Fisheries and Oceans Canada / Pêches et Océans Canada

NOAA FISHERIES
NATIONAL MARINE FISHERIES SERVICE

CERT

Comité d'évaluation des ressources transfrontalières

Document de référence 2017/01
Ne pas citer sans
autorisation des auteurs

TRAC

Transboundary Resources Assessment Committee

Reference Document 2017/01
Not to be cited without
permission of the authors

Assessment of Eastern Georges Bank Atlantic Cod for 2017

R. Martin[1], C.M. Legault[2], Y. Wang[1], E.N. Brooks[2]

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

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

Ce document est disponible sur l'Internet à :

This document is available on the Internet at :

http://www.mar.dfo-mpo.gc.ca/science/TRAC/trac.html

Canada

ABSTRACT

The combined 2016 Canada/USA Atlantic cod catches were 537 mt with a quota of 625 mt. Catches in all three research surveys increased since the 2016 assessment. 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 and consideration of an empirical approach. 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 2017 was estimated at 13,944 mt, which was about 25% 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 2016. 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 2018, a 50% probability of not exceeding fishing reference point F=0.11 corresponds to catches of 1,270 mt. Due to the expected contribution of the strong 2013 year class, a catch of 1,270 mt is expected to result in a < 25% chance of seeing a decrease in adult biomass from 2018 to 2019. In 2019, a catch of 1,032 mt corresponds to a 50% probability of not exceeding F=0.11; however, even with no fishing in 2019 there is a 90% risk of a decrease in age 3+ biomass from 2019 to 2020 due to the 2013 year class entering the ages of high natural mortality. 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.

In 2016, an empirical method was developed as one of the approaches for providing quota advice for Eastern Georges Bank cod. This method adjusts recent quotas by recent population biomass trends from three research surveys. An increase in CV weighted survey biomass in 2016 (NMFS Fall) and 2017 (DFO and NMFS spring) resulted in a 2018 quota advice of 1,156 mt. The 25th and 75th percentiles produce quota advice of 1,133 mt and 1,164 mt, respectively.

Considering the low productivity of cod, despite model uncertainties, all assessment results indicate that low catches are needed to promote rebuilding.

INTRODUCTION

The 2017 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 2016, including commercial landings and discards, the Fisheries and Oceans Canada (DFO) survey updated to 2017, the National Marine Fisheries Services (NMFS) spring survey updated to 2017 and the NMFS fall survey updated to 2016.

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 2016 were 537 mt, including 17 mt of discards (Table 1; Figure 2). Catches included USA and Canadian discards in all years where discard estimates were available.

In 2016, total Canadian catch (extracted landings on May 23, 2017), including discards, was 440 mt against a quota of 488 mt, taken primarily between June and December by otter trawl and longline (Figures 3 and 4). All 2016 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 2016 were calculated as 3 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 2016, the estimated discards of cod by the Canadian scallop fishery were 9 mt (Table 1).

Total USA catch (landings and discards combined) was 97 mt for calendar year 2016 (Table 1; Figure 5). The majority of USA landings were taken by the second calendar quarter with the least amount landed during the fourth quarter (Figure 4). Otter trawl gear accounted for 67% and gillnet gear 33% of the 92 mt landings during 2016.

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 2016 (Table 1; Figure 5).

SIZE AND AGE COMPOSITION

The size and age compositions of the 2016 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 61 cm (24 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 55 cm (22 in) (Figure 8). The Canadian combined cod discards size composition by length was derived from at-sea sampling and peaked at 31 cm (12 in) (Figure 7, Figure 8).

Otoliths taken from port samples and surveys 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/). Catch-at-age composition was obtained by applying quarterly fishery age-length keys to the size composition.

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). Landings by length peaked at 56 cm (22 in) and discards by length peaked at 47 cm (19 in) in 2016 (Figure 9). The 2016 total catch composition peaked at 55 cm (22 in) for the Canadian fishery and at 56 cm (22 in) for the USA fishery (Figure 10).

The 2016 combined Canada/USA landings and discards fishery age composition, by number, was the highest for the 2013 year class at age 3 (47%) and the 2012 year class at age 4 (18%) (Table 3; Figure 11). By weight, the 2013 year class dominated the 2016 fishery (34%) followed by the 2011 year class (26%) (Figure 11). The contribution of age 7 and older fish continue to be low in recent years, amounting to 1.3% by number and 3% by weight in 2016 (Table 3; Figure 12).

Following a decline throughout the 1990s, fishery weights at age remained low throughout the 2000s (Table 4; Figure 13). Compared to 2015, the weights at age in 2016 decreased for all ages except ages 5 and 9.

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 Andrushchenko et al. (2016). In 2017, the DFO survey was conducted by the *CCGS Teleost* due to mechanical issues with the usual survey vessel, the *Alfred Needler*, which delayed the 2017 DFO survey by approximately 2-3 weeks relative to the usual timing. 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 also delayed by approximately one month due to mechanical issues with the research vessel. Consequently, the 2016 NMFS spring survey ages were not available at the time of the 2016 assessment, so the ALK from the 2016 DFO spring survey was applied. The 2016 NMFS spring survey ages were available for the 2017 assessment and were used to update 2016 NMFS spring survey data. Updating the 2016 NMFS spring ages resulted in a minimal impact on 2017 3+ biomass when compared to using the 2016 DFO ALK.

The spatial distribution of ages 3 and older cod caught during the 2016 NMFS fall, 2017 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 2017 DFO survey increased from 2016 to above the time series mean (1986-2017) (Table 5). The 2013 year class at age 4 contributed 71% by number, followed by the 2014 year class at age 3 (20%). The 2016 year class at age 1 contributed 0.06% of the catch and there was no catch of fish older than 7 (Table 5; Figure 19). The 2017 NMFS spring survey catch increased from 2016, but is still below the time series mean (1970-2017) (Table 6). The 2013 year class at age 4 was dominant (57% by