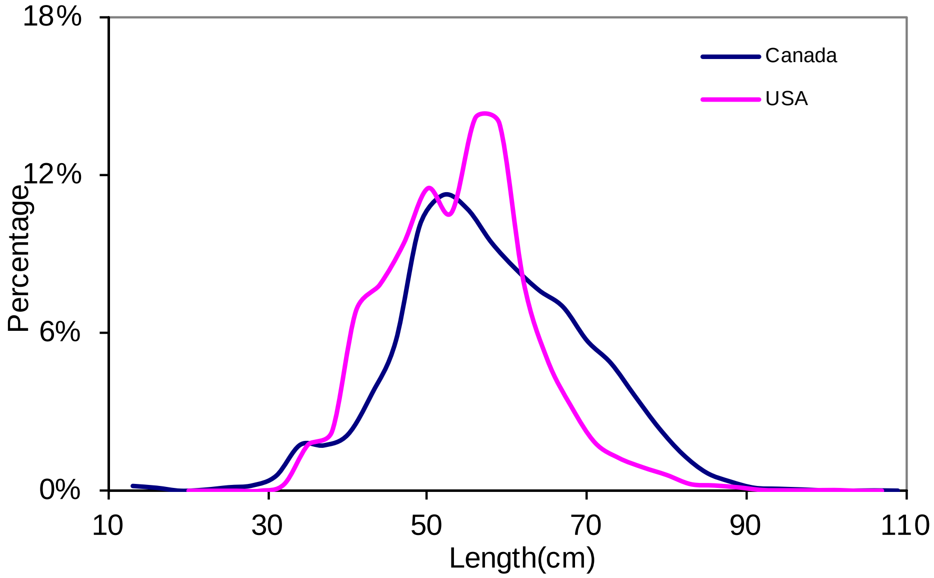


Figure 10. Cod length frequency from the 2013 Canadian and USA fisheries on eastern Georges Bank.

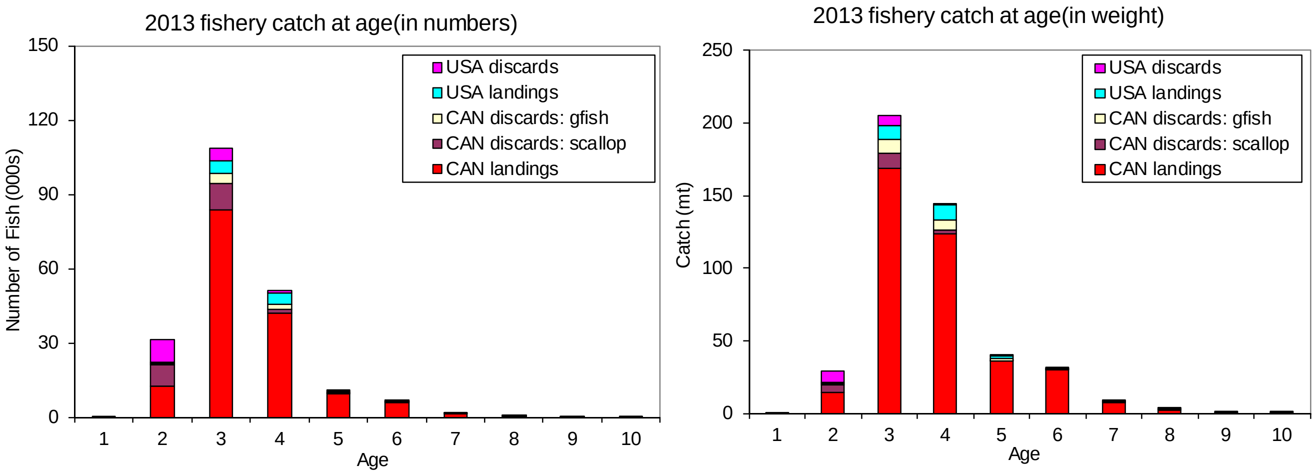


Figure 11. Catch at age in numbers (left) and weight (right) for landings and discards of cod from the 2013 eastern Georges Bank fisheries.

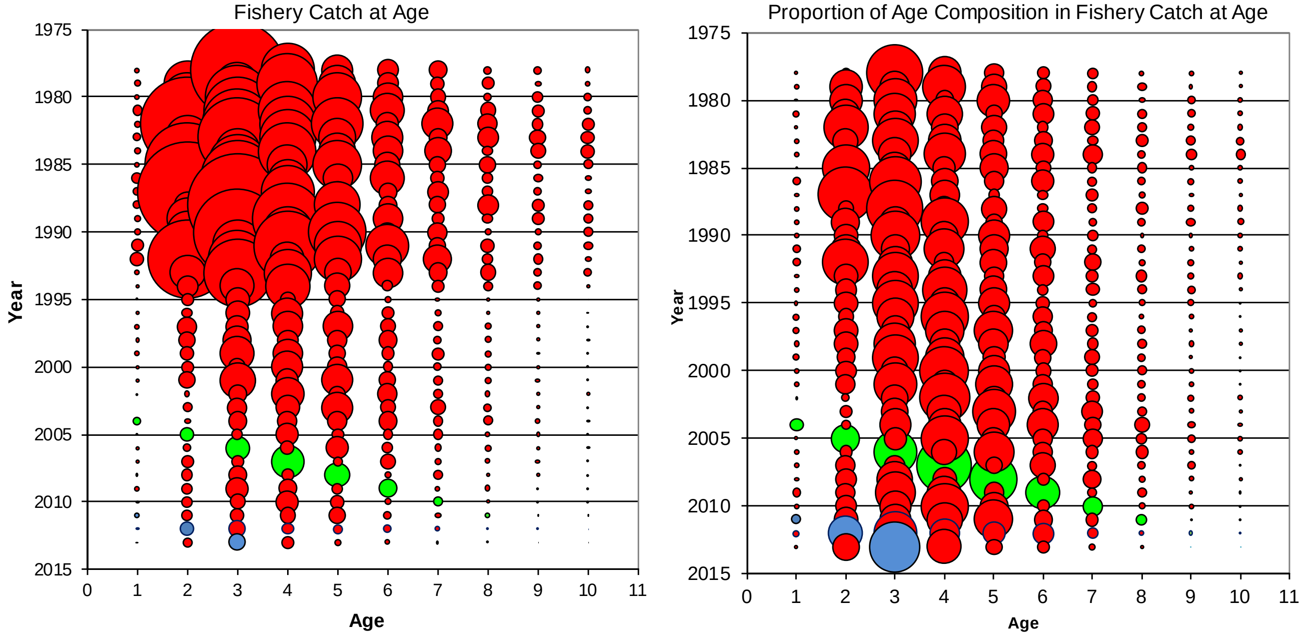


Figure 12. Total catch at age (numbers) of cod (left) and proportion of catch at age from eastern Georges Bank for 1978 to 2013. The bubble area is proportional to the magnitude. The light green circles are the 2003 year class and the light blue circles are the 2010 year class.

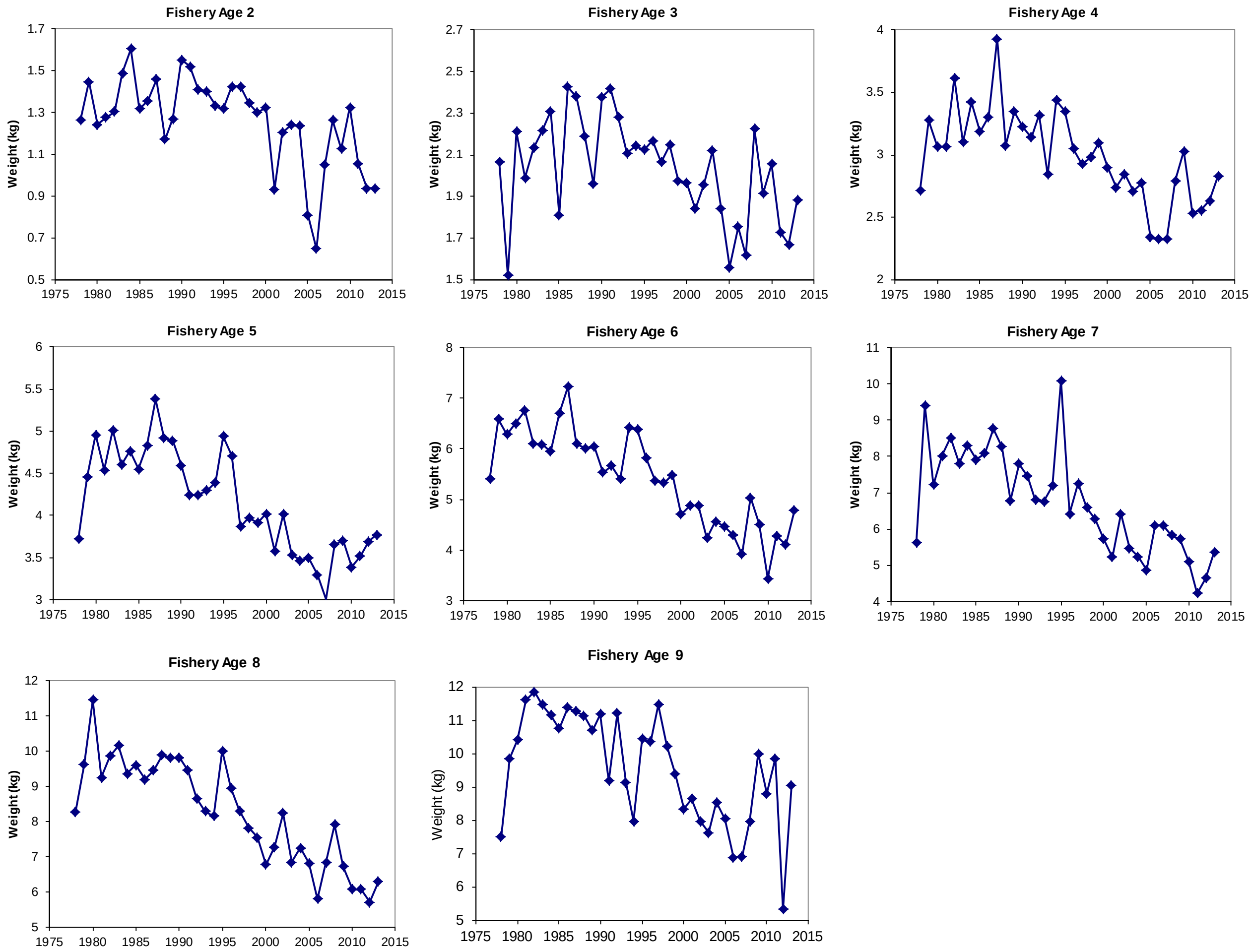


Figure 13. Average weight at age for ages 2 to 9 of cod from the eastern Georges Bank fishery, 1978 to 2013.

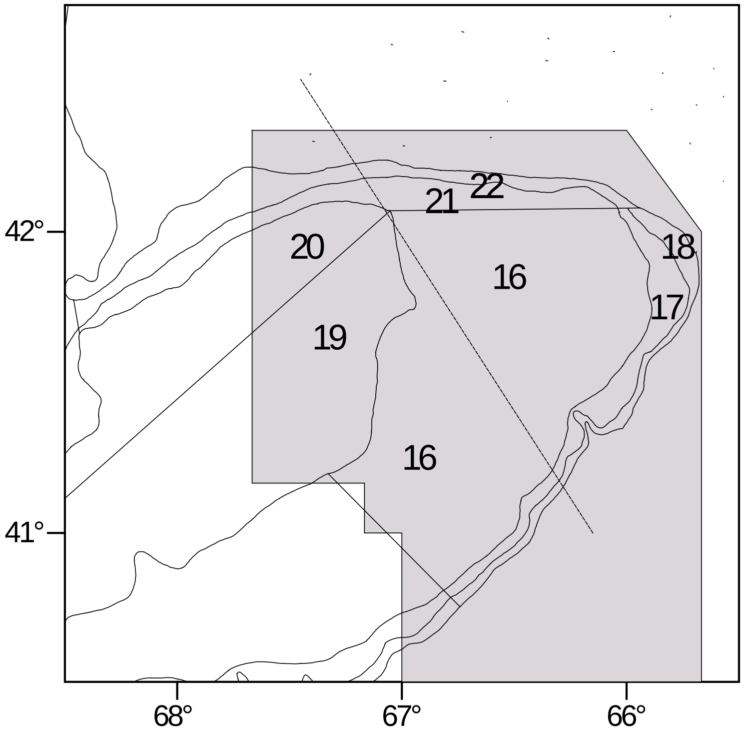


Figure 14. Stratification used for the NMFS surveys. The eastern Georges Bank management unit is indicated by shading.

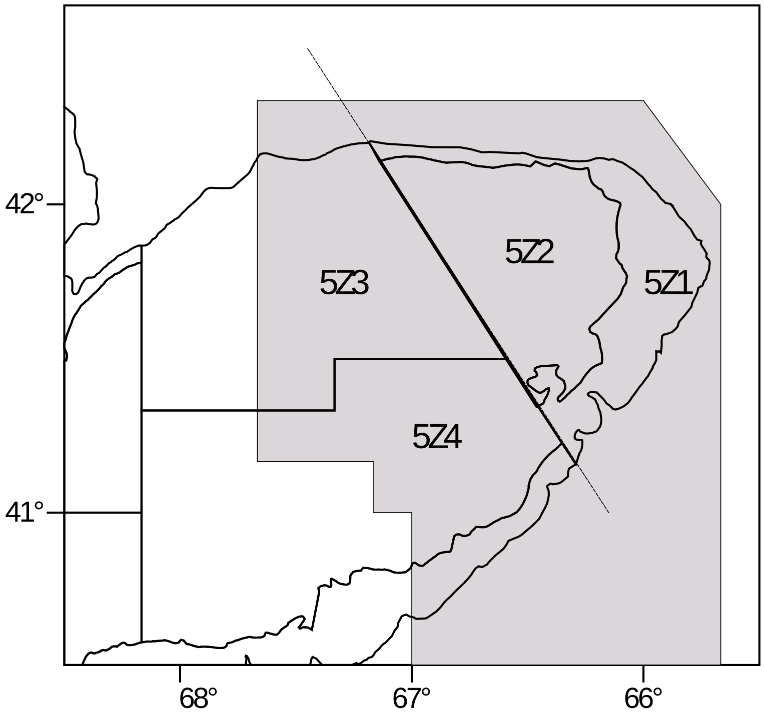


Figure 15. Stratification used for the DFO survey. The eastern Georges Bank management unit is indicated by shading.

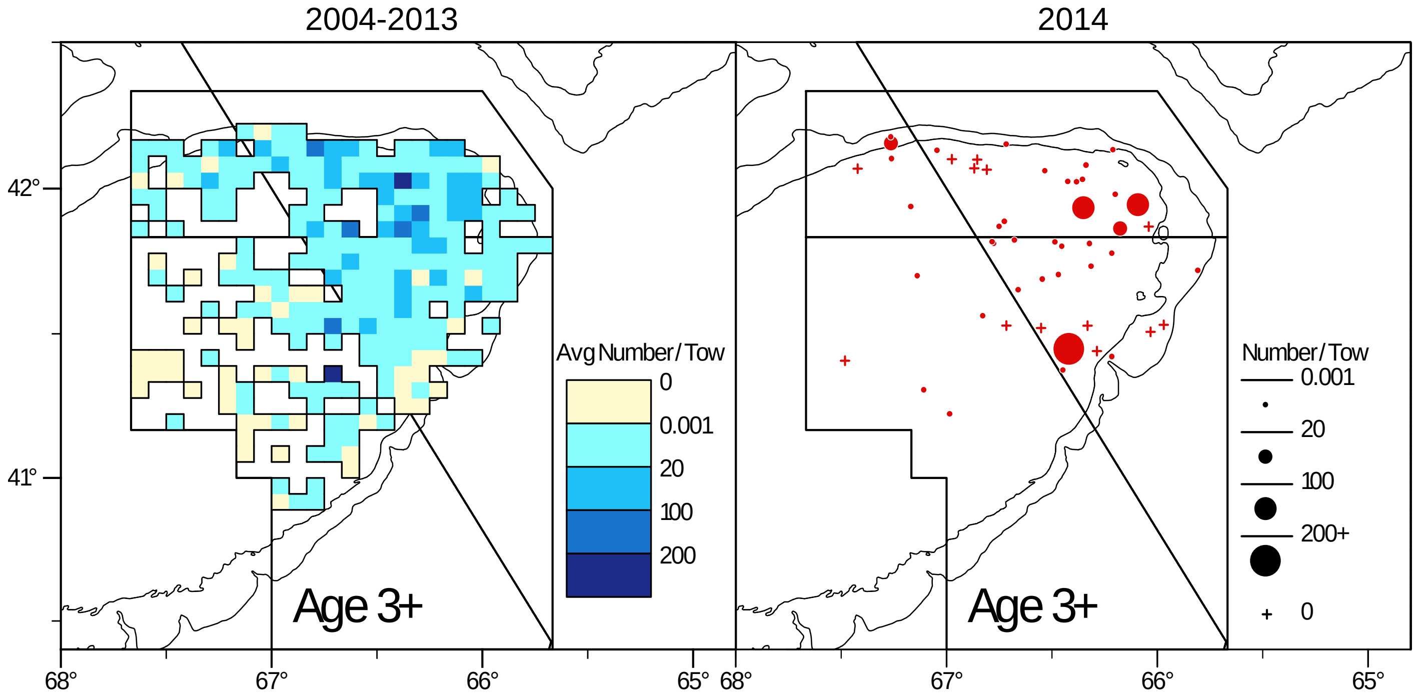


Figure 16. Spatial distribution of age 3+ cod on eastern Georges Bank from the DFO survey for 2014 (right panel) compared to the average for 2004 to 2013 (left panel).

