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Assessment of Eastern Georges Bank Atlantic Cod for 2016

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ABSTRACT

The combined 2015 Canada/USA Atlantic cod catches were 608 mt with a quota of 650 mt. Catches in all three research surveys increased since the 2015 assessment, but were still amongst the lowest in the time series. Both fishery and survey catches showed truncated age structure in recent years.

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

While management measures have resulted in a decreased exploitation rate since 1995, total mortality has remained high and adult biomass has fluctuated at a low level. The adult population biomass at the beginning of 2016 was estimated at 11,026 mt, which was about 20% of the adult biomass in 1978. Fishing mortality was high prior to 1994 (0.33 to 0.51) but was estimated to be 0.05 in 2015. Recruitment at age 1 has been low in recent years. High natural mortality, lower weights at age in the population in recent years and poor recruitment have contributed to the lack of rebuilding.

In 2017, a 50% probability of not exceeding fishing reference point F=0.11 corresponds to catches of 1,319 mt. Due to the expected contribution of the strong 2010 and 2013 year classes, a catch of 1,319 mt is expected to result in a < 25% chance of seeing a decrease in adult biomass from 2017 to 2018. In 2018, a catch of 1,483 mt corresponds to a 50% probability of not exceeding F=0.11 and a < 25% probability that 2019 age 3+ biomass will be lower than 2018. However, given the extremely low spawning stock biomass (SSB), the Transboundary Resources Assessment Committee (TRAC) advises that management aim to rebuild SSB.

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

INTRODUCTION

The 2016 assessment for the management unit of cod on eastern Georges Bank (Figure 1) was updated using the 2013 benchmark model formulations (Claytor and O'Brien 2013). The assessment used Canadian and USA fishery information updated to 2015, including commercial landings and discards, the Fisheries and Oceans Canada (DFO) survey updated to 2016, the National Marine Fisheries Services (NMFS) spring survey updated to 2016 and the NMFS fall survey updated to 2015.

FISHERY

COMMERCIAL FISHERY CATCHES

Combined Canada/USA catches averaged 17,200 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 2015 were 608 mt, including 25 mt of discards (Table 1; Figure 2). Catches included USA and Canadian discards in all years where discard estimates were available.

In 2015, total Canadian catch (extracted landings on June 1, 2016), including discards, was 492 mt against a quota of 526 mt, taken primarily between June and December by otter trawl and longline (Figures 3 and 4). All 2015 landings were subject to dockside monitoring.

For the Canadian otter trawl fishery on eastern Georges Bank, 130 mm square mesh has been the standard mesh size in codends since 1995. In 2014, a test project with alternative codend meshes of 125 mm square and 145 mm diamond was undertaken for the purpose of improving the catch rate of haddock and reducing cod bycatch relative to haddock catches (Morin 2014). Based on the results, 125 mm square mesh was approved for use in 2015 and 2016 (Appendix A).

Discarding of cod from the Canadian groundfish fishery on eastern Georges Bank (EGB) is not permitted. Since 1997 discards of cod have been estimated using the observed ratio of cod to haddock catch (Van Eeckhaute and Gavaris 2004; Hunt et al. 2005; Gavaris et al. 2006, 2007a; Clark et al. 2008) and in 2015 were calculated as 7 mt from the mobile gear fishery (Table 1).

The Canadian scallop fishery has not been permitted to land cod since 1996. Since 2005, estimates of cod discards from the scallop fishery have been obtained by applying a 3-month moving average observed discard rate to the effort of the fleet (Gavaris et al. 2007b). In 2015, the estimated discards of cod by the Canadian scallop fishery were 13 mt (Table 1).

Total USA catch (landings and discards combined) was 116 mt for calendar year 2015 (Table 1; Figure 5). The majority of USA landings were taken in the second calendar quarter with the least amount landed during the fourth quarter (Figure 4). Otter trawl gear accounted for 75% and gillnet gear about 25% of the 111 mt landings during 2015.

Discard ratios (discard:kept, d:k) in the US fisheries are estimated on a trip basis (Wigley et al. 2008) and total discards (mt) then estimated from the product of d:k and total commercial landings. In the 2012 SAW55 cod benchmark meeting (NEFSC 2013), 'Delphi' determined mortality rates (otter trawl: 75%) were applied to the final estimates of USA discards (Table 1). In July 2013, there was a reduction in the minimum size for the US fishery from 22 inches to 19 inches. The estimated discards of cod in the groundfish fishery were 5 mt in 2015 (Table 1; Figure 5). Cod discarded by the lobster fleet in eastern

Georges Bank were about 4 mt but given these are preliminary estimates, were not included in the total discard estimate.

SIZE AND AGE COMPOSITION

The size and age compositions of the 2015 Canadian groundfish fishery landings were derived from the pooled port and at-sea samples from all principal gears and seasons (Table 2; Figure 6). Landings by length peaked at 55 cm (22 in) for bottom trawlers and 70 cm (28 in) for longliners. Gillnetters caught fewer cod but these fish were larger, peaking at 79 cm (31 in) (Figure 7). The combined landings for all gears peaked at 58-73 cm (23-29 in) (Figure 8). The Canadian combined cod discards size composition by length was derived from at-sea sampling, and peaked at 37 cm (15 in) (Figure 7, Figure 8).

Otoliths taken from port samples were used for age determinations. Past comparisons have indicated generally good agreement between DFO and NMFS age readers, (http://www.nefsc.noaa.gov/fbp/QA-QC/). In 2015 the agreement between readers for DFO samples from quarters two and three was lower than expected (66% compared to >84% for all other samples), resulting in additional training being initiated in 2016. Catch-at-age composition was obtained by applying quarterly fishery age-length keys to the size composition. The age-length key from the 2015 DFO survey was used to augment the first quarter key.

Details of the methodology used for the determination of size and age composition of USA fishery landings and discards on eastern Georges Bank are described in Wang et al. (2015). The 2015 catch at age calculations were supplemented with age and length samples from statistical area (SA) 522 due to low samples from SA 561 and 562. Landings by length peaked at 56 cm (22 in) and discards by length peaked at 41 cm (16 in) in 2015 (Figure 9). The 2015 total catch composition peaked at 58-73 cm (23-29 in) for the Canadian fishery and at 56 cm (22 in) for the USA fishery (Figure 10).

The 2015 combined Canada/USA landings and discards fishery age composition, by number, was the highest for the 2011 year class at age 4 (31%) and the 2013 year class at age 2 (29%) (Table 3; Figure 11). By weight, the 2011 year class dominated the 2015 fishery (38%) followed by the 2010 year class (31%) (Figure 11). The contribution of age 7 and older fish continue to be low in recent years, amounting to 0.4% by number and 1% by weight in 2015 (Table 3; Figure 12).

Following a decline throughout the 1990s, fishery weights at age remained low throughout the 2000s, but showed an improvement in 2015 for all ages except age 3 (Table 4; Figure 13). This is consistent with observations made by members of the industry at the 2015 TRAC that fish are appearing healthier than they have over the past 8-10 years (Curran and Brooks 2015).

ABUNDANCE INDICES

RESEARCH SURVEYS

Surveys of Georges Bank have been conducted by DFO every February/March since 1986, and by NMFS each spring (April) since 1968 and fall (October) since 1963. All surveys use a stratified random design (Figures 14 and 15) and historic changes in vessels and nets are documented in Wang et al. (2015). In 2016, the DFO survey was conducted by the *CCGS Teleost* instead of the usual survey vessel, the *Alfred Needler*. 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). The 2016 NMFS spring survey was delayed by approximately one month due to mechanical issues with the research vessel. Consequently, ages were not available for the 2016 NMFS spring survey, so the ALK from the 2016 DFO spring survey was applied.

The spatial distribution of ages 3 and older cod caught during the 2015 NMFS fall, 2016 DFO and NMFS spring surveys were similar to observations from those surveys over the previous decade, with most fish concentrated on the northeastern part of Georges Bank (Figures 16-18).

The swept area abundance from the 2016 DFO survey increased slightly from 2015, but remained amongst the lowest in the time series (1986-2016) (Table 5). The 2013 year class at age 3 contributed 54% by number, followed by the 2011 year class at age 5 (15%) and the 2012 year class at age 4 (11%). The 2015 year class at age 1 contributed 0.4% of the catch and there was no catch of fish older than 8 (Table 5; Figure 19). The 2016 NMFS spring survey catch increased from 2015 (the series low since 1995), but continues to remain below the series mean since 1995 (Table 6). The 2013 year class at age 3 was dominant (65% by number), followed by the 2014 year class at age 2 (16%) and 2012 year class at age 4 (8%). The catch from the 2015 NMFS fall survey increased to the highest value since 2004. The age 2 fish (2013 year class) dominated the catch by number (65%), followed by the 2014 year class at age 1 (12% by number). Consistent with trends seen since 2010, the fall survey continues to see few or no fish over the age of 5 (Table 7; Figure 19). Overall, the survey abundance at age shows poor recruitment since the 1990 year class in all three surveys and representation of older ages in recent years has decreased (Tables 5-7; Figure 19).

The coefficient of variation (CV) of stratified mean catch number per tow for the three surveys is shown in Table 8 and Figure 20. In 2016, the DFO and NMFS fall surveys had smaller CVs compared to the NMFS spring survey which had one of the highest values in the time series. The high variability in catches from the NMFS spring survey was largely influenced by two big tows. The catch from all three surveys became more variable after mid-1990s, which might be caused by patchy distribution of cod at low abundance.

Survey swept area biomass for all three surveys increased from last year, but remains among the lowest in the time series for the spring surveys (Table 9; Figure 21).

The number weighted average weights at age derived from the DFO survey and NMFS spring survey were used to represent the population weight at age for the beginning of the year (Table 10, Figure 22). Fulton's condition factor (K) for all three surveys showed a notable downward trend throughout the series until 2009, when condition began to increase rapidly for the US surveys (Figure 23); in 2015, NMFS fall survey reached a series high. The condition of cod in the DFO survey showed high variability and a slower rate of increase since 2009, but did reach the series average in 2016 (Figure 23). The exact effect of the 2016 NMFS spring survey delay on cod condition has not yet been examined. Overall, trends in condition are consistent with industry comments made during the 2015 TRAC meeting (Curran and Brooks, 2015).

The total mortality (Z) was calculated by two age groups (ages 4-5 and ages 6-8) using DFO survey and NMFS spring survey abundance indices separately (Figure 24). It showed that Z of ages 4 and 5 has been generally lower than the older age group, except in 2015 for the NMFS spring survey when the two were equivalent (Figure 24). Z has remained high throughout the assessment time period for both age groups, even increasing in recent years for DFO, although relative F (fishery catch at age per survey abundance indices) has declined significantly since the 1990s (Figure 25).

ESTIMATION AND DIAGNOSTICS

CALIBRATION OF VIRTURAL POPULATION ANALYSIS (VPA)

At the benchmark assessment review in 2013 there was no consensus on a benchmark model, however, the TRAC did agree to provide catch advice based on a virtual population analysis (VPA) “M 0.8” model, in conjunction with a consequence analysis that compares the VPA and ASAP model (presented below) projection results (Claytor and O’Brien 2013). The VPA used fishery catch statistics and size and age composition of the catch from 1978 to 2015 (including discards). The adaptive framework, ADAPT (Gavaris 1988), was used for calibrating the VPA with trends in abundance from three research bottom trawl survey series: DFO, NMFS spring and NMFS fall. Computational formulae used in ADAPT are described in Rivard and Gavaris (2003a).

In this model, natural mortality (M) was assumed equal to 0.2 for all years and ages, except for ages 6+ since 1994 where it 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=1978-2015, 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… 2015.17, 2016.00.

$I_{2,a,t}$ = 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… 2015.28, 2016.00.

$I_{4,a,t}$ = NMFS fall survey for ages a=1 to 5 and time t=1978.69, 1979.69… 2014.69, 2015.69.

The population was calculated to the beginning of 2016; therefore the DFO and NMFS spring survey indices for 2016 were designated as occurring at the beginning of the year. 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. In the 2016 assessment, fishing mortality on age 9 for 1978-2013 and 2015 was assumed to be equal to the population weighted average fishing mortality on ages 7 and 8. As there were no age 9 cod caught in the 2014 fishery, the population at age 9 in 2014 was estimated (as done for the 2015 assessment).

This approach is considered a deviation from the 2013 benchmark formulation, but no specific guidance exists on how to address a situation without age 9 cod in the CAA.

Estimation was based on minimization of the objective function:

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

where s indexes survey. The estimated model parameters were:

$v_{a,t} = lnN_{a,t} = ln$ population abundance for ages a=2 to 9 at beginning of 2016; age 9 in 2014.

$K_{1,a} = ln$ DFO survey catchability for ages a=1 to 8 at time t=1986-2016.

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

$K_{3,a} = ln$ NMFS spring survey (Yankee 36) catchability for ages a=1 to 8 at time t=1982-2016.

$K_{4,a} = ln$ NMFS fall survey catchability for ages a=1 to 5 at time t=1978-2015.

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

For the beginning of 2016, the population abundance estimate of the 2014 year classes at age 2 exhibited the largest relative bias of 21% and relative error of 77% (Table 11). The relative bias for other ages ranged between 2% and 9% and the relative error ranged between 28% and 43%. The population abundance of the 2005 year class at age 9 in 2014 was estimated as 0.1 million, with relative bias of 2% and relative error of 22%. Survey catchability (q) at age progressively increased until age 5 for DFO and age 4 for the NMFS spring surveys; catchability at age for the NMFS fall survey remains very low (Table 11, 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), though at-age residual patterns suggest obvious year effects (Figure 28). Average fishing mortality (F4-9) by time blocks for 1978-1993, 1994-2010 and 2011-2015 was 0.48, 0.25 and 0.07 respectively, which is consistent with fishery management effort trends. The fishery partial recruitment (PR) has domed substantially since 2011, especially when compared to the relatively flat pattern seen in the earlier time periods for ages 6 through 9 (Figure 29). The causes and consequences of this change in partial recruitment need to be examined further. Of particular concern is the appropriateness of F=0.11 as a fishing mortality reference point, which assumes flat-top PR.

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). However, when the 2013 assessment was updated with data through 2013 (Wang and O’Brien 2013a), the 2003 year class was estimated to be substantially smaller (4.1 million at age 1) than the estimate from the 2013 benchmark model formulation (13.5 million at age 1) with one less year of data (Figure 30); estimates from all subsequent assessment were ~4.4 million, mirroring the 2013 assessment estimate (Table 14 in Wang et al. 2014). The average Mohn’s rho was calculated for the seven retrospective relative differences in assessment years 2009-2015. The values for Mohn’s rho were 0.47 for SSB, -0.32 for F, and -0.02 for age 1 recruitment (Table 12).

Possible reasons for the appearance of a retrospective bias were explored during the 2013 and 2014 assessments (Wang and O’Brien 2013a; Wang et al. 2014) and included:

- Error in the fishery catch which caused low catch of the 2003 year class at age 9 in 2012 or, conversely, error which caused high catch of the 2003 year class at the younger ages (3-6).

- Actual natural mortality experienced by the 2003 year class between ages 8 and 9 was higher than the assumed M=0.8 (Z>>1 from surveys using catch curve analysis). Using the assumed natural mortality would artificially reduce the abundance of the entire 2003 cohort in the backward calculation (even if the 0.8 is a good approximation of M among ages 6 and 7).

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

The 2015 assessment (Wang et al. 2015) proposed a fix for the retrospective bias ('est 2003 yc' model) by estimating the 2003 year class. This document updates the 'est 2003 yc' model for consistency with last year's assessment (Figure 31). The average Mohn's rho was calculated for the seven retrospective relative differences in years 2009-2016. The values for Mohn's rho were 0.27 for SSB, -0.11 for F, and 0.07 for age-1 recruitment (Table 12).

Applying the Mohn's rho adjustment was thought not to be appropriate and was not conducted in this assessment. Residuals of the 2003 year class from the three surveys were predominantly positive, which means that the 2003 year class was underestimated in the 2013 through 2016 assessments from the "M 0.8" model (Figure 32); Mohn's rho adjustment would further underestimate the biomass. The sensitivity analysis in the 2013 and 2014 assessment illustrated the terminal year population abundance estimate and projection from the VPA "M 0.8" model is robust to the uncertainties in the estimate of the 2003 year class.

STATE OF RESOURCE

The estimates presented below are from the 2016 VPA "M 0.8" model (Tables 13-15).

Adult population biomass (ages 3+) declined substantially from 1990 to 1995, fluctuating between 5,900 mt and 18,800 mt since then (Table 13; Figure 33). The increases of age 3+ biomass throughout the mid-2000s and again since 2011 were largely due to the recruitment and growth of the 2003 and 2010 year classes. The adult population biomass at the beginning of 2016 was estimated to be 11,026 mt (80% confidence interval: 9,238 – 13,876 mt) by the 2016 "M 0.8" model, or one-fifth of the 1978 biomass (Table 13; Figure 33). An assumption of high natural mortality, lower weights at age in recent years and generally poor recruitment likely have contributed to the lack of sustained rebuilding.

Recruitment at age 1 has been low in recent years , with the 2003 year class remaining the highest estimated recruitment since 2000 at 4.5 million fish; a number which constitutes less than half of the average recruitment seen between 1978 and 1990 (Table 14; Figure 33). The 2016 "M0.8" model estimate of the 2010 year class at age 1 is 3.5 million, which constitutes two thirds of the 2003 year class based on the 2016 assessment. Recruitment for the 2002, 2004, 2008 and 2012 year classes are the lowest on record and the current biomass remains below the level above which chances of higher recruitment increase (Figure 34). The current estimate of the 2013 year class is 4.4 million fish (Table 14).

Fishing mortality (population number weighted average of ages 4-9) was high prior to 1994 (Table 15; Figure 35) but declined in 1995 to F=0.11 due to restrictive management measures. F in 2015 was estimated to be 0.05 (80% confidence interval: 0.045-0.071). The assessment showed that F has been declining since 2007 and has been at or below F=0.11 since 2011.

PRODUCTIVITY

Trends in recruitment, natural mortality, age structure, fish growth, and spatial distribution typically reflect changes in the productive potential of a population. While management measures have resulted in a decreased exploitation rate since 1995 (Figure 25), total mortality has remained high and adult biomass has fluctuated at a low level. The current biomass is well below 30,000 mt; the threshold above which historically there is a better chance for higher recruitment (Figure 33). Average weight at length, used to reflect condition, has been stable in the past, but has started to decline in recent years. Fishery weight at age had been declining throughout the 1990s and 2000s, but is beginning to show some signs of improvement for select ages since 2010 (Table 4; Figure 13). The research survey spatial distribution patterns of adult (age 3+) cod have not changed over the past decade (Figures 16-18). High natural mortality of age 6+, low weights at age in the population in recent years and poor recruitment have contributed to the lack of rebuilding.

HARVEST STRATEGY

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

OUTLOOK

This outlook is provided in terms of consequences with respect to the harvest reference points for alternative catch quotas in 2017 and 2018 (Gavaris and Sinclair 1998; Rivard and Gavaris 2003b).

Uncertainty about current biomass generates uncertainty in forecast results, which is expressed here as the probability of exceeding F=0.11 in 2017 and 2018, as well as the change in adult biomass from 2017 to 2018 and from 2018 to 2019. The risk calculations assist in evaluating the consequences of alternative catch quotas by providing a general measure of the uncertainties. However, risk calculations are dependent on the data, and model assumptions and do not include uncertainty due to variations in weight at age, PR to the fishery, natural mortality, systematic errors in data reporting or the possibility that the model may not reflect stock dynamics closely enough.

For projections, the average of the most recent three years of fishery and survey weights at age is used for fishery and beginning year population biomass for 2017-2019. The 2016-2018 PR is based on the most recent five years of estimated PR (Table 16). The 2010-2014 average recruitment at age 1 is used for 2016-2019 projections. The uncertainties for this estimate are not reflected in the projection, but the projection could be optimistic if the abundance of the 2015 and 2016 year classes is lower.

During the 2015 TRAC assessment it was discovered that the age-specific difference in natural mortality was not accounted for in calculations of stochastic risk projections for the VPA “M = 0.8” model (Wang et al. 2015). Following meeting recommendations, this error was corrected and the implications of this on catch advice since 2009 is summarized in Table 21.

2017 Projection and Risk Analysis

Assuming a 2016 catch equal to the 625 mt total quota, both deterministic (Table 17) and stochastic (Table 18; Figure 36) projections based on F reference point 0.11 are provided. In 2017, a 50% risk of not exceeding F=0.11 corresponds to a catch of 1,319 mt, and a lower risk (25%) corresponds to a catch of 1,138 mt (Table 18; Figure 36). Due to the expected contribution of the 2013 yearclass, which is larger compared to other recent year classes, the higher catch of 1,319 mt results in a <25% chance of a biomass decrease from 2017 to 2018 (Table 18, Figure 36).

2018 Projection and Risk Analysis

Assuming a 2016 catch equal to the 625 mt total quota and a 2017 fishing mortality of 0.11, the deterministic projection for 2018 is shown in Table 17. In 2018, a 50% risk of not exceeding F=0.11 corresponds to a catch of 1,483 mt, while a lower risk (25%) corresponds to a catch of 1,289 mt (Table 18; Figure 37). Similar to the 2017 projection, given the strength of the 2013 yearclass, even a higher catch of 1,483 mt has a less than 25% chance of a biomass decrease from 2018 to 2019 (Figure 37).

Consequence Analysis (Risks Associated with 2017-2018 Projected Catch)

A consequence analysis to understand the risks associated with assumptions of the VPA “M 0.8” and ASAP “M 0.2” models (Appendix B) was examined. This consequence analysis shows (Table 19):

1. The projected catch (ages 1+) at Fref=0.18 and F=0.11 and percent change in biomass, as if each model represented the “true state” of the resource; and

2. The consequences to fishing mortality and expected biomass (ages 3+) when ‘true state’ catch levels are removed under the assumptions of the other “alternate state” model.

In 2017, a catch of 1319 mt at F=0.11 would result in the 2018 biomass increasing by 5.1% in the VPA “true state” and decreasing by 0.5% in the ASAP “alternate state”. A catch of 515 mt at F_{ref}=0.18 would result in the 2018 biomass increasing by 19% based on the ASAP “true state” and an increase of 10.6% in the VPA “alternate state”.

In 2018, a catch of 1483 mt at F=0.11 would result in 2019 biomass increasing by 9.3% in the VPA “true state” and increasing by 10.4% in the ASAP “alternate state”. A catch of 646 mt at Fref=0.18 would result in the 2019 biomass increasing by 29% based on the ASAP “true state”, and increasing by 26.9% based on the VPA “alternate state”.

SPECIAL CONSIDERATIONS

Table 20 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 ages 3+ biomass from the assessment following the catch year are compared to results from this assessment. These comparisons were kindly provided in 2011 by Tom Nies (staff member of the New England Fishery Management Council, NEFMC) and updated for this assessment. The inconsistency of TRAC advice in the past, with the realized stock conditions from the recent assessment, was mainly due to assessment model changes following the 2009 benchmark assessment. Further, the retrospective bias in the assessment also accounted for part of this inconsistency.

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

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TABLES

Table 1. Catches (mt) of cod from eastern Georges Bank, 1978 to 2015.

	Canada				USA			Total
Year	Landings	Discards Scallop	Discards Groundfish	Total	Landings	Discards	Total	
1978	8,777	98	-	8,875	5,502	-	5,502	14,377
1979	5,979	103	-	6,082	6,408	-	6,408	12,490
1980	8,066	83	-	8,149	6,418	-	6,418	14,567
1981	8,508	98	-	8,606	8,092	-	8,092	16,698
1982	17,827	71	-	17,898	8,565	-	8,565	26,463
1983	12,131	65	-	12,196	8,572	-	8,572	20,769
1984	5,761	68	-	5,829	10,558	-	10,558	16,387
1985	10,442	103	-	10,545	6,641	-	6,641	17,186
1986	8,504	51	-	8,555	5,696	-	5,696	14,251
1987	11,844	76	-	11,920	4,793	-	4,793	16,713
1988	12,741	83	-	12,824	7,645	-	7,645	20,470
1989	7,895	76	-	7,971	6,182	84	6,267	14,238
1990	14,364	70	-	14,434	6,414	69	6,483	20,917
1991	13,467	65	-	13,532	6,353	112	6,464	19,997
1992	11,667	71	-	11,738	5,080	177	5,257	16,995
1993	8,526	63	-	8,589	4,019	57	4,077	12,665
1994	5,277	63	-	5,340	998	5	1,003	6,343
1995	1,102	38	-	1,140	543	0.2	544	1,683
1996	1,924	56	0.0	1,980	676	1	677	2,657
1997	2,919	58	428	3,405	549	6	555	3,960
1998	1,907	92	273	2,272	679	7	686	2,959
1999	1,818	85	253	2,156	1,195	9	1,204	3,360
2000	1,572	69	0.0	1,641	772	16	788	2,429
2001	2,143	143	0.0	2,286	1,488	146	1,634	3,920
2002	1,278	94	0.0	1,372	1,688	9	1,697	3,069
2003	1,317	200	-	1,528	1,851	85	1,935	3,463
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	226	1,671
2007	1,108	114	0.0[1]	1,222	234	279	513	1,735
2008	1,390	36	103	1,529	224	20	244	1,774
2009	1,003	69	137	1,209	433	147	580	1,789
2010	748	44	48	840	357	97	454	1,294
2011	702	29	13	743	267	20	287	1,030
2012	395	42	31	468	96	52	148	616
2013	385	18	21	424	24	16	40	464
2014	430	15	13	458	114	2	116	574
2015	472	13	7	492	111	5	116	608
Minimum	385	13	0	424	24	<1	40	464
Maximum	17,827	200	428	17,898	10,558	279	10,558	26,463
Average	5,190	75	131	5,310	3,172	66	3,219	8,529

[1] Discards for the Mobile Fleet were calculated to be 0. Discards for the Fixed Gear fleet were not calculated due to low observer coverage.

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

Year	USA		Canada	
	Lengths	Ages	Lengths	Ages
1978	2,294	384	7,684	1,364
1979	2,384	402	3,103	796(205)
1980	2,080	286	2,784	728(192)
1981	1,498	455	4,147	897
1982	4,466	778	4,705	1,126(268)
1983	3,906	903	3,822	754(150)
1984	3,891	1,130	1,889	1,243(858)
1985	2,076	597	7,031	1,309(351)
1986	2,145	643	5,890	991(103)
1987	1,865	524	9,133	1,429(193)
1988	3,229	797	11,350	2,437(510)
1989	1,572	347	8,726	1,561
1990	2,395	552	31,974	2,825(1,153)
1991	1,969	442	27,869	1,782
1992	2,048	489	29,082	2,215(359)
1993	2,215	569	31,588	2,146
1994	898	180	27,972	1,268
1995	2645	14	6,660	548
1996	4,895	1,163	26,069	828
1997	1,761	82	31,617	1,216
1998	1,301	338	26,180	1,643
1999	726	228	26,232	1,290(410)
2000	500	121	20,582	1,374
2001	1,434	397	19,055	1,505
2002	1,424	429	16,119	1,252
2003	1,367	416	19,757	1,070
2004	1,547	517	18,392	1,357
2005	297	65	23,937	1,483(697)
2006	446	151	44,708	1,460(648)
2007	589	183	141,607	1,647(456)
2008	972	295	64,387	1,709(495)
2009	1,286	326	48,335	1,725(246)
2010	1,446	333	30,594	1,455(433)
2011	1,203	213	40,936	1,655(536)
2012	598	746[1]	49,447	1,115(216)
2013	2,951	842	75,275	1,334(319)
2014	547	85	50,501	1,141(184)
2015	4,677	1,049[2]	74,028	970 (202)

[1] Age and length data supplemented with ages from statistical areas 522 and 525.
[2] Age and length data supplemented with ages from statistical area 522.

Table 3. Annual catch at age numbers (thousands) for eastern Georges Bank cod for 1978-2015.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1978	1	8	108	3,644	1,167	394	163	127	22	23	6	2	1	0.1	0.3	0.4	0.2	5,668
1979	1	15	890	735	1,520	543	182	74	61	11	3	2	1	0.01	1	0.0	0.0	4,037
1980	2	6	973	1,650	301	968	354	97	26	46	16	4	1	0.0	0.0	0.0	0.0	4,445
1981	3	35	860	1,865	1,337	279	475	181	96	59	21	2	1	0.0	0.0	0.0	0.0	5,216
1982	0.01	15	3516	1,971	1,269	1,087	196	399	155	49	14	22	6	3	4	1	0.0	8,707
1983	10	22	783	2,510	1,297	562	398	118	182	102	25	28	12	1	3	1	0.07	6,055
1984	0.1	17	231	805	1,354	546	377	279	39	90	38	17	7	2	3	0.0	1	3,806
1985	33	9	2861	1,409	661	987	271	110	110	21	27	3	4	1	1	0.1	0.0	6,508
1986	1	41	451	2,266	588	343	456	68	48	29	4	8	1	0.0	0.0	0.0	0.0	4,303
1987	2	22	4116	846	1,148	163	132	174	41	24	8	3	1	0.06	0.0	0.0	0.0	6,680
1988	1	23	289	4,189	680	855	130	116	182	52	21	13	4	1	0.05	0.1	0.0	6,556
1989	1	18	680	811	1,983	228	373	56	40	59	15	7	5	0.1	0.4	0.0	0.0	4,278
1990	1	16	726	3,109	1,038	1,374	145	153	12	12	24	3	2	1	0.0	0.5	0.002	6,617
1991	0.4	63	991	1,008	1,927	904	746	105	69	21	11	8	4	2	0.4	1	0.0	5,862
1992	0.0	68	2581	1,379	460	889	314	315	45	34	3	5	2	1	0.0	0.0	0.0	6,096
1993	0.0	10	501	1,894	909	299	359	133	97	25	17	3	0.08	0.2	0.0	0.0	0.0	4,246
1994	1	6	182	483	788	270	45	61	30	21	2	1	0.0	0.1	0.01	0.009	0.0	1,889
1995	3	1	57	237	94	105	18	7	4	4	0.1	0.08	0.009	0.0	0.0	0.0	0.0	531
1996	0.1	5	40	234	398	79	60	13	4	3	0.3	0.1	0.0	0.0	0.003	0.0	0.0	837
1997	1	9	148	205	358	358	84	37	13	4	1	1	0.05	0.0	0.0	0.0	0.0	1,219
1998	0.1	5	101	314	161	158	134	23	13	4	1	0.3	1	0.04	0.0	0.0	0.0	916
1999	0.1	9	79	483	337	109	61	57	14	2	1	0.08	0.0	0.01	0.0	0.0	0.0	1,152
2000	1	3	62	110	380	151	37	22	12	3	0.2	0.3	0.005	0.0	0.08	0.0	0.0	783
2001	1	3	107	511	211	398	105	32	17	7	1	0.3	0.07	0.0	0.0	0.0	0.0	1,394
2002	1	1	10	125	447	108	156	30	9	6	2	1	0.4	0.0	0.04	0.0	0.0	896
2003	13	0.0	35	148	243	405	81	89	19	4	1	0.3	0.0	0.0	0.0	0.0	0.0	1,039
2004	0.0	23	12	140	151	147	139	35	30	7	1	1	0.2	0.0	0.009	0.002	0.02	686
2005	0.0	4	71	45	201	50	34	35	10	5	1	0.02	0.1	0.1	0.004	0.002	0.0	457
2006	0.0	3	19	226	78	195	48	18	18	2	2	0.3	0.1	0.0	0.0	0.0	0.0	608
2007	0.005	2	53	62	421	34	85	11	7	7	0.4	0.1	0.0	0.0	0.0	0.0	0.0	682
2008	0.0	1	45	141	61	249	15	33	4	2	1	0.1	0.0	0.01	0.0	0.0	0.0	552
2009	1	7	43	200	139	46	137	9	10	1	1	0.05	0.0	0.0	0.0	0.0	0.0	594
2010	0.02	3	44	96	211	74	15	35	3	2	0.3	0.04	0.003	0.0	0.0	0.0	0.0	481
2011	0.0	9	43	76	93	115	26	12	7	0.2	0.2	0.006	0.0	0.0	0.0	0.0	0.0	382
2012	0.0	2	70	105	49	29	25	6	1	1	0.02	0.0	0.0	0.0	0.0	0.0	0.0	289
2013	0.5	1	27	112	52	11	7	2	0.4	0.03	0.08	0.0	0.0	0.0	0.0	0.0	0.0	212
2014	0.0	4	17	82	103	28	4	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	238
2015	0.0	1	67	38	71	47	6	1	0.03	0.03	0.3	0.002	0.0	0.0	0.0	0.0	0.0	231

Table 4. Average fishery weights at age (kg) of cod from eastern Georges Bank.