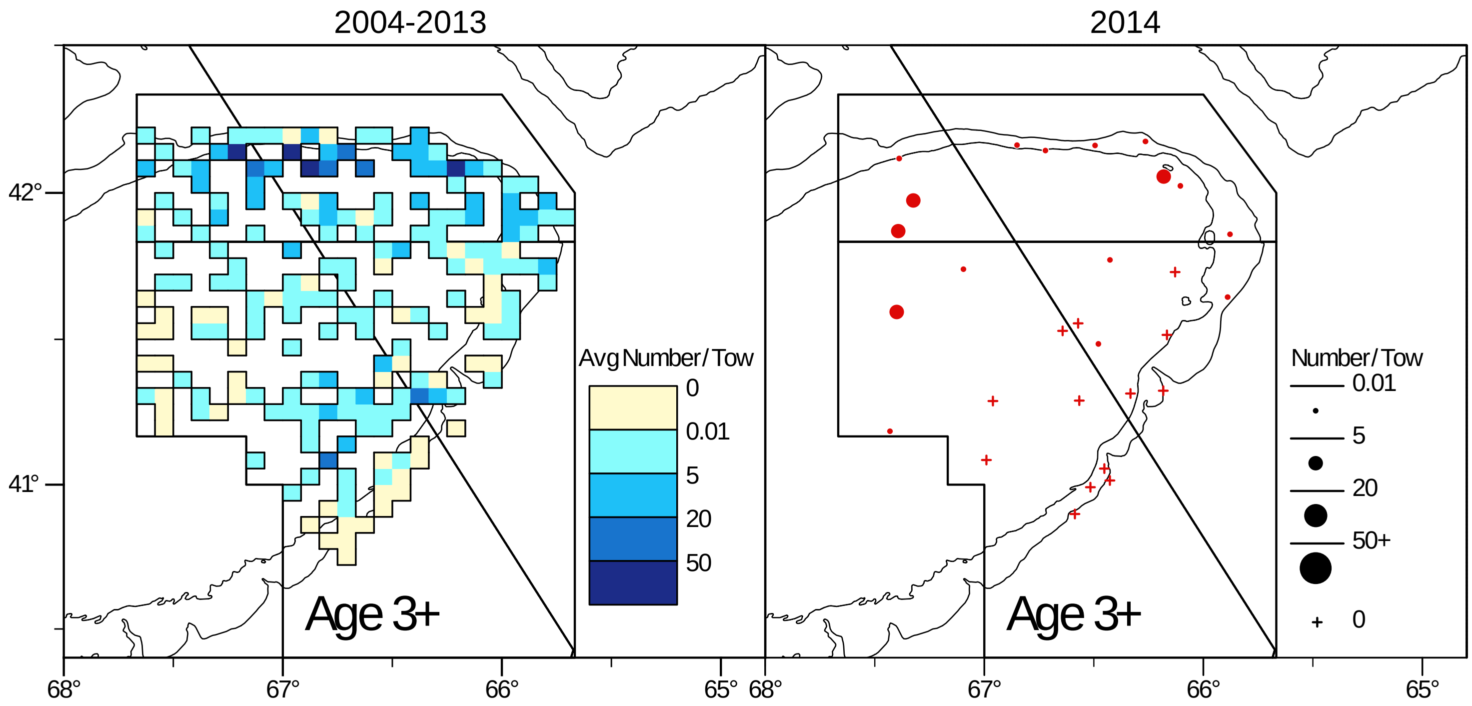


Figure 17. Spatial distribution of age 3+ cod on eastern Georges Bank from the NMFS spring survey for 2014 (right panel) compared to the average for 2004-2013(left panel).

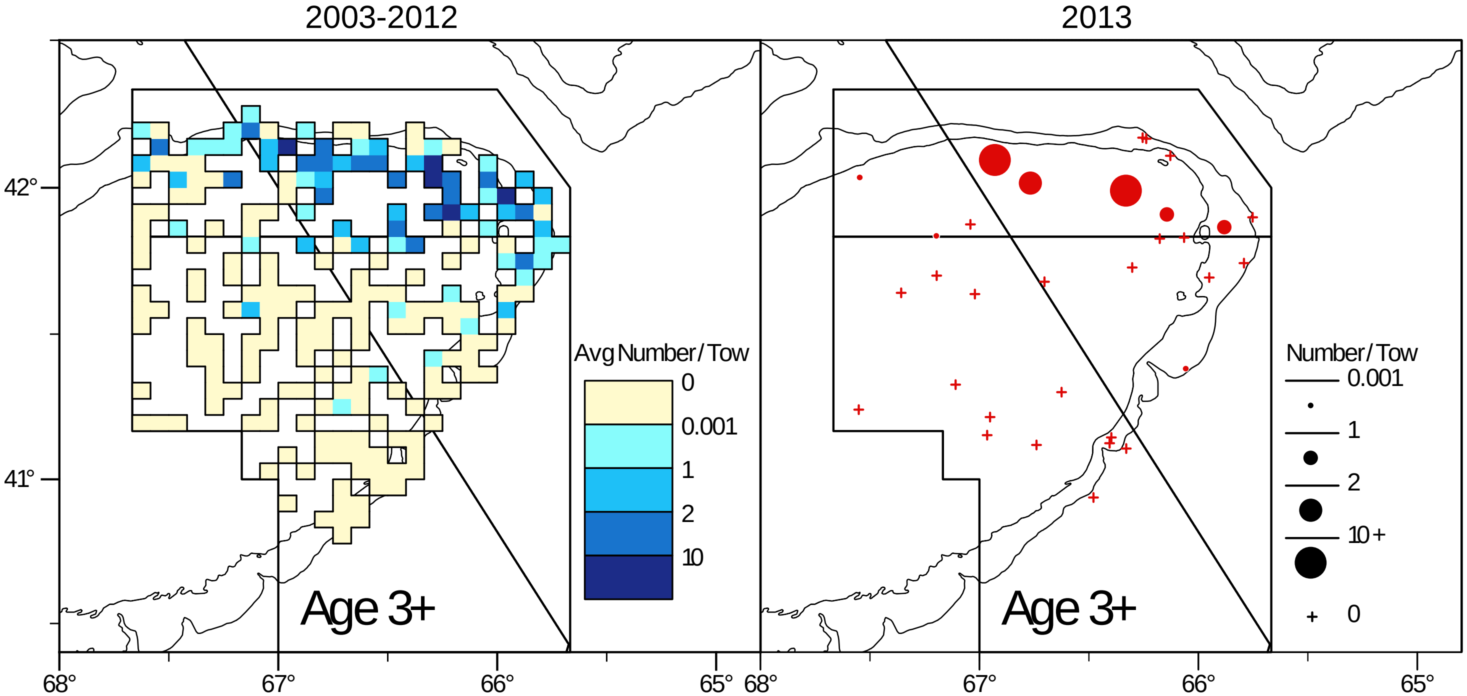


Figure 18. Spatial distribution of age 3+ cod on eastern Georges Bank from the NMFS fall survey for 2013 (right panel) compared to the average for 2003-2012 (left panel).

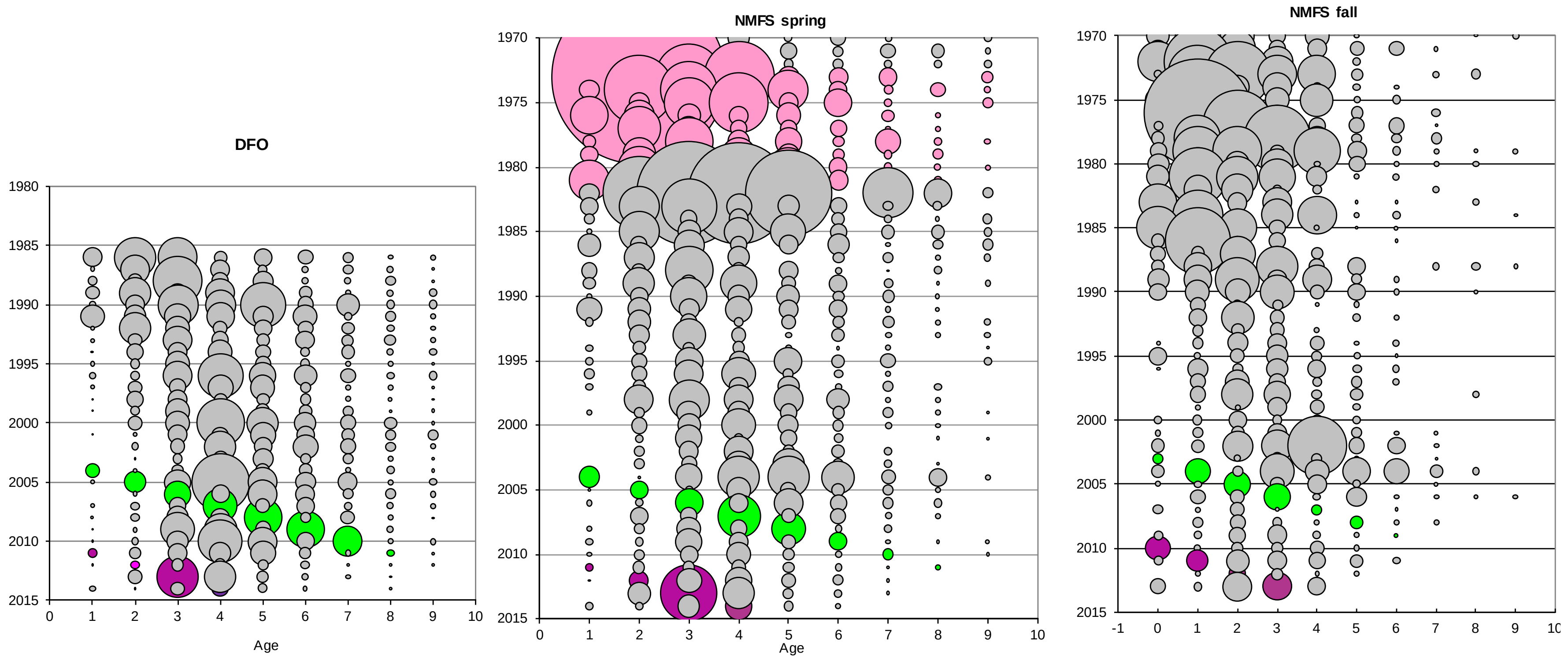
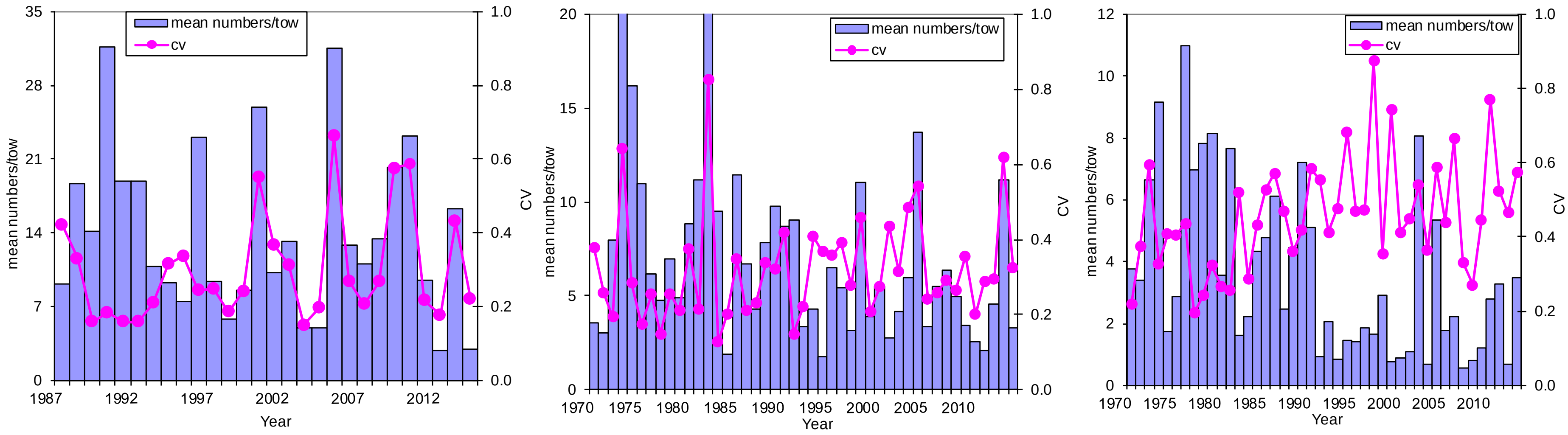


Figure 19. Survey abundance at age (numbers) of eastern Georges Bank cod. The bubble area is proportional to magnitude within each survey. Conversion factors to account for changes in door type, net and survey vessel were applied to the NMFS surveys. The NMFS spring survey was conducted using a modified 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.



DFO **NMFS Spring** **NMFS Fall**

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

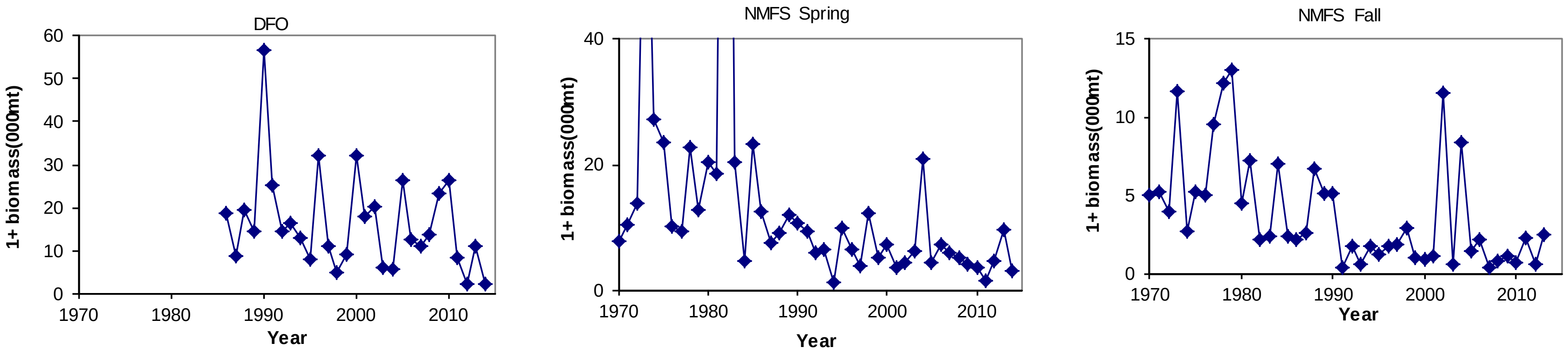


Figure 21. Survey biomass indices (ages 1+) for eastern Georges Bank cod from the DFO spring and NMFS spring and fall surveys, 1978-2014.

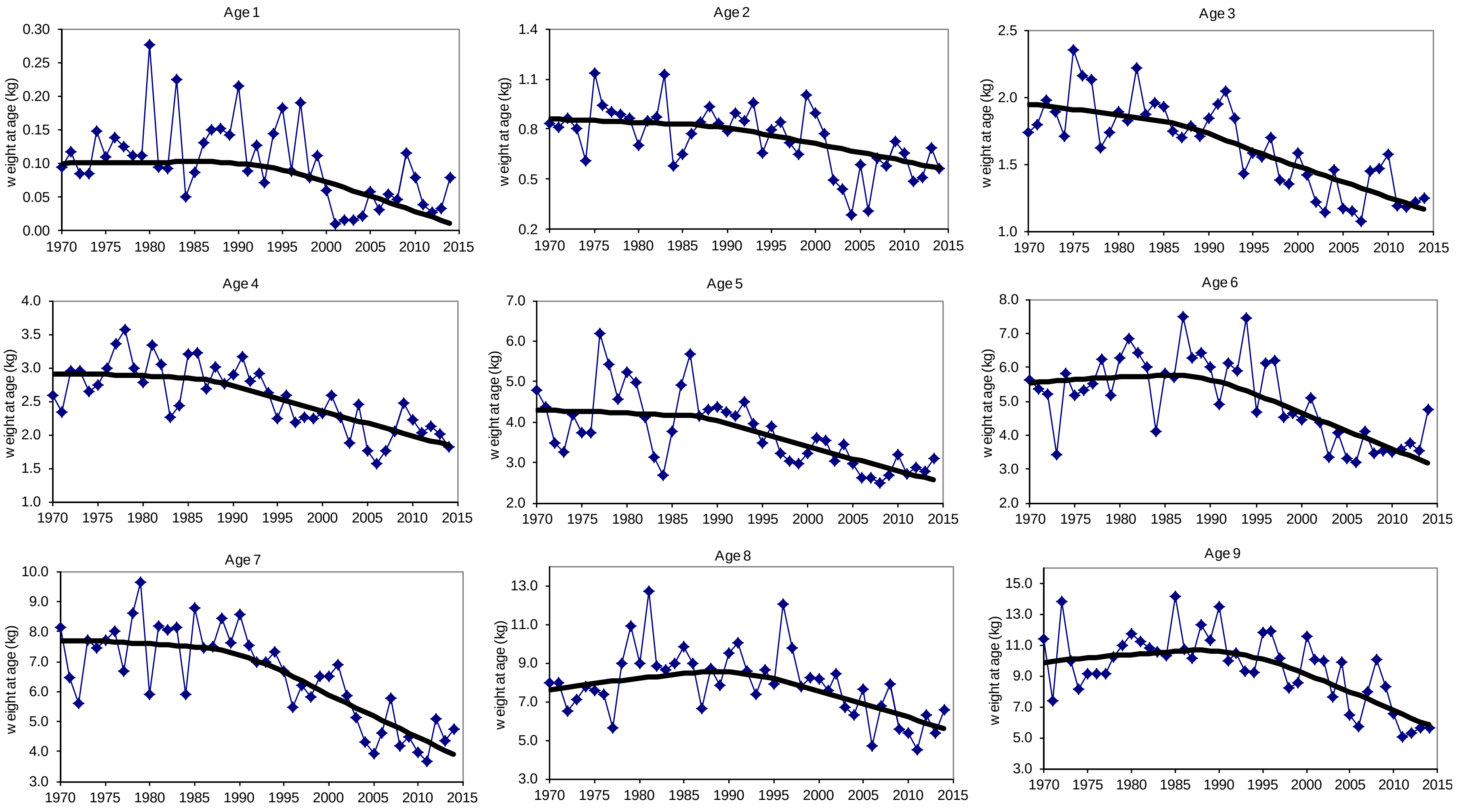


Figure 22. Beginning of year weight at age of eastern Georges Bank cod from DFO and NMFS spring surveys. The lines show the smoothed values using the LOESS method.

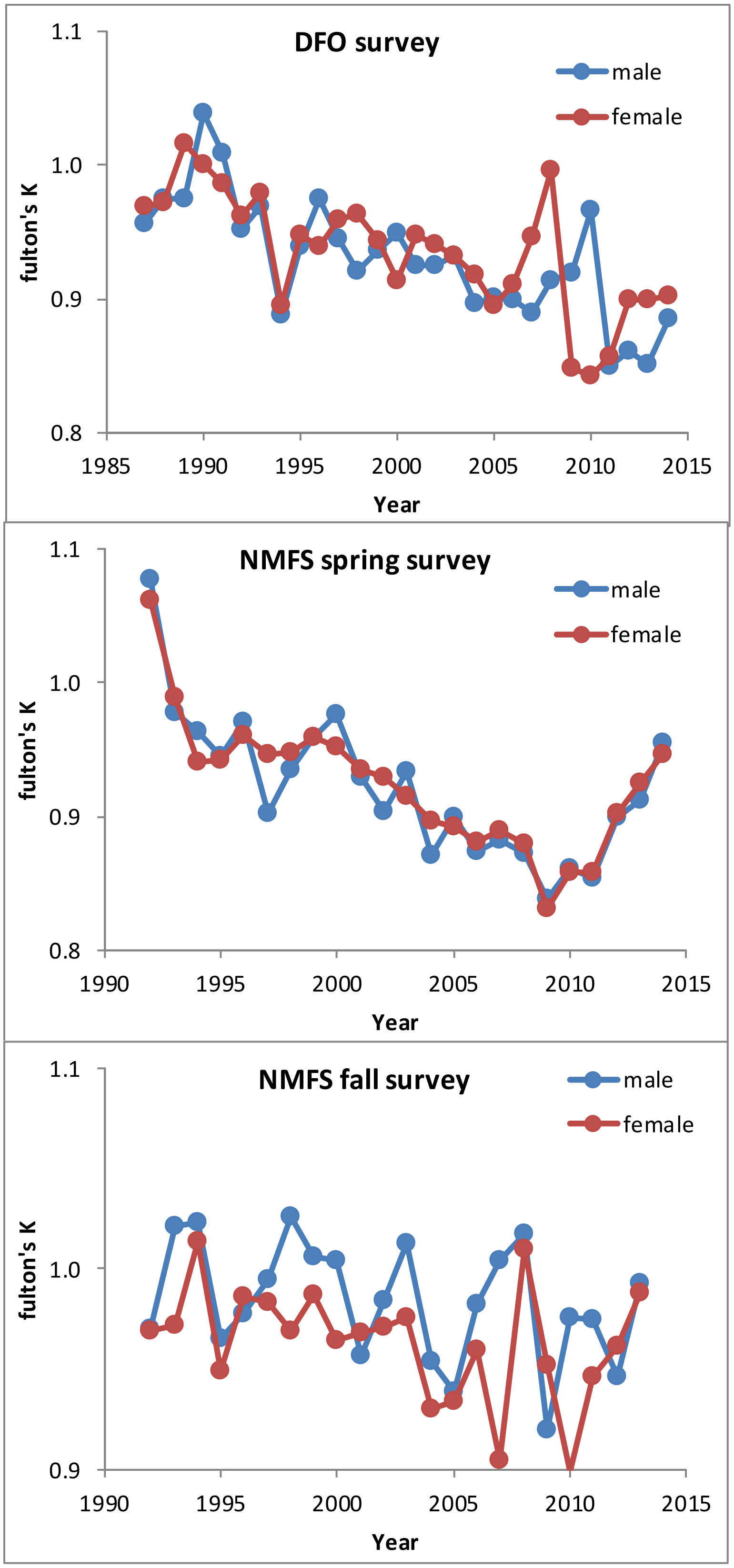
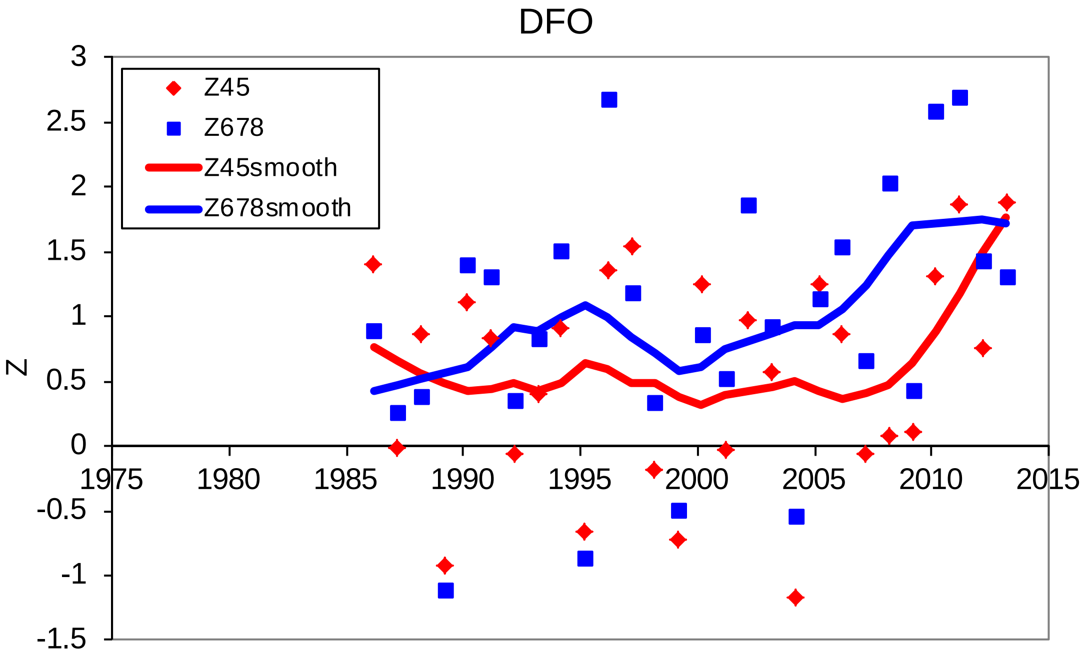


Figure 23. Fish condition (Fulton's K) for eastern Georges Bank cod.



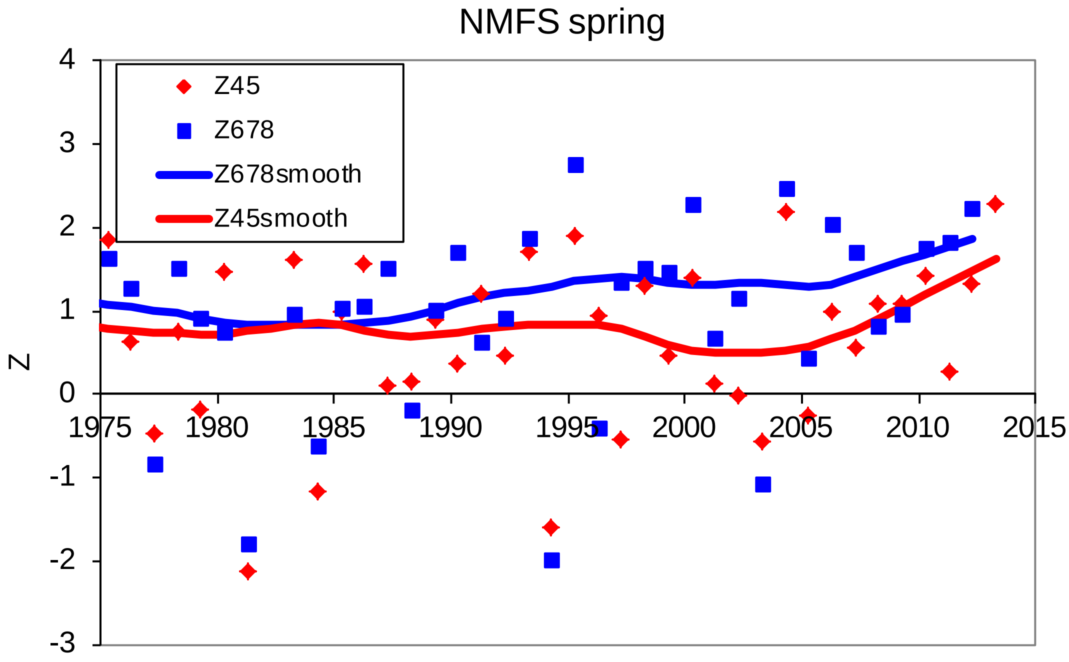


Figure 24. Total mortality(Z) calculated using the DFO and NMFS spring surveys data for eastern Georges Bank cod.

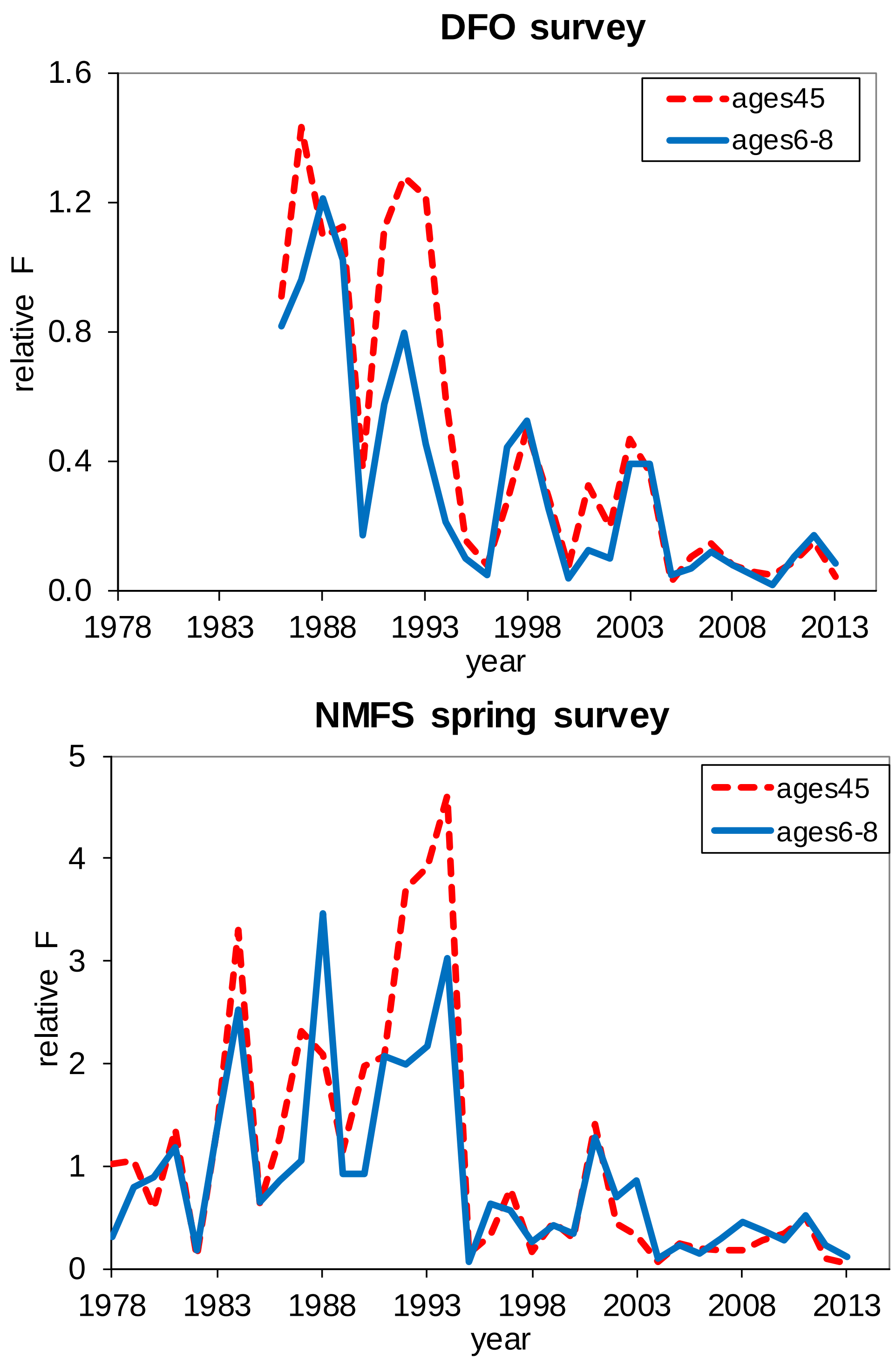


Figure 25. Relative F for eastern Georges Bank cod.

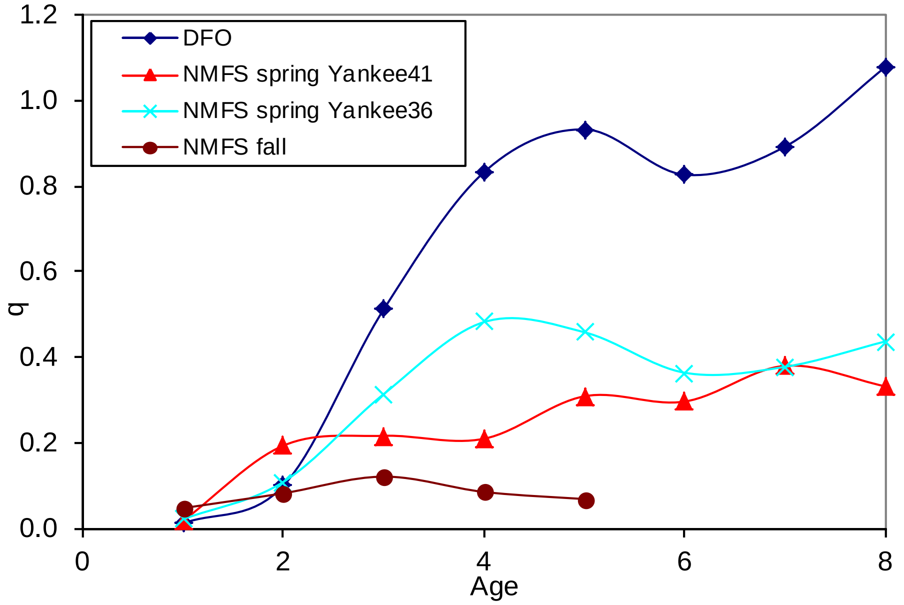


Figure 26. Survey catchability (q) of the DFO, NMFS spring and NMFS fall surveys for eastern Georges Bank cod.

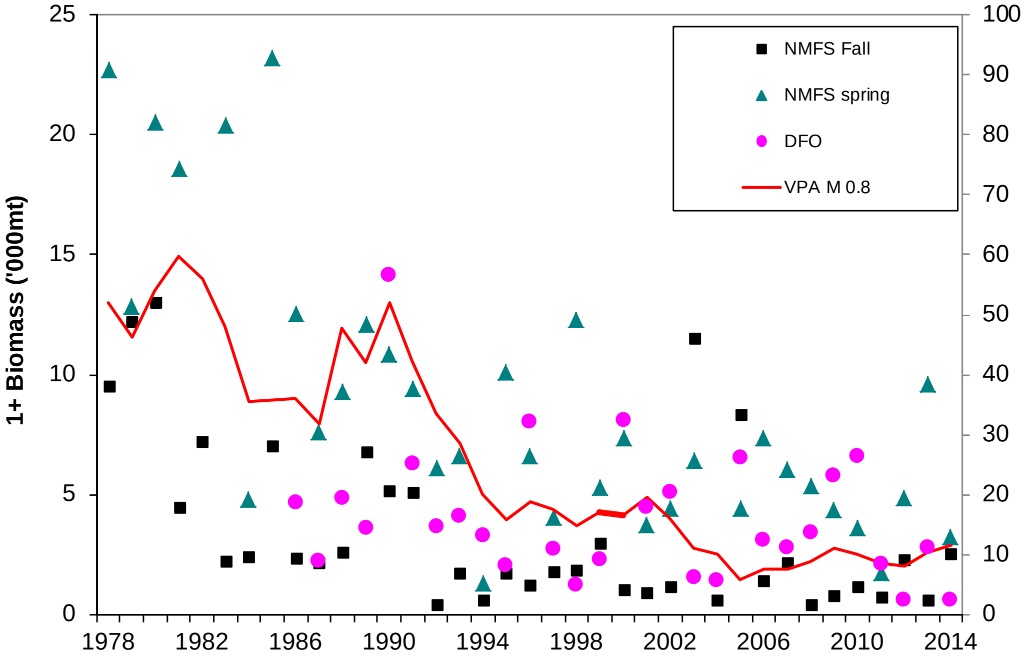


Figure 27. Age 1+ biomass from survey and VPA estimation.

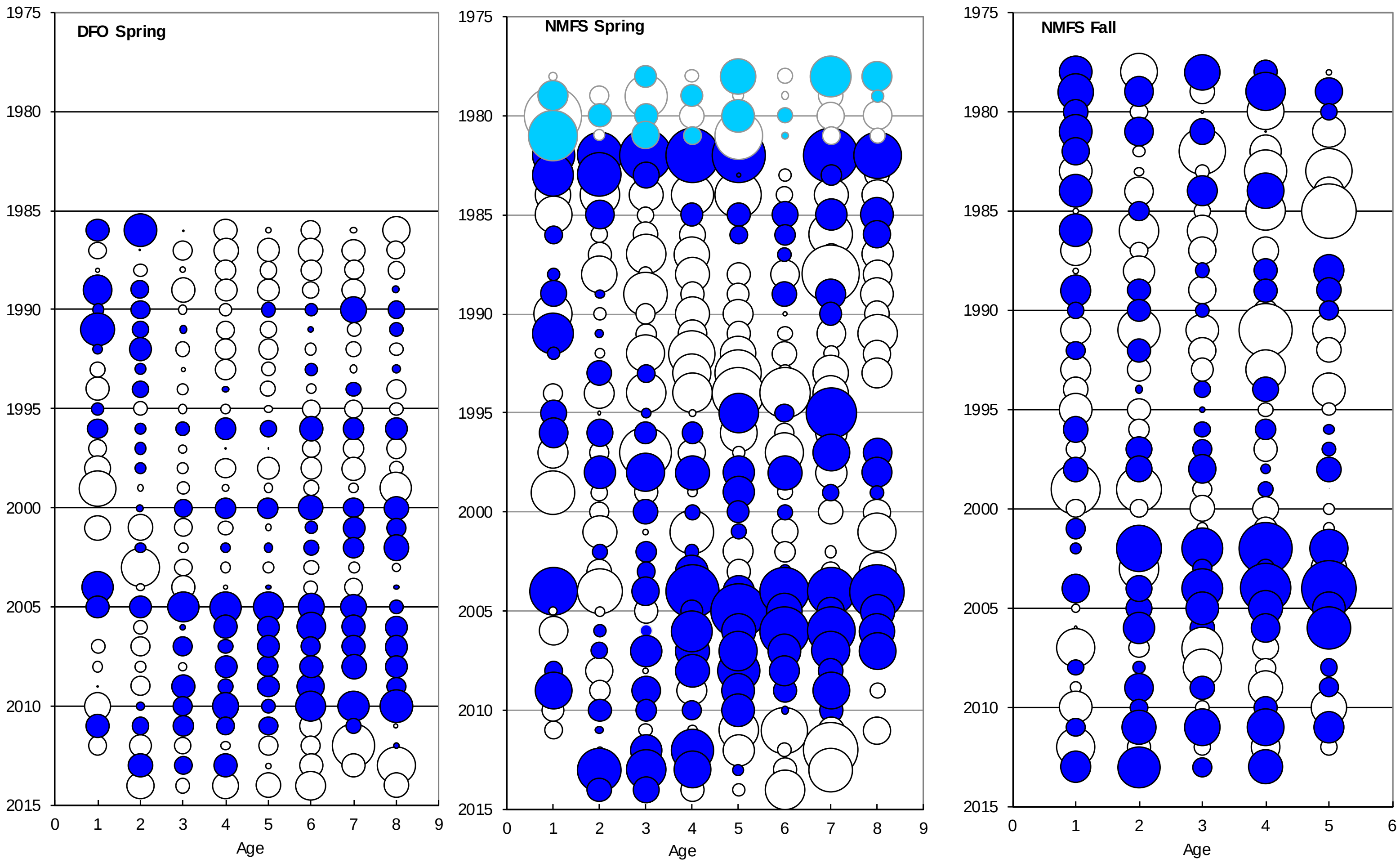


Figure 28. Residuals by year and age group from survey indices for eastern Georges Bank cod. Solid bubbles indicate positive values, open bubbles indicate negative values and the bubble area is proportional to magnitude. The NMFS spring survey was conducted using a modified Yankee 41 from 1978 to 1981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

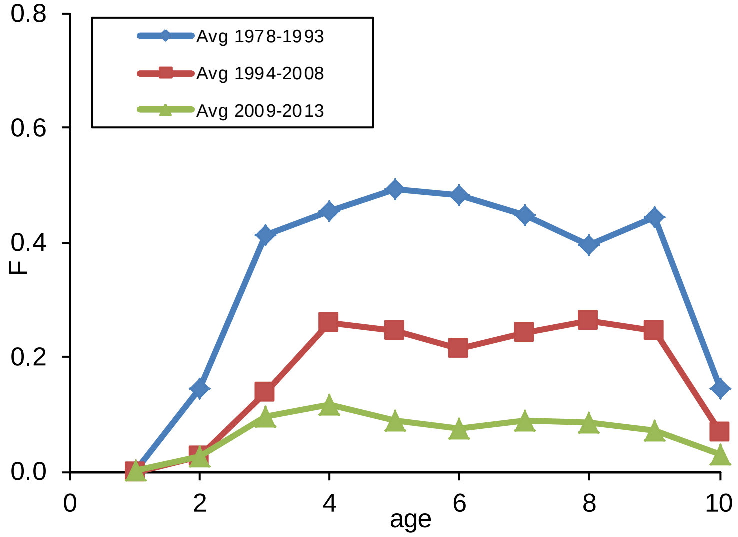


Figure 29. Average fishing mortality (F) for eastern Georges Bank cod in three time series blocks (1978-1993, 1994-2008, 2009-2013).