Year/Age	1	2	3	4	5	6	7	8	9	10	Ave
1978	0.44	1.26	2.07	2.72	3.72	5.41	5.61	8.28	7.50	11.32	4.83
1979	0.73	1.45	1.52	3.28	4.45	6.59	9.41	9.62	9.86	14.18	6.11
1980	0.38	1.24	2.21	3.07	4.96	6.29	7.22	11.46	10.41	12.54	5.98
1981	0.52	1.28	1.99	3.06	4.54	6.50	8.02	9.25	11.62	15.19	6.20
1982	0.56	1.30	2.13	3.61	5.01	6.76	8.51	9.86	11.86	13.98	6.36
1983	0.90	1.49	2.21	3.10	4.60	6.10	7.81	10.15	11.47	13.20	6.10
1984	0.68	1.60	2.31	3.42	4.76	6.09	8.30	9.35	11.16	12.03	5.97
1985	0.54	1.32	1.81	3.19	4.55	5.95	7.91	9.60	10.75	12.52	5.81
1986	0.54	1.36	2.43	3.30	4.83	6.70	8.08	9.20	11.38	11.46	5.93
1987	0.58	1.46	2.38	3.93	5.38	7.23	8.76	9.46	11.27	12.01	6.25
1988	0.62	1.17	2.19	3.07	4.91	6.10	8.27	9.89	11.14	12.49	5.99
1989	0.62	1.27	1.96	3.35	4.89	6.02	6.79	9.80	10.70	12.77	5.82
1990	0.69	1.55	2.38	3.22	4.59	6.04	7.80	9.81	11.19	12.82	6.01
1991	0.75	1.52	2.42	3.14	4.24	5.53	7.45	9.46	9.18	13.28	5.70
1992	0.86	1.41	2.28	3.32	4.24	5.66	6.80	8.66	11.22	14.85	5.93
1993	0.60	1.40	2.11	2.84	4.29	5.40	6.76	8.29	9.14	11.13	5.19
1994	0.60	1.33	2.14	3.44	4.39	6.42	7.19	8.15	7.97	11.40	5.30
1995	0.32	1.32	2.12	3.35	4.94	6.38	10.10	10.01	10.44	15.35	6.43
1996	0.51	1.42	2.17	3.05	4.70	5.83	6.42	8.96	10.35	10.38	5.38
1997	0.67	1.42	2.07	2.93	3.86	5.36	7.26	8.31	11.48	9.88	5.32
1998	0.70	1.34	2.15	2.98	3.97	5.33	6.59	7.82	10.23	12.88	5.40
1999	0.54	1.30	1.97	3.10	3.91	5.48	6.27	7.54	9.38	13.52	5.30
2000	0.60	1.33	1.97	2.90	4.02	4.70	5.72	6.77	8.35	14.05	5.04
2001	0.21	0.93	1.84	2.74	3.58	4.87	5.22	7.27	8.65	11.07	4.64
2002	0.33	1.20	1.96	2.84	4.01	4.88	6.41	8.23	7.98	10.11	4.80
2003	-	1.24	2.12	2.71	3.53	4.24	5.47	6.84	7.63	8.13	4.66
2004	0.24	1.23	1.84	2.77	3.46	4.56	5.24	7.24	8.54	8.64	4.38
2005	0.40	0.83	1.56	2.35	3.49	4.50	4.85	6.74	7.88	9.26	4.19
2006	0.27	0.64	1.73	2.30	3.29	4.28	6.10	5.78	6.89	7.18	3.85
2007	0.46	1.04	1.61	2.32	2.99	3.91	6.10	6.84	6.90	9.35	4.15
2008	0.30	1.27	2.22	2.79	3.65	5.03	5.82	7.92	7.97	8.73	4.57
2009	0.66	1.13	1.92	3.03	3.71	4.51	5.74	6.73	10.00	10.26	4.77
2010	0.48	1.28	2.04	2.53	3.38	3.44	5.10	6.08	8.84	10.87	4.40
2011	0.31	1.08	1.72	2.56	3.51	4.28	4.23	6.06	9.85	9.37	4.30
2012	0.29	0.93	1.66	2.64	3.69	4.10	4.64	5.70	5.33	5.23	3.42
2013	0.33	1.01	1.85	2.77	3.73	4.86	5.37	5.87	7.89	7.17	4.09
2014	0.30	0.98	2.10	2.60	3.48	4.49	6.24	8.26	-	-	3.56
2015	0.42	1.17	1.97	3.21	4.00	5.09	7.64	13.28	10.41	6.31	5.35
Min	0.21	0.64	1.52	2.30	2.99	3.44	4.23	5.70	5.33	5.23	3.16
Max	0.90	1.60	2.43	3.93	5.38	7.23	10.10	13.28	11.86	15.35	7.20
Avg.[1]	0.36	1.08	1.89	2.72	3.63	4.38	5.54	7.54	8.46	7.79	4.34

[1]for 2010-2015

Table 5. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the DFO survey, 1986-2016.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1986	0	770	3538	3204	331	692	445	219	35	66	0	10	0	0	0	0	0	9311
1987	0	48	1791	642	753	162	89	181	89	13	13	0	13	16	0	0	0	3812
1988	0	148	450	5337	565	838	95	79	179	18	12	4	0	16	0	0	0	7741
1989	0	350	2169	764	1706	258	332	42	85	112	5	32	8	5	0	0	0	5868
1990	20.06	106	795	3471	1953	4402	535	1094	144	157	289	65	52	37	0	0	5	13125
1991	0	1198	1019	1408	1639	882	1195	148	249	38	45	30	12	5	8	0	0	7876
1992	0	48	2049	1221	409	643	451	300	93	38	0	3	3	18	0	0	0	5276
1993	0	31	355	1723	622	370	754	274	268	51	31	0	20	6	0	0	0	4504
1994	0	13	629	691	1289	477	182	363	84	119	12	0	0	0	8	5	0	3871
1995	0	32	187	1240	757	520	186	44	67	28	18	8	6	0	0	0	0	3093
1996	0	90	203	1744	4337	1432	1034	445	107	149	39	4	0	0	5	0	0	9590
1997	0	30	376	568	1325	1262	216	50	35	23	17	0	3	0	0	0	0	3905
1998	0	6	582	831	322	317	238	56	29	7	8	3	4	0	0	0	0	2402
1999	0	3	156	1298	1090	449	317	190	10	28	5	9	0	3	0	0	0	3561
2000	0	0	423	1294	4967	2157	1031	510	317	20	23	12	0	0	0	0	0	10754
2001	0	3	37	802	519	1391	645	334	224	225	36	24	7	0	0	0	0	4248
2002	0	0	118	477	2097	694	1283	458	188	63	76	7	0	0	0	0	0	5462
2003	0	0	8	200	510	867	194	219	69	12	0	0	0	0	0	0	0	2078
2004	0	427	40	246	381	422	353	59	108	25	5	0	3	0	0	0	0	2069
2005	0	25	1025	1398	7149	1766	816	743	60	87	8	4	0	0	0	0	0	13082
2006	0	0	41	1500	673	1779	757	217	216	83	34	10	15	0	0	0	0	5325
2007	0	18	130	549	2606	379	653	119	81	53	0	4	0	0	0	0	0	4591
2008	0	12	147	1027	755	2978	194	392	41	4	20	0	0	0	0	0	0	5569
2009	0	11	51	2487	2261	519	2955	0	82	0	0	0	18	0	0	0	0	8384
2010	0	5	92	956	4105	1781	703	1828	65	84	5	0	0	0	0	0	0	9623
2011	0	193	271	766	952	1324	256	67	112	14	8	2	0	0	0	0	0	3965
2012	0	9	149	327	315	195	158	7	18	4	0	0	0	0	0	0	0	1182
2013	0	0	431	3754	2173	285	81	52	10	0	0	0	0	0	0	0	0	6786
2014	0	76	9	360	538	169	35	0	27	0	0	0	0	0	0	0	0	1213
2015	0	0	476	152	598	439	97	7	0	0	0	0	0	0	0	0	0	1770
2016	0	8	197	1004	199	273	147	16	4	0	0	0	0	0	0	0	0	1845

Table 6. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS spring survey, 1970-2016. 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. DFO 2016 Spring ALK was applied to the 2016 NMFS spring survey, as ages were not available in time.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1970	0	354	1115	302	610	73	263	48	0	71	24	0	48	0	0	0	0	2907
1971	0	185	716	503	119	326	124	257	227	40	40	79	0	0	0	0	0	2615
1972	56	1578	1856	2480	393	114	136	60	88	73	18	14	0	0	14	0	0	6879
1973	0	665	37880	5474	6109	567	467	413	0	163	231	0	0	0	95	0	0	52064
1974	0	461	5877	4030	759	2001	360	91	267	45	48	54	0	0	0	0	0	13991
1975	0	0	467	3061	4348	446	960	79	0	122	0	0	0	0	0	0	0	9483
1976	84	1733	1111	620	444	759	0	167	35	0	0	0	0	48	0	0	0	5001
1977	0	0	2358	736	354	307	334	22	35	0	0	0	0	0	0	0	0	4145
1978	373	187	0	2825	615	916	153	787	62	43	40	0	0	0	0	0	0	6001
1979	71	339	1332	122	1430	543	176	91	130	0	0	0	0	0	0	0	0	4234
1980	0	11	2251	2168	169	1984	410	78	48	31	0	47	0	0	0	0	0	7197
1981	283	1956	1311	2006	1093	43	453	197	59	0	0	0	0	0	0	0	0	7399
1982	44	455	6642	13614	12667	9406	0	3088	992	120	0	0	0	0	0	0	0	47027
1983	0	389	2017	3781	779	608	315	106	98	0	70	0	0	0	0	0	35	8197
1984	0	103	117	344	483	92	182	74	18	105	0	0	0	0	0	0	0	1518
1985	58	36	2032	633	1061	1518	328	217	213	83	116	34	23	0	0	0	0	6352
1986	97	619	339	1132	298	427	536	20	109	142	0	0	0	0	0	0	0	3719
1987	0	0	1194	247	568	0	152	148	30	54	0	0	0	0	0	0	0	2394
1988	138	320	243	2795	274	461	51	5	67	0	0	10	0	0	0	0	0	4364
1989	0	174	1238	338	1685	234	396	99	12	36	48	24	0	0	0	0	0	4284
1990	24	45	360	1687	586	634	152	164	19	0	0	24	0	0	0	0	0	3696
1991	217	725	620	514	903	460	382	44	17	0	24	53	0	0	0	0	0	3957
1992	0	81	666	349	103	261	152	159	27	52	0	0	0	0	0	0	0	1850
1993	0	0	462	1284	262	46	182	46	43	46	12	0	0	0	0	0	0	2382
1994	38	54	194	152	185	44	11	33	0	8	0	0	0	0	0	0	0	720
1995	384	70	294	927	495	932	191	253	0	68	0	0	0	0	0	0	0	3614
1996	0	139	300	990	1343	121	94	28	0	0	0	0	0	0	0	0	0	3016
1997	271	54	218	48	402	519	53	126	57	0	0	0	0	0	0	0	0	1747
1998	54	0	1040	1985	995	983	609	30	31	0	0	0	0	0	0	0	0	5729
1999	22	22	145	673	624	370	172	107	34	8	0	0	0	0	0	0	0	2176
2000	36	0	304	643	1348	492	138	52	20	0	0	0	0	0	0	0	0	3032
2001	0	0	64	889	96	350	109	0	12	10	0	0	0	0	0	0	0	1530
2002	36	0	121	470	1081	175	214	61	0	0	0	0	0	0	0	0	0	2158
2003	0	0	125	287	812	1154	135	78	9	0	0	0	0	0	0	0	0	2599
2004	0	549	10	838	2091	2105	1351	239	382	29	0	0	0	0	0	0	0	7595
2005	36	15	345	70	747	287	190	131	34	0	0	0	0	0	0	0	0	1855
2006	0	37	73	952	411	1007	340	151	79	0	0	0	0	0	0	0	0	3050
2007	0	0	369	308	2258	239	291	47	28	0	0	0	0	0	0	0	0	3540
2008	43	37	112	675	372	1385	51	66	0	0	0	0	0	0	0	0	0	2741
2009	0	61	86	875	408	219	377	24	12	15	0	0	0	0	0	0	0	2078
2010	0	25	126	367	667	168	44	147	0	12	0	0	0	0	0	0	0	1556
2011	0	88	164	164	266	144	56	9	24	0	0	0	0	0	0	0	0	914
2012	3	3	450	749	834	209	127	13	0	0	0	0	0	0	0	0	0	2389
2013	0	0	653	3864	1202	129	64	15	0	0	0	0	0	0	0	0	0	5926
2014	0	55	64	568	922	109	27	0	0	0	0	0	0	0	0	0	0	1746
2015	0	9	165	71	222	331	23	0	0	0	0	0	0	0	0	0	0	820
2016	4	4	324	1,345	156	153	72	3	14	0	0	0	0	0	0	0	0	2074

Table 7. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS fall survey, 1970-2015. 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
2014	98	144	47	145	223	28	14	0	0	0	0	0	0	0	0	0	0	697
2015	42	223	1208	94	162	131	0	0	0	0	0	0	0	0	0	0	0	1859

Table 8. Mean weight and number per tow indices for each survey with accompanying CVs.

Year	DFO N/Tow		DFO Kg/Tow		NMFS Spring N/Tow		NMFS Spring Kg/Tow		NMFS Fall N/Tow		NMFS Fall Kg/Tow	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1970	-	-	-	-	3.58	0.38	9.61	0.43	3.77	0.22	5.84	0.23
1971	-	-	-	-	3.02	0.26	12.07	0.42	3.41	0.37	6.11	0.30
1972	-	-	-	-	7.95	0.19	15.93	0.22	6.65	0.59	4.56	0.40
1973	-	-	-	-	60.20	0.64	95.18	0.55	9.16	0.33	14.13	0.45
1974	-	-	-	-	16.18	0.28	31.53	0.28	1.72	0.41	3.38	0.42
1975	-	-	-	-	10.96	0.17	37.81	0.16	2.89	0.41	6.07	0.44
1976	-	-	-	-	6.16	0.25	12.76	0.23	10.97	0.44	6.26	0.32
1977	-	-	-	-	4.79	0.15	10.79	0.22	6.97	0.19	13.92	0.17
1978	-	-	-	-	6.94	0.26	26.28	0.27	7.80	0.24	17.88	0.24
1979	-	-	-	-	4.90	0.21	14.84	0.22	8.13	0.32	19.10	0.25
1980	-	-	-	-	8.87	0.37	25.29	0.32	3.54	0.27	6.58	0.28
1981	-	-	-	-	11.18	0.22	28.07	0.18	7.64	0.26	10.62	0.26
1982	-	-	-	-	68.83	0.83	252.19	0.89	1.63	0.52	2.56	0.41
1983	-	-	-	-	9.48	0.13	23.56	0.24	2.22	0.29	2.83	0.43
1984	-	-	-	-	1.87	0.20	5.93	0.22	4.32	0.43	8.12	0.64
1985	-	-	-	-	11.46	0.35	41.83	0.27	4.77	0.53	4.31	0.83
1986	21.54	-	-	-	6.71	0.21	22.61	0.28	6.13	0.57	3.92	0.47
1987	9.18	0.42	21.25	0.35	4.32	0.23	13.74	0.25	2.45	0.47	4.75	0.47
1988	18.64	0.33	46.84	0.30	7.87	0.34	16.77	0.34	4.44	0.36	12.20	0.45
1989	14.13	0.16	35.03	0.19	9.78	0.32	27.64	0.30	7.20	0.42	11.75	0.42
1990	31.60	0.18	136.44	0.26	8.72	0.42	25.53	0.30	5.10	0.58	11.69	0.70
1991	18.96	0.16	60.36	0.16	9.04	0.15	21.44	0.17	0.91	0.55	1.23	0.53
1992	12.70	0.17	35.11	0.27	3.34	0.22	11.03	0.20	2.05	0.41	3.13	0.46
1993	10.84	0.21	39.84	0.21	4.30	0.41	11.90	0.31	0.83	0.48	1.38	0.58
1994	9.32	0.32	31.64	0.50	1.75	0.37	3.15	0.31	1.44	0.68	3.23	0.82
1995	7.45	0.34	19.55	0.34	6.52	0.36	18.24	0.49	1.41	0.47	2.20	0.62
1996	23.09	0.24	77.47	0.30	5.44	0.39	11.93	0.42	1.85	0.47	3.44	0.43
1997	9.40	0.25	26.50	0.25	3.15	0.28	7.31	0.22	1.64	0.88	3.38	0.96
1998	5.78	0.19	12.05	0.22	11.01	0.46	23.58	0.47	2.90	0.35	5.60	0.28
1999	8.57	0.24	22.10	0.35	3.92	0.21	9.57	0.24	0.78	0.74	1.88	0.66
2000	25.89	0.55	77.77	0.45	5.47	0.28	13.30	0.27	0.89	0.41	1.62	0.35
2001	10.23	0.37	43.43	0.44	2.76	0.44	6.71	0.45	1.08	0.45	2.09	0.58
2002	13.15	0.31	48.96	0.42	4.15	0.32	8.52	0.26	8.07	0.54	20.79	0.67
2003	5.00	0.15	14.97	0.17	5.94	0.48	14.63	0.54	0.67	0.36	1.39	0.45
2004	4.98	0.20	13.63	0.29	13.70	0.54	38.02	0.62	5.36	0.59	15.06	0.78
2005	31.50	0.66	63.09	0.59	3.35	0.24	7.95	0.24	1.76	0.44	2.61	0.44
2006	12.82	0.27	30.21	0.28	5.50	0.26	13.22	0.27	2.23	0.66	4.16	0.79
2007	11.05	0.21	27.03	0.26	6.39	0.29	10.94	0.28	0.54	0.33	0.77	0.38
2008	13.41	0.27	32.88	0.28	4.94	0.26	9.61	0.26	0.80	0.27	1.43	0.30
2009	20.19	0.58	55.81	0.67	3.75	0.36	7.83	0.31	1.14	0.45	2.17	0.39
2010	23.17	0.59	63.45	0.65	2.81	0.20	6.47	0.22	1.36	0.77	1.32	0.40
2011	9.55	0.22	20.31	0.25	1.76	0.29	3.32	0.35	2.36	0.52	4.16	0.70
2012	2.85	0.18	5.90	0.21	4.31	0.30	8.77	0.26	0.60	0.46	1.10	0.39
2013	16.34	0.43	26.76	0.49	10.69	0.62	17.35	0.62	1.26	0.58	4.63	0.65
2014	2.92	0.22	5.80	0.27	3.17	0.32	5.87	0.31	1.26	0.53	2.48	0.51
2015	4.26	0.33	8.65	0.38	1.48	0.20	3.15	0.22	3.35	0.41	6.44	0.40
2016	4.45	0.21	8.80	0.23	3.74	0.67	6.46	0.22	-	-	-	-

Table 9. 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 ($B_{survey}=B_{bigelow}/1.58$).

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	4,343	23,180
2010	732	3,587	26,352
2011	2,304	1,724	8,437
2012	609	4,864	2,449
2013	2,566	9,616	11,113
2014	1,376	3,254	2,409
2015	3,570	1,748	3,594
2016	-	3,579	3,656

Table 10. 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	11.607
2002	0.016	0.495	1.214	2.269	3.538	4.385	5.856	8.436	10.001	11.607
2003	0.016	0.441	1.141	1.882	3.046	3.361	5.120	6.702	7.661	11.607
2004	0.022	0.288	1.454	2.447	3.449	4.086	4.312	6.320	9.923	11.607
2005	0.058	0.589	1.167	1.770	2.972	3.297	3.936	7.655	6.448	11.607
2006	0.031	0.307	1.151	1.574	2.621	3.182	4.615	4.684	5.729	11.607
2007	0.054	0.625	1.073	1.764	2.622	4.098	5.789	6.810	7.981	11.607
2008	0.046	0.577	1.450	2.041	2.504	3.465	4.165	7.931	10.050	11.607
2009	0.114	0.724	1.470	2.482	2.701	3.527	4.479	5.594	8.285	11.607
2010	0.079	0.657	1.575	2.214	3.194	3.501	3.963	5.380	6.520	11.607
2011	0.038	0.482	1.193	2.036	2.709	3.581	3.670	4.484	5.080	11.607
2012	0.020	0.508	1.189	2.158	2.907	3.760	5.106	6.329	5.300	11.607
2013	0.029	0.685	1.216	2.016	2.785	3.557	4.343	5.350	7.047	11.607
2014	0.079	0.565	1.243	1.821	3.116	4.745	4.724	6.580	7.050	11.607
2015	0.043	0.493	1.124	2.352	2.813	3.586	5.620	6.086	7.050	11.607
2016	0.140	0.904	1.131	2.255	2.999	3.995	4.136	7.225	7.050	11.607
Average	0.098	0.744	1.621	2.550	3.732	5.033	6.455	7.859	9.543	13.604
Minimum	0.010	0.288	1.073	1.574	2.504	3.182	3.670	4.484	5.080	11.607
Maximum	0.276	1.132	2.354	3.564	6.182	7.487	9.629	12.712	14.114	14.635

Table 11. Statistical properties of estimates for population abundance (numbers in thousands) for age 9 in 2014 (row number 1), beginning of year population estimates for 2016 (row numbers 2 to 9) and survey catchability (dimensionless, row numbers 10 to 38) from the "M 0.8" benchmark model formulation for eastern Georges Bank cod obtained from a bootstrap with 1000 replications.

Row Number	Parameter	Estimate (thousands)	Standard Error	Relative Error	Relative Bias
1	N[2014 9]	106	23	0.22	2%
2	N[2016 2]	2901	2230	0.77	21%
3	N[2016 3]	3157	1273	0.40	9%
4	N[2016 4]	266	115	0.43	9%
5	N[2016 5]	560	190	0.34	5%
6	N[2016 6]	1091	304	0.28	2%
7	N[2016 7]	112	34	0.30	3%
8	N[2016 8]	46	13	0.28	5%
9	N[2016 9]	40	13	0.32	4%
10	DFO age 1	0.01	0.002	0.20	2%
11	DFO age 2	0.10	0.02	0.18	1%
12	DFO age 3	0.53	0.09	0.18	1%
13	DFO age 4	0.88	0.17	0.20	2%
14	DFO age 5	0.93	0.18	0.19	3%
15	DFO age 6	0.79	0.15	0.19	2%
16	DFO age 7	0.81	0.15	0.18	0%
17	DFO age 8	1.05	0.21	0.20	0%
18	NMFS Spring Y41 age 1	0.02	0.01	0.61	14%
19	NMFS Spring Y41 age 2	0.19	0.14	0.73	19%
20	NMFS Spring Y41 age 3	0.22	0.14	0.64	14%
21	NMFS Spring Y41 age 4	0.21	0.13	0.60	12%
22	NMFS Spring Y41 age 5	0.31	0.19	0.62	11%
23	NMFS Spring Y41 age 6	0.30	0.19	0.63	16%
24	NMFS Spring Y41 age 7	0.38	0.22	0.59	13%
25	NMFS Spring Y41 age 8	0.33	0.21	0.64	17%
26	NMFS Spring Y36 age 1	0.02	0.00	0.21	1%
27	NMFS Spring Y36 age 2	0.11	0.02	0.18	1%
28	NMFS Spring Y36 age 3	0.33	0.06	0.18	2%
29	NMFS Spring Y36 age 4	0.50	0.09	0.18	0%
30	NMFS Spring Y36 age 5	0.46	0.08	0.18	2%
31	NMFS Spring Y36 age 6	0.35	0.06	0.17	1%
32	NMFS Spring Y36 age 7	0.36	0.07	0.19	1%
33	NMFS Spring Y36 age 8	0.42	0.09	0.21	2%
34	NMFS Fall age 1	0.05	0.01	0.17	1%
35	NMFS Fall age 2	0.09	0.01	0.16	1%
36	NMFS Fall age 3	0.13	0.02	0.17	1%
37	NMFS Fall age 4	0.09	0.02	0.18	2%
38	NMFS Fall age 5	0.07	0.01	0.18	1%

Table 12. a) the Mohn's rho values for Age-1 recruitment, SSB, and F with 7-year peels for the VPA "M 0.8" model and b) the sensitivity run "est 2003 yc"

a)

Peel	Age 1	3+ Biomass	F
1	-0.27	0.18	-0.20
2	-0.31	0.37	-0.28
3	-0.33	0.45	-0.09
4	0.67	0.54	-0.26
5	0.11	0.39	-0.41
6	0.52	0.59	-0.37
7	-0.25	0.76	-0.63
Mohn's Rho	**0.02**	**0.47**	**-0.32**

b)

Peel	Age-1	3+ Biomass	F
1	-0.26	0.18	-0.15
2	-0.29	0.36	-0.22
3	-0.31	0.47	-0.13
4	0.47	0.44	-0.24
5	0.00	0.28	-0.29
6	0.27	0.21	0.05
7	-0.35	-0.03	0.21
Mohn's Rho	**-0.07**	**0.27**	**-0.11**

Table 13. Beginning of year population biomass (mt) for eastern Georges Bank cod during 1978-2016 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2016. The dash (-) at age 1 in 2016 indicates that age 1 in the final year is not estimated in the model.

Year	Age											
	1	2	3	4	5	6	7	8	9	10+	1+	3+
1978	1391	2962	17458	14216	7106	4461	5335	946	1135	1463	56474	52120
1979	1174	8843	4591	16585	10125	3742	4220	4264	729	2098	56372	46354
1980	2778	6032	14275	4181	16615	8341	2526	2623	3132	2289	62791	53981
1981	1654	7011	11170	15681	4761	11839	6296	3331	2431	4181	68356	59691
1982	524	12411	13223	10171	10866	3433	7952	4125	1382	4906	68993	56058
1983	1144	5256	15969	7040	4992	7152	2137	3897	2561	4256	54403	48003
1984	719	2420	6058	11564	3744	3300	3635	981	2117	4143	38681	35542
1985	460	7539	6160	5816	10058	3773	2802	2528	774	3778	43686	35687
1986	3159	3319	12155	4375	4397	7369	2139	1462	1189	2995	42559	36081
1987	1237	16627	5312	9886	3333	3178	4867	1161	912	3244	49757	31893
1988	2152	6262	22150	5426	8271	2095	1932	3283	1311	3270	56153	47740
1989	730	9611	8949	17664	3712	5530	1199	654	1649	2771	52467	42126
1990	1600	3297	16302	10339	15106	3007	3178	746	444	2889	56908	52011
1991	847	5461	5414	14112	8437	7860	2109	1672	530	2204	48646	42338
1992	464	6638	8372	3823	8015	5029	4526	1155	775	1811	40608	33505
1993	332	2802	7580	6149	3195	4609	2736	1845	654	1775	31677	28543
1994	511	2538	2798	4398	3634	2329	2346	1741	1086	1707	23088	20038
1995	384	2320	4762	2615	2313	2395	747	829	843	1323	18531	15828
1996	316	1440	3633	5824	3395	2754	1185	548	529	1026	20653	18896
1997	1075	2114	2322	3710	4757	3967	1015	870	184	722	20737	17548
1998	171	3008	3153	2118	3257	4012	1363	387	258	393	18121	14942
1999	544	1793	4990	3546	1852	3414	2038	746	119	326	19368	17032
2000	116	3593	2214	6027	3217	1837	1897	856	364	207	20328	16620
2001	12	1206	4575	2694	6406	3454	1111	881	393	213	20944	19726
2002	38	486	1437	4950	2350	4814	1392	438	412	240	16556	16031
2003	9	877	908	1611	4218	1500	2013	586	135	257	12114	11228
2004	100	136	2321	1268	1665	3146	640	759	270	165	10470	10234
2005	37	2230	437	2090	858	867	1012	339	224	152	8246	5979
2006	124	162	3496	418	2059	610	445	436	76	198	8023	7737
2007	81	2077	444	4027	386	1917	323	218	244	125	9843	7685
2008	76	713	3873	579	3731	312	649	141	98	163	10335	9546
2009	106	983	1428	5111	480	3513	139	273	44	101	12178	11089
2010	86	495	1688	1363	4983	364	1425	43	100	59	10607	10026
2011	134	428	690	1614	854	4335	137	624	10	92	8917	8356
2012	30	1453	817	874	1644	584	2690	58	306	47	8505	7021
2013	15	843	2773	942	800	1554	233	1244	25	317	8747	7889
2014	348	244	1222	3217	1047	1070	907	152	735	160	9101	8509
2015	121	1770	380	1718	3807	896	555	524	73	616	10460	8569
2016	-	2082	3255	547	1600	4257	449	318	272	328	13467	11026

Table 14. Beginning of year population abundance (numbers in thousands) for eastern Georges Bank cod during 1978-2016 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2016. The dash (-) at age 1 in 2016 indicates that age 1 in the final year is not estimated in the model.