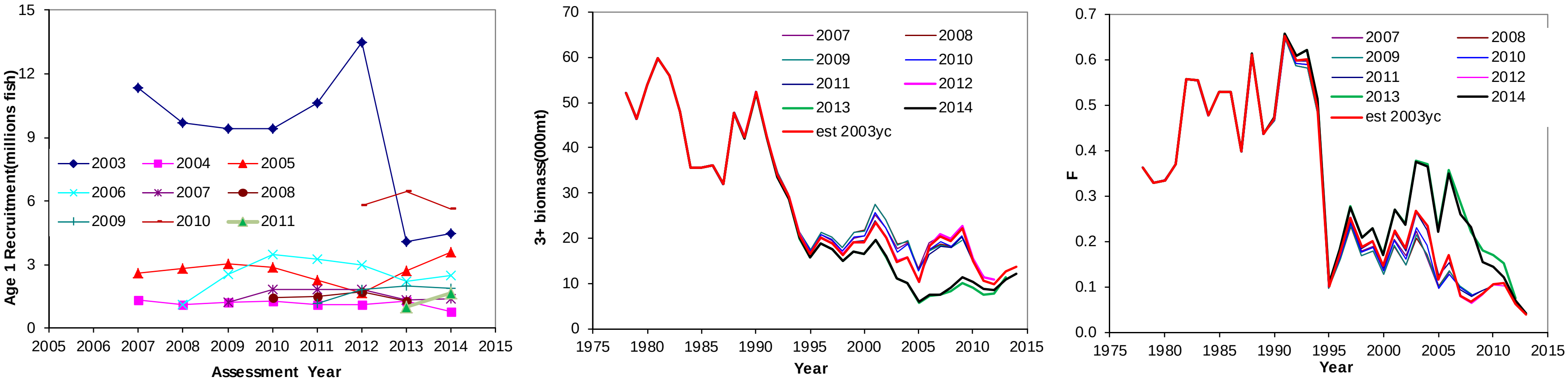


Figure 30. Retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the “M 0.8” model in 2013 assessment. ‘estimate 2003yc’ is the sensitivity run in 2014.

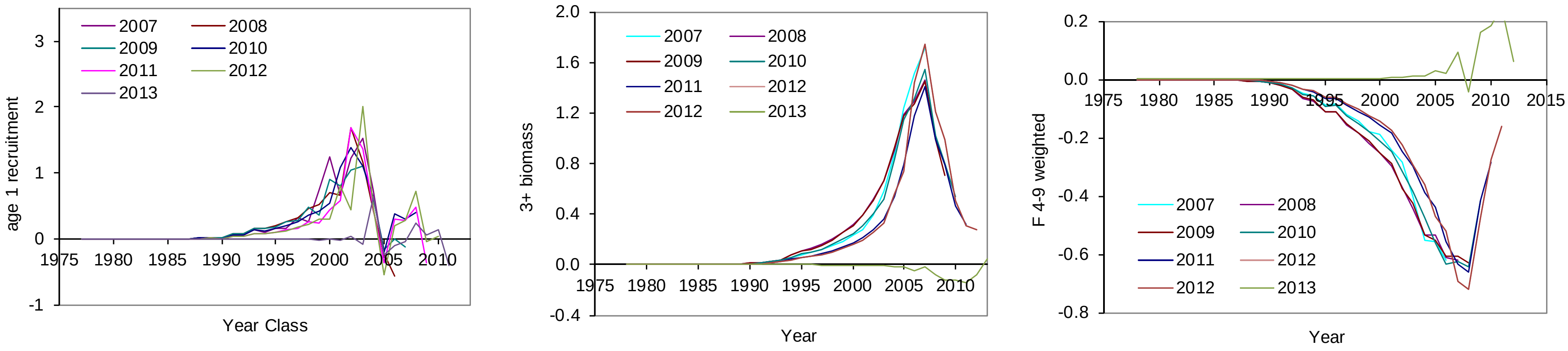
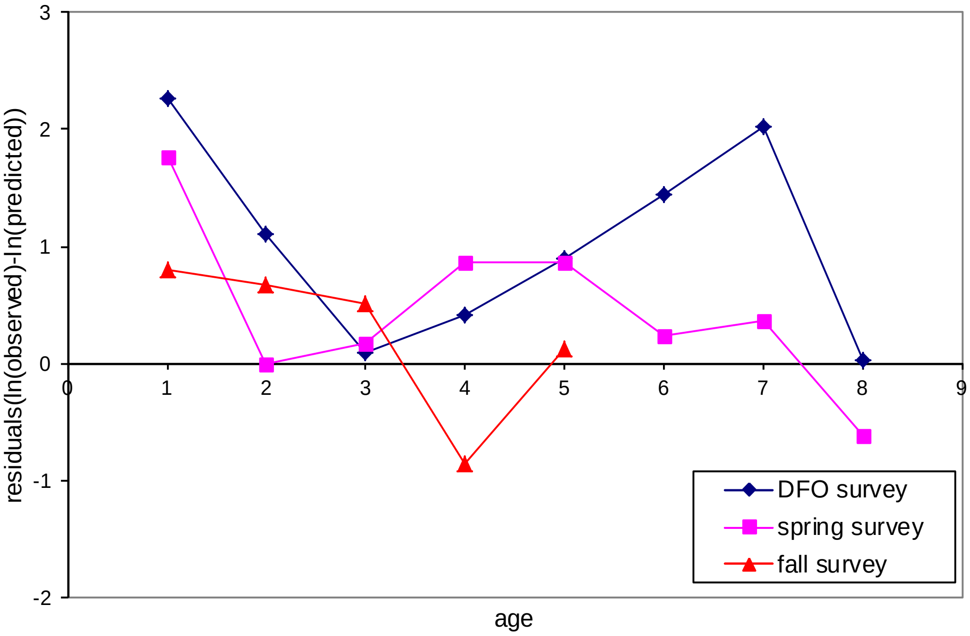
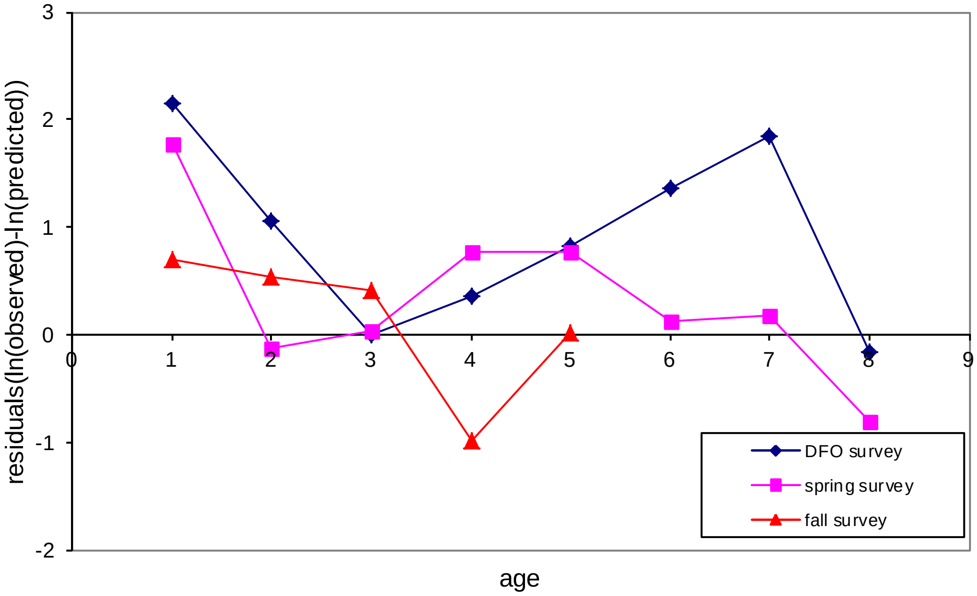


Figure 31. Relative retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the “M 0.8” model in 2014 assessment.



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.

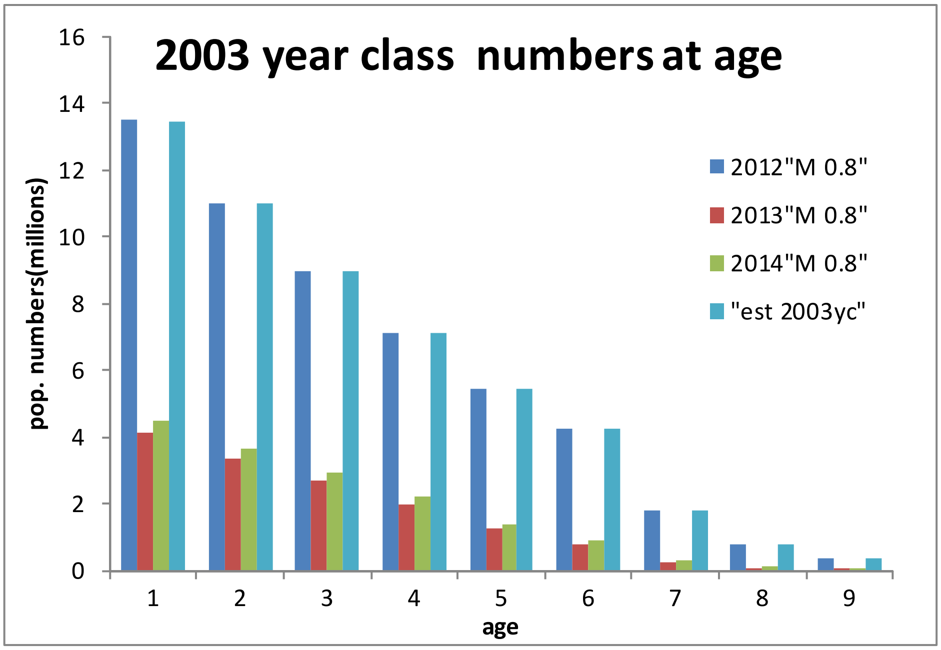


Figure 33. The estimated population abundance at age of the 2003 year class from different model formulations of eastern Georges Bank cod.

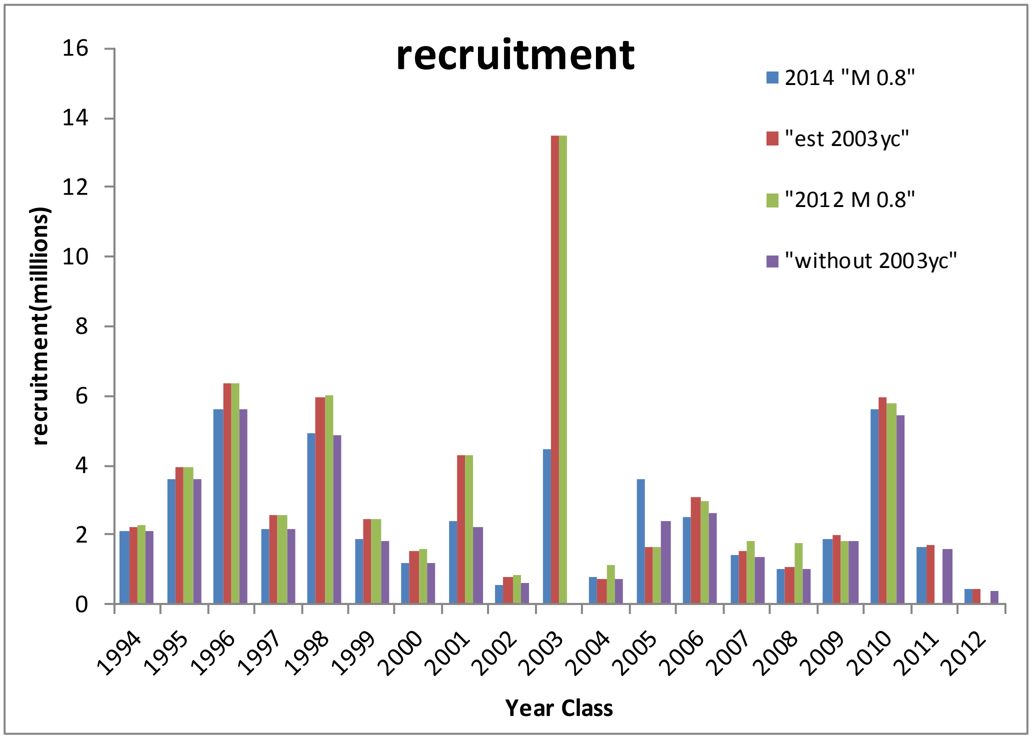


Figure 34. The estimated recruitment from different model formulations of eastern Georges Bank cod.

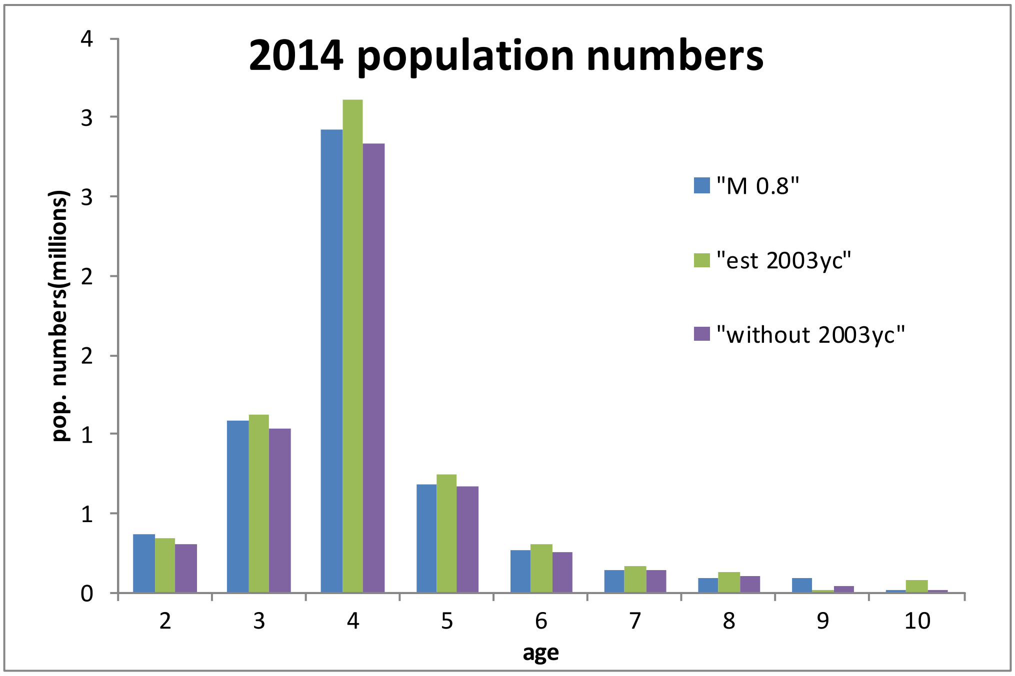


Figure 35. The estimated beginning of year 2014 population abundance at age from different model formulations of eastern Georges Bank cod.

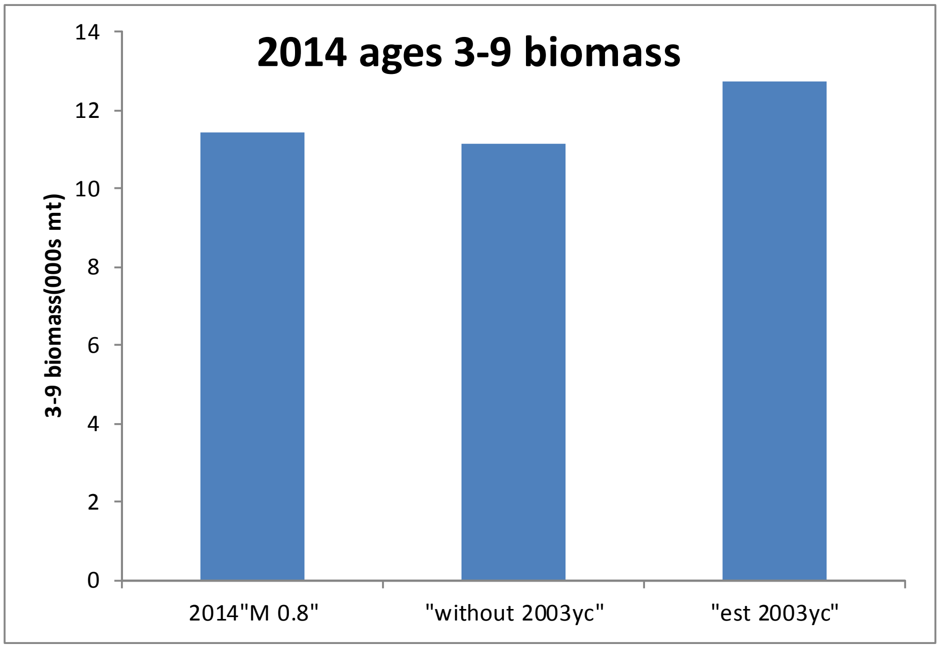


Figure 36. The estimated beginning of year 2014 ages 3-9 population biomassfrom different model formulations of eastern Georges Bank cod.

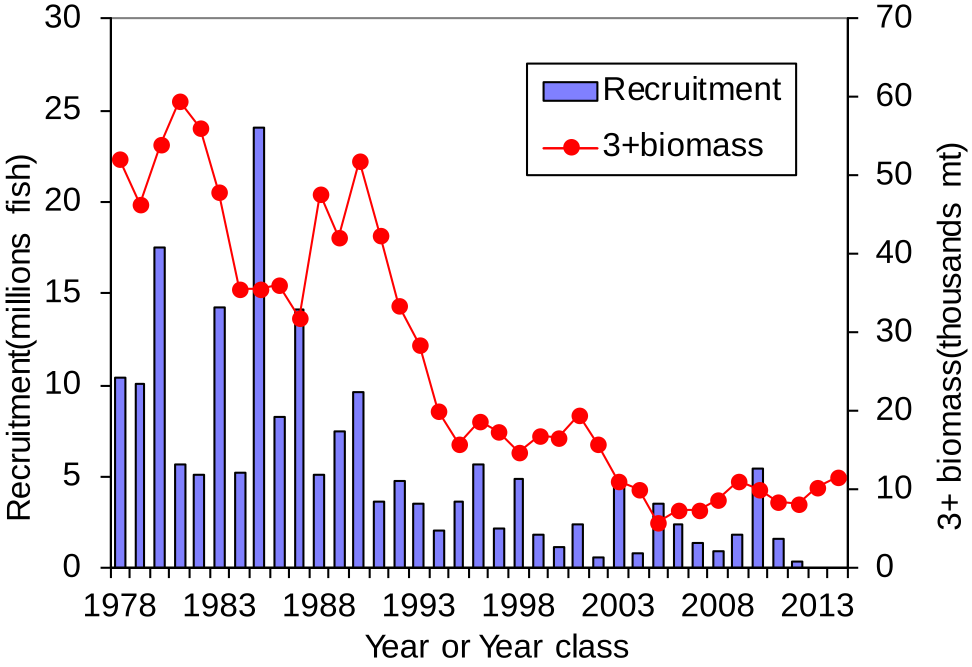


Figure 37. Adult biomass (ages 3+) and year class abundance at age 1 for eastern Georges Bank cod.

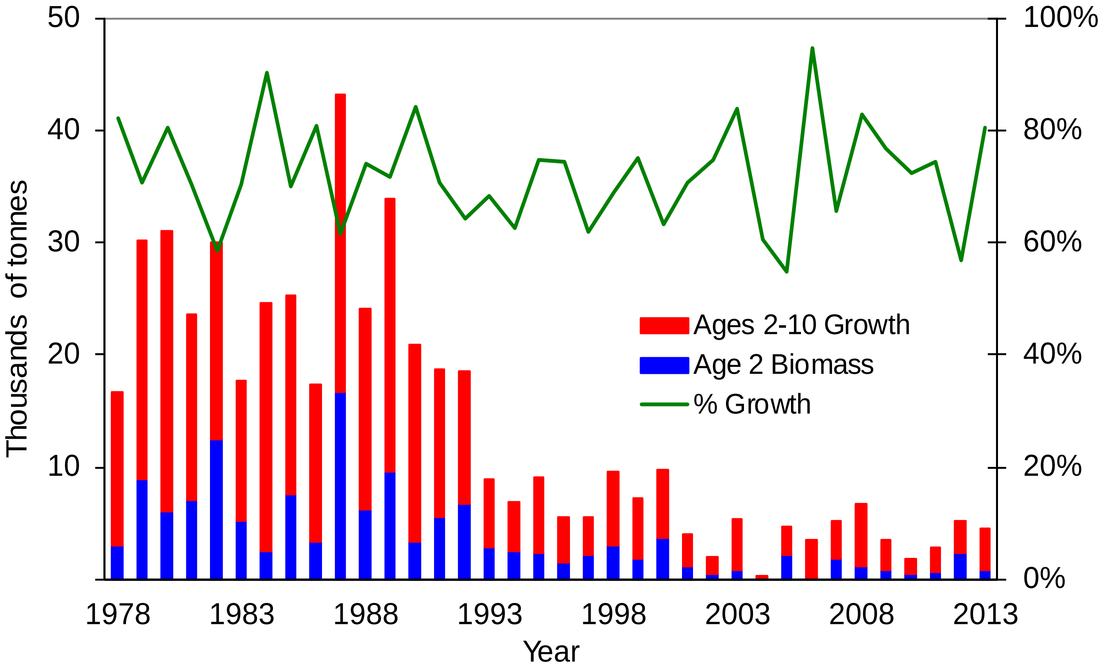


Figure 38. Components of annual production for eastern Georges Bank cod attributable to growth of ages 2 to 10 and to the amount contributed by incoming year classes at age 2.

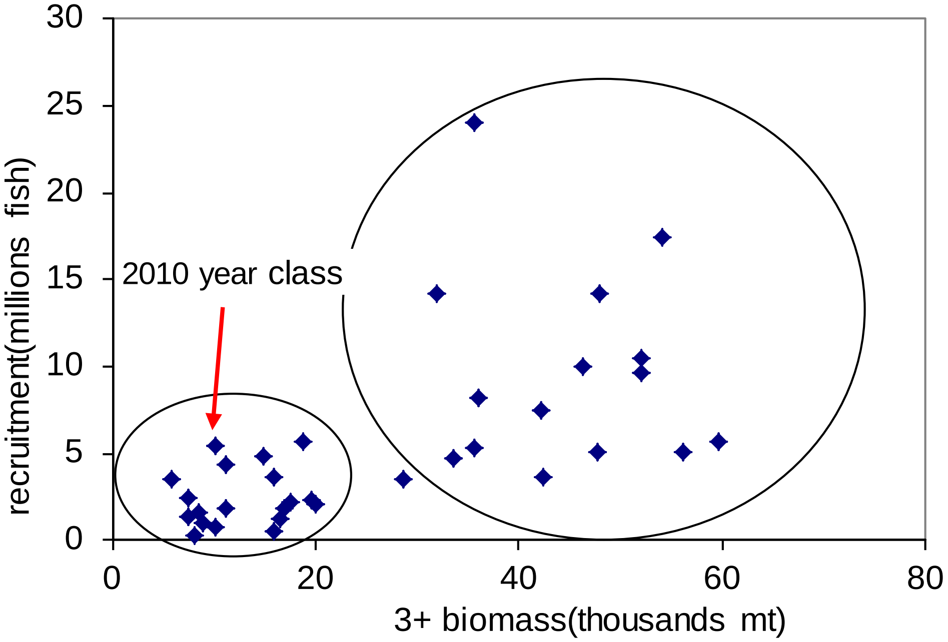


Figure 39. Relationship between adult biomass (ages 3+) and recruits at age 1 for eastern Georges Bank cod. The red arrow indicate the 2010 year class at age 1.

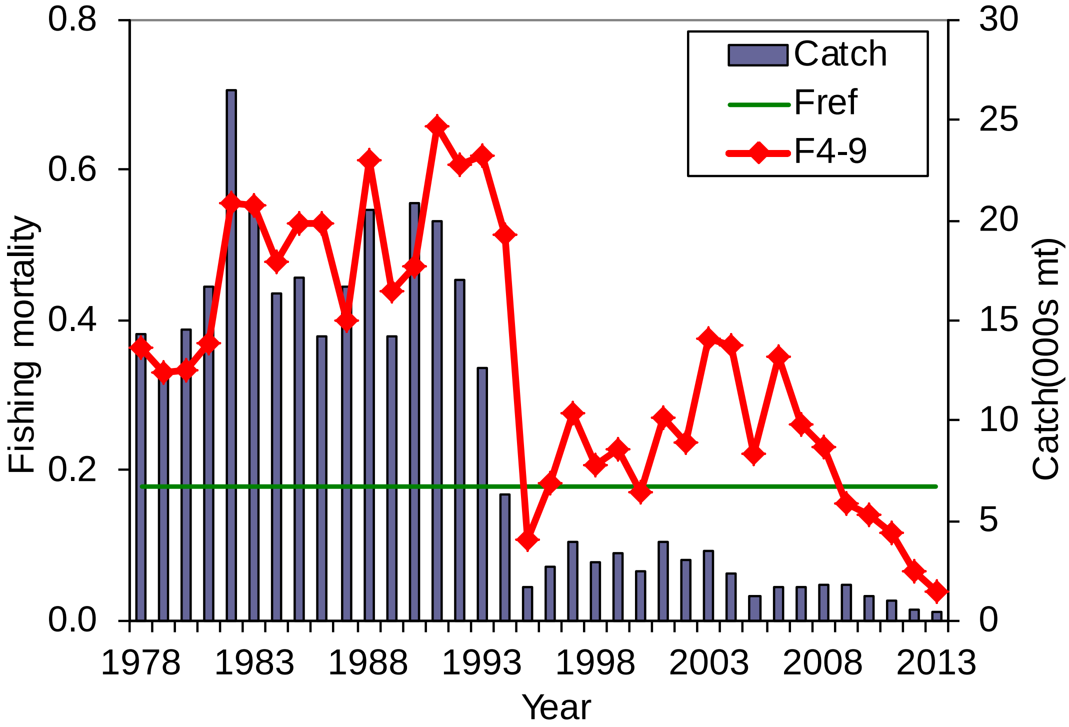


Figure 40. Average fishing mortality rate at ages 4 to 9 and catches for eastern Georges Bank cod. The established fishing mortality threshold reference, F_{ref} = 0.18.

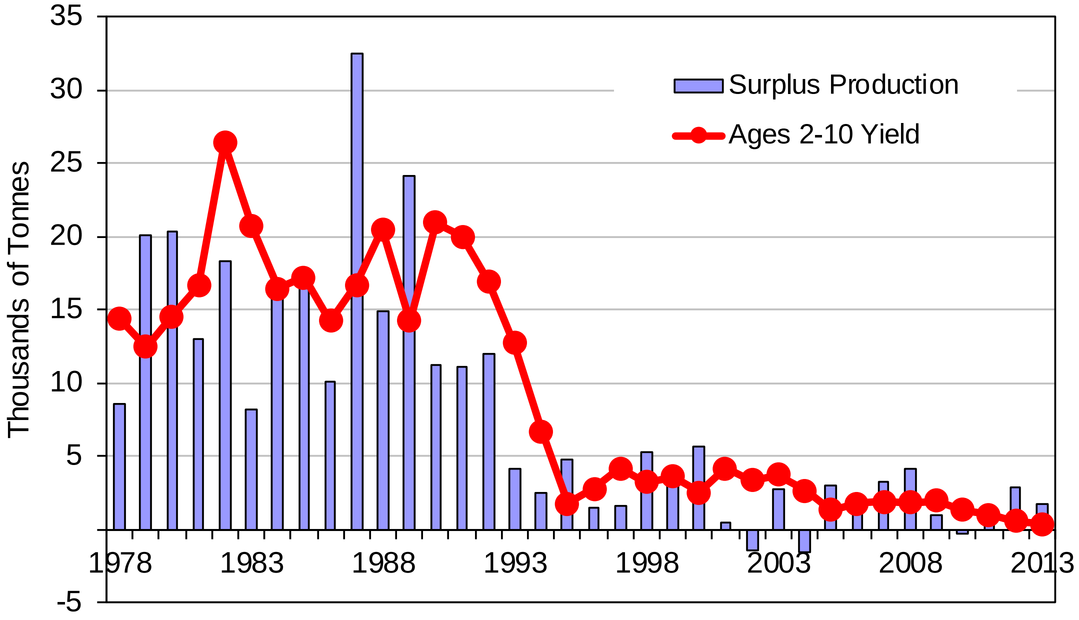


Figure 41. Surplus production of eastern Georges Bank cod compared to harvested yield.

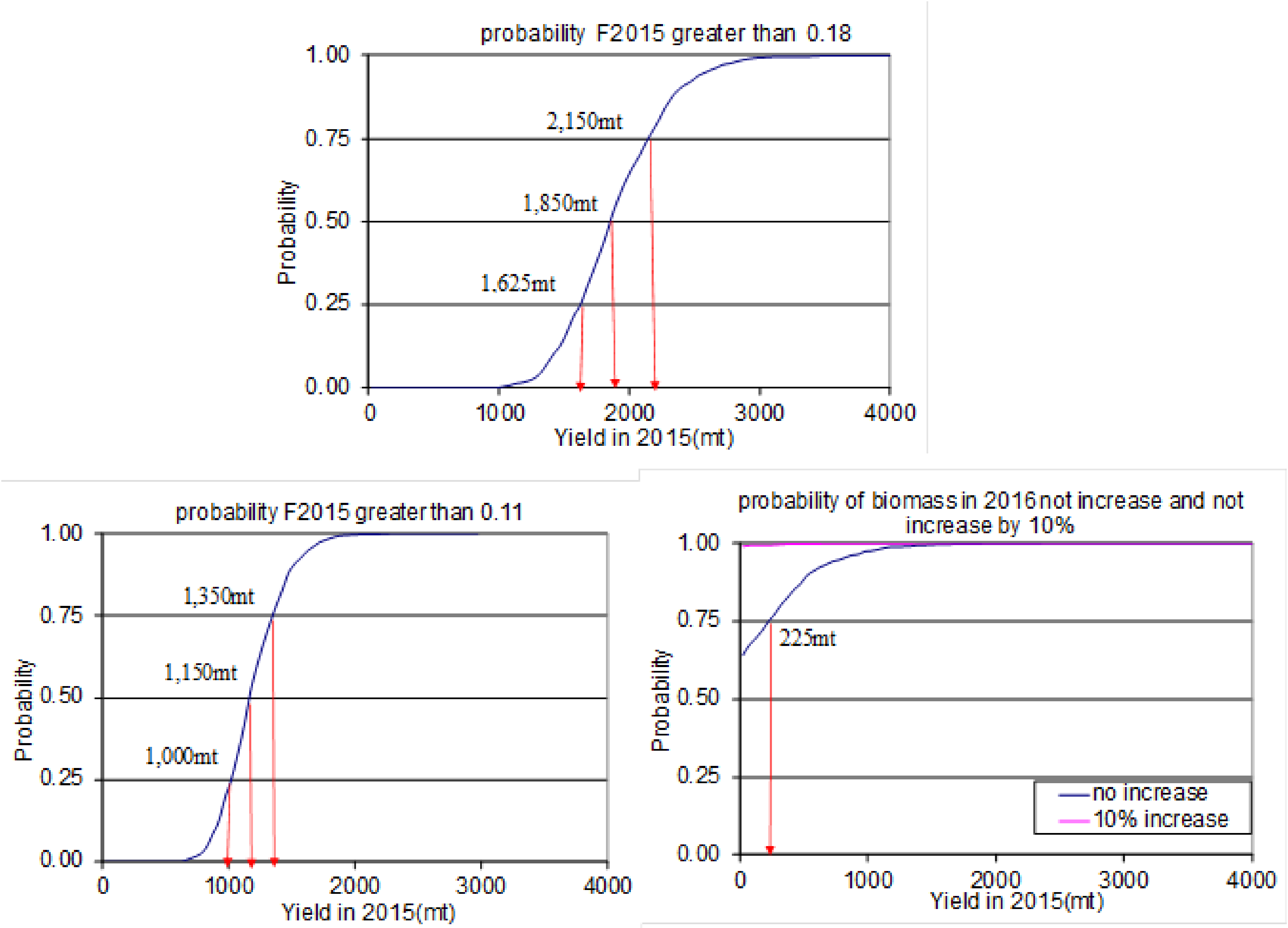


Figure 42. Risk of 2015 fishing mortality exceeding proposed F_{ref} = 0.11 and 2016 biomass not increasing, and 2016 biomass not increasing by 10% from 2015 for alternative total yields of eastern Georges Bank cod from the "M 0.8" model formulation.

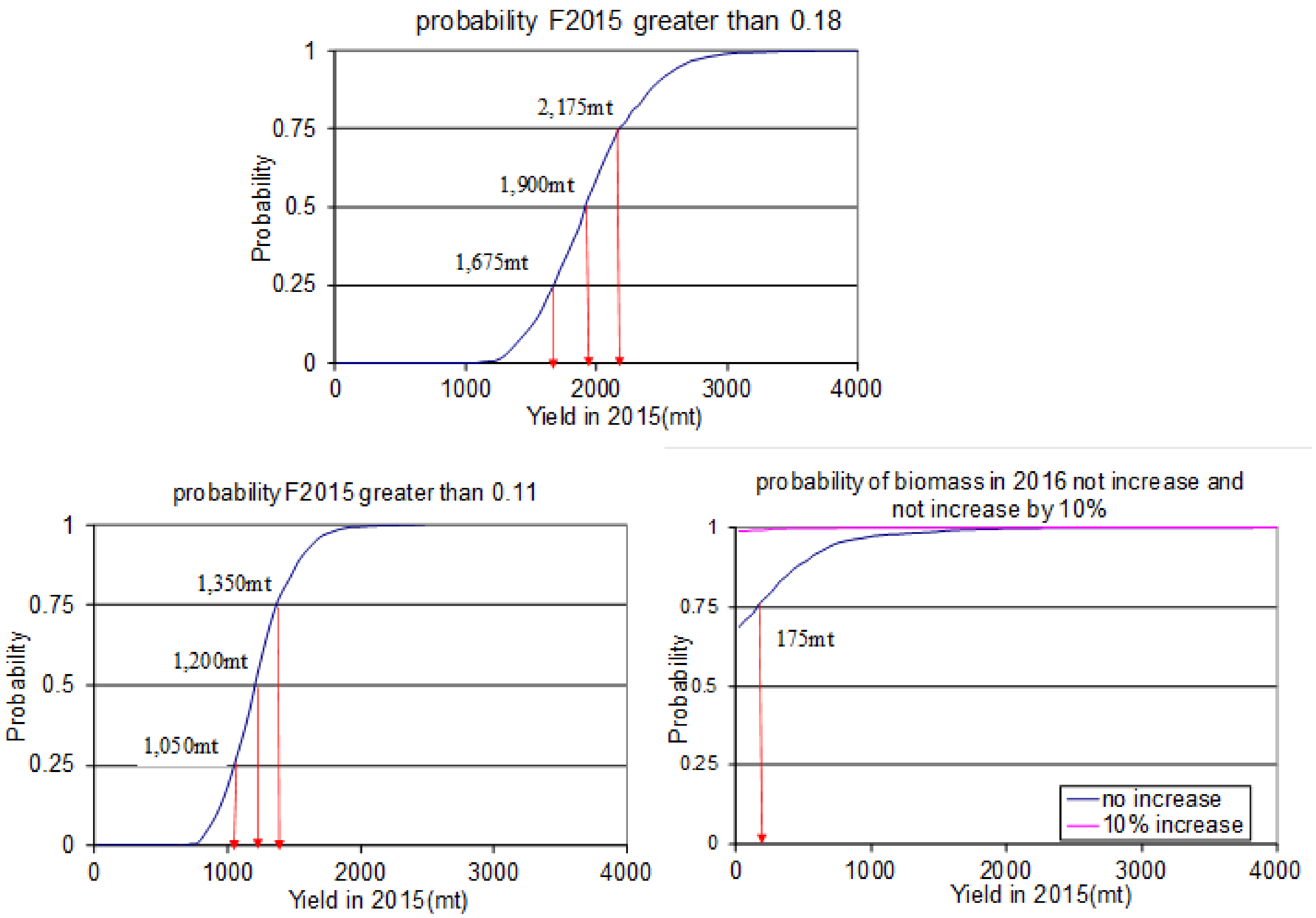


Figure 43. Risk of 2015 fishing mortality exceeding proposed F_{ref} = 0.11 and 2016 biomass not increasing, and 2016 biomass not increasing by 10% from 2015 for alternative total yields of eastern Georges Bank cod from the "estimate 2003yc" formulation.

APPENDIX

APPENDIX A. 2014 STATISTICAL CATCH AT AGE (ASAP) MODEL UPDATE FOR EASTERN GEORGES BANK ATLANTIC COD

Introduction

This assessment presents an update of the statistical catch at age model 'Age Structured Assessment Program' (ASAP) reviewed at the 2013 April Eastern Georges Bank cod benchmark model meeting. The ASAP model was not chosen by the TRAC as a benchmark model for stock status or catch advice, however, the TRAC agreed to apply the ASAP model results in a consequence analysis (Appendix A) 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, a subcomponent of the Georges Bank stock, is managed by the Transboundary Management Guidance Committee (TMGC) and the whole stock is managed by the New England Fishery Management Council (NEFMC), similarly scaled biomass estimates 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 age 1 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 (main document - 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 (Table A1) 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 surveys have been standardized to account for different vessels over the time series and for a change in trawl doors in 1985 (Table 7). The NEFSC surveys have been conducted by the NOAA ship *Henry B. Bigelow* since 2009 and these indices have been calibrated to former NOAA ship *Albatross IV* units (Table 8). No conversion factors are applied to the DFO survey indices. The maturity ogive was age and time invariant and knife edge maturity was assumed at age 3 as in previous EGB cod assessments. Natural mortality (M) was age and time invariant and 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 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 #41, 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 Table A2 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 (Table A2).