Year	Age										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	**1+**
1978	12459	3342	10752	3989	1312	714	618	105	111	100	33504
1979	10450	10193	2639	5537	2218	721	438	392	66	143	32798
1980	10052	8542	7543	1501	3169	1328	427	292	266	156	33276
1981	17482	8224	6117	4692	958	1725	769	262	216	286	40731
1982	5693	14281	5958	3334	2641	534	986	467	128	335	34359
1983	5107	4648	8533	3111	1594	1190	262	450	243	291	25428
1984	14264	4161	3100	4733	1387	801	617	109	206	283	29662
1985	5274	11663	3199	1815	2660	647	319	256	55	258	26146
1986	24078	4310	6978	1360	894	1293	288	163	111	205	39680
1987	8243	19676	3122	3681	588	424	651	174	90	222	36872
1988	14136	6729	12408	1797	1984	334	229	376	106	223	38322
1989	5134	11553	5249	6403	862	860	157	84	146	189	30636
1990	7455	4187	8845	3567	3463	501	370	78	33	197	28697
1991	9652	6090	2774	4456	1988	1606	280	166	53	151	27215
1992	3660	7845	4093	1369	1925	821	648	135	74	124	20694
1993	4732	2935	4109	2115	708	783	391	250	70	121	16215
1994	3574	3866	1953	1673	919	312	320	201	118	117	13052
1995	2100	2921	3000	1165	666	510	112	105	71	90	10741
1996	3608	1719	2340	2243	869	451	217	46	44	70	11607
1997	5662	2949	1371	1705	1479	640	164	89	18	49	14125
1998	2194	4627	2281	938	1074	888	234	50	31	27	12344
1999	4910	1791	3696	1585	623	737	313	90	14	22	13782
2000	1914	4012	1396	2591	995	412	292	104	32	14	11760
2001	1204	1564	3227	1043	1779	679	161	117	39	18	9830
2002	2430	983	1184	2182	664	1098	238	52	41	21	8892
2003	575	1989	796	856	1385	446	393	87	18	22	6567
2004	4651	471	1597	518	483	770	148	120	27	14	8799
2005	647	3787	374	1181	289	263	257	44	35	13	6891
2006	4060	527	3037	266	786	192	96	93	13	17	9086
2007	1512	3321	414	2283	147	468	56	32	31	11	8274
2008	1659	1236	2671	284	1490	90	156	18	10	14	7627
2009	929	1357	971	2059	178	996	31	49	5	9	6584
2010	1087	754	1072	616	1560	104	360	8	15	5	5581
2011	3504	887	578	793	315	1211	37	139	2	8	7475
2012	1505	2861	687	405	565	155	527	9	58	4	6778
2013	528	1230	2281	467	287	437	54	233	4	27	5548
2014	4389	431	983	1766	336	226	192	23	104	14	8464
2015	2815	3589	338	730	1353	250	99	86	10	53	9325
2016	-	2304	2878	242	534	1066	108	44	39	28	9794

Table 15. Annual fishing mortality rate for eastern Georges Bank cod during 1978-2015 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2016.

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	0.68	0.71	0.53	0.61	0.56	0.22	0.66
1992	0.02	0.45	0.46	0.46	0.70	0.54	0.75	0.46	0.70	0.11	0.61
1993	0.00	0.21	0.70	0.63	0.62	0.69	0.47	0.55	0.50	0.19	0.62
1994	0.00	0.05	0.32	0.72	0.39	0.23	0.32	0.24	0.29	0.03	0.51
1995	0.00	0.02	0.09	0.09	0.19	0.05	0.10	0.06	0.08	0.00	0.11
1996	0.00	0.03	0.12	0.22	0.11	0.21	0.09	0.12	0.10	0.01	0.18
1997	0.00	0.06	0.18	0.26	0.31	0.21	0.39	0.24	0.34	0.05	0.28
1998	0.00	0.02	0.16	0.21	0.18	0.24	0.15	0.47	0.21	0.12	0.21
1999	0.00	0.05	0.16	0.27	0.21	0.13	0.30	0.25	0.29	0.05	0.23
2000	0.00	0.02	0.09	0.18	0.18	0.14	0.12	0.19	0.14	0.07	0.17
2001	0.00	0.08	0.19	0.25	0.28	0.25	0.33	0.24	0.29	0.08	0.27
2002	0.00	0.01	0.12	0.25	0.20	0.23	0.20	0.28	0.21	0.25	0.24
2003	0.00	0.02	0.23	0.37	0.39	0.30	0.39	0.37	0.38	0.12	0.37
2004	0.01	0.03	0.10	0.38	0.41	0.30	0.41	0.44	0.42	0.24	0.36
2005	0.01	0.02	0.14	0.21	0.21	0.20	0.22	0.40	0.24	0.20	0.21
2006	0.00	0.04	0.08	0.39	0.32	0.43	0.30	0.31	0.31	0.18	0.34
2007	0.00	0.02	0.18	0.22	0.29	0.30	0.35	0.38	0.36	0.08	0.24
2008	0.00	0.04	0.06	0.27	0.20	0.27	0.36	0.40	0.36	0.10	0.23
2009	0.01	0.03	0.26	0.07	0.33	0.21	0.54	0.35	0.43	0.11	0.14
2010	0.00	0.06	0.10	0.47	0.05	0.22	0.14	0.64	0.16	0.10	0.17
2011	0.00	0.05	0.15	0.13	0.50	0.03	0.60	0.08	0.18	0.04	0.13
2012	0.00	0.03	0.18	0.14	0.05	0.25	0.02	0.14	0.02	0.01	0.08
2013	0.00	0.02	0.05	0.12	0.04	0.02	0.04	0.01	0.01	0.004	0.05
2014	0.00	0.04	0.09	0.06	0.09	0.02	0.00	0.01	0.00	0.00	0.05
2015	0.00	0.02	0.12	0.10	0.04	0.03	0.01	0.00	0.00	0.01	0.05

Table 16. Projection inputs for eastern Georges Bank cod.

Parameter	Age									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
Natural Mortality										
2016-2018	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)										
2016-2018	0.01	0.27	0.98	1.00	1.01	0.45	0.40	0.27	0.09	0.09
Fishery Weight at Age										
2016-2018	0.35	1.05	1.97	2.86	3.74	4.81	6.42	9.14	9.15	11.61
Population Beginning of Year Weight at Age										
2016	0.14	0.90	1.13	2.26	3.00	3.99	4.14	7.22	7.05	11.61
2017-2019	0.09	0.65	1.17	2.14	2.98	4.11	4.83	6.63	7.05	11.61

Table 17. Deterministic projection results for eastern Georges Bank cod based on F reference point 0.11 from the "M 0.8" model. Shaded values are the 2010 year class (dark grey cells) and the 2013 year class (light grey cells). Bolded values show the year classes with assumed recruitments. A dash (-) indicates that this value was not calculated.

Parameter	Age												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	**1+**	**3+**	**4+**
Fishing Mortality													
2016	0.001	0.02	0.06	0.06	0.06	0.03	0.03	0.02	0.01	0.01	-	-	-
2017	0.001	0.03	0.11	0.11	0.11	0.06	0.04	0.03	0.01	0.01	-	-	-
2018	0.001	0.03	0.11	0.11	0.11	0.06	0.04	0.03	0.01	0.01	-	-	-
Projected Population Numbers													
2016	2550	2304	2878	242	534	1066	108	44	39	28	-	-	-
2017	2550	2086	1852	2215	187	411	464	48	19	30	-	-	-
2018	2550	2085	1653	1358	1624	137	175	200	21	22	-	-	-
2019	2550	2085	1652	1212	996	1191	58	75	87	19	-	-	-
Projected Population Biomass													
2016	357	2074	3252	548	1601	4252	449	318	272	328	-	11022	7769
2017	230	1356	2167	4740	556	1688	2242	315	137	347	-	12192	10025
2018	230	1356	1934	2907	4841	562	844	1324	146	254	-	12811	10877
2019	230	1356	1933	2594	2969	4897	281	498	612	220	-	14003	12070
Projected Catch Numbers													
2016	1	39	157	13	29	22	2	1	0	0	-	-	-
2017	3	61	175	209	18	15	14	1	0	0	-	-	-
2018	3	61	156	128	154	5	5	4	0	0	-	-	-
Projected Catch Biomass													
2016	1	40	309	38	109	108	12	5	2	1	625	-	-
2017	1	64	345	599	66	73	89	10	1	3	1251	-	-
2018	1	64	308	367	575	24	33	41	1	2	1417	-	-

Table 18. Projection and risk analysis result for eastern Georges Bank cod from the "M 0.8" model formulations: a) risk of fishery catch will exceed F reference point 0.11 in 2017 and 2018; and b) risk of ages 3+ biomass will not increase from 2017 to 2018 and from 2018 to 2019.

a)

Probability	**0.25**	**0.5**	**0.75**
2017	1,138 mt	1,319 mt	1,607 mt
2018(F_{2017}=0.11)	1,289 mt	1,483 mt	1,763 mt

b)

Probability	**0.25**	**0.5**	**0.75**
2017 to 2018	1,687 mt	2,180 mt	2,848 mt
2018 to 2019 (F_{2017}=0.11)	2,424 mt	2,739 mt	3,073 mt

Table 19. Consequence analysis of risks of different management actions taken for Atlantic cod from eastern Georges Bank. Projected catch and ages 3+ biomass are presented for each of two 'true state of nature' management models: VPA "M0.8" model with F=0.11 and ASAP M=0.2 model with Fref=0.18 during 2016- 2018 on the main diagonal ("true state"). The risks of the alternative management actions "alternate state" are on the counter diagonal (see text). Fishing mortality (F), January 1 stock biomass, and percent change in biomass (% B) from the previous year are presented for each projection.

CONSEQUENCE ANALYSIS				
Catch 2015		492 mt		
Quota 2016		625 mt		
			VPA 0.8	**ASAP**
2015 biomass (3+)			10,048	1,717
2016 biomass (3+)			11,026	N/A
Projected catch				
VPA F=0.11			"true state"	"alternate state"
2017 catch = 1319 mt		2017 F	0.11	0.53
		2018 Biomass (mt)	12,811	3,215
		% B from 2017	5.1%	-0.5%
2018 catch = 1483 mt		2018 F	0.11	0.62
		2019 Biomass (mt)	14,003	3,551
		% B from 2018	9.3%	10.4%
ASAP F=0.18			"alternate state"	"true state"
2017 catch = 515 mt		2017 F	0.044	0.18
		2018 Biomass (mt)	13,484	4,016
		% B from 2017	10.6%	19%
2018 catch = 646 mt		2018 F	0.046	0.18
		2019 Biomass (mt)	15,477	5,185
		% B from 2018	26.9%	29%
(green)		F<=Fref & biomass increase > 10%		
(blue)		F< =Fref & biomass increase < 10%		
(peach)		F> Fref and biomass increase < 10%		
(grey)		F> Fref and biomass increase > 10%		

Table 20. Comparison of TRAC catch advice, TMGC quota decision, actual catch, and resulting fishing mortality and biomass changes for eastern Georges Bank cod.

TRAC	**Catch Year**	**TRAC Analysis/Recommendation**		**TMGC Decision**		**Actual Catch[1] /Compared to Risk Analysis**	**Actual F Result[2]**
		Amount	**Rationale**	**Amount**	**Rationale**		
1999[3]	1999	3,100 mt		NA	NA	3,000 mt	*Near* $F_{0.1}$
2000	2000	3,750 mt	$F_{0.1}$	NA	NA	2,250 mt	*Less than* $F_{0.1}$
2001	2001	3,500 mt	$F_{0.1}$	NA	NA	3,500 mt	*Above* $F_{0.1}$
2002	2002	1,900 mt	$F_{0.1}$	NA	NA	2,800 mt	*F = 0.23*
Transition to TMGC process in following year; note catch year differs from TRAC year in following lines							
2003	2004	1,300 mt	Neutral risk of exceeding Fref. 20% chance of decrease in biomass from 2004-2005.	1,300 mt	Neutral risk of exceeding Fref. 20% chance of decrease in biomass from 2004-2005.	2,332 mt Exceed Fref and biomass to decline	*F=0.16* *Biomass decreased 23%* Now F = 0.36 Biomass decreased 42% 04 - 05
2004	2005	1,100 mt	Neutral risk of exceeding Fref. Greater than 50% risk of decline in biomass from 2005 - 2006.	1,000 mt	Low risk of exceeding Fref, neutral risk of stock decline	1,287 mt Greater than neutral risk of exceeding $F_{0.1}$; biomass expected to decline 10%	*F=0.10* *Biomass stabled* Now F = 0.21 Biomass increased 29% 05 - 06
2005	2006	2,200 mt	Neutral risk of exceeding Fref. Low risk of less than 10% biomass increase from 2006 - 2007.	1,700 mt	Low risk of exceeding Fref, 75% probability of stock increase of 10%	1,705 mt Approx 25% risk of exceeding Fref; biomass increase not likely to be 20%	*F=0.15* *Biomass stabled* Now F = 0.34 Biomass decreased 1% 06 - 07
2006[4]	2007	(1) 2,900 mt (2) 1,500 mt	(1) Neutral risk of exceeding Fref. (2) Neutral risk of biomass decline from 2007 – 2008.	1,900 mt	Low risk of exceeding Fref, nominal decline in stock size	1,811mt No risk of exceeding Fref; neutral risk of biomass decline	*F=0.13* *Biomass stabled* Now F = 0.24; Biomass increased 24% 07-08
2007[4]	2008	2,700 mt	Neutral risk of exceeding Fref and a neutral risk of stock decline	2,300 mt	Low risk of exceeding Fref, nominal stock size increase	1,780 mt No risk of exceeding Fref; biomass not expected to increase	*F = 0.25 or 0.17* *Biomass increased 16%/19%*

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch[1] /Compared to Risk Analysis	Actual F Result[2]
			from 2008 - 2009			10%	Now 0.23; Biomass increased 16% 08-09;
2008[4]	2009	(1) 2,100 mt (2) 1,300 mt	(1) Neutral risk of exceeding Fref (2) neutral risk of stock decline from 2009 - 2010	1,700 mt	Low risk of exceeding Fref, high risk biomass will not increase	1,837 mt Slightly less than neutral risk of exceeding Fref; biomass almost certain not to increase	*F = 0.33 or 0.20 Biomass stable or declined 7%* Now F=0.14; Biomass decreased 10% 09-10;
2009[4]	2010	(1) 1,300 – 1,700 mt (2) 1,800 – 900 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock decline from 2010 - 2011	1,350 mt	Neutral risk of biomass decline	1,326 mt	*F = 0.41 or 0.25 Biomass decreased 15%/ 17%* Now F=0.17; Biomass decreased 17% 10-11;
2010[4]	2011	(1) 1,000 – 1,400 mt (2) 1,850 – 1,350 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock decline from 2011 - 2012	1,050 mt	Low risk of exceeding Fref, and biomass growth of up to 10%.	1,037 mt	*F = 0.49 or 0.28 Biomass increased 6%/stable* Now F= 0.13; Biomass decreased 16% 11-12
2011	2012	(1) 600 – 925 mt (2) 1,350 – 900 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock decline from 2012 – 2013	675 mt	Low risk of exceeding Fref, and low to neutral risk of biomass decline	614 mt	*F=0.07; Biomass increased 16%* Now F= 0.08; Biomass increased 12% 12-13
2012	2013	(1) 400 – 775 mt (2) 400 – 575 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock not increase by 20% from 2013 – 2014	600mt	Neutral risk of exceeding Fref, and stock biomass increase more than 10%	463 mt	*F=0.04; Biomass increased 9%* F=0.05; Biomass increased 8% 13-14
2013	2014	600mt	(1) low risk of	700mt	Low risk of exceeding	574 mt	*F=0.04;*

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch[1] /Compared to Risk Analysis	Actual F Result[2]
			exceeding Fref (2) Neutral risk of stock not increase by10% from 2014 – 2015		Fref, and stock biomass increase close to 10%		*Biomass increased 10%* F=0.05; Biomass increased by 1% 14-15
2014	2015	<675mt	(1) low risk of exceeding Fref (2) even with no fishing in 2016 there is a greater than 50% risk of a decrease in adult biomass from 2016 to 2017	650 mt	Low risk of exceeding Fref, but high risk of decrease in adult biomass	608 mt	*F=0.05* *Biomass increased 29%*
2015	2016	<650mt	(1) Neutral risk of exceeding Fref (2) even with no fishing in 2016 there is a greater than 50% risk of a decrease in adult biomass from 2016 to 2017	625 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

Table 21. Corrected catch at neutral risk of exceeding Fref since 2009 assessment of cod on Eastern Georges Bank.

Models and Uref used in the assessments	**Stochastic Projection (neutral risk Catch>Fref, mt)**		**Difference(mt)**	**TMGC Decision (mt)**
	Uref	**Fref**		
2009 “Split M 0.2" (Fref=0.18, M=0.2, Uref=15%)	1,300	1,300	0	1,350
2009 “Split M 0.5" (Fref=0.18, M=0.2, Uref=15%)	1,700	1,650	50	
2010 “Split M 0.2" (Fref=0.18, M=0.2, Uref=15%)	1,000	1,000	0	1,050
2010 “Split M 0.5" (Fref=0.18, M=0.2, Uref=15%)	1,400	1,325	75	
2011 “Split M 0.2" ((Fref=0.18, M=0.2, Uref=15%)	600	600	0	675
2011 “Split M 0.5" (Fref=0.18, M=0.5, Uref=13%)	925	975	-50	
2012 “Split M 0.2" ((Fref=0.18, M=0.2, Uref=15%)	400	400	0	600
2012 “Split M 0.5" (Fref=0.18, M=0.5, Uref=13%)	775	800	-25	
2013 " M 0.8"(Fref=0.11, M=0.8, Uref=7%)	1,225	1,300	-75	700
2014" M 0.8"(Fref=0.11, M=0.8, Uref=7%)	1,150	1,250	-100	650
2015 " M 0.8"(Fref=0.11, M=0.8, Uref=7%)	675	875	-200	625

FIGURES

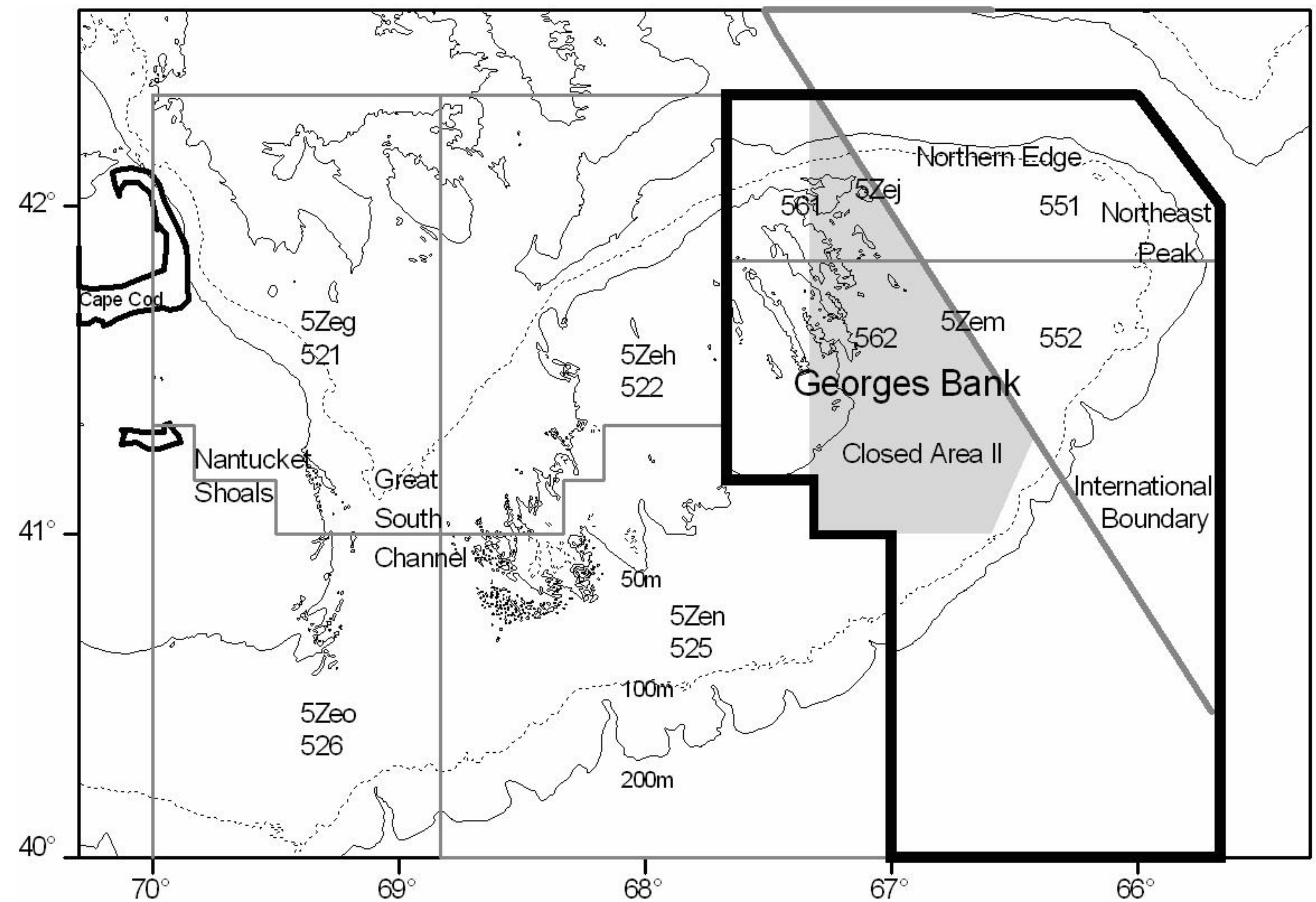


Figure 1. Fisheries statistical areas (Canada and USA) in NAFO Subdivision 5Ze. The eastern Georges Bank Atlantic Cod management unit is outlined by a heavy black line.

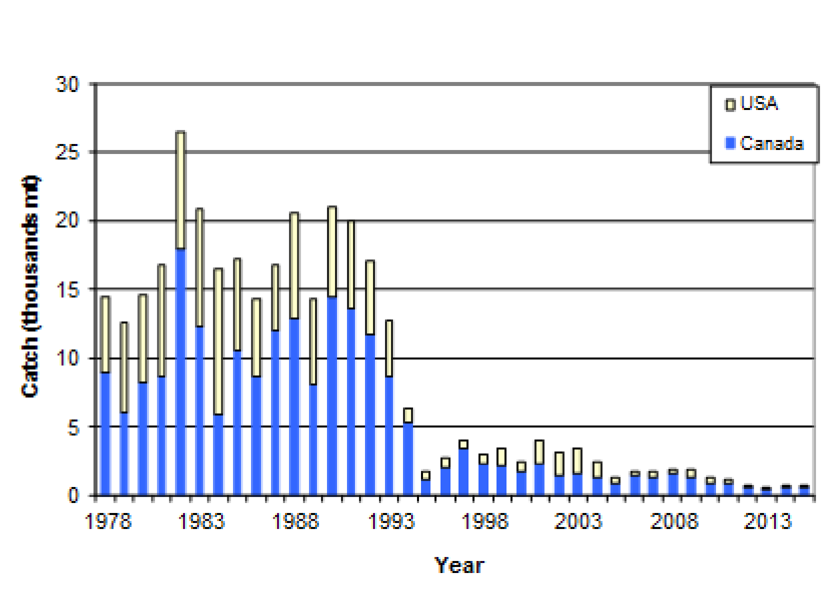


Figure 2. Catches eastern Georges Bank cod, 1978 to 2015.

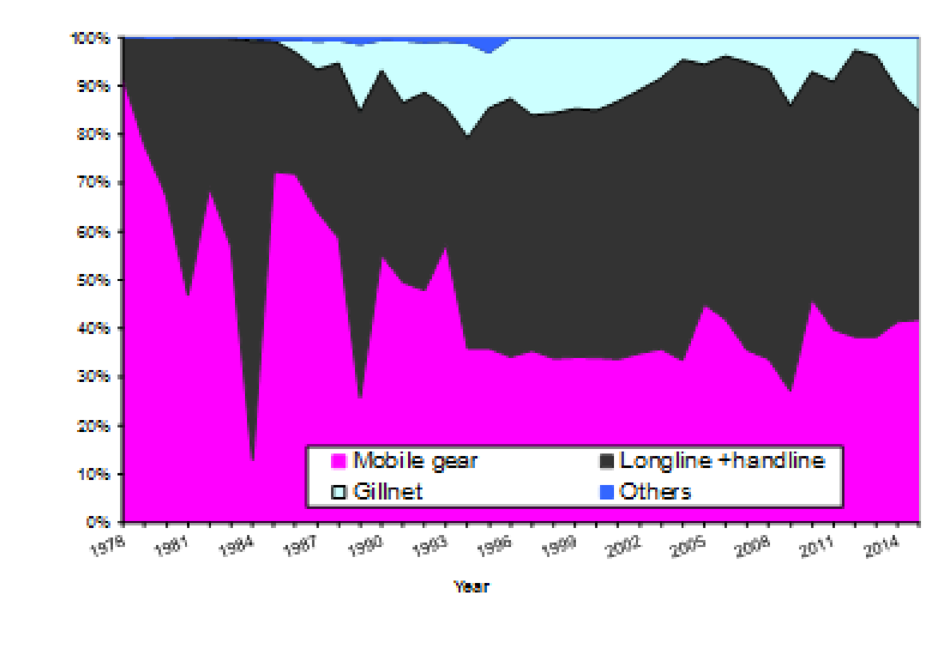


Figure 3. Proportion of Canadian gear specific landings of cod from eastern Georges Bank for 1978 to 2015.

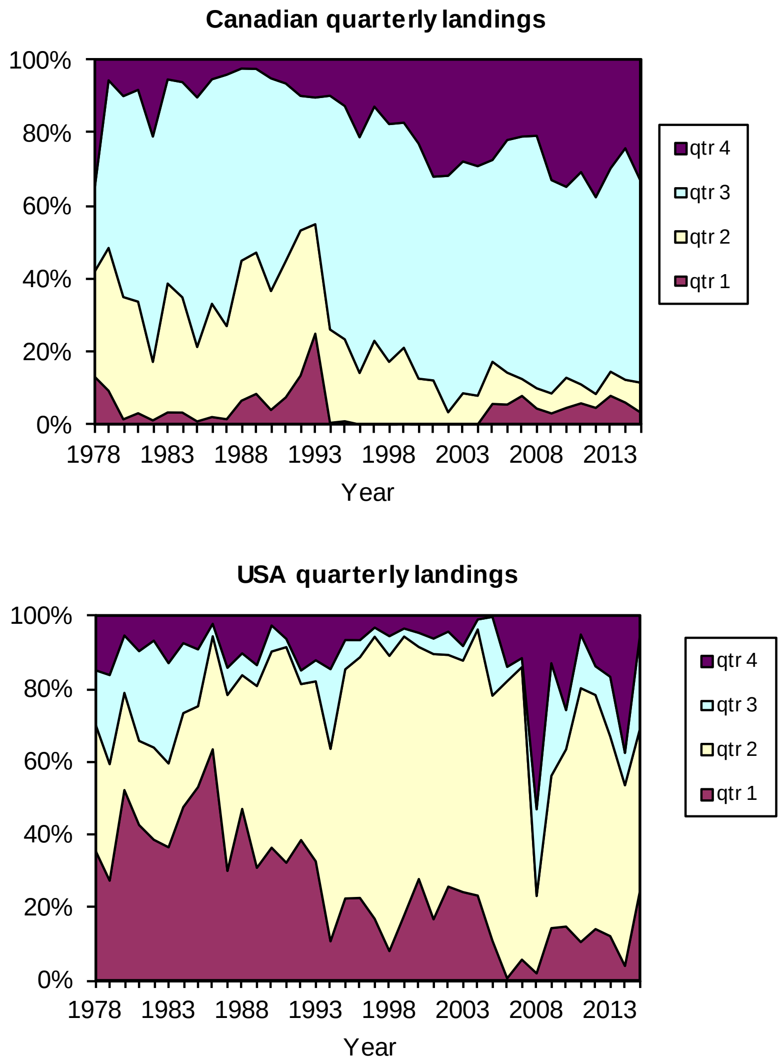
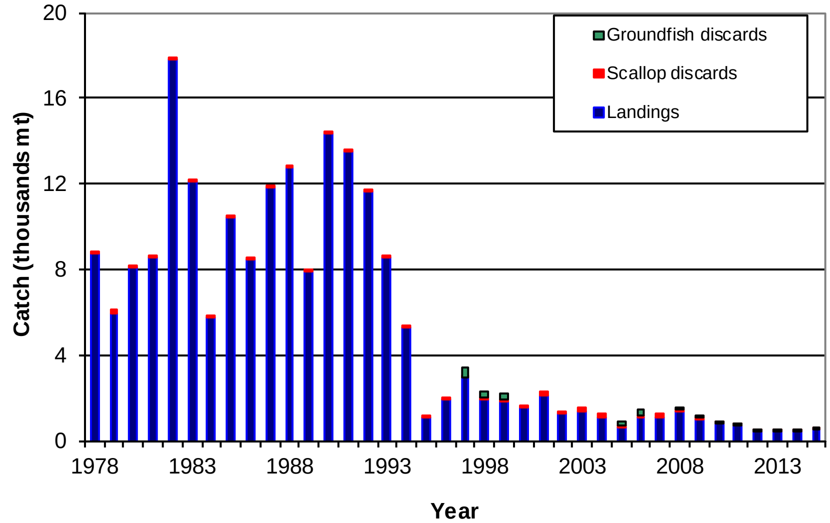


Figure 4. Proportion of Canadian (upper) and USA (lower) quarterly landings of cod from eastern Georges Bank, 1978 to 2015.