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 (Figure A1). The catch age composition exhibits larger residuals early in the time period, with a pattern of negative residuals for age 3 (Figure A2). The magnitude of the input ESS appears appropriate given that the predicted ESS generally bisects the observed ESS (Figure A3).

Indices

The fit of the predicted indices through the observed DFO survey indices was better during the period 1995-2000 than before or after that period; in recent years the model fit does not bisect the survey confidence bounds for all years (Figure A4). A pattern of negative residuals in the older age groups during 1986-1995 and in the younger ages during 2000-2013 is apparent in the age composition (Figure A5). The final DFO survey ESS was set at 50 and appears appropriate given that the predicted ESS generally bisects the observed ESS (Figure A6).

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

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

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

Fishing Mortality, SSB, and Recruitment

Fully recruited F (unweighted, ages 5+) was estimated at 0.33 in 2013 (Table 3A and Figure A16), a 59% decrease from 2012. SSB in 2013 was estimated at 2,142 mt, a 80% increase from 2012 (Table A3 and Figure A16). 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 (Table A3 and Figures A16-A17).

Retrospective Analysis

A retrospective analysis was performed to evaluate how well the ASAP calibration would have estimated F, SSB, and recruits at age 1 for seven years (2006-2012) prior to the terminal year, 2013. The pattern of overestimating SSB and underestimating F relative to the terminal year is stronger than in the 2013 ASAP model (Wang and O'Brien, 2013), and there is a pattern of underestimating recruitment relative to the terminal year estimate (Figure A18). The retrospective rho values, the average of the last 7 years of the relative retrospective peels, were 0.46 for SSB, -0.32 for $F_{5+,}$ and -0.25 for recruitment. Applying a retrospective adjustment ((1/(1+rho)) * estimate) results in estimates for 2013 of F = 0.49, SSB = 1,470 mt, age 1 recruitment = 0.17 million fish.

Model Uncertainty – Monte Carlo Markov Chain (MCMC)

A Monte Carlo Markov chain (MCMC) simulation was performed to estimate uncertainty in the model estimates. The MCMC provides posterior probability distributions of the SSB and average F5+ time series. Two MCMC chains of initial length of 5.0 million were simulated with every 2,500th value saved. The trace of each chain's saved draws suggests good mixing for both SSB and F (Figure A19). The lagged autocorrelations showed variable correlation with increased lag, with correlations ≤ 0.1 beyond lag 0 for SSB and F (Figure A200). From the MCMC distributions, a 90% probability interval (PI) was calculated to provide a measure of uncertainty for the model point estimates for SSB and average F5+. Time series plots of the 90% PIs as well as plots of the posterior probability distributions for SSB2012 and average F5+ are shown in Figures A21-A22.

The 2013 SSB MCMC estimate of 2,134 mt has a 90% PI of 1,384 mt – 3,345 mt and the 2013 MCMC average F5+ = 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 (Table A2) 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 EGB cod model benchmark meeting, 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 SSBMSY based on F40% 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, and
- SSB_{msy} = 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 EGB cod model benchmark meeting, long term (100 years) stochastic projections were run using the same input data as the YPR with F_{ref} = 0.18. Following the NEFSC GB cod accepted assessment projection formulation (NEFSC, 2013), recruitment was estimated from a 2 stage cumulative distribution function (CDF) based on either 19 low estimates or 14 high estimates of age 1 recruitment. Based on a visual examination of the stock recruit plot (Figure A17), when SSB is < 15,000 mt recruitment is drawn from the low recruitment CDF, and when SSB >15,000 mt then recruitment is drawn from the high recruitment CDF.

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

- F_{ref} = 0.18,
- MSY = 11,059 mt (80% CI: 2,065 mt - 14,180 mt), and
- 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 the 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[1]). Lack of large numbers of older repeat spawners in the EGB cod population since the mid-1980s may contribute to the long-term low productivity. Cod have a low success rate of hatching for first and second time spawners (13% and 62%) until the third spawning (100%), suggesting that an expanded age structure of fish that have spawned 3 or more times would contribute to higher productivity (Trippel, 1998). Long-term overfishing may have also had indirect effects. Fishing activity disrupts the spawning aggregation and thus behaviors and rituals of cod, reducing the potential of good recruitment (Dean, 2012). Spawning of cod involves complex behaviors that have only recently been observed including arrival and departure of fish on the spawning ground at different times dependent upon sex, age, and stage of maturity (Lawson and Rose, 2000) and the formation of spawning leks, where the males set up and defend territory (Windle and Rose, 2007).

The updated model formulation exhibits an increase in the retrospective bias in F and SSB compared to the 2013 ASAP model results. In the 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 - Tables

Table A1. 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

Table 2A. 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

Table A3. ASAP model results for January 1st 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 - Figures

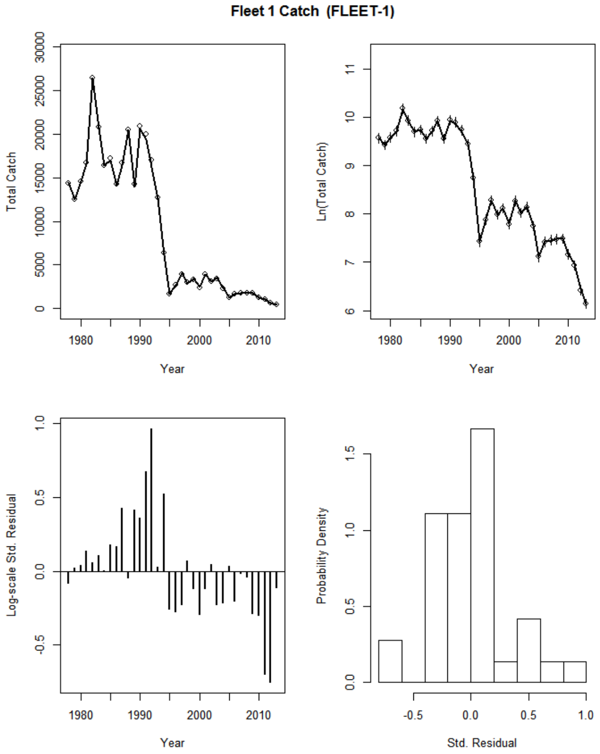

Figure A1. ASAP model fit to total catch of eastern Georges Bank cod, 1978-2013.

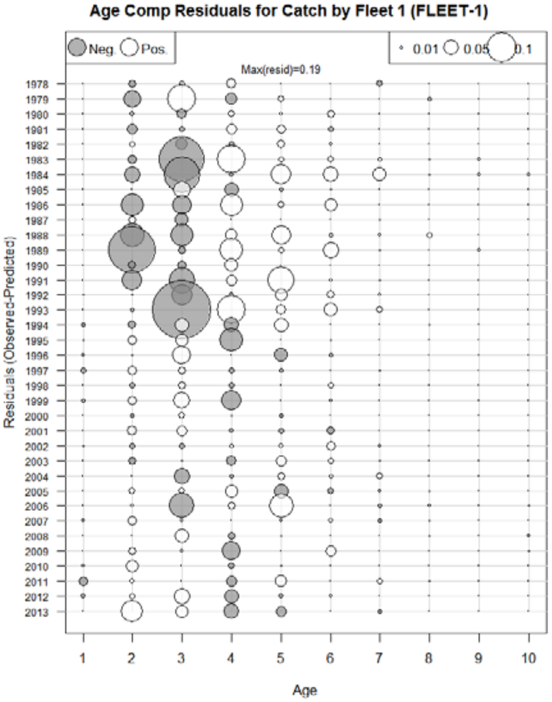

Figure A2. ASAP model residuals for the commercial catch age composition of eastern Georges Bank cod, 1978-2013.

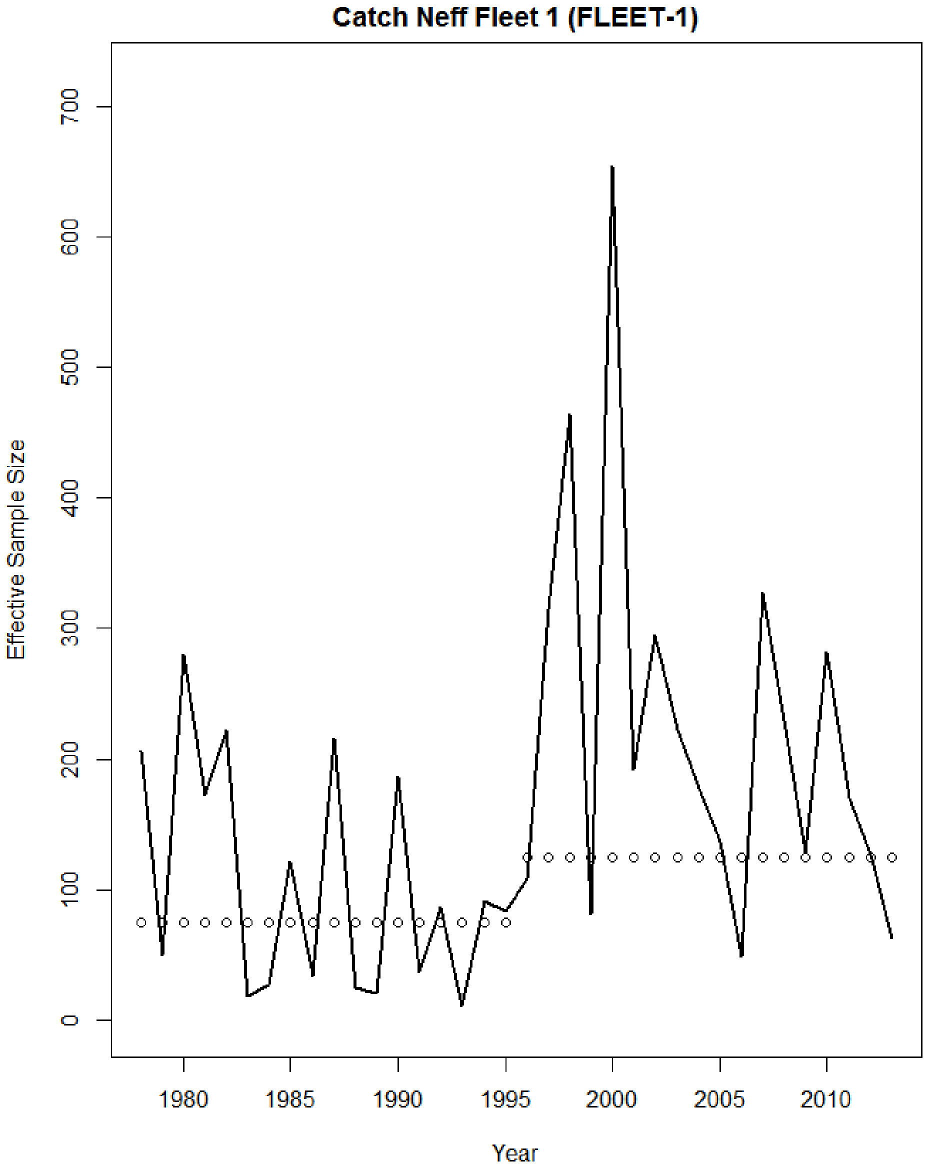

Figure A3. ASAP model observed (line) and predicted (circles) effective sample size of eastern Georges Bank cod in the total catch, 1978-2013.

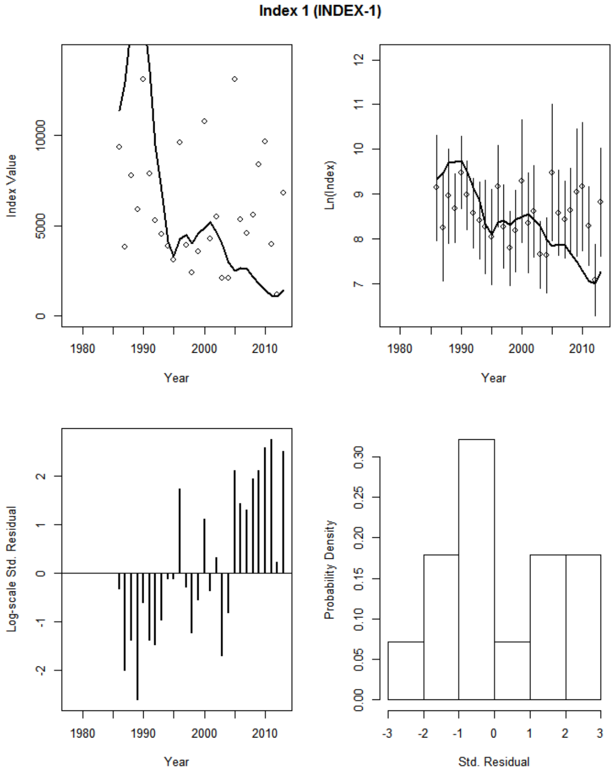

Figure A4. ASAP model fit to DFO survey indices of eastern Georges Bank cod, 1986-2013.

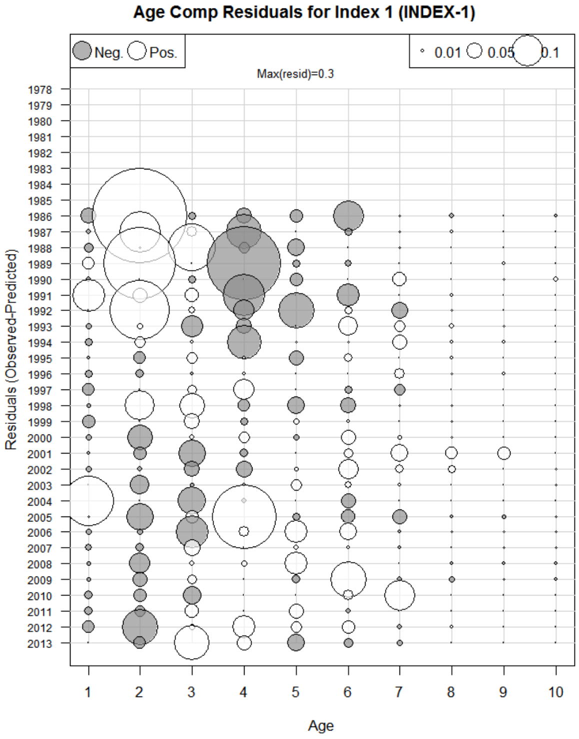

Figure A5. ASAP model run age composition residuals for DFO survey index of eastern Georges Bank cod, 1986-2013.

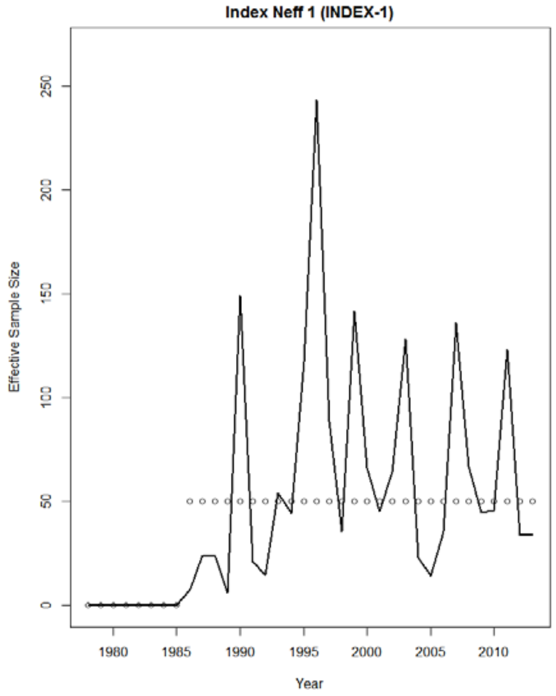

Figure A6. ASAP model observed (line) and predicted (circles) effective sample size of eastern Georges Bank cod in the DFO survey, 1986-2013.

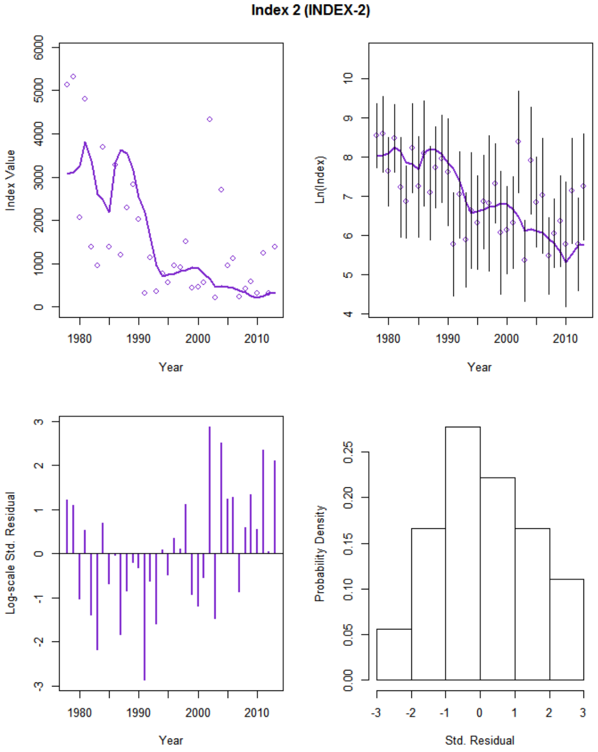

Figure A7. ASAP model fit to NEFSC autumn survey indices of eastern Georges Bank cod, 1978-2013.

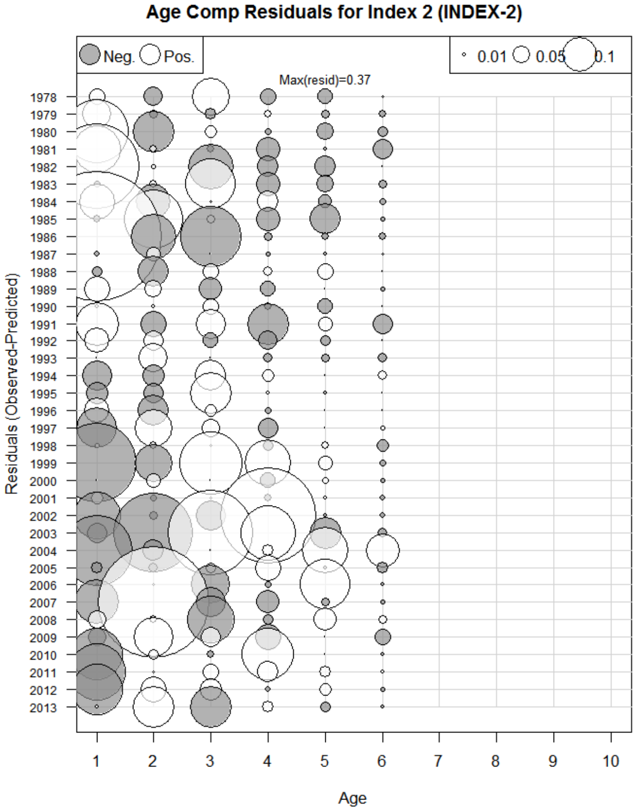

Figure A8. ASAP model age composition residuals for NEFSC autumn survey index of eastern Georges Bank cod, 1978-2013.

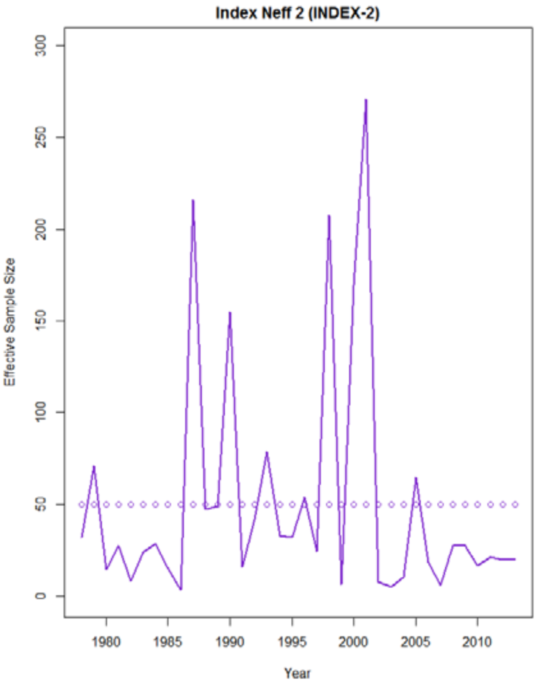

Figure A9. ASAP model observed (line) and predicted (circles) effective sample size of eastern Georges Bank cod in the NEFSC autumn survey, 1978-2013.

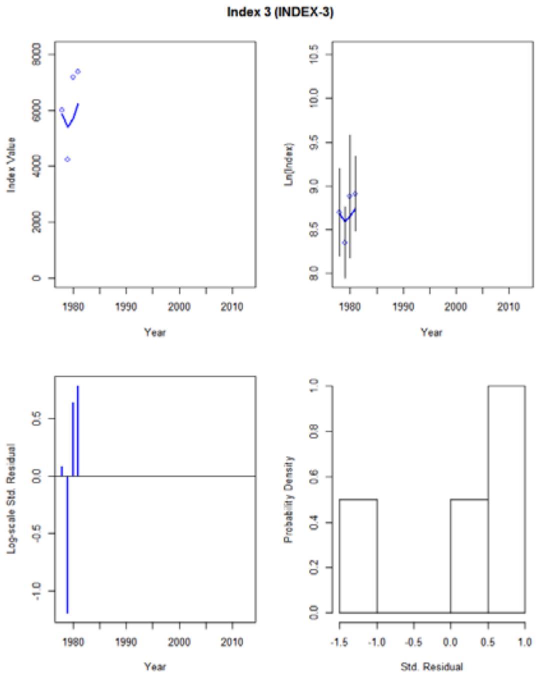

Figure A10. ASAP model fit to NEFSC spring Yankee #41 trawl survey indices of eastern Georges Bank cod, 1978-1981.

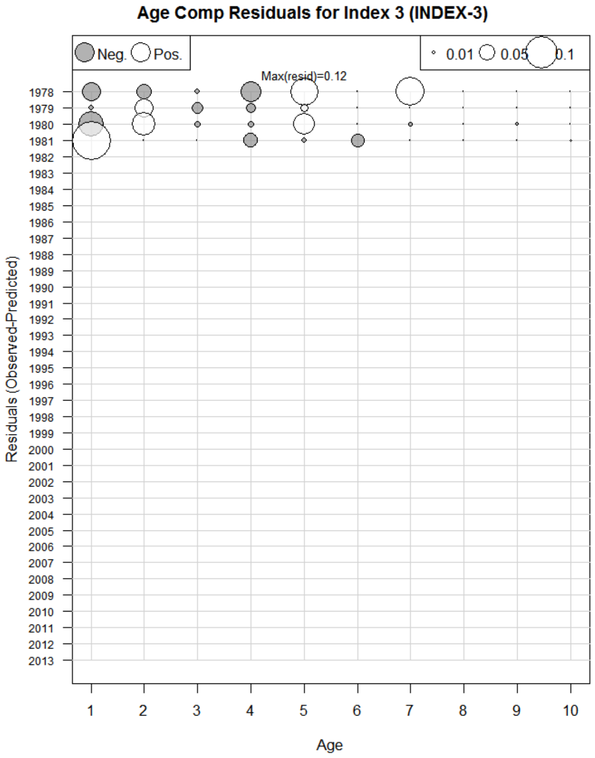

Figure A11. ASAP model age composition residuals for NEFSC spring Yankee #41 trawl survey index of eastern Georges Bank cod, 1978-1981.

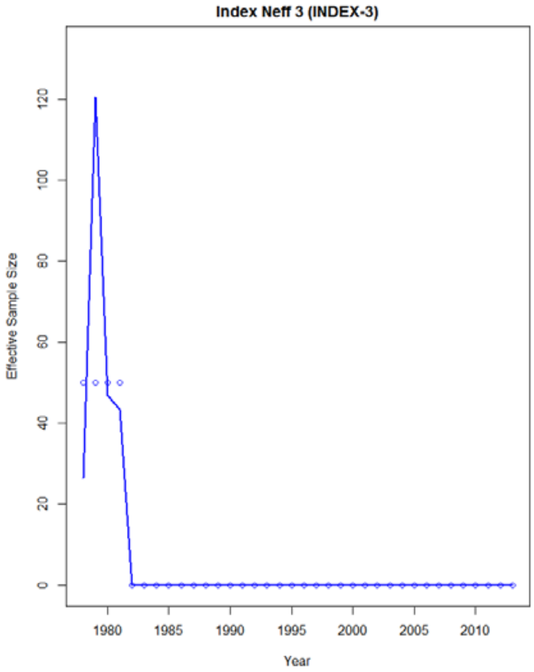

Figure A12. ASAP model observed (line) and predicted (circles) effective sample size of eastern Georges Bank cod in the NEFSC spring Yankee #41 trawl survey, 1978-1981.

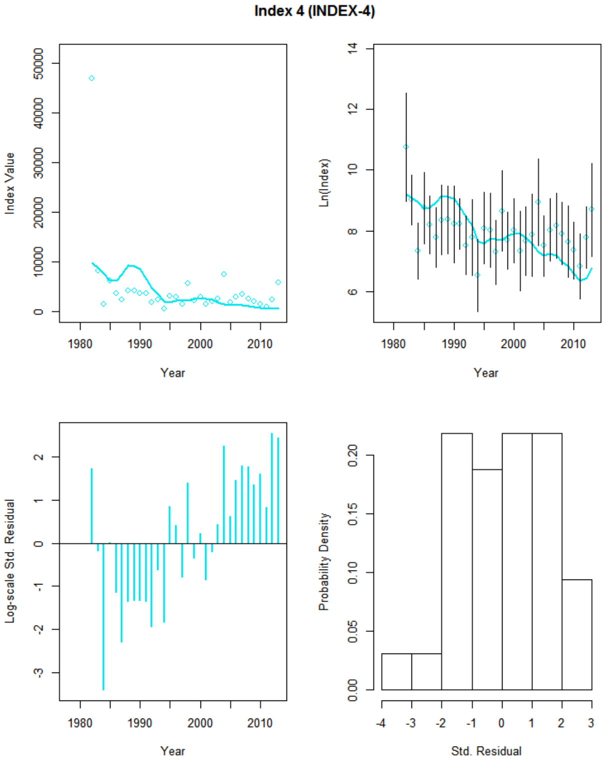

Figure A13. ASAP model fit to NEFSC spring Yankee #36 trawl survey indices of eastern Georges Bank cod, 1982-2013.

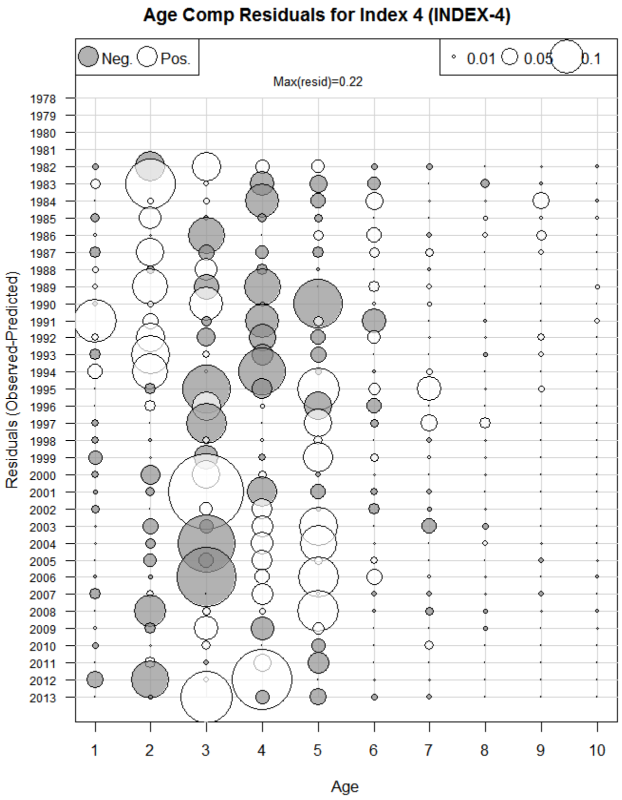

Figure A14. ASAP model age composition residuals for NEFSC spring Yankee #36 trawl survey index of eastern Georges Bank cod, 1982-2013.

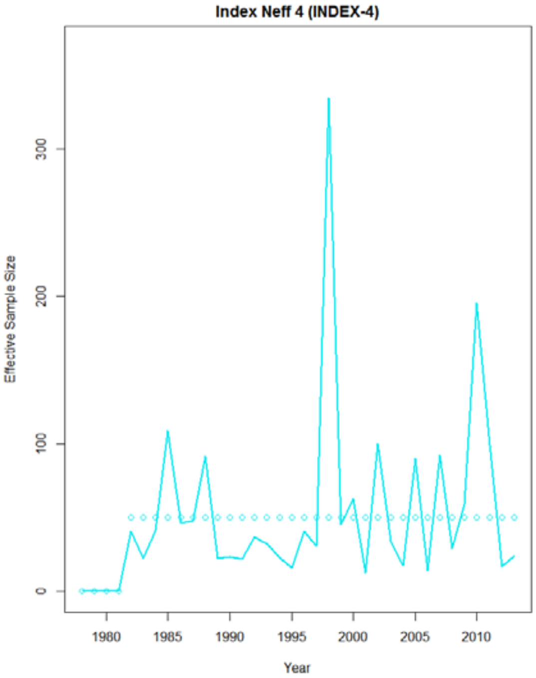

Figure A15. ASAP model observed (line) and predicted (circles) effective sample size of eastern Georges Bank cod in the NEFSC spring Yankee #36 trawl survey, 1982-2013.

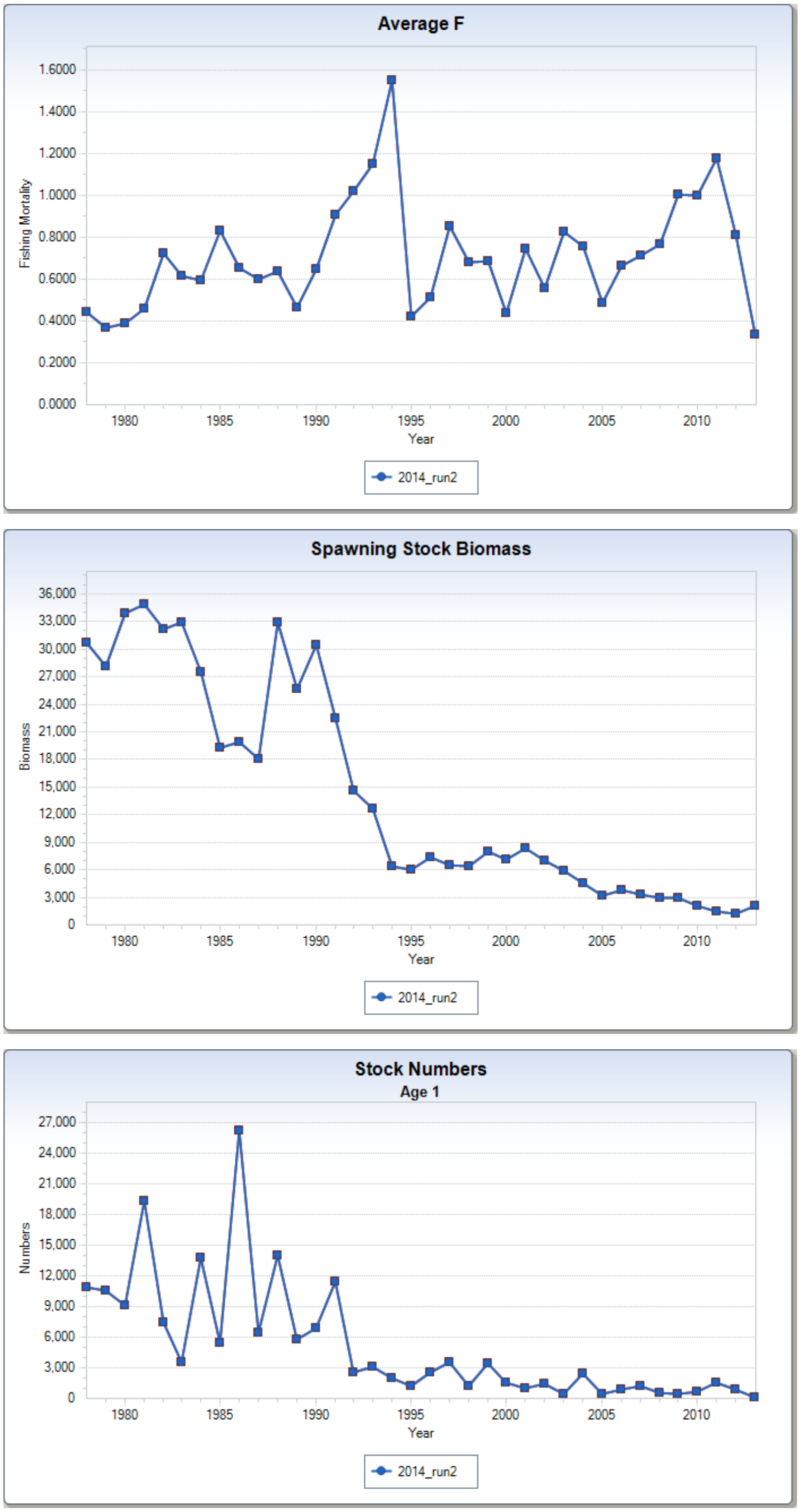

Figure A16. ASAP model results for fishing mortality (ages 5+), spawning stock biomass, and recruitment (age1; 000s fish), 1978-2013.

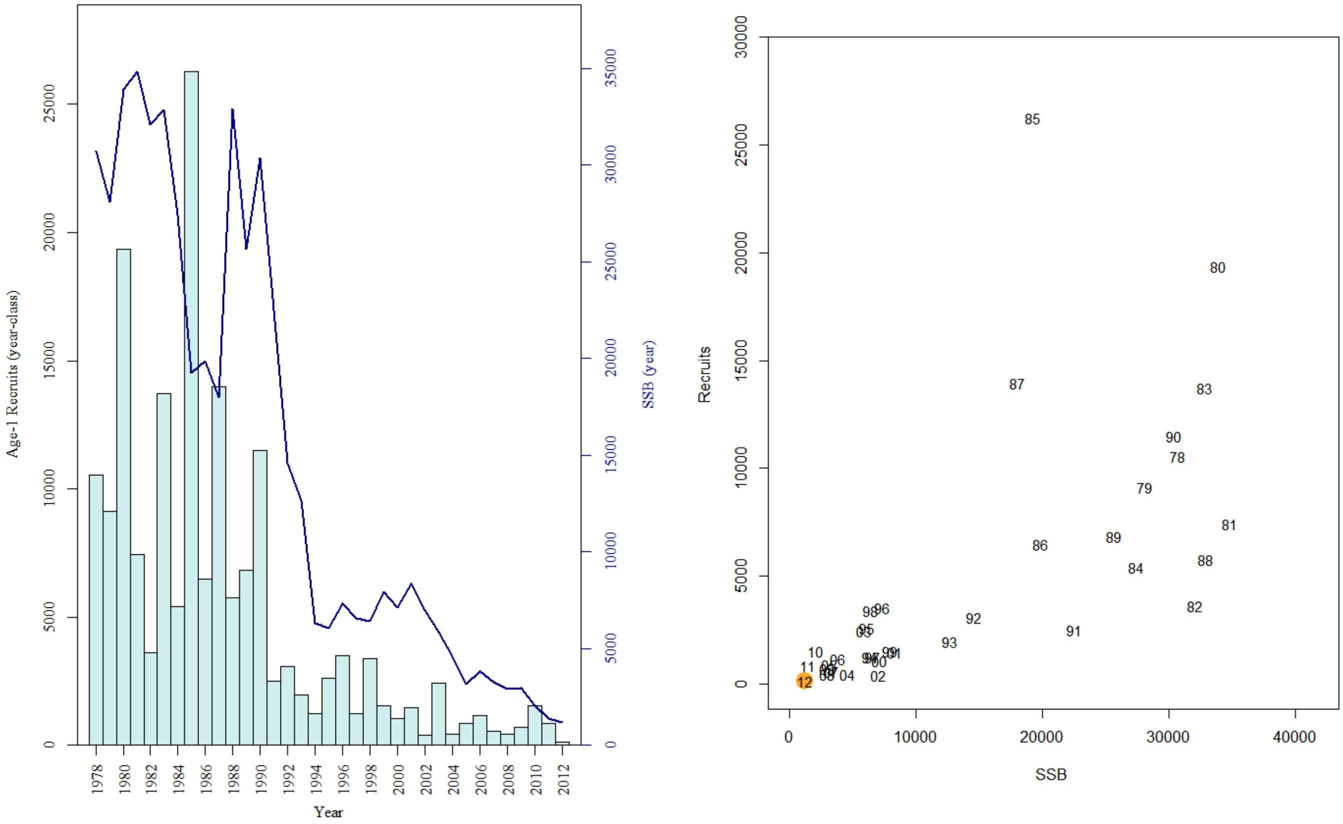

Figure A17. ASAP model results (left panel) for spawning stock biomass (mt, line) and recruitment (age1; 000s fish, bars) and the stock – recruitment plot (right panel) with year-class designation, 1978-2013.