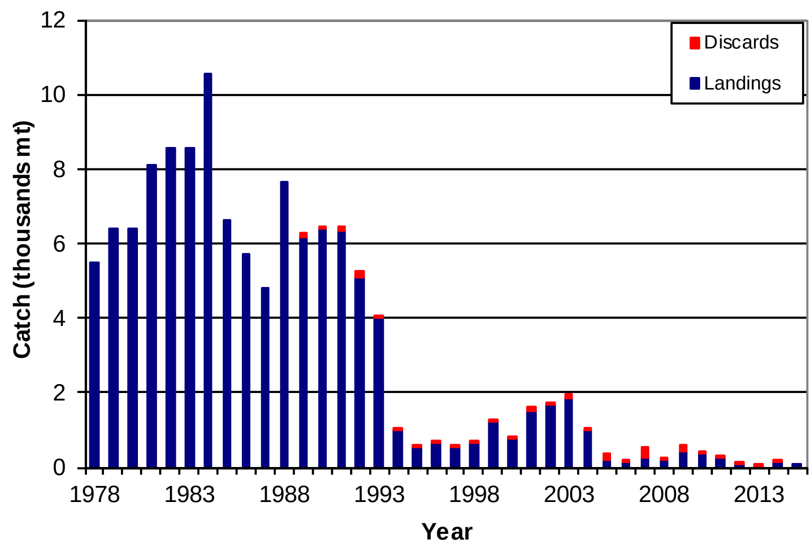


Figure 5. Canadian (upper) and USA (lower) landings and discards of eastern Georges Bank cod, 1978 to 2015.

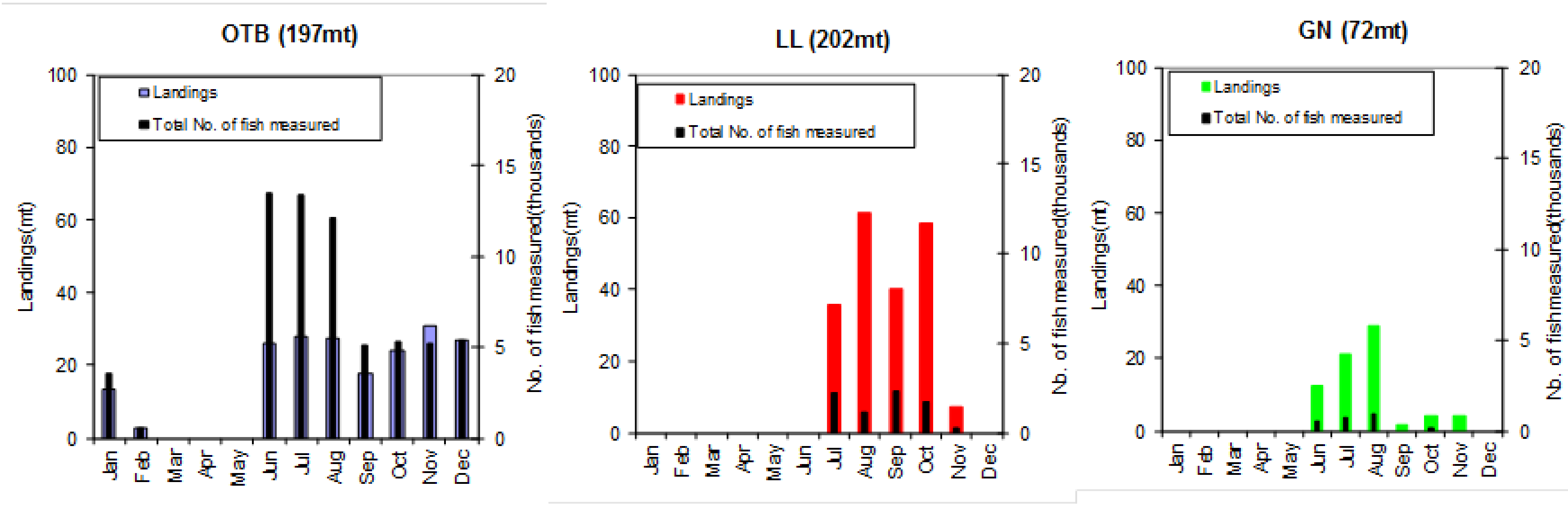


Figure 6. Landings (wide bars) and sampling (narrow dark bars) of cod by gear and month from the 2015 Canadian bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on eastern Georges Bank.

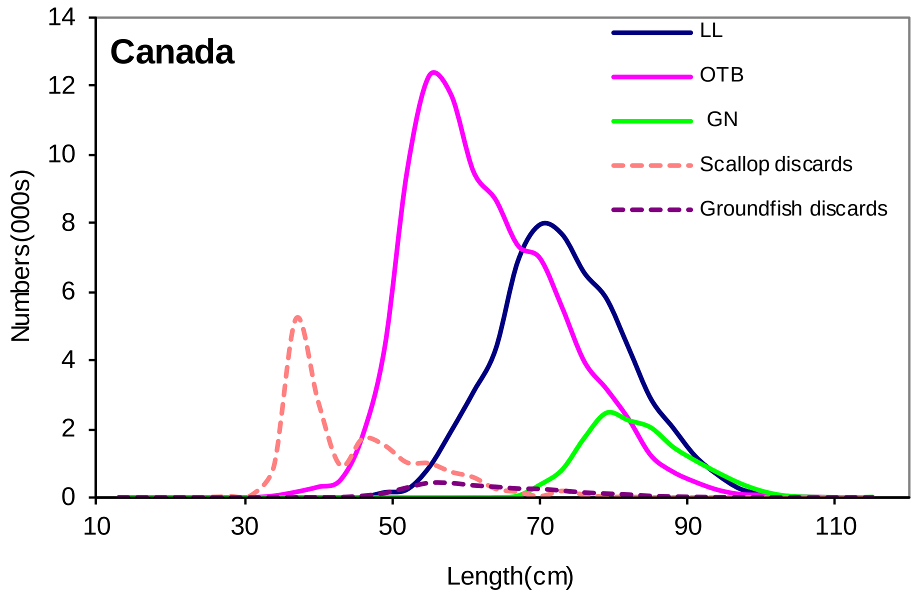


Figure 7. Cod catches at length by gear from the 2015 Canadian fisheries bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on eastern Georges Bank

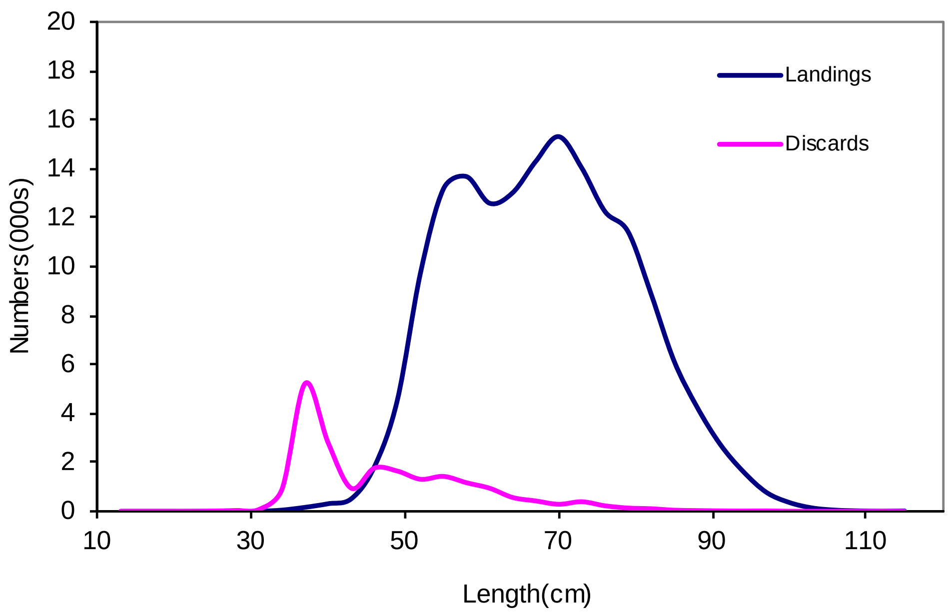


Figure 8. Cod landings and discards at length from the 2015 Canadian fisheries on eastern Georges Bank.

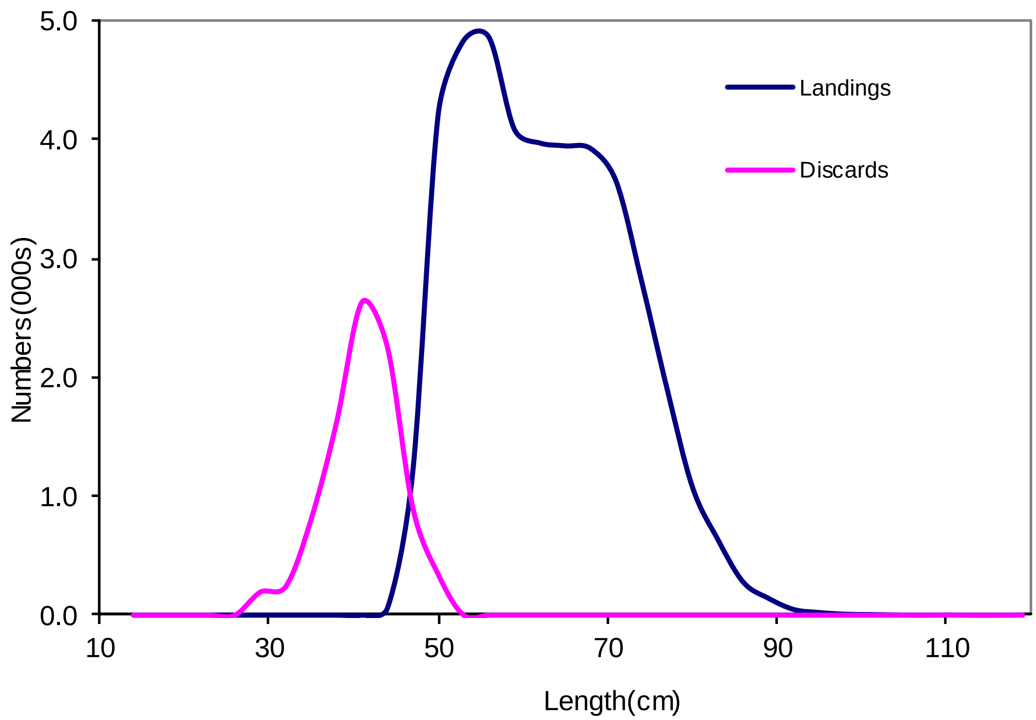


Figure 9. Cod landings and discards at length from the 2015 USA fisheries on eastern Georges Bank.

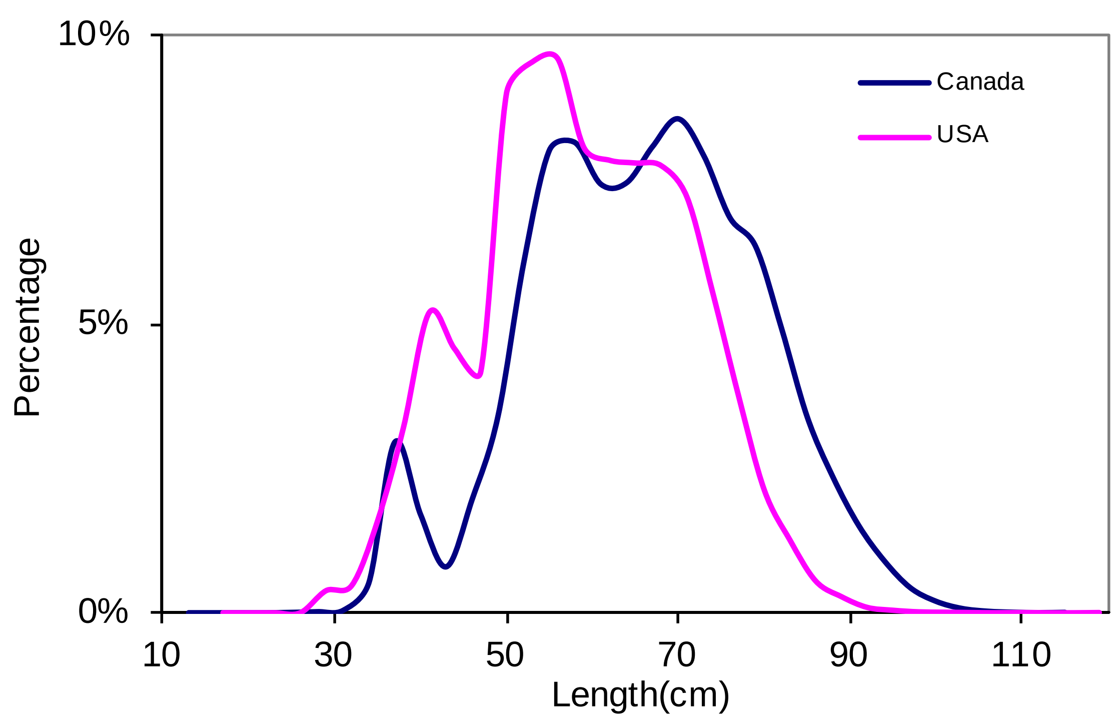


Figure 10. Cod length frequency from the 2015 Canadian and USA fisheries on eastern Georges Bank.

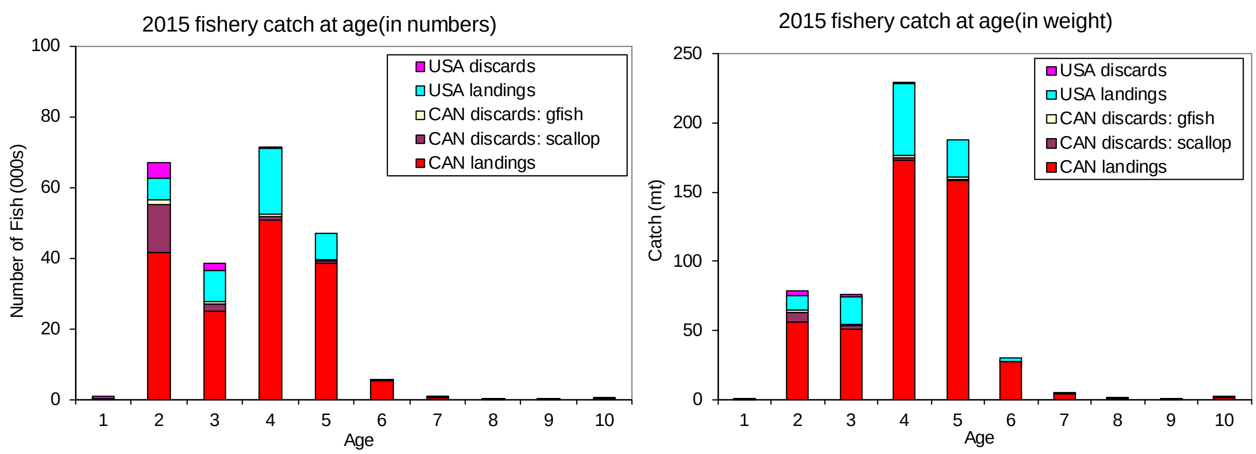


Figure 11. Catch at age in numbers (left) and weight (right) for landings and discards of cod from the 2015 eastern Georges Bank fisheries.

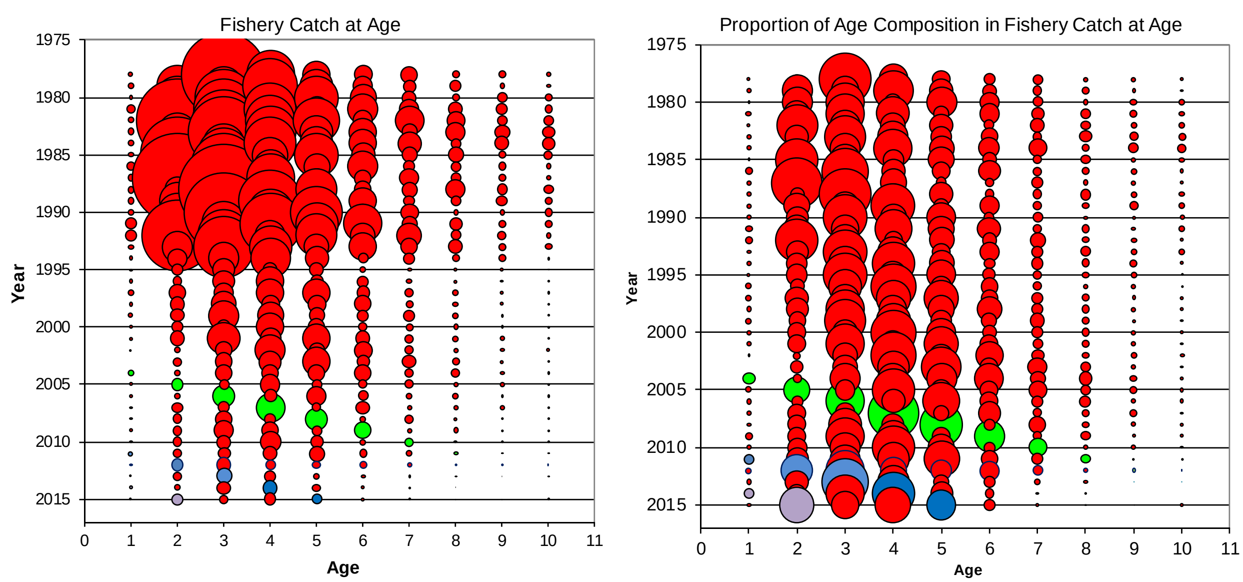


Figure 12. Total catch at age (numbers) of cod (left) and proportion of catch at age from eastern Georges Bank for 1978 to 2015. The bubble area is proportional to the magnitude. The green denotes the 2003 year class, the blue denotes the 2010 year class and the purple denotes the 2013 year class.

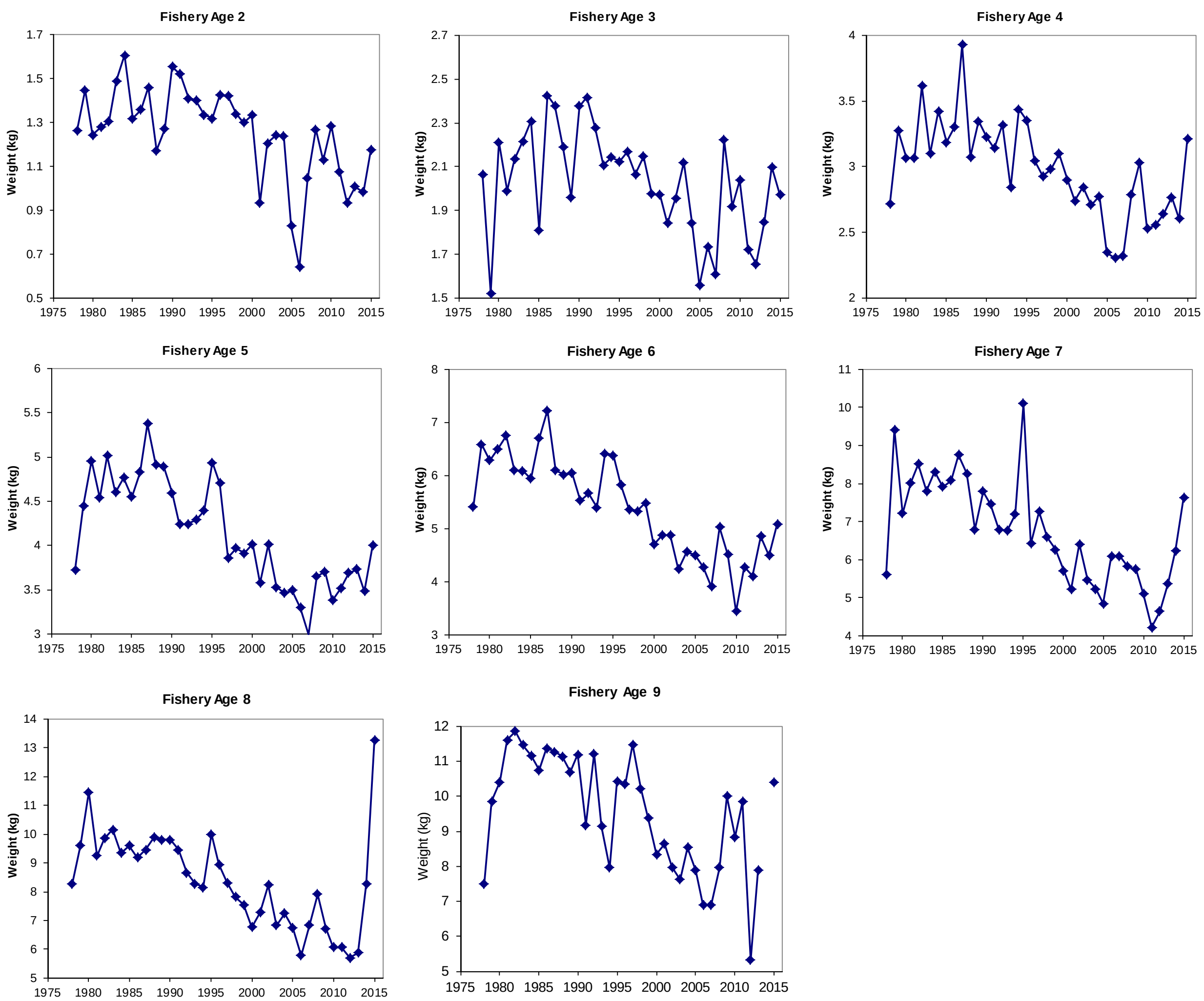


Figure 13. Average weight at age for ages 2 to 9 of cod from the eastern Georges Bank fishery, 1978-2015

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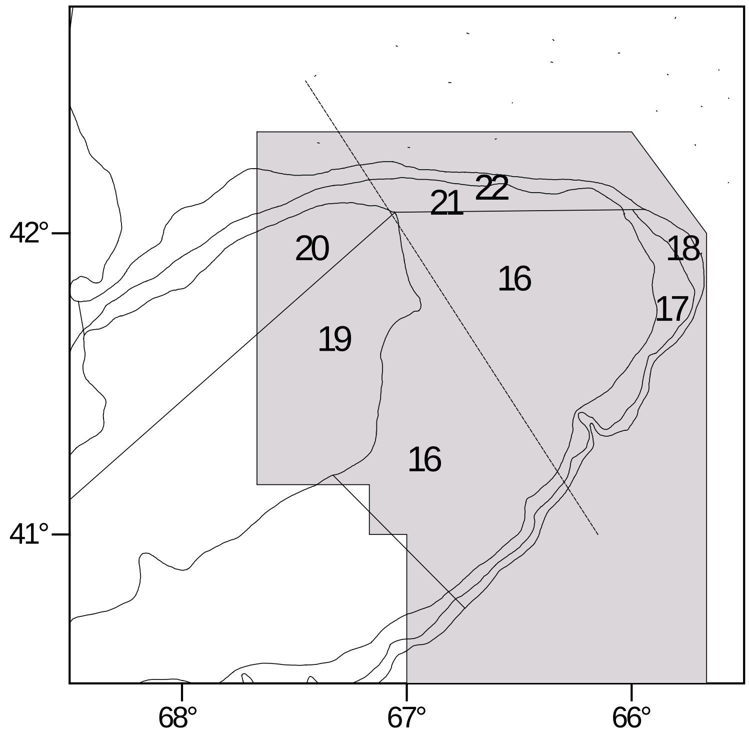


Figure 14. Stratification used for the NMFS surveys. The eastern Georges Bank management unit is indicated by shading.

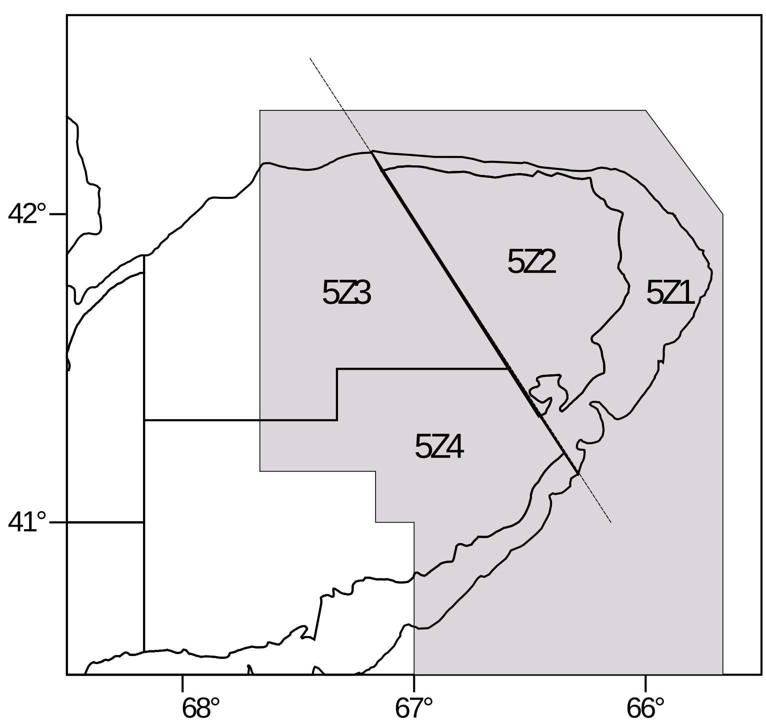


Figure 15. Stratification used for the DFO survey. The eastern Georges Bank management unit is indicated by shading.

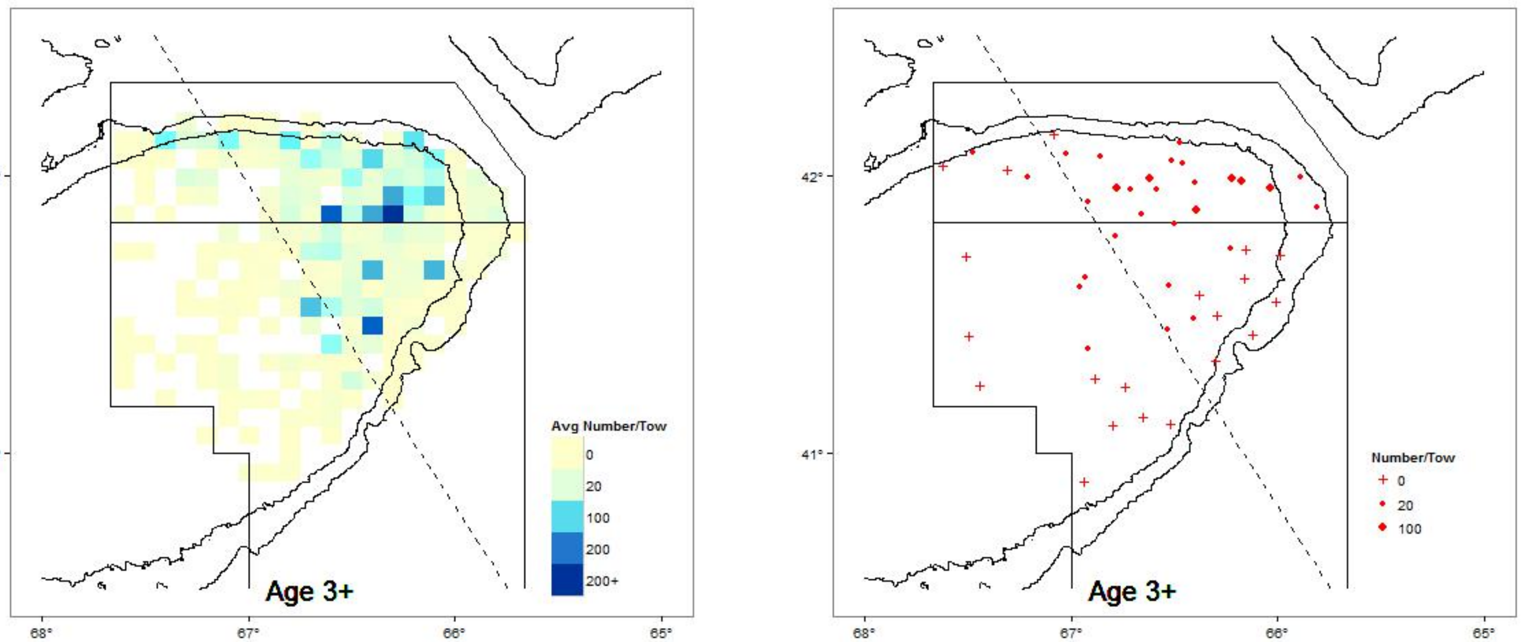


Figure 16. Spatial distribution of age 3+ cod on eastern Georges Bank from the DFO survey for 2016 (right) compared to the average for 2006-2015 (left).

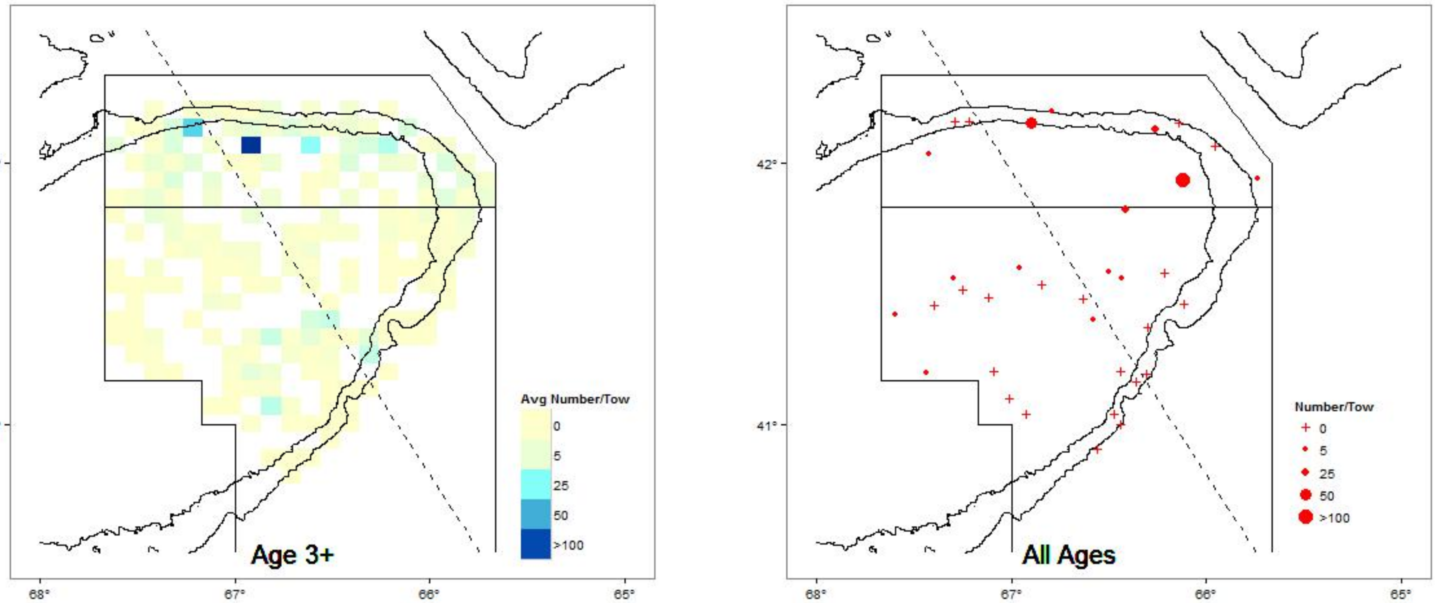


Figure 17. Spatial distribution of cod (all ages) on eastern Georges Bank from the NMFS spring survey for 2016 (right panel) compared to the average age 3+ cod for 2006-2015 (left panel).