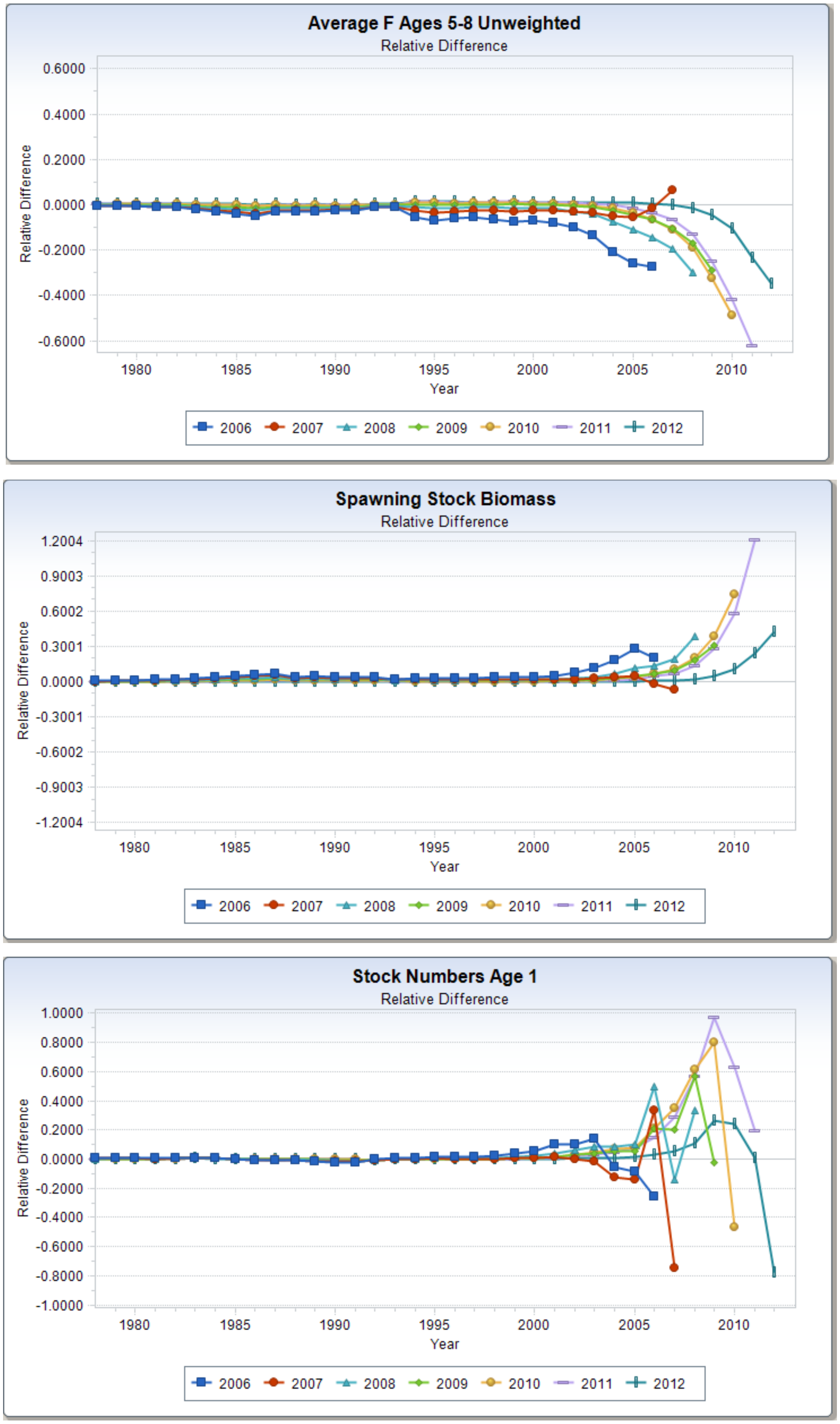

Figure A18. ASAP model results of retrospective bias of fishing mortality (F), spawning stock biomass (SSB), and age1 recruitment. Retrospective bias adjustment for F = -0.32, SSB = 0.46, and age 1 recruitment = -0.25.

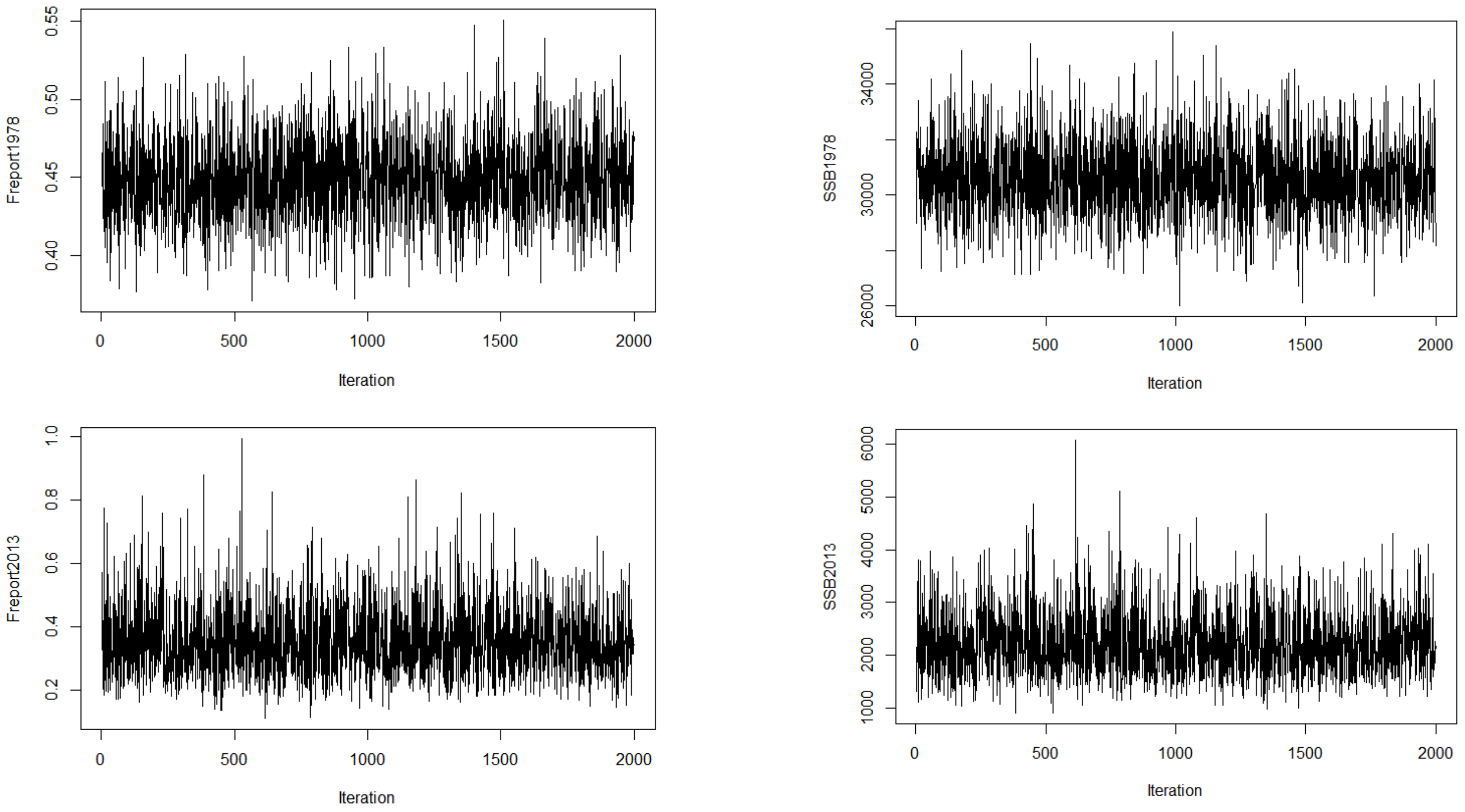

Figure A19. ASAP model results of trace of MCMC chains for eastern Georges Bank cod fishing mortality (left) and spawning stock biomass (right) for 1978 and 2013. Each chain had an initial length of 5.0 million and was thinned at a rate of one out of every 2,500th resulting in a final chain length of 2000.

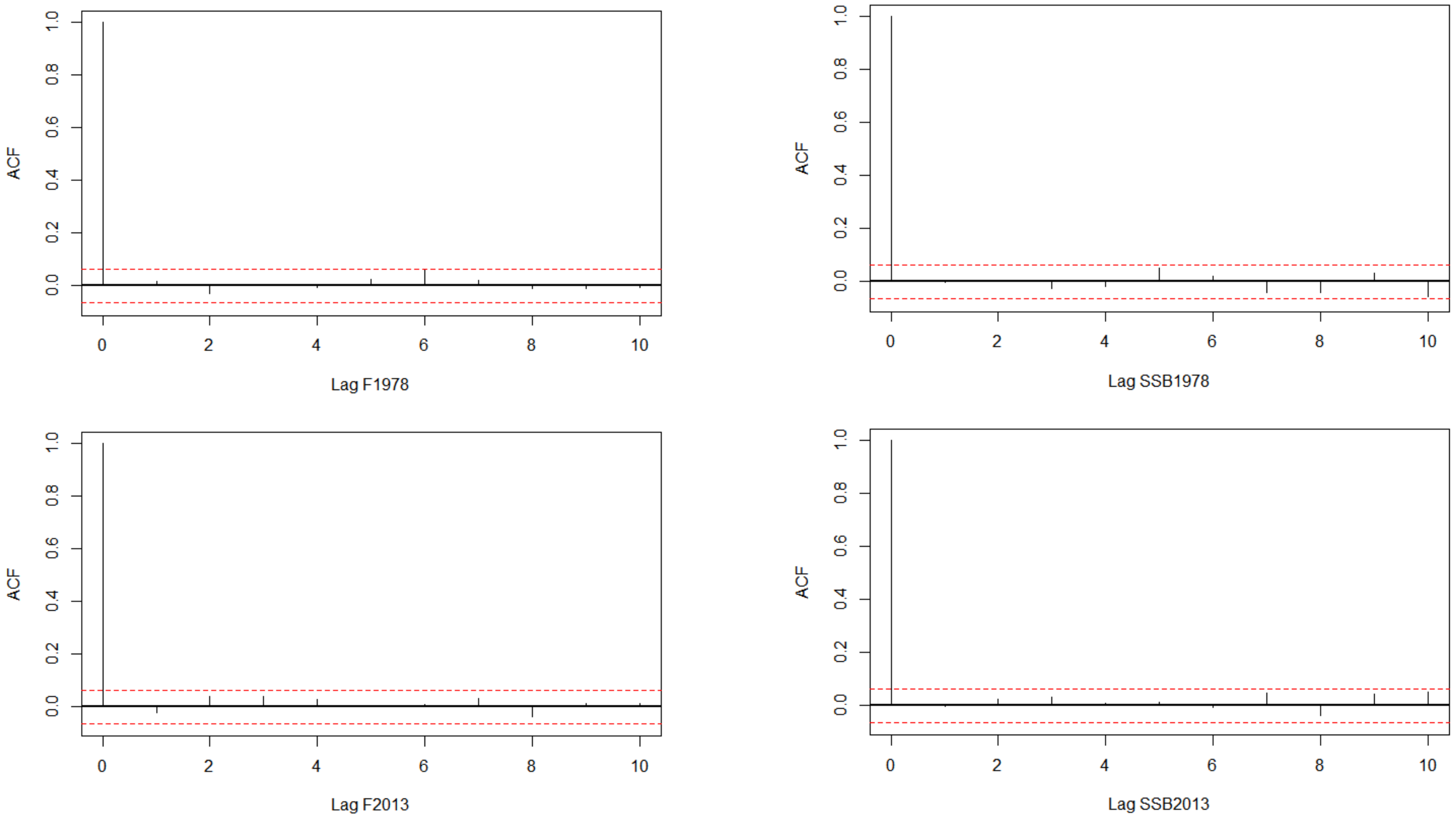

Figure A20. ASAP model autocorrection within the 1978 and 2013 MCMC chains for fishing mortality (F, left panel) and spawning stock biomass (SSB, right panel) for eastern Georges Bank cod.

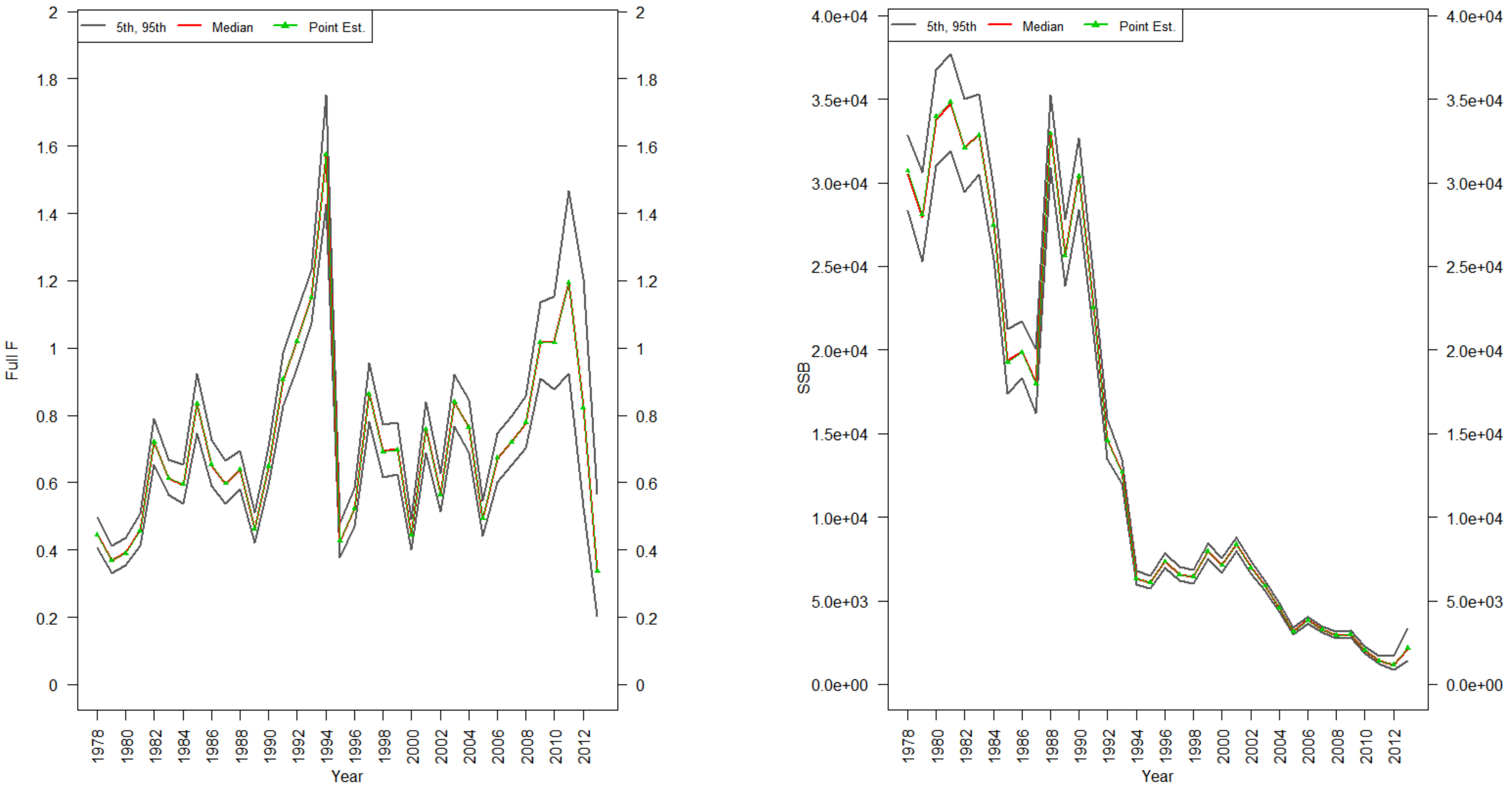

Figure A21. ASAP model 90% probability interval for eastern Georges Bank fishing mortality (left) and cod spawning stock biomass (SSB). The median value is in red, while the 5th and 95th percentiles are in dark grey. The point estimate from the model (joint posterior modes) is shown in the thin green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

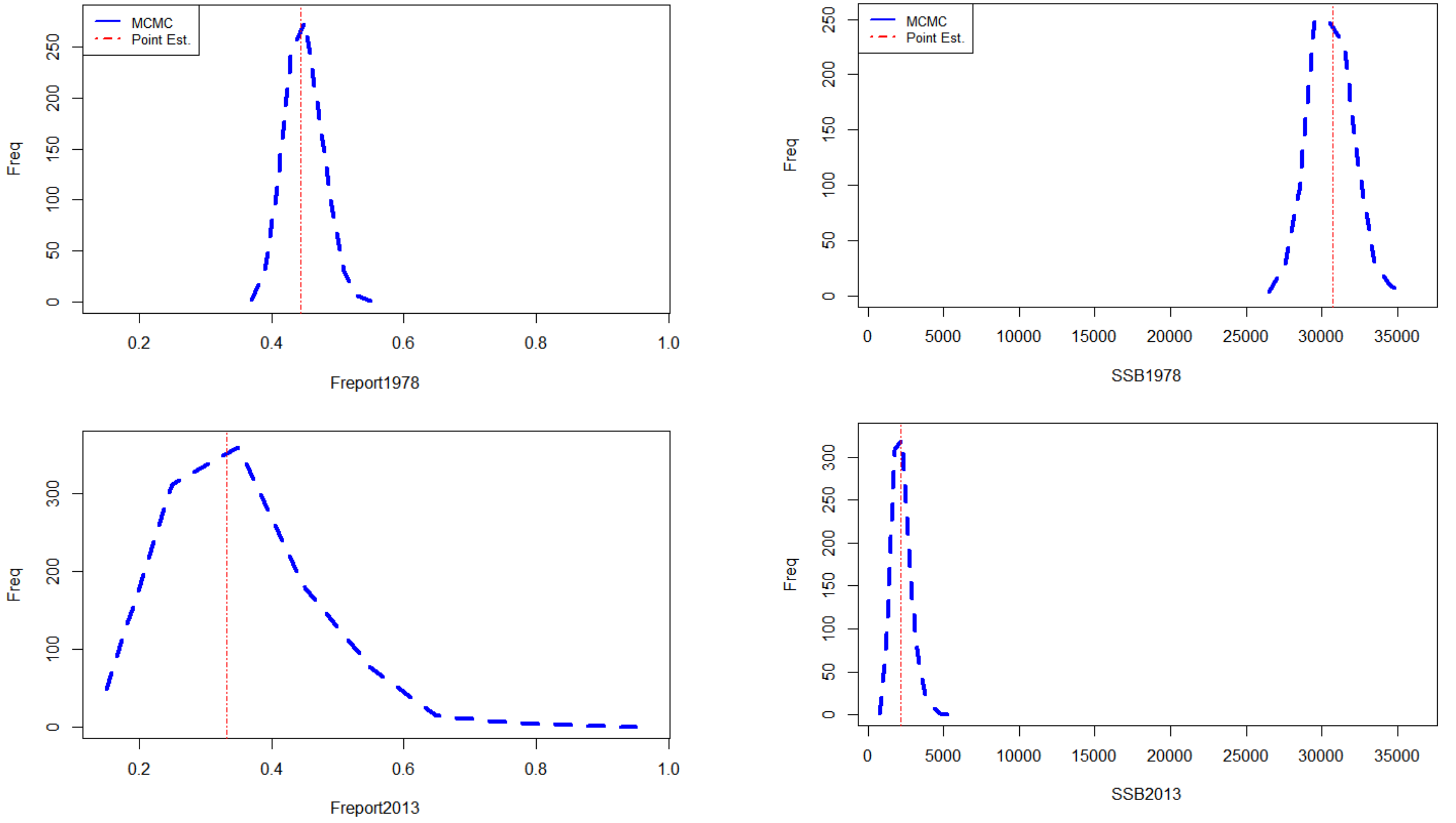

Figure A22. ASAP model MCMC distribution of eastern Georges Bank and fishing mortality (F, left panel) and cod spawning stock biomass (SSB, right panel) in 1978 and 2013. The model point estimate is indicated by the dashed red line.