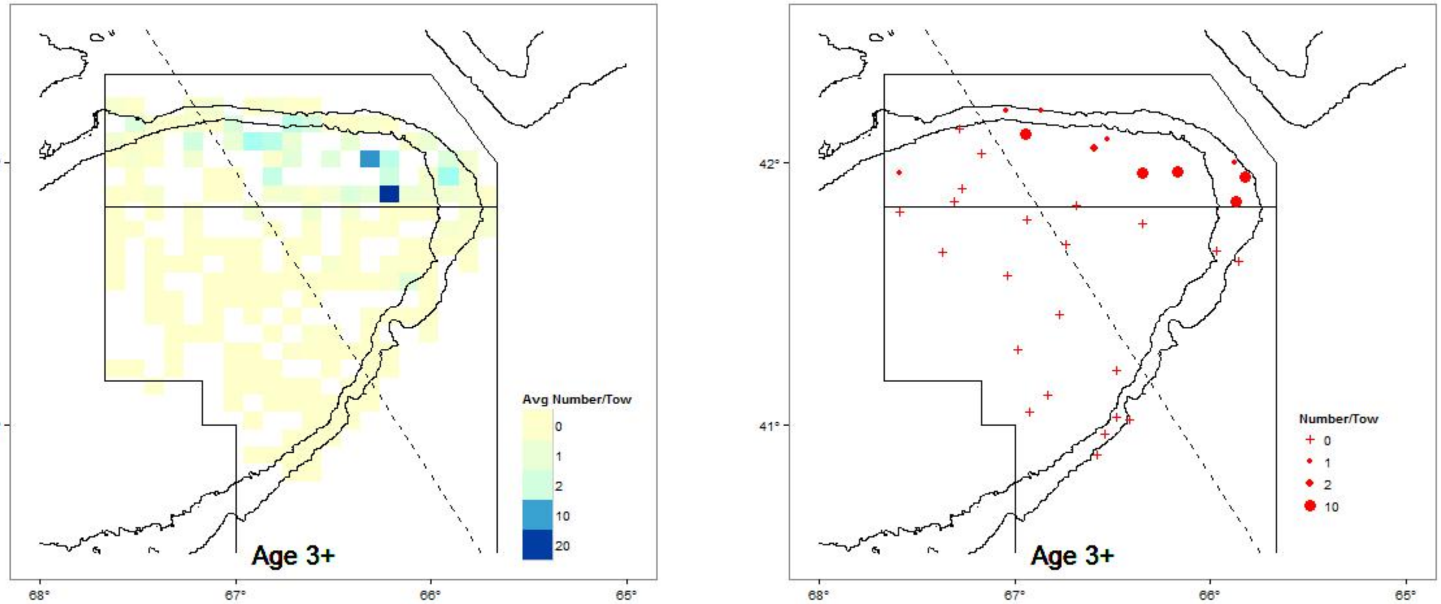


Figure 18. Spatial distribution of age 3+ cod on eastern Georges Bank from the NMFS fall survey for 2015 (right) compared to the average for 2005-2014 (left).

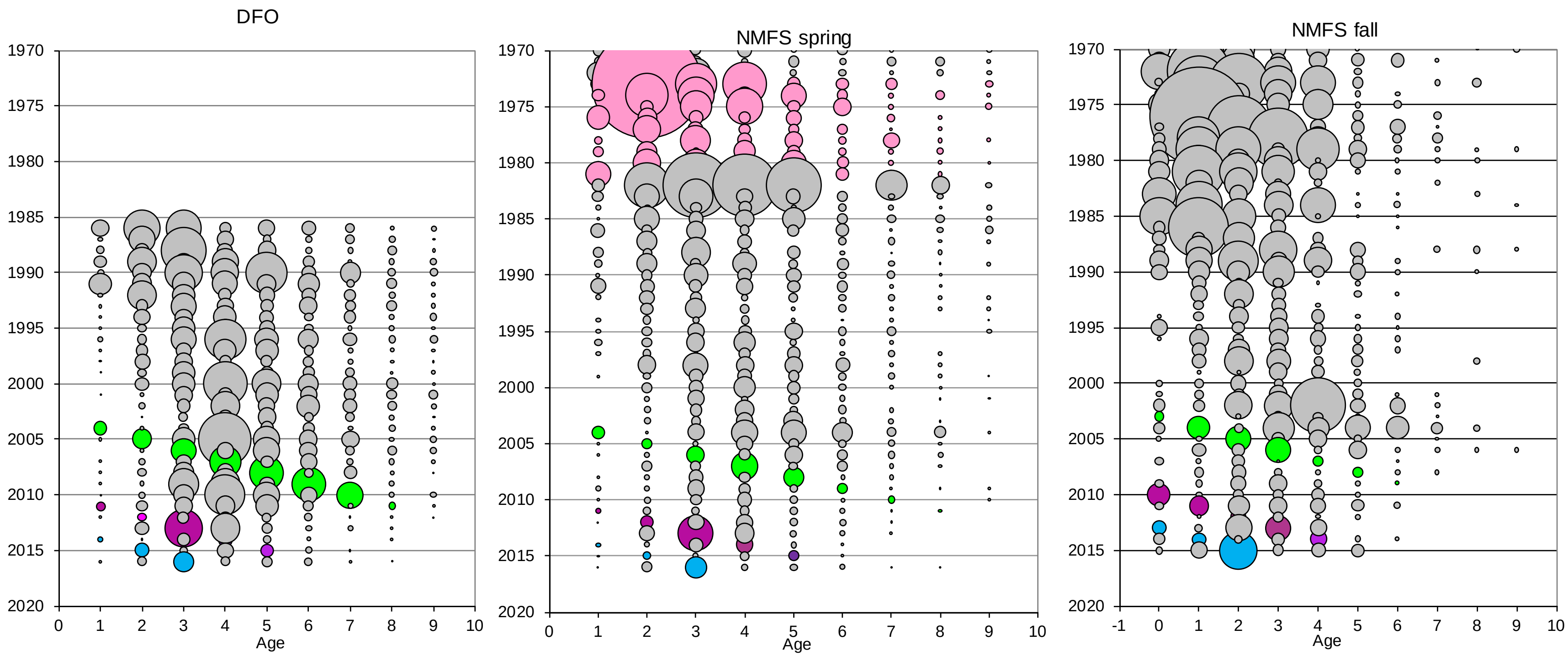


Figure 19. Survey abundance at age (numbers) of eastern Georges Bank cod. The bubble area is proportional to magnitude within each survey. Conversion factors to account for changes in door type, net and survey vessel were applied to the NMFS surveys. The NMFS spring survey was conducted using a modified Yankee 41 during 1978 to 1981 (lighter bubbles). The 2003 year class is identified with green bubbles, the purple bubbles show the 2010 year class and the blue show the 2013 yearclass. The 2016 NMFS spring ages were not available at the time of the assessment, so the 2016 DFO spring ALK was applied to the 2016 NMFS spring data.

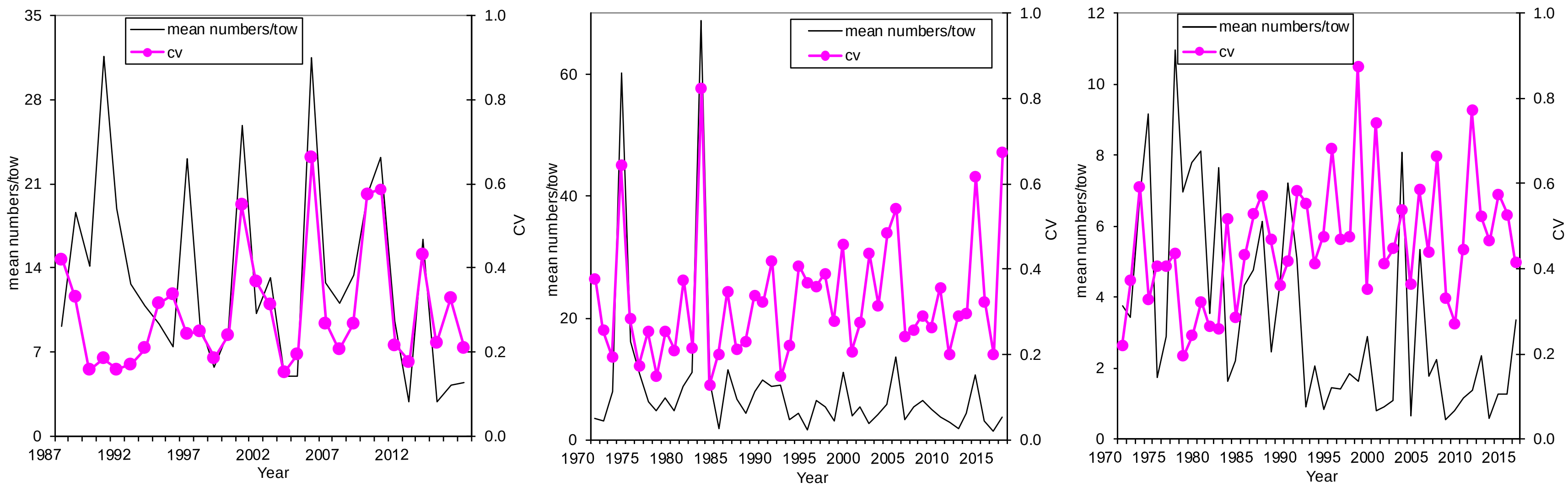


Figure 20. Stratified mean number per tow and coefficient of variation (CV) for DFO (left), NMFS spring (middle) and NMFS fall (right) survey catch of eastern Georges Bank cod.

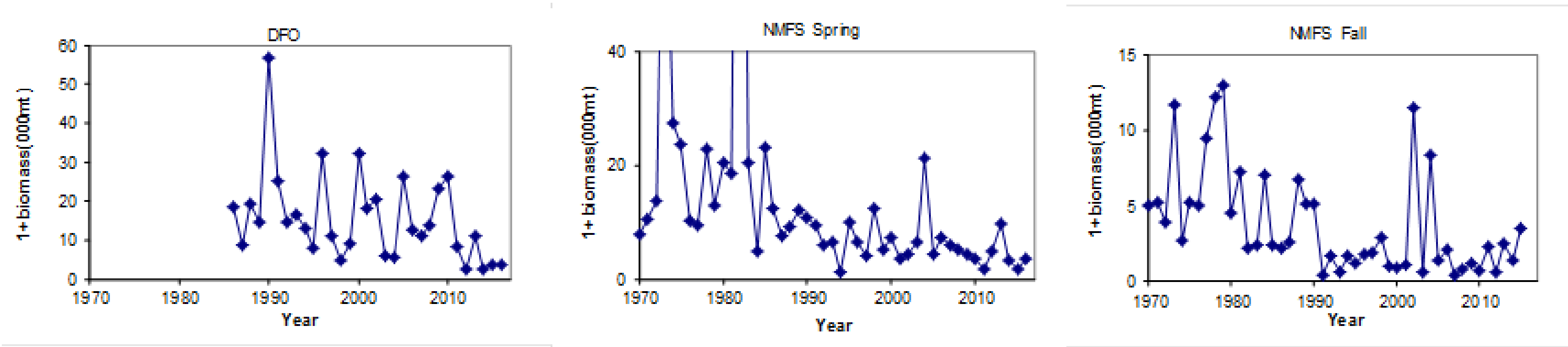


Figure 21. Survey biomass indices (ages 1+) for eastern Georges Bank cod from the DFO spring (left), NMFS spring (middle) and NMFS fall (right) surveys, 1978-2016.

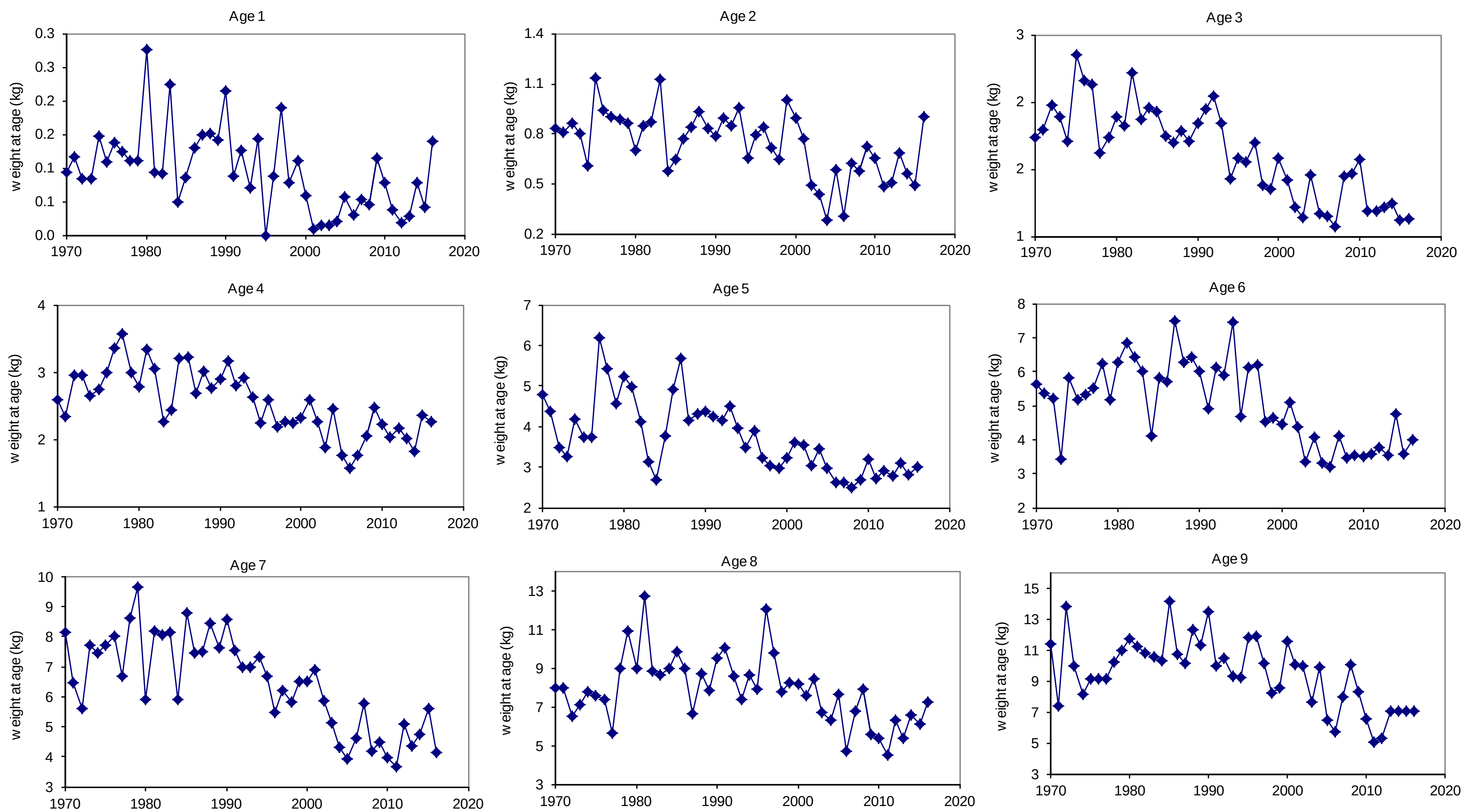


Figure 22. Beginning of year weight at age of eastern Georges Bank cod from DFO and NMFS spring surveys.

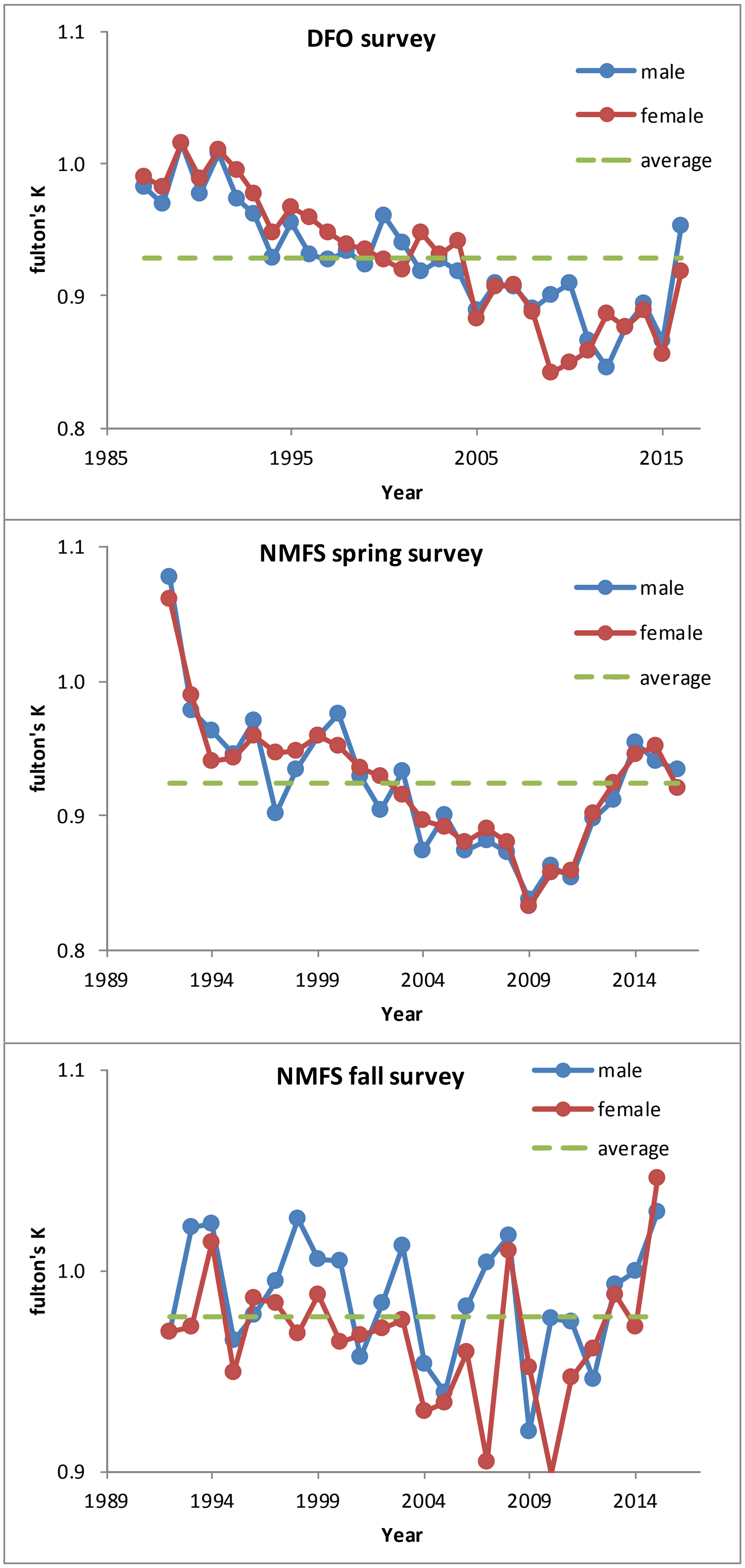


Figure 23. Fish condition (Fulton's K) of post-spawning cod for eastern Georges Bank.

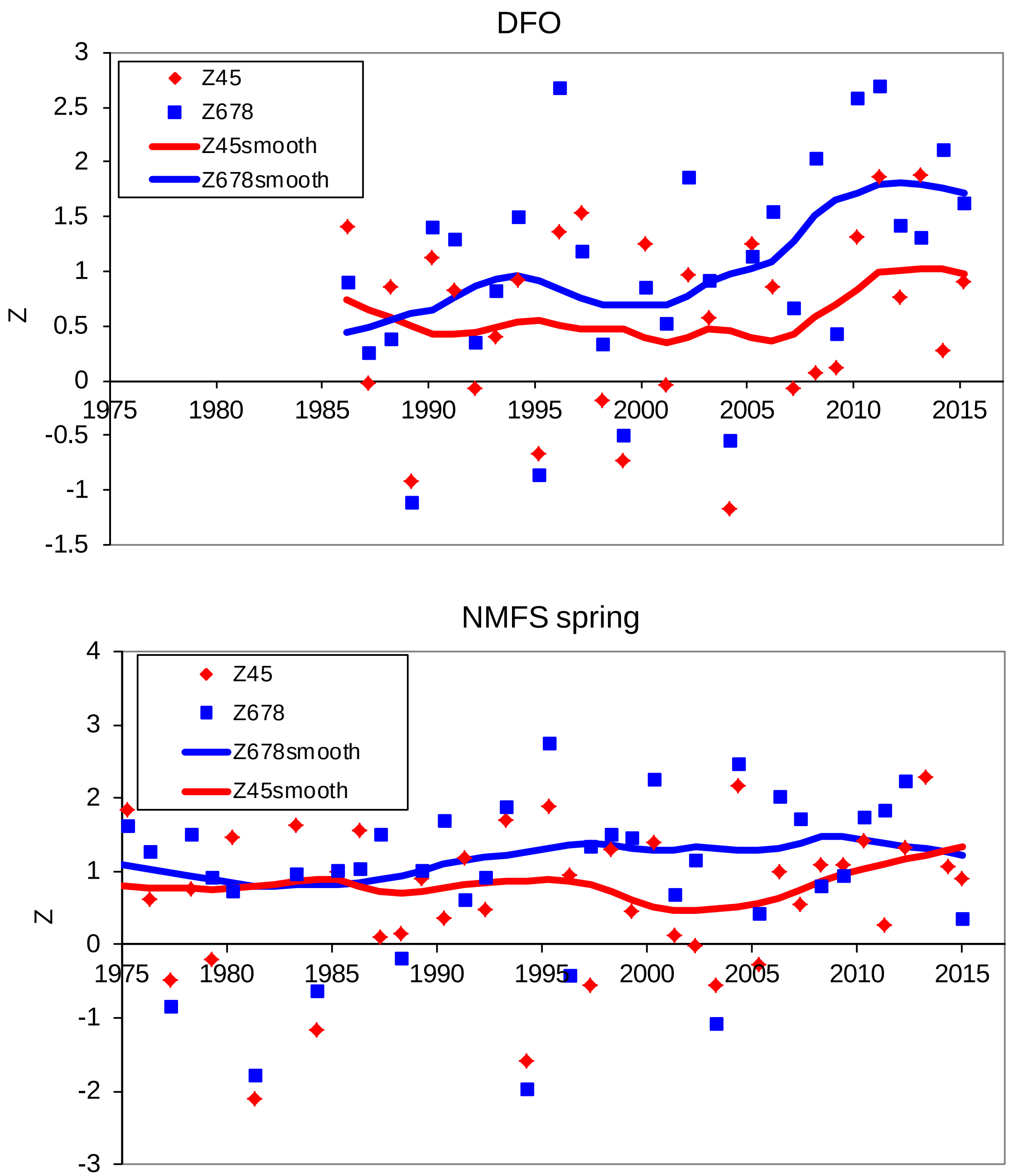


Figure 24. Total mortality(Z) calculated using the DFO and NMFS spring surveys data for eastern Georges Bank cod.

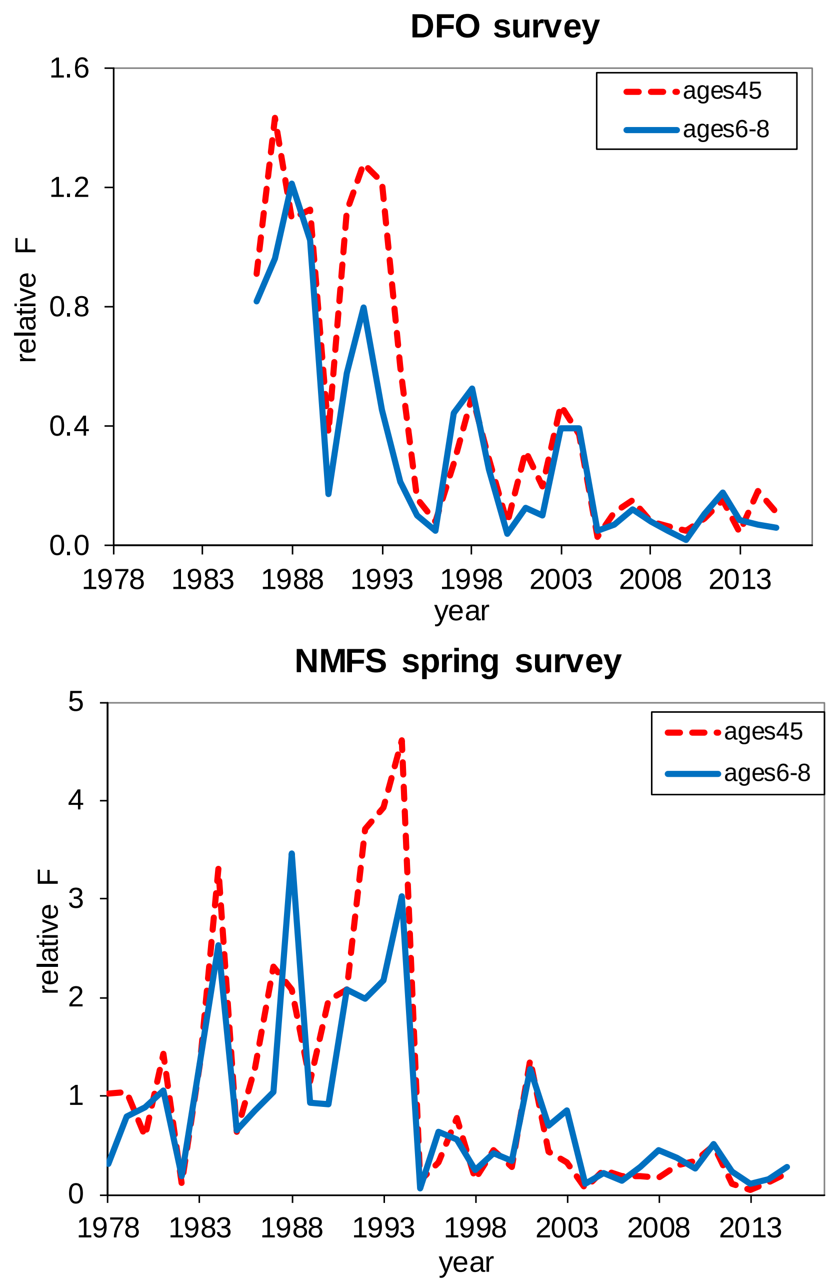


Figure 25. Relative F for eastern Georges Bank cod.

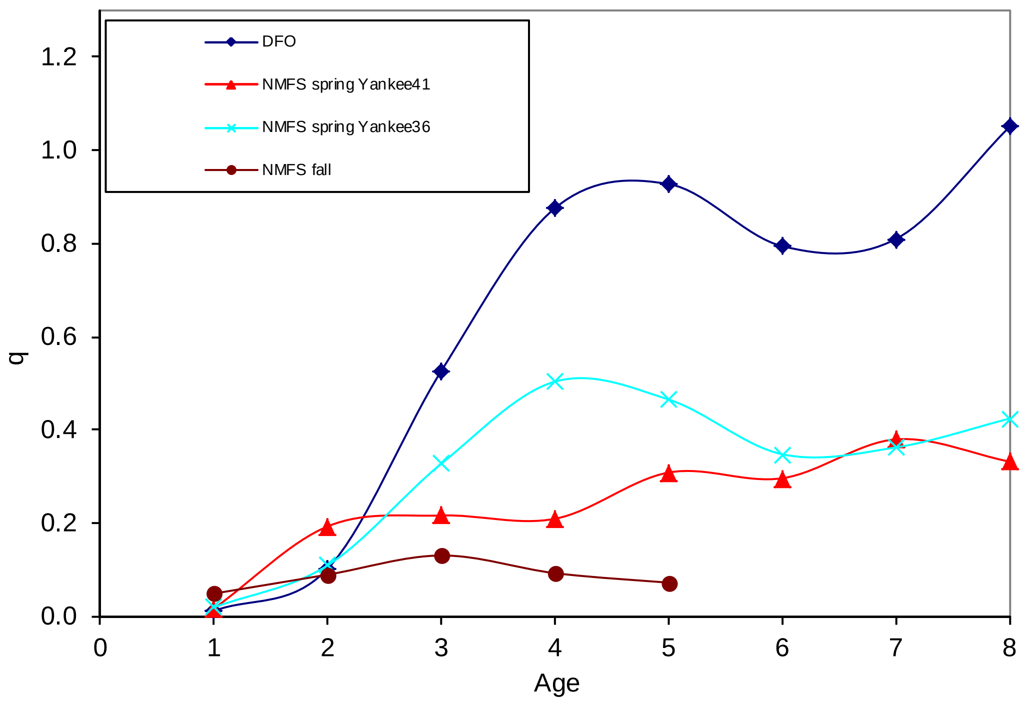


Figure 26. Survey catchability (q) of the DFO, NMFS spring and NMFS fall surveys for eastern Georges Bank cod.

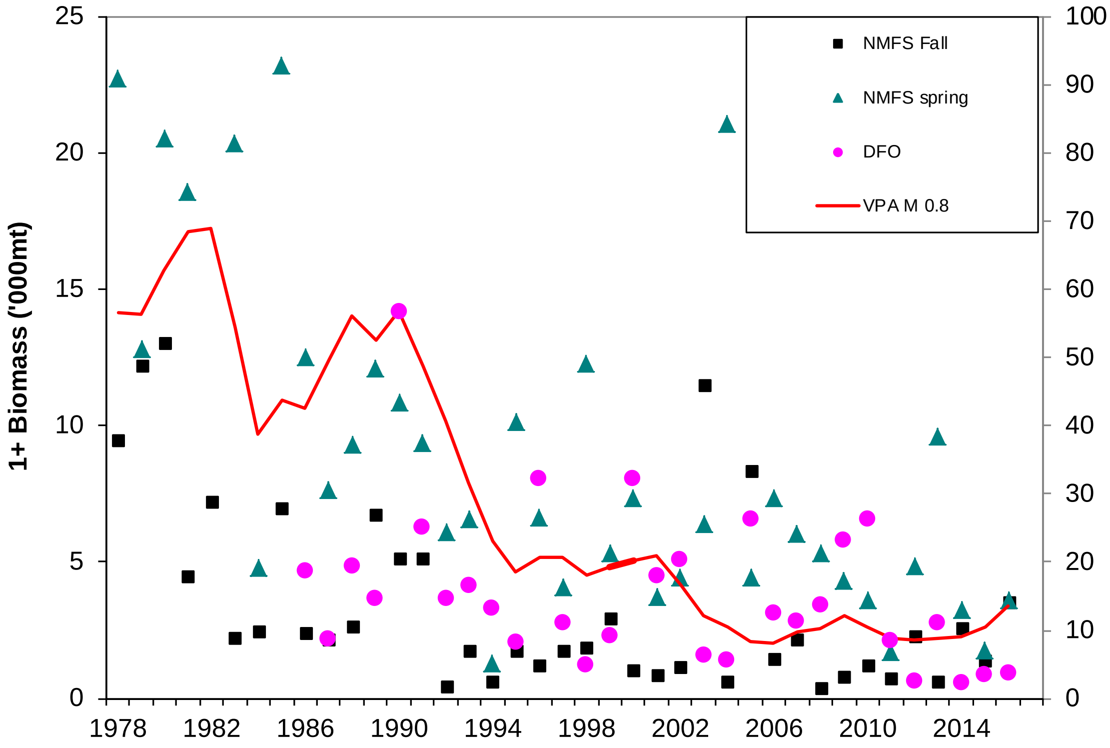


Figure 27. Age 1+ biomass from survey and VPA estimation.

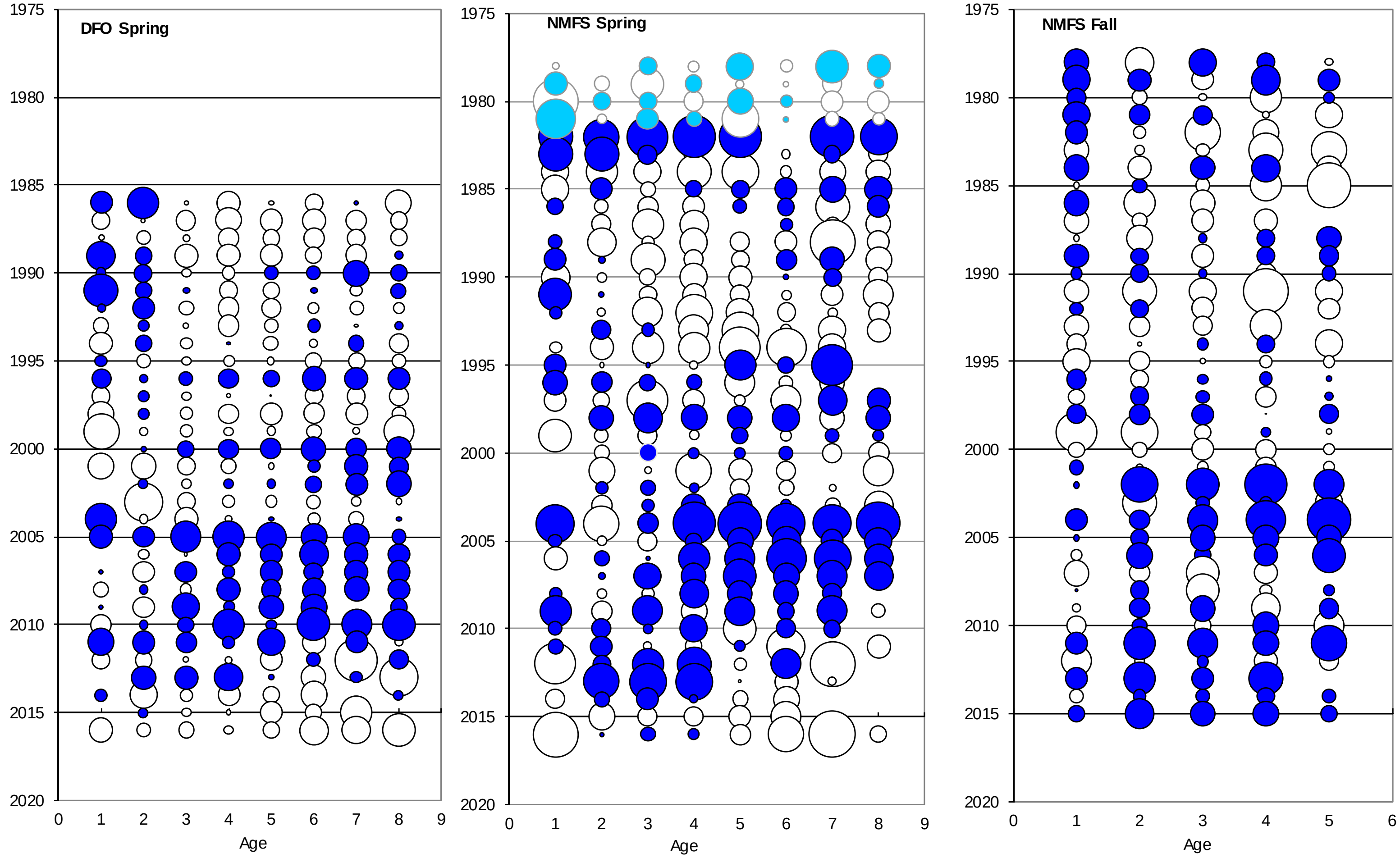
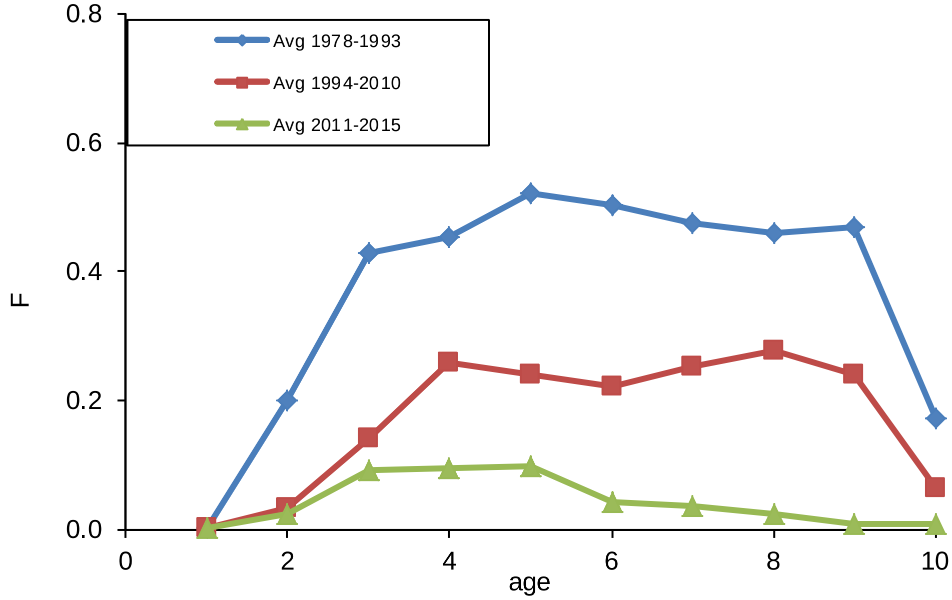


Figure 28. Residuals by year and age group from survey indices for eastern Georges Bank cod. Solid bubbles indicate positive values, open bubbles indicate negative values and the bubble area is proportional to magnitude. The NMFS spring survey was conducted using a modified Yankee 41 from 1978 to 1981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



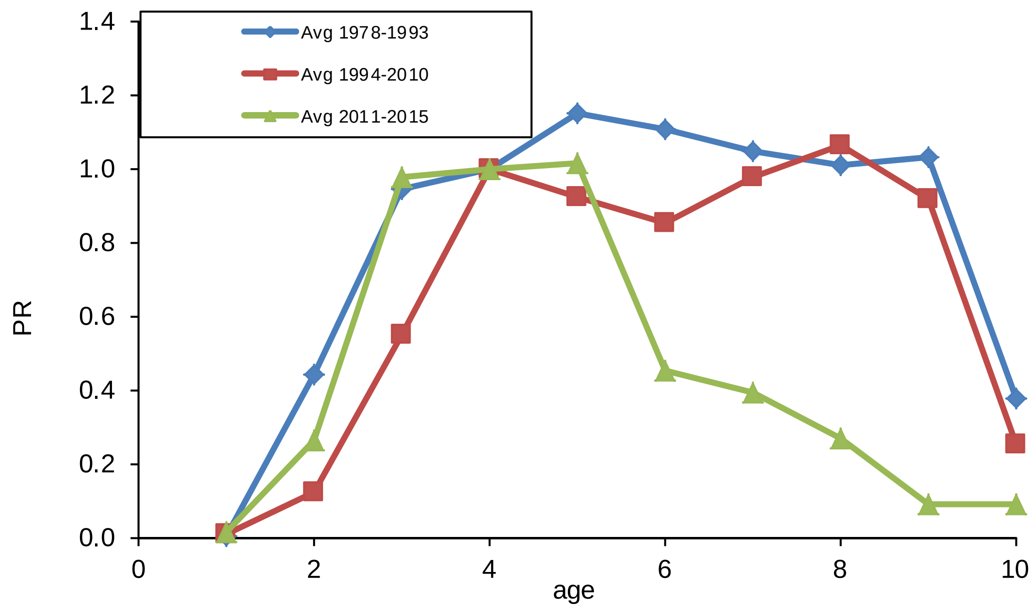


Figure 29. Average fishing mortality (F, upper panel) for eastern Georges Bank cod in three time series blocks (1978-1993, 1994-2010, 2011-2015).

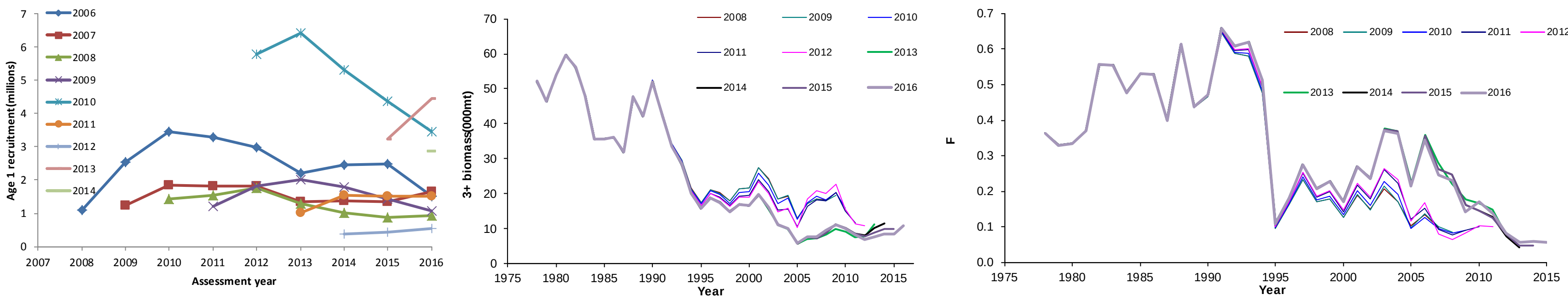


Figure 30. Retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the "M 0.8" model in 2016 assessment.

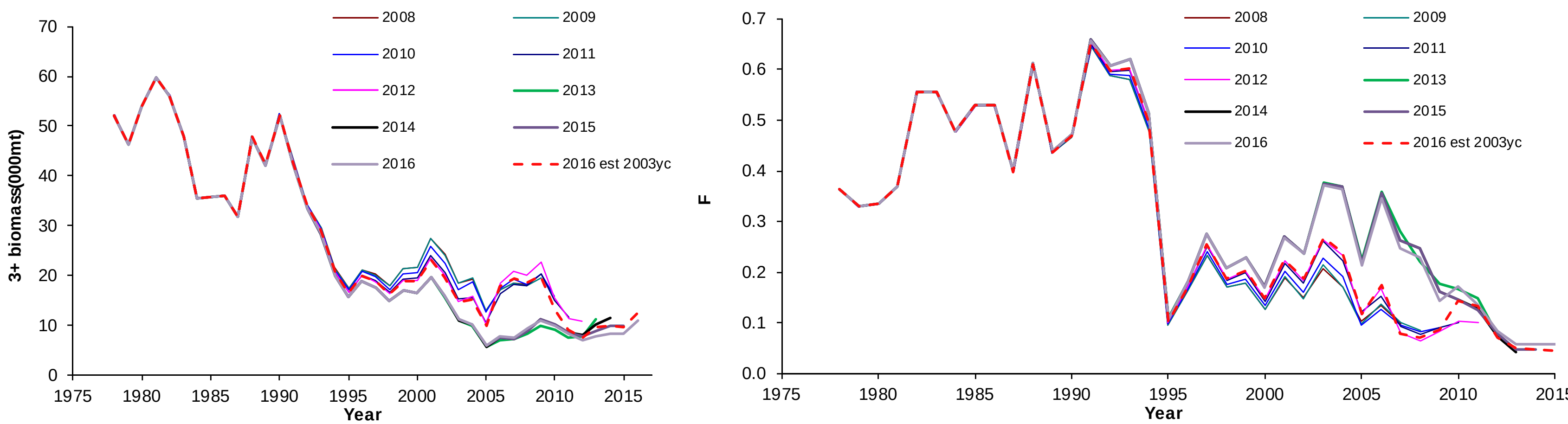


Figure 31. Comparison of sensitivity run "2015 est 2003yc" with the "M 0.8" model.

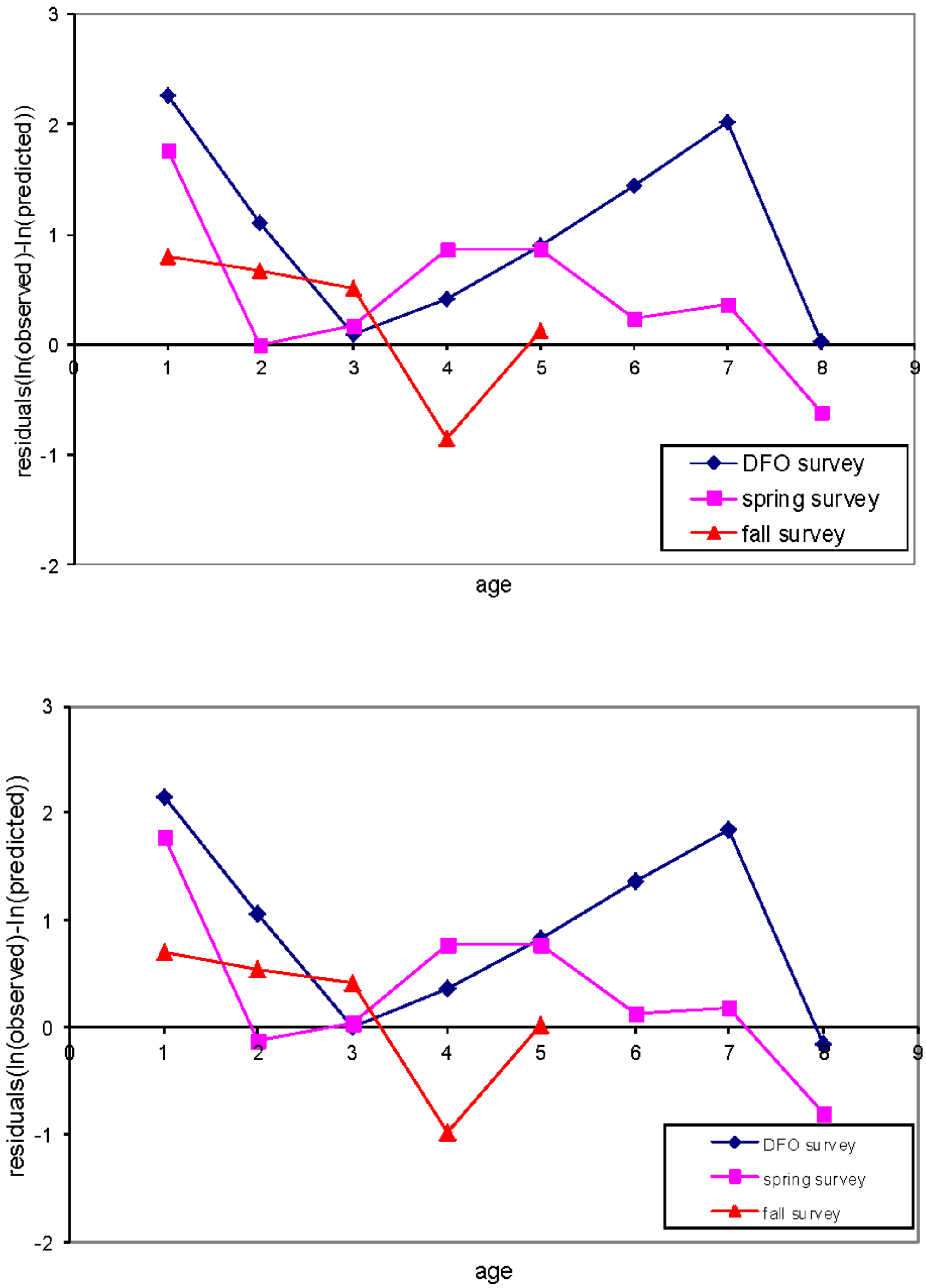


Figure 32. Residuals of the predicted survey values of the 2003 year class for the "M 0.8" model in 2013 (upper) and 2014 (lower) assessment.

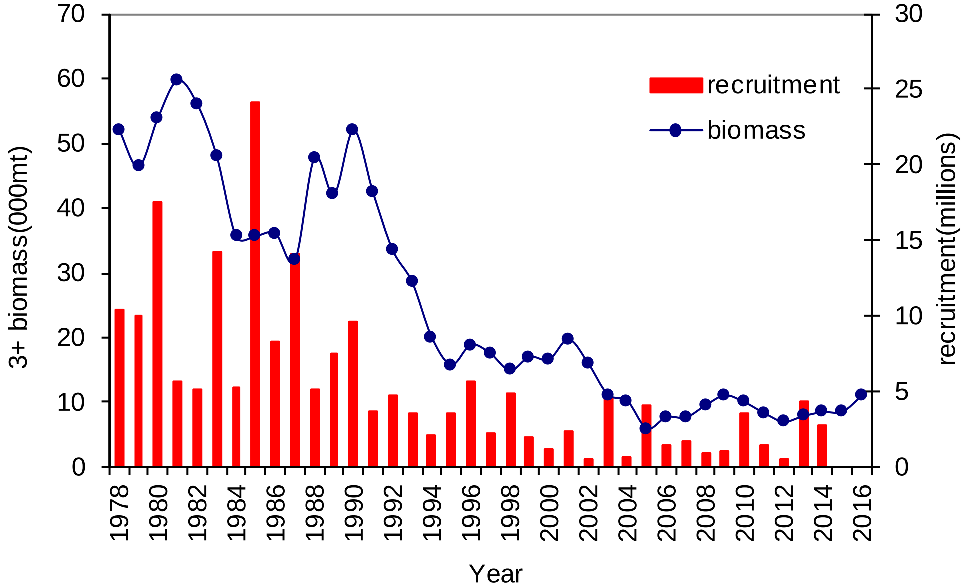


Figure 33. Adult biomass (ages 3+) and year class abundance at age 1 for eastern Georges Bank cod.

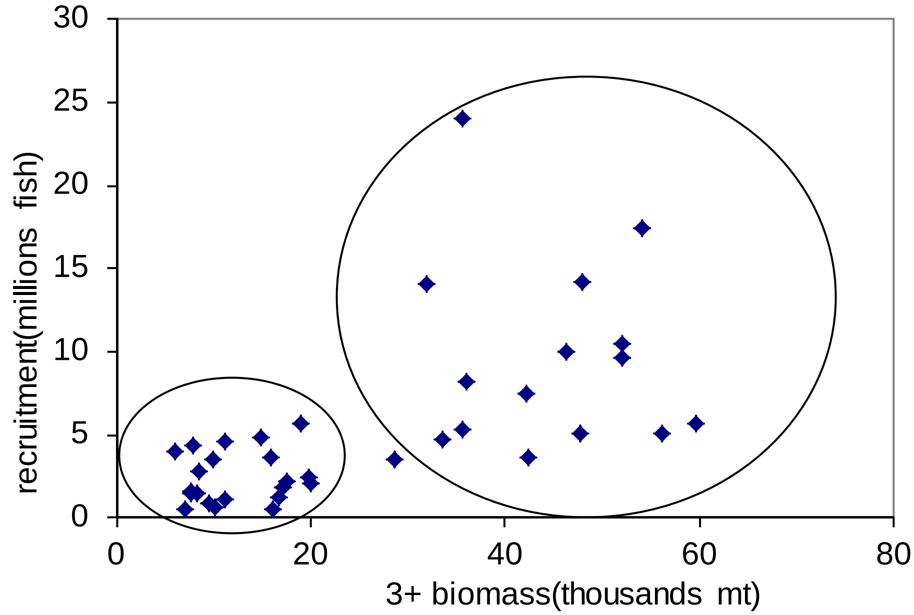


Figure 34. Relationship between adult biomass (ages 3+) and recruits at age 1 for eastern Georges Bank cod.

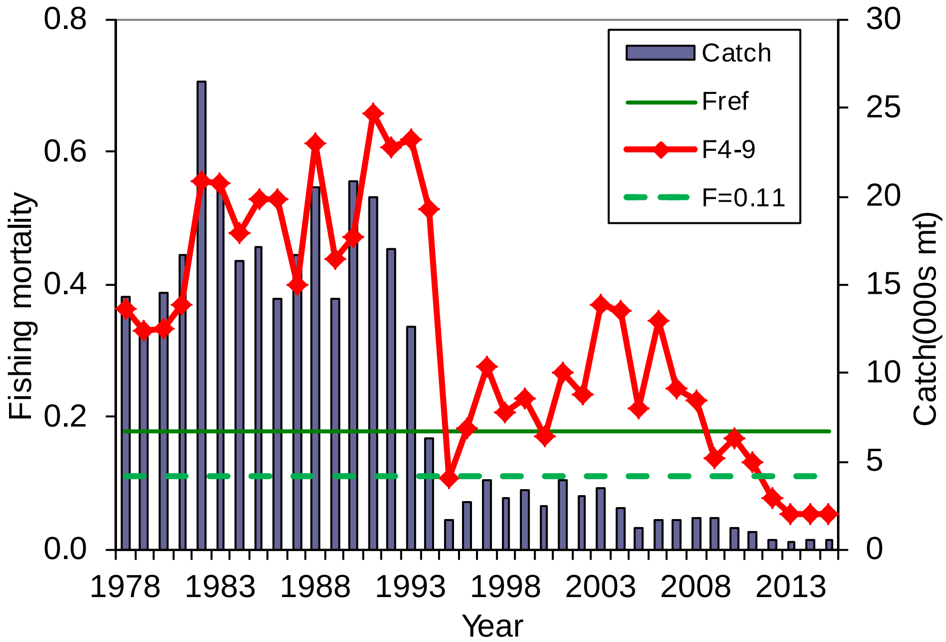


Figure 35. Average fishing mortality rate at ages 4 to 9 and catches for eastern Georges Bank cod. The established fishing mortality threshold reference, Fref=0.18. The F reference point for the "M 0.8" model is 0.11.

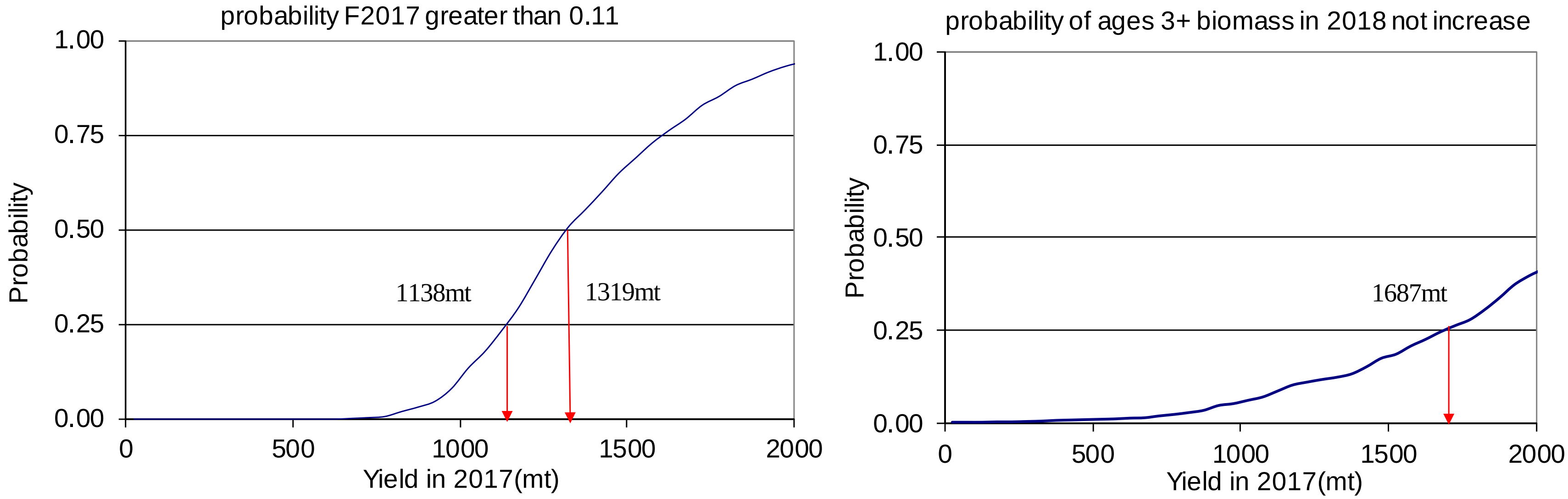


Figure 36. Risk of 2017 fishing mortality exceeding F reference point 0.11 and 2018 biomass not increasing from 2017 for alternative total yields of eastern Georges Bank cod from the "M 0.8" model formulation.

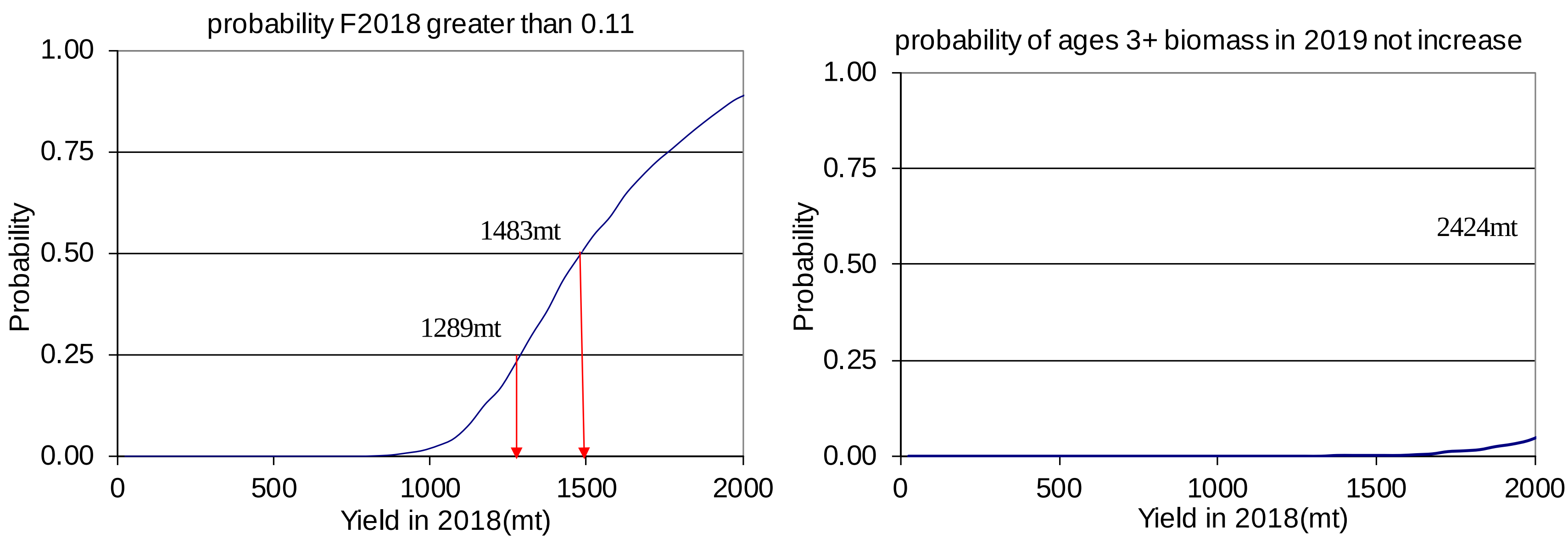


Figure 37. Assuming F2017=0.11, risk of 2018 fishing mortality exceeding F reference point 0.11 and 2019 biomass not increasing from 2018 for alternative total yields of eastern Georges Bank cod from the "M 0.8" model formulation.

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

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

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

Year	Canadian Management History
2002	TAC=1,192mt
2003	TAC=1,301mt
2004	TAC=1,000mt; Canada-USA resource sharing agreement on Georges Bank.
2005	TAC=740mt; Exploratory winter fishery Jan. to Feb. 18, 2005; Spawning protocol: 25% of maturity stages at 5 and 6.
2006	TAC=1,326mt; Exploratory winter fishery Jan. to Feb.6, 2006; Spawning protocol: 30% of maturity stages at 5 to 7.
2007	TAC=1,406mt; Exploratory winter fishery Jan. to Feb. 15, 2007; High mobile gear observer coverage (99%); Spawning protocol: 30% of maturity stages at 5 to 7.
2008	TAC=1,633mt; Winter fishery from Jan.1 to Feb. 8, 2009; At sea observer coverage 38% by weight of the mobile gear fleet landings and 21% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2009	TAC=1,173mt; Winter fishery from Jan. 1 to Feb. 21, 2009; At sea observer coverage 23% by weight of the mobile gear fleet landings and 15% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2010	TAC=1,350mt; Winter fishery from Jan. 1 to Feb. 8, 2010; At sea observer coverage 18% by weight of the mobile gear fleet landings and 6% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2011	TAC=1,050mt; Winter fishery from Jan. 1 to Feb. 5, 2011; At sea observer coverage 19% by weight of the mobile gear fleet landings, 20% by weight of the fixed gear landings and 3% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2012	TAC=513mt; Winter fishery from Jan. 1 to Feb. 6, 2012; At sea observer coverage 42% by weight of the mobile gear fleet landings, 26 % by weight of the fixed gear landings and 35% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2013	TAC=504mt; Winter fishery from Jan. 1 to Feb. 3, 2013; At sea observer coverage 78% by weight of the mobile gear fleet landings, 29%by weight of the fixed gear landings and 19% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2014	TAC=546mt; Winter fishery from Jan. 1 to Feb. 9, 2014; A test project with alternative codend meshes of 125mm square and 145 diamond for the purpose of improving the catch rate of haddock and reducing cod bycatch relative to haddock catches; At sea observer coverage 60% by weight of the mobile gear fleet landings, 45%by weight of the fixed gear landings and 14% by weight of the gillnet fleet landings Spawning protocol: 30% of maturity stages at 5 to 7.
2015	TAC=650mt; Winter fishery from Jan. 1 to Feb 2, 2015; Based on results of the 2014 test project 125mm square mesh was approved for use in 2015 and 2016. At sea observer coverage 75% by weight of the mobile gear fleet landings, 33%by weight of the fixed gear landings and 11% by weight of the gillnet fleet landings Spawning protocol: 30% of maturity stages at 5 to 7.

b) USA fishery management history of cod on eastern Georges Bank, 1978 to 2016.

Year	Regulatory Actions
1953	ICNAF era
1973-1986	TAC implemented for Div 5Zcod; 35,000/year
1977	Groundfish Fishery Management Plan (FMP) Magnuson-Stevesn Conservation Management Act (MSCMA)
1982	Interim FMP
1984	Hague Line implemented
1985	Multi-species FMP
1989	Amendment 2
1994	Emergency Rule - December Year round closures in effect
1994	Amendment 5; Days at Sea (DAS) monitoring ; Mandatory reporting : Vessel Trip Reports (VTR)
	Amendment 6
1996	Amendment 7; accelerated DAS reduction
	Sustainable Fisheries Act (SFA)
1999	Amendment 9
2002	Interim rule ; 20 % reduction in DAS
2004	Amendment 13; further reduction in DAS; hard TAC on EGB haddock and cod
	Eastern US/CA Area haddock Special Access Program (SAP) Pilot Progam
2005	DAS vessels limited to one trip/month in Eastern US/CA Area until April 30;
	Limited accesss DAS vessels required to use separator panel trawl in the area
2006	Haddock separator trawl or flounder net required in Eastern US/CA area
2008	Sept - Ruhle trawl (eliminator trawl) allowed in Eastern US/CA area
2009	Nov- Eastern US/CA area , trawl vessels requried to use separator/Ruhle south 41-40N
2010	Amendment 16, Framwork 44 implemented; Sector management ;
	US/CA area:prohibition on discarding legal size fish
	Common pool: 500 lbs/day, 5,000 lbs/trip
2012	US/CA area open May 1 for trawl gear: haddock separator, rhule or flounder trawl
2015-16	Inside US/CA GB cod: common pool : 100 lb/DAS , 500 lb/trip
	Inside US/CA GB cod: common pool : 100 lb/DAS , 500 lb/trip
	Common pool may fish inside US/CA area uing haddock sparatore trawl, Ruhle trawl, or flounder net
2016	May 1: sectors allowed to convert eGB allocation into western GB cod allocation during FY, and 2 weeks into new fishing year to cover any overage during previous FY
	Mesh Sizes (inches)
1953	4.5
1977	5.125
1983	5.5
1987	6.0
1989	eliminate 6 inch increase
1994	6.0
1999	6.5 square mesh/ 6.0 diamond mesh
2000	6.5 square mesh/ 6.5 diamond mesh
2002	6.5 square mesh/ 6.5 diamond mesh/6.5 gill net
	Minimum Size
1977	16 inches(40.6 cm) commercial and recreational
1982	17 inches (43.2 cm) commercial; 15 inches (38.1 cm) recreational
1986	19 inches (48.3 cm) commercial; 17 inches (43.2 cm) recreational
1988	19 inches (48.3 cm) commecial and recreational
1997	21 inches (53.3) recreational
2002	22 inches (55.9 cm) commercial; 23 inches (58.4 cm) recreational
2003	21 inches (53.3 cm) recreational
2013	19 inches (48.3 cm) commercial, July start

Year	Trip Limits
2004	GB cod: 1,000 lbs/day; 10,000 lbs/trip; EGB: hard TAC on cod
	500 lbs/day; 5,000 lbs/trip in Eastern US/CA area
2005	500 lbs/day; 5,000 lbs/trip in Eastern US/CA area
	Starting July, one trip/month in Eastern US/CA area until Apr. 30, 2006
2006	500 lbs/day; 5,000 lbs/trip in Eastern US/CA area
2007	1000 lbs/trip of cod in Eastern US/ CA area or Haddock SAP
2008	1000 lbs/trip of cod in Eastern US/ CA area fishing EGB exlclusively
2009	Mar-500 lbs/ trip of cod in Eastern US/CA area; back to 1000 in April
2010	GB Cod: 2000 lbs/ day; 20000/trip ; EGB cod: 500 lbs/day, 5000 lbs/trip
2011	March- 3,000 lbs day during April
	500 lbs/day after April in EGB area
2012	common pool: GB cod 1500 lbs/A DAS up to 4500 lbs/Trip
	Handgear B 75 lb/trip
2013	Jan1 : Common pool: GB cod 3000 lbs/A DAS up to 30,000 lbs/Trip
	Handgear B 125 lb/trip
	May 1: Handgear A 300 lb/trip; handgear B 75 lb/trip
2014	Common pool closure: GB cod Aug 18 thru April 30, 2015
	Closures
1970	Area 1(A) and 2 (B) Mar-Apr
1972-1974	Area 1(A) and 2 (B) Mar-May
1977	seasonal spawning closure
1987	modify closed area I to overlap with haddock spawning area
1994	Jan. CA II expanded, closed Jan-May, CA I closed to all vessels except sink gillnet
	Dec. CA I and II closed year round to all vessels
1999	scallopers allowed limited access to CA II
2004	May to Dec. access to northern corner of CLII & adjacent area to target haddock w/ separator trawl
	Oct - EGB area closed to multispecies DAS permits
2005	Jan - Eastern US/CA area reopened
	Apr-Eastern US/CA area closed until April 30
	Aug -Eastern US/CA area closed)GB cod TAC projected near 90%)
2006	Eastern US/CA haddock SAP delayed opening until Aug.1
2007	April 25 - Eastern US/CA area closed until Apr. 30
	Jun - Eastern US/CA area closed to limited access multispecies TAC (due to cod catch)
	Oct- Eastern US/CA area open to limited access multispecies TAC until Nov 30
	Dec- Eastern US/CA area closes
2008	May- Eastern US/CA area delayed opening until Aug. 1;
	Jun- Eastern US/CA area delayed opening until Aug. 1 for all gear (prevent catching 1st qtr cod TAC)
2009	Apr 16 - Eastern US/CA area closed ; May-Eastern US/CA area closed until Aug. 1 for trawl vessels
2010	Eastern US/CA Area closed Apr 20-30, TAC harvested; May 1 opening delayed until August;
2011	Eastern US/CA area closed from May -Jul for trawl gear (common pool vessels only)
2013	Common pool closure: July 30- Aug 31 for GB cod

APPENDIX B

2016 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 management unit benchmark model meeting. No model was chosen by the TRAC as a benchmark model for stock status, however, the TRAC agreed (Claytor and O'Brien 2013) to use the VPA model results for catch advice with the ASAP model results in a consequence analysis (Appendix B) of projection results to be provided to managers for catch advice.

The ASAP model provided estimates of instantaneous fishing mortality and stock size in 2015. A retrospective analysis was performed for terminal year fishing mortality, spawning stock biomass, and age 1 recruitment. Stochastic projections from model results provide estimated landings and spawning stock biomass (SSB) in 2017-2019.

Assessment Model Formulation

Model description

ASAP, a forward projecting statistical catch at age model (Legault and Restrepo 1998) was applied in this assessment and can be downloaded from the NOAA Fisheries Toolbox (NFT, http://nft.nefsc.noaa.gov/). A brief description of the model can be found in the previous assessment (Wang et al. 2015) and for further details, the reader is referred to the technical manual (Legault 2008).

Data input

Input to the ASAP model is the same as for the VPA 0.8 model, with two exceptions. The ASAP uses beginning year weight-at-age that is back-calculated from the mid-year catch weight-at-age (Rivard 1982; Appendix.Table 1) rather than using the weight estimated from an average of the DFO and NEFSC spring research survey weight-at-age (Table 16). The ASAP also does not use the most recent terminal year +1 surveys (e.g.DFO 2016 and NEFSC 2016).

Natural mortality (M) was age and time invariant and assumed to be 0.2 , which was also applied in earlier assessment models for cod from eastern Georges Bank (Wang and O'Brien 2012).

Model formulation

The ASAP model formulation (base_rivard) presented and reviewed at the June 2015 TRAC (Wang et al. 2015) was updated for the 2016 assessment. A multinomial distribution was assumed for both fishery catch at age and survey age compositions. The catch CV was set equal to 0.05 and the recruitment CV set equal to 0.5, however, the recruitment deviations were set with lambda = 0, so the deviations did not contribute to the objective function.

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

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

At the 2013 benchmark (O’Brien and Wang 2013) the CV for each survey was initially set at the value generated from the survey estimate of stratified mean number per tow (DFO STRANAL). 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 2016 update.

For the 2016 TRAC, several sensitivity model formulations were also run to determine the best model to reduce the retrospective bias. The model formulation that resulted in minimal retrospective bias (run 8) is similar to the base_rivard run with the exception of increased CV on the catch (CV= 0.2). This formulation was explored based on recent analyses indicating that cod caught in the eastern GB statistical areas (561, 562) are potentially either under- or over-reported in the vessel trip report (VTR) database (Palmer, pers. comm., see Palmer and Wigley 2007, 2009). Landings ranged from over-reporting of 18 mt to under reporting of 310 mt which resulted in landings being over-reported by 4.2% - 6.2% and under-reported by 14% - 730% during 2008-2015. The model results of run 8 will be presented and compared to the base_rivard formulation.

Model Results

Model results, including the objective function (OF), components to the OF, the root mean square error (RMSE) computed from standardized residuals, SSB, fishing mortality (F), recruitment estimates at age 1, and the Mohn’s rho retrospective bias adjustments are summarized in Appendix Table 2 for three of the model runs conducted, run 1 (base_repeat): rerun of 2015 model with terminal year (TY) 2014; run3 (base_rivard): update of ASAP model with TY 2015 data, and run 8: base_rivard formulation with an increase in catch CV from 0.05 to 0.2. The following model results are for run 8.

<u>2016 ASAP – Run 8</u>

Model diagnostics are very similar to last years’ assessment (Wang et al. 2015) and to the 2016 base run with the exception of the retrospective bias. Model fit to total catch indicates generally lower predicted catch prior to 1995 and generally higher predicted catch from 1995 onward (Appendix Figure 1). Patterns in residuals still persist in both the catch and in the surveys, (Appendix Figures 2- 8). The effective sample size (ESS) for the catch and surveys is still appropriate.

Fishing mortality, SSB, and recruitment

Fully recruited F (unweighted, ages 5+) was estimated at 0.39 in 2015 (Appendix Table 3, Appendix Figure 9), a 46% decrease from 2014. SSB in 2015 was estimated at 1,577 mt, a 1% decrease from 2014 (Appendix Table 3, Appendix Figures 9-10). Recruitment (millions of age 1 fish) of the 2014 year class is estimated at 0.375 million, the second smallest year class, whereas the 2012 year class (0.282 million age 1 fish) is the smallest year class. The 2013 year class is estimated at 1.732 million fish , the largest year class since the 2003 year class, now estimated at 2.549 million age 1 fish (Appendix Table 3, Appendix Figures 9-10).

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 (2008-2014) prior to the terminal year, 2015. The pattern of overestimating SSB and underestimating F relative to the terminal year persists in this assessment, and there is a general pattern of underestimating recruitment relative to the terminal year estimate (Appendix Figure 11), however, the magnitude of the bias is less in run 8 than in the base_rivard run. The retrospective rho values, the average of the last 7 years of the relative retrospective peels, were 0.42 for SSB, -0.40 for F_{5+}, and -0.23 for recruitment. Applying a retrospective adjustment (1/(1+rho)) * estimate) results in estimates of 2015 F = 0.64, SSB = 1,114 mt, and age 1 recruitment = 0.3485 million fish. Since the retrospective adjusted values of SSB and F are within the 90% probability intervals (see below), the model results do not need to be adjusted for retrospective bias (Figure 12).

Model uncertainty - MCMC

A Monte Carlo Markov chain (MCMC) simulation was performed to estimate uncertainty in the model estimates. Two MCMC chains of initial length of 5.0 million were simulated with every 2,500th value saved. The trace of each chain's saved draws suggests relatively good mixing for both SSB and F (Appendix Figure 13), i.e. there were no long-term trends to indicate that successive iterations were highly correlated. The lagged autocorrelations showed variable correlation with increased lag, with correlations <= 0.1 beyond lag 0 for SSB and F (figure not shown). The 2015 SSB MCMC estimate of 1,624 mt has a 90% probability interval (PI) of 1,046 mt – 2,364 mt and the 2015 MCMC average F_{5+} = 0.38 has a 90% PI of 0.21 – 0.75.

Biological Reference Points

The current negotiated eastern Georges Bank cod fishing mortality reference point is F_{ref} =0.18 (TMGC 2002).

Projections

Short term stochastic projections under F_{ref} =0.18 were performed from the 2016 ASAP run 8 model results to estimate landings and SSB during 2017-2019. The input values for mean catch and stock weights, partial recruitment (PR), and maturity were estimated as 3-year averages from 2012-2014. Recruitment was estimated from a 2-stage cumulative distribution function (CDF) based on either 21 low estimates or 14 high estimates of age 1 recruitment. Based on a visual examination of the stock recruit plot (Appendix Figure 10), a cut-point of 15,000 mt was established, such that, when SSB is less than 15,000 mt, recruitment is drawn from the low recruitment CDF, and when SSB is greater than 15,000 mt, recruitment is drawn from the high recruitment CDF. Catch in 2016 was estimated based on the assumption that the 2016 quota of 625 mt would be caught.

The results of the short term projections indicate under F_{ref} = 0.18, catch is projected to decrease in 2017 and increase in 2018. SSB is projected to increase in 2017 and again in 2018.

Year	SSB	F	Catch
2016	2802	0.33	625
2017	3201	0.18	515
2018	3787	0.18	646

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 2013). 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 et al. 2013). Lack of large numbers of older repeat spawners in the EGB cod population since the mid-1980s may contribute to the long-term low productivity. Cod have a low success rate of hatching for 1st and 2nd time spawners (13% and 62%) until the 3rd spawning (100%), suggesting that an expanded age structure of fish that have spawned 3 or more times would contribute to higher productivity (Trippel 1998, Carr and Kaufman 2009). Long-term overfishing may have also had indirect effects. Fishing activity disrupts the spawning aggregation and thus behaviors and rituals of cod, reducing the potential of good recruitment (Dean 2012). Spawning of cod involves complex behaviors that have only recently been observed including arrival and departure of fish on the spawning ground at different times dependent upon sex, age, and stage of maturity (Lawson and Rose 2000) and the formation of spawning leks, where the males set up and defend territory (Windle and Rose 2007).

The 2016 updated base model formulation provides similar results to the 2015 ASAP assessment (Wang et al. 2015) but with an increase in the retrospective bias in F and SSB. However, the run 8 model formulation, with increased uncertainty in the catch estimates, decreases the retrospective bias such that retrospective adjustment of SSB and F is not necessary. Run 8 model results were used in the projection analyses.

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Appendix. Table 1. January 1 catch weight-at-age (kg) for ages 1-10+, for eastern Georges Bank cod, 1978-2015.

	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	12.907
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	15.040
1984	0.486	1.202	1.853	2.753	3.843	5.290	7.116	8.545	10.646	13.621
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	14.000
1990	0.469	0.981	1.738	2.513	3.921	5.435	6.849	8.163	10.475	13.000
1991	0.544	1.027	1.937	2.732	3.695	5.041	6.711	8.587	9.494	14.000
1992	0.675	1.026	1.861	2.831	3.650	4.898	6.130	8.033	10.299	15.000
1993	0.403	1.097	1.723	2.544	3.773	4.787	6.186	7.504	8.896	12.000
1994	0.410	0.895	1.731	2.691	3.532	5.249	6.232	7.421	8.125	13.000
1995	0.153	0.893	1.682	2.679	4.119	5.293	8.052	8.482	9.223	17.000
1996	0.307	0.677	1.690	2.543	3.970	5.365	6.399	9.510	10.178	11.000
1997	0.475	0.852	1.715	2.518	3.430	5.023	6.505	7.303	10.139	11.000
1998	0.511	0.947	1.745	2.480	3.409	4.536	5.945	7.535	9.220	14.000
1999	0.341	0.952	1.625	2.579	3.413	4.666	5.780	7.050	8.566	14.000
2000	0.485	0.846	1.599	2.393	3.527	4.288	5.599	6.517	7.936	13.000
2001	0.087	0.750	1.566	2.323	3.221	4.423	4.954	6.449	7.654	11.000
2002	0.169	0.501	1.351	2.288	3.316	4.180	5.589	6.554	7.617	11.000
2003	0.138	0.638	1.598	2.303	3.169	4.123	5.167	6.622	7.924	9.000
2004	0.133	0.595	1.512	2.425	3.063	4.013	4.709	6.293	7.643	10.000
2005	0.312	0.450	1.387	2.079	3.113	3.948	4.703	5.941	7.556	10.000
2006	0.134	0.504	1.198	1.894	2.780	3.867	5.240	5.296	6.817	7.000
2007	0.277	0.526	1.016	2.006	2.626	3.588	5.109	6.458	6.318	10.000
2008	0.156	0.763	1.523	2.119	2.909	3.879	4.770	6.947	7.382	9.000
2009	0.475	0.582	1.559	2.596	3.215	4.055	5.374	6.259	8.897	11.000
2010	0.321	0.921	1.516	2.201	3.202	3.570	4.798	5.908	7.713	11.000
2011	0.179	0.719	1.486	2.283	2.980	3.803	3.812	5.564	7.738	10.000
2012	0.155	0.539	1.334	2.131	3.070	3.798	4.457	4.908	5.685	5.230
2013	0.191	0.539	1.313	2.141	3.137	4.233	4.695	5.222	6.706	7.174
2014	0.151	0.569	1.453	2.193	3.106	4.094	5.507	6.663	7.330	6.772
2015	0.302	0.592	1.391	2.595	3.228	4.210	5.858	9.102	9.275	6.371

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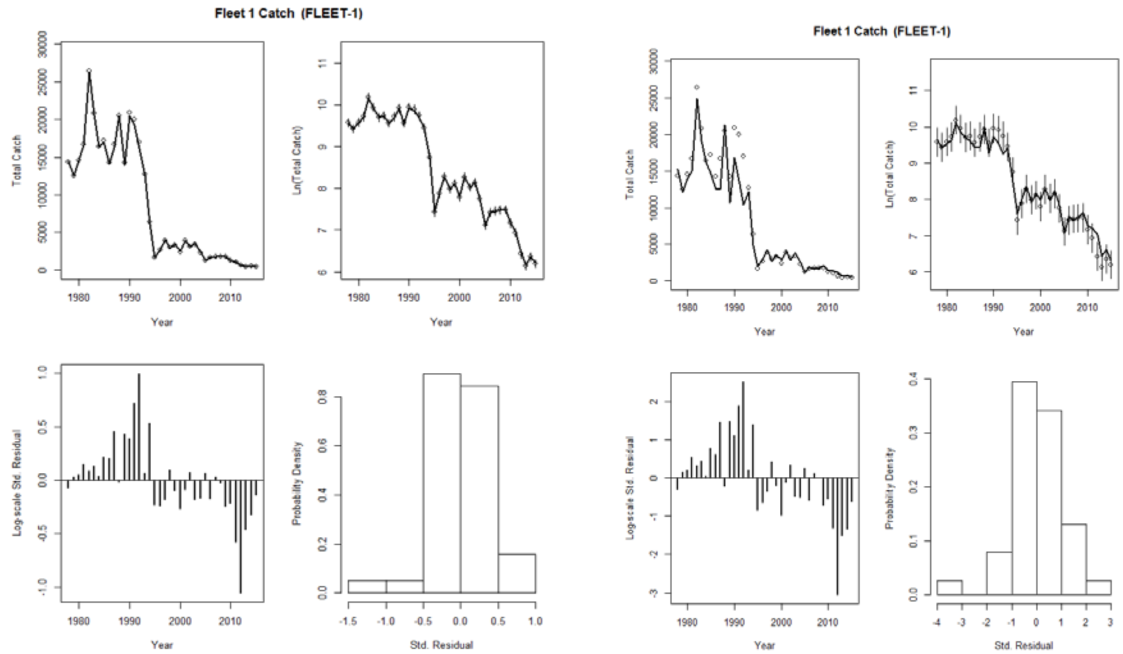
Appendix.Table 2. ASAP model diagnostics and results of three model formulations: total objective function (OF) value, contribution to the OF by components, root mean square error (RMSE) of the standardized residuals, catch and survey coefficient of variation (CV) and effective sample size (ESS) and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

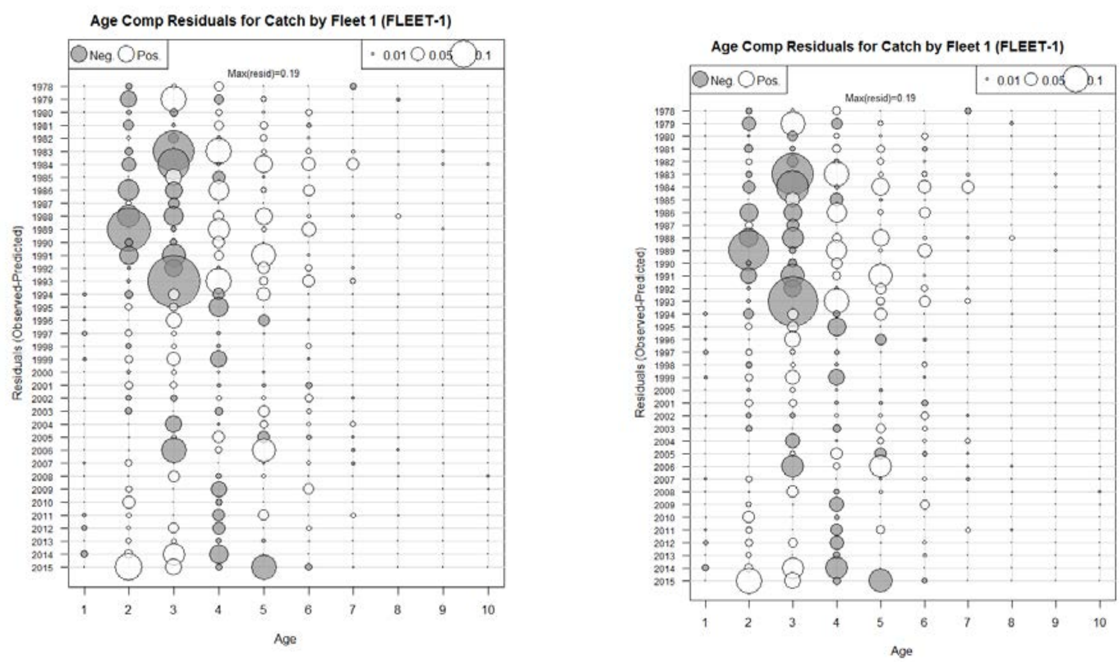
		run 1	run 3	run8
		TY=2014	TY=2015	TY=2015
Model		base_repeat	base_rivard	base_cat.cv.2
objective function		3163.31	3316.3	3343.58
components of obj. function				
	catch total	234.975	243.773	313.171
		0.00	0.00	0.00
	index fit total	914.99	978.73	956.53
	catch age composition	588.49	621.09	615.74
		0.00	0.00	0.00
	Index age composition	1424.86	1472.71	1458.14
	Recruit deviations			
RMSE	**Catch fleet**	0.33	0.35	1.01
	total catch	0.33	0.35	1.01
	discards	0.00	0.00	0.00
	total discards	0.00	0.00	0.00
	DFO	1.53	1.59	1.39
	Autumn	1.34	1.45	1.36
	Spring 41	0.78	0.77	0.79
	Spring 36	1.50	1.58	1.40
	Index total	1.43	1.51	1.37
CV	catch	0.05	0.05	0.2
	dfo	0.25+	0.25+	0.25+
	fall	0.2+	0.2+	0.2+
	spring #41	1x	1x	1x
	spring #36	0.3+	0.3+	0.3+
ESS	catch	75/125('96)	75/125('96)	75/125('96)
	dfo	50	50	50
	fall	50	50	50
	41	50	50	50
	36	50	50	50
Jan 1 biomass		2702	2794	2662
SSB TY mt		2248	1676	1577
SSB TY retro bias adj		1413	933	1114
F TY (age 5+)		0.37	0.31	0.39
F TY retro bias adj.		0.58	0.58	0.64
TY age 1 (millions)		1.073	0.398	0.375
TY age 1 retro bias adj.		1.304	0.413	0.485
rho F		-0.36	-0.46	-0.40
rho SSB		0.59	0.80	0.42
rho rct		-0.18	-0.04	-0.23

Appendix.Table 3. ASAP model run 8 results for January 1 biomass (mt), spawning stock biomass (SSB (mt), age 3+), fishing mortality (F) and recruitment (age 1,000s fish), 1978-2015.

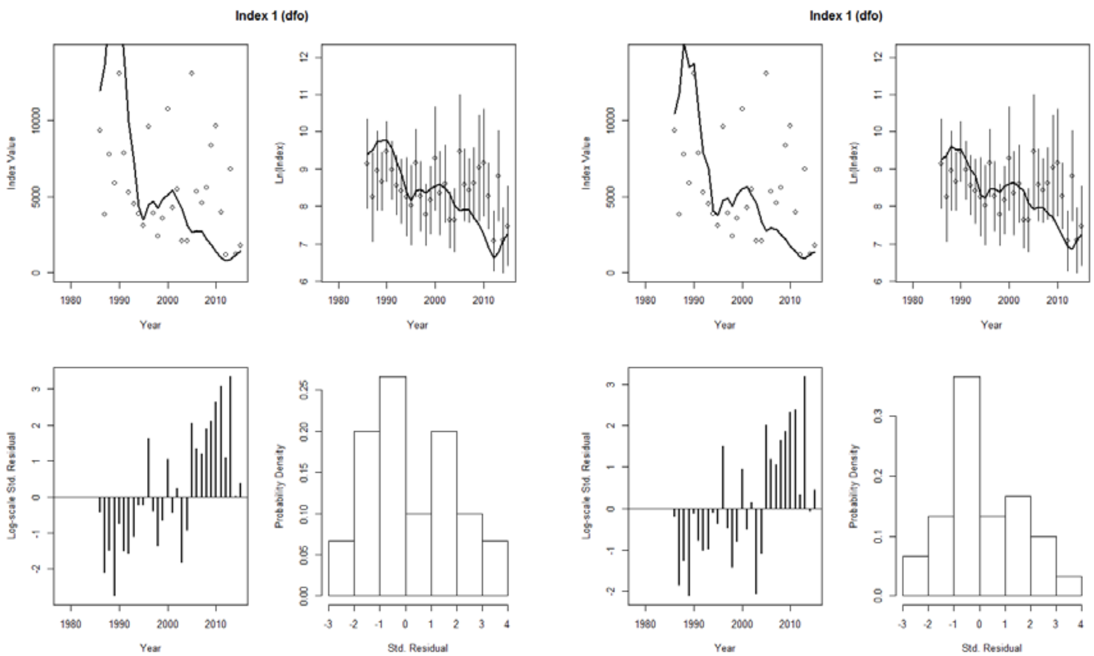
Year	Jan 1 Biomass	SSB	F	Recruitment
1978	37988	29909	0.49	10320
1979	41333	26355	0.38	9831
1980	44280	31510	0.41	8477
1981	46458	32052	0.45	17911
1982	49218	29784	0.74	6842
1983	41847	30216	0.62	3224
1984	37765	25002	0.66	11859
1985	30548	16693	0.84	4608
1986	30430	17121	0.68	22699
1987	35925	15337	0.53	5345
1988	42149	28702	0.80	10772
1989	31463	19688	0.46	4281
1990	32737	23199	0.71	4989
1991	29120	16494	0.88	9570
1992	23024	11353	0.78	2444
1993	18245	11681	1.22	3193
1994	10203	5877	1.23	2049
1995	8764	6543	0.45	1263
1996	10022	7690	0.55	2695
1997	11390	6674	0.89	3691
1998	10698	6509	0.61	1282
1999	11528	8403	0.66	3528
2000	11483	7498	0.50	1613
2001	10687	8509	0.74	1117
2002	8674	7210	0.50	1567
2003	8174	6285	0.84	410
2004	6009	4784	0.79	2549
2005	4653	3256	0.44	451
2006	4827	4030	0.71	952
2007	4578	3359	0.66	1339
2008	4537	3184	0.69	653
2009	4482	3385	0.99	501
2010	3338	2365	0.95	663
2011	2579	1628	1.31	1132
2012	1965	1071	1.92	672
2013	1743	1255	0.86	282
2014	2176	1596	0.72	1732
2015	2662	1577	0.39	375



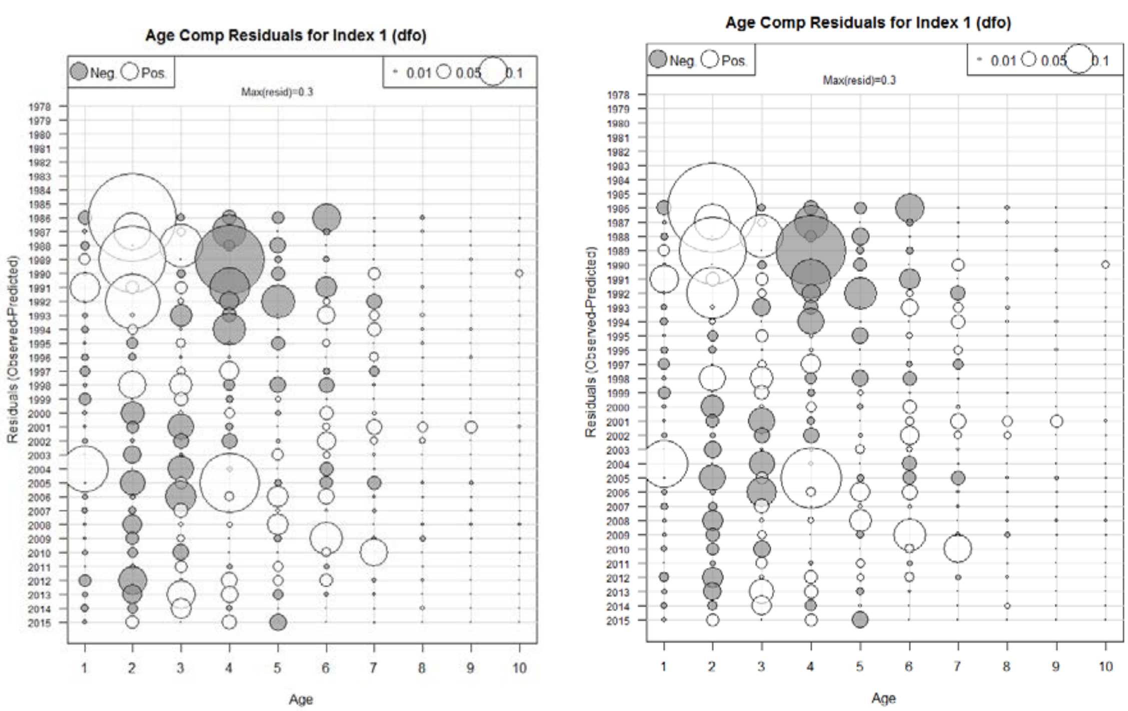
Appendix Figure 1. ASAP model fit to total catch of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1978-2015.



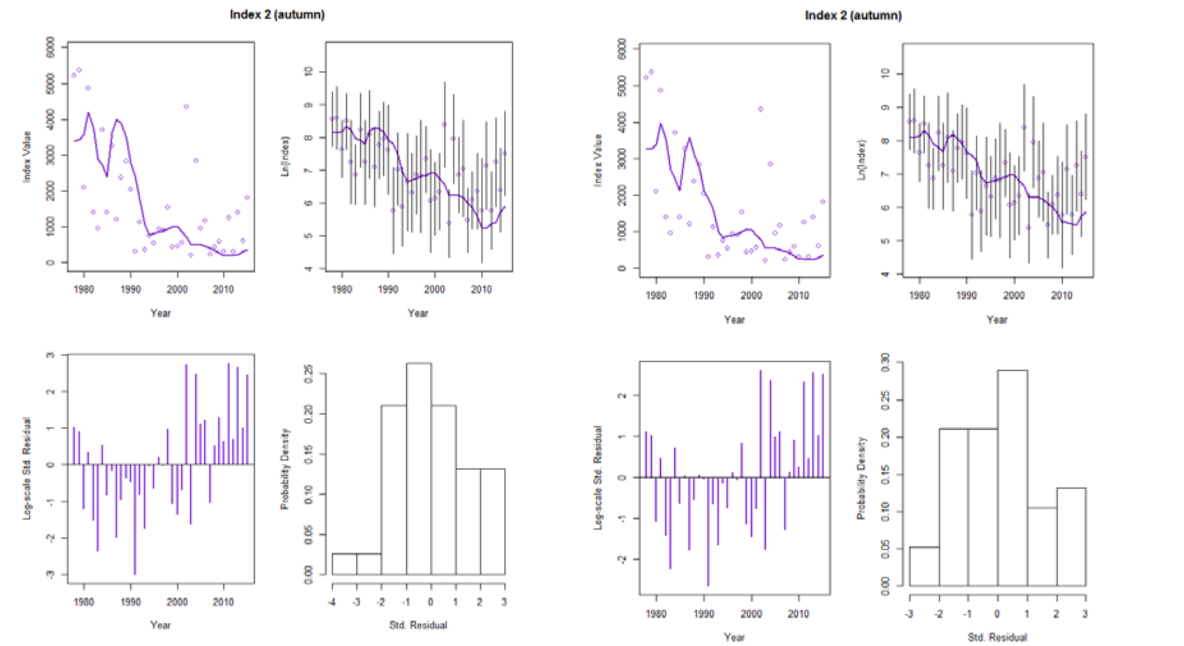
Appendix Figure 2. ASAP model residuals for the commercial catch age composition of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1978-2015.



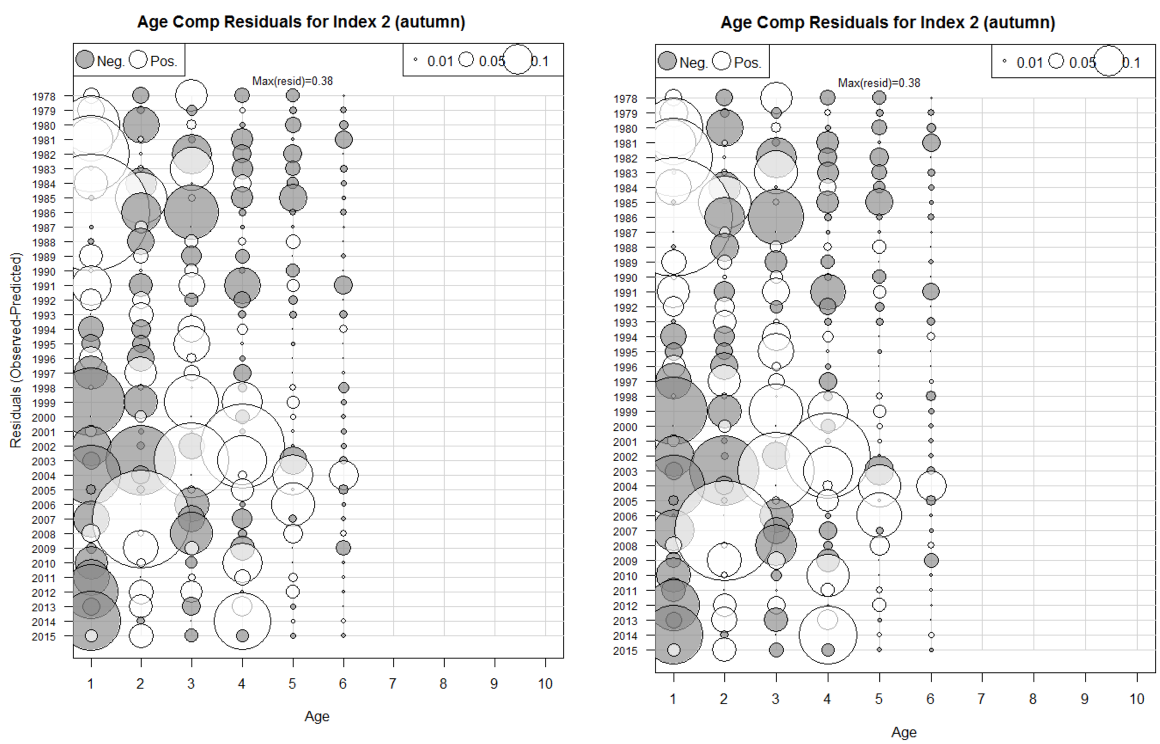
Appendix Figure 3. ASAP model fit to DFO survey indices of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1986-2015.



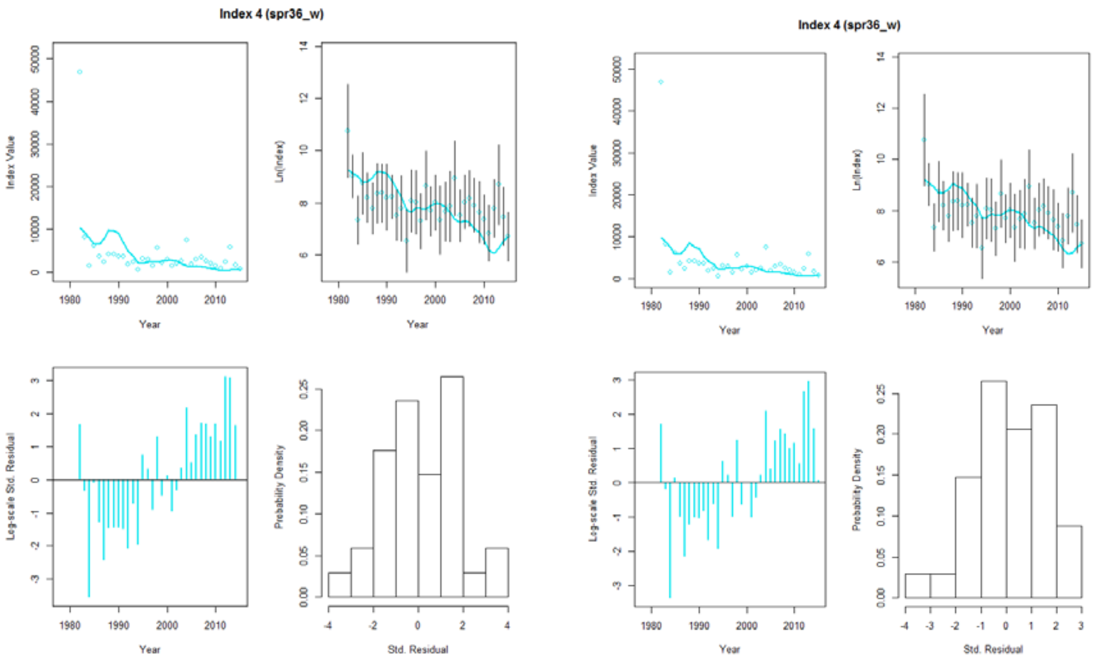
Appendix Figure 4. ASAP model run age composition residuals for DFO survey index of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1986-2015.



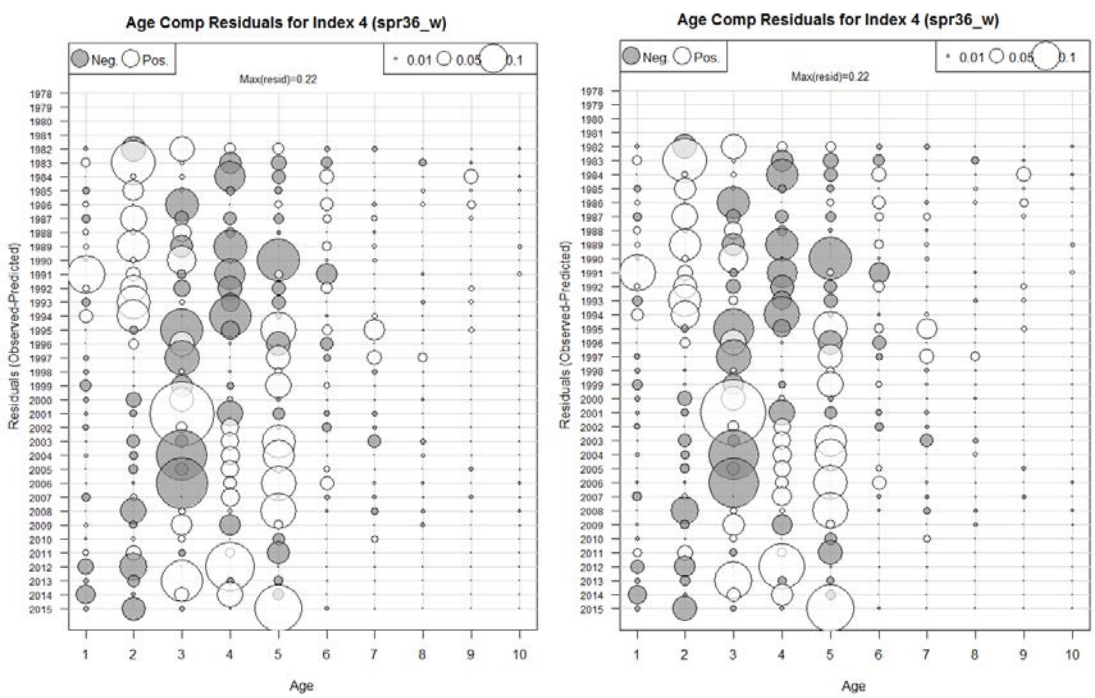
Appendix Figure 5. ASAP model fit to NEFSC autumn survey indices of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1978-2015.



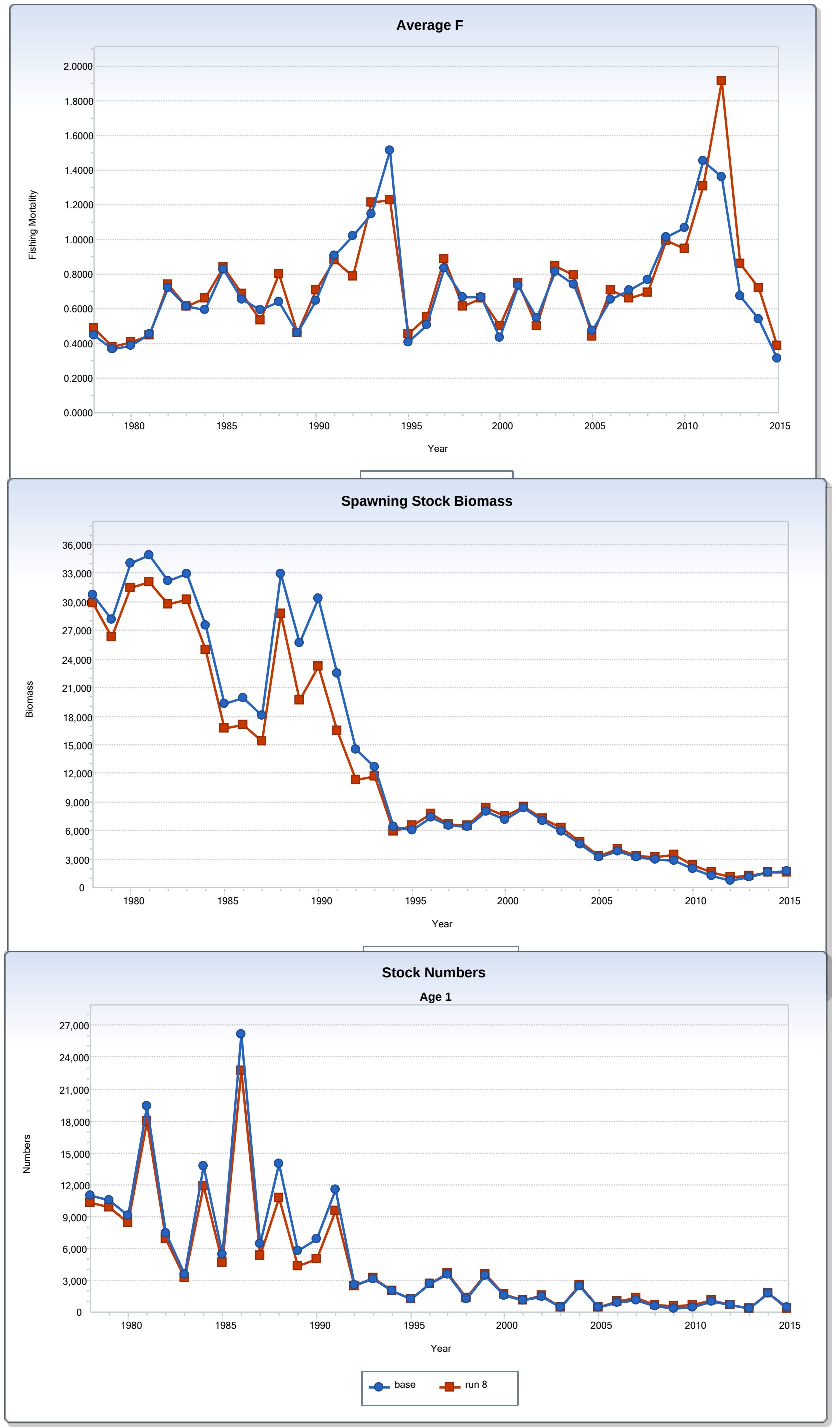
Appendix Figure 6. ASAP model age composition residuals for NEFSC autumn survey index of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1978-2015.



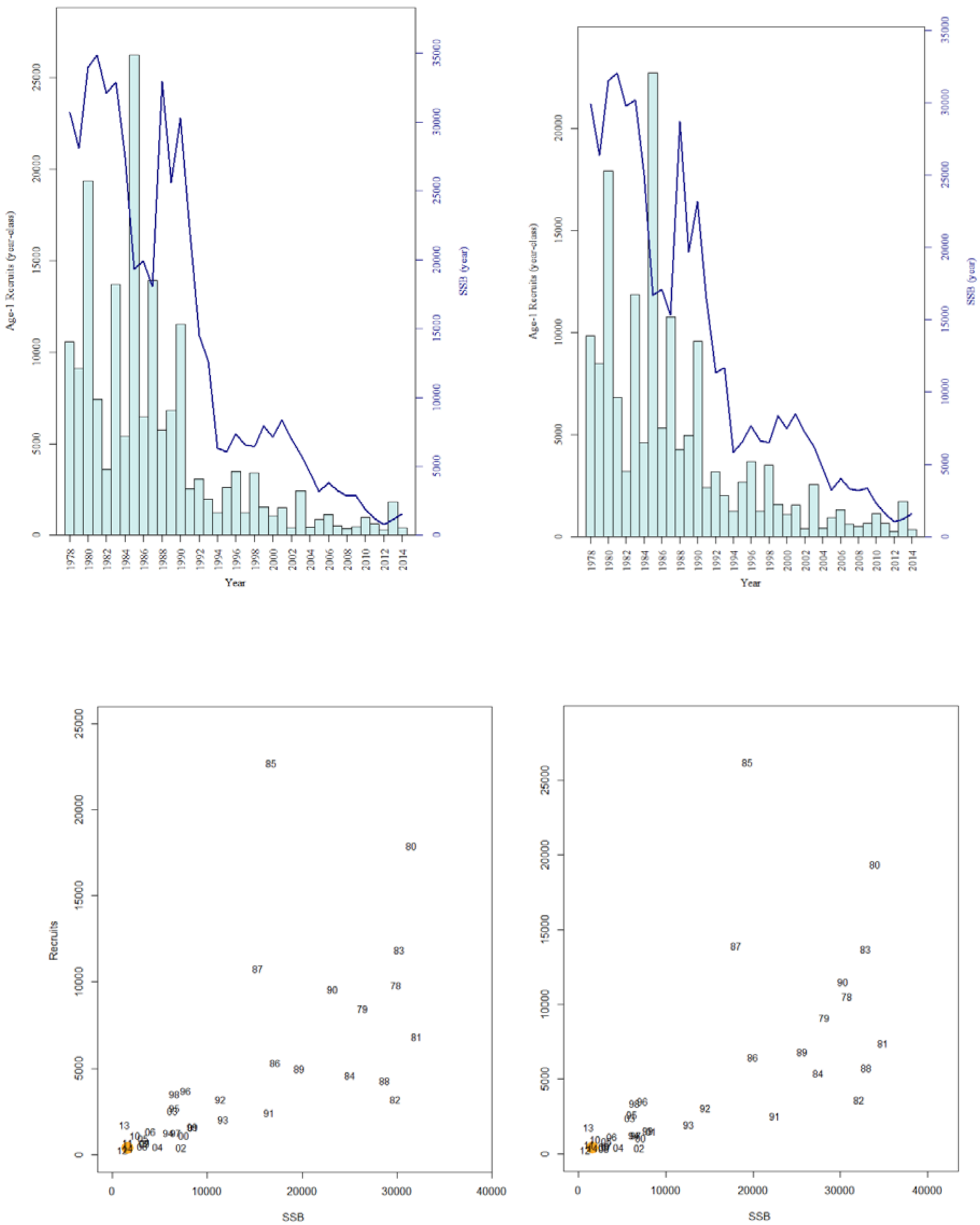
Appendix Figure 7. ASAP model fit to NEFSC spring Yankee #36 trawl survey indices of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1982-2015.



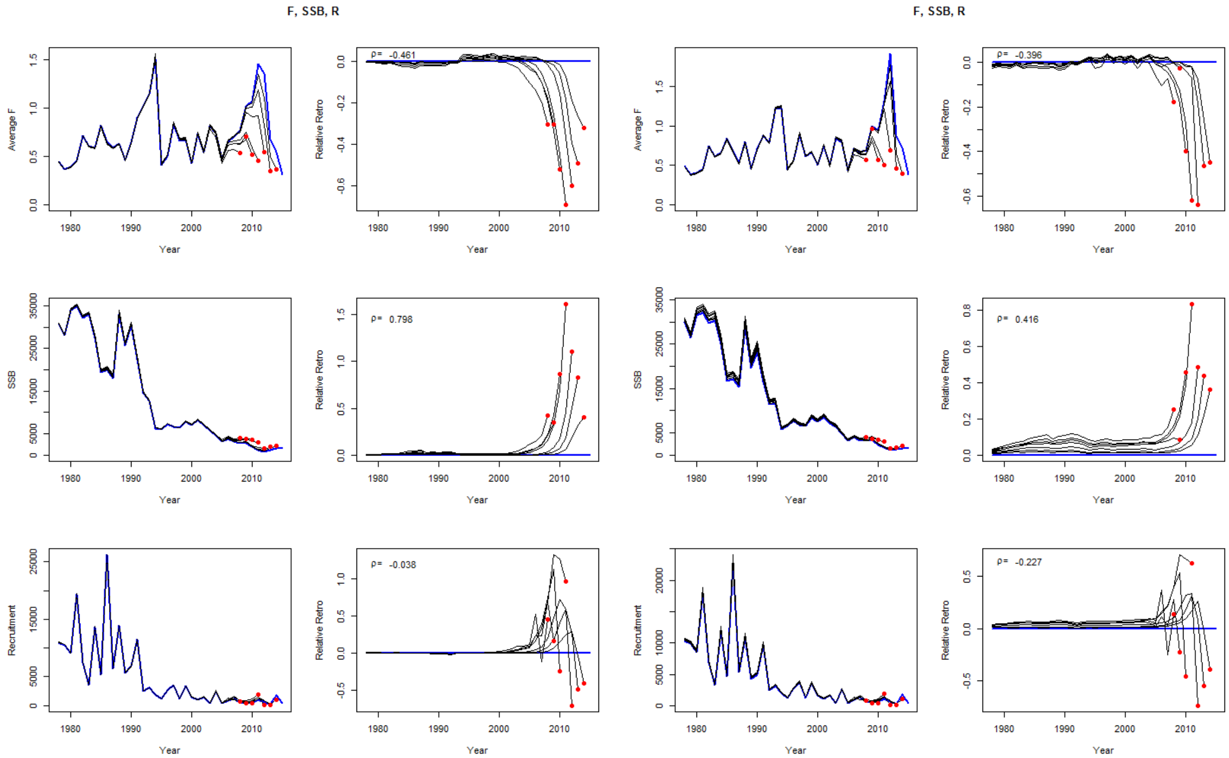
Appendix Figure 8. ASAP model age composition residuals for NEFSC spring Yankee #36 trawl survey index of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1982-2015.



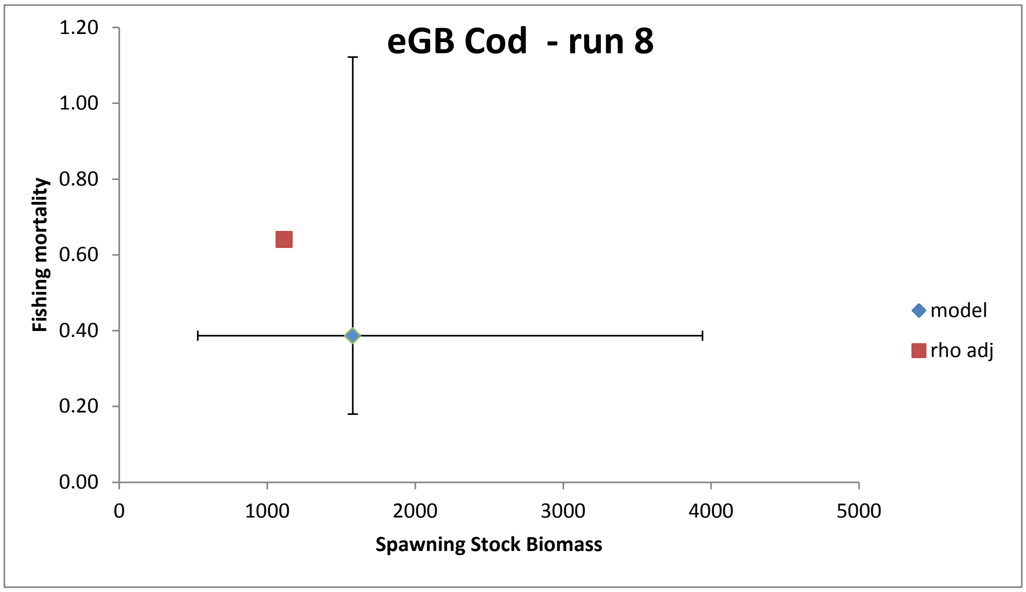
Appendix Figure 9. ASAP model results for fishing mortality (ages 5+), spawning stock biomass, and recruitment (age1, 000s fish), base and run 8, 1978-2015.



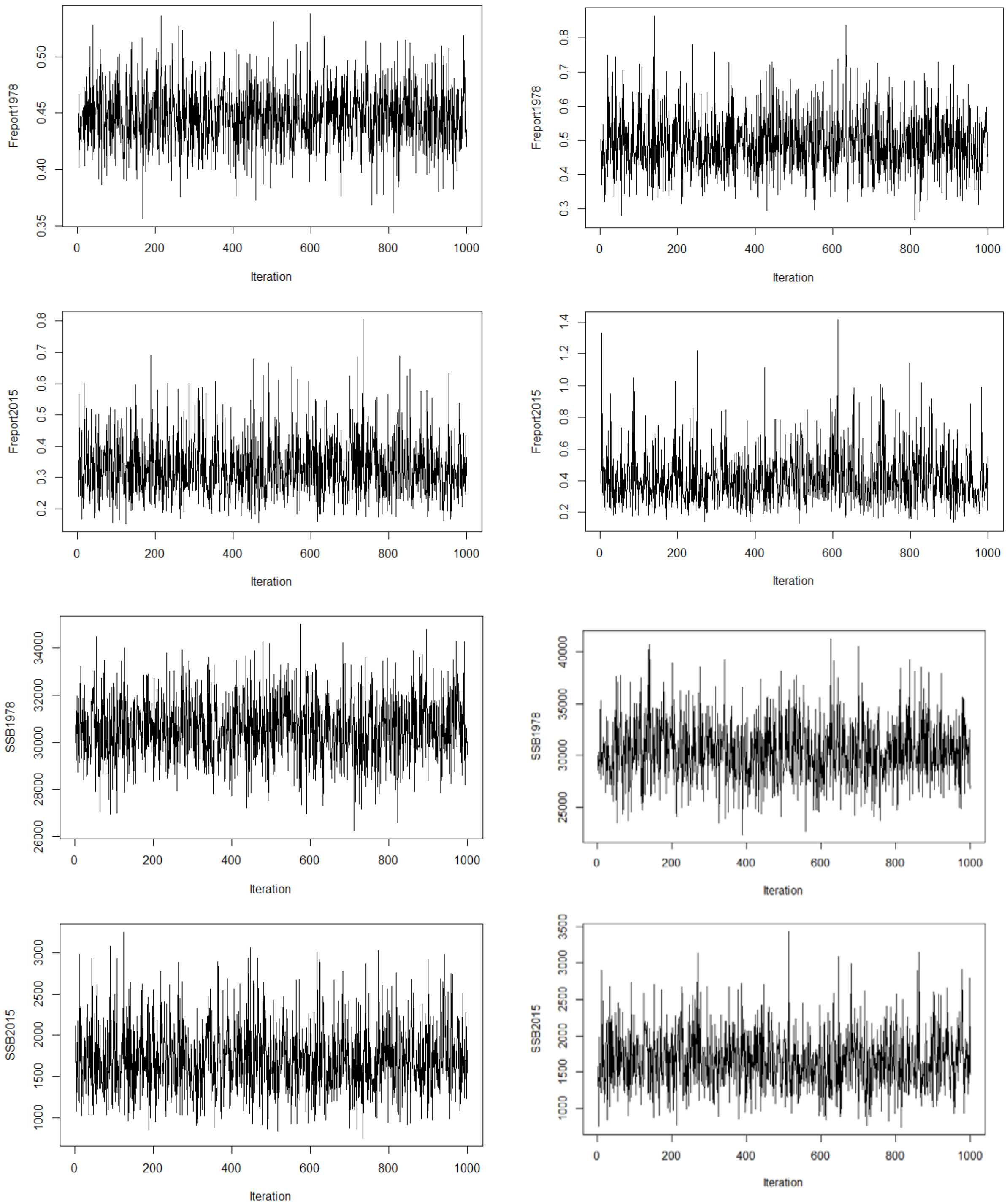
Appendix Figure 10. ASAP model results for spawning stock biomass (mt, line) and recruitment (age1, 000s fish, bars; upper panels) and the stock – recruitment plot (lower panels) with year-class designation, 1978-2015 ; base (left panels), run 8 (right panels).



Appendix Figure 11. ASAP model results of retrospective bias of fishing mortality (F), spawning stock biomass (SSB), and age1 recruitment; base (left panels), run 8 (right panels).



Appendix Figure 12. Terminal year 2015 ASAP estimates of spawning stock biomass (SSB) and fishing mortality (F) with respective 90% probability intervals, and the rho-adjusted value of SSB and F from ASAP run 8.



Appendix Figure 13. ASAP model results of trace of MCMC chains for eastern Georges Bank cod fishing mortality (top panels) and spawning stock biomass (bottom panels) for 1978 and 2015. 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; base (left panels), run 8 (right panels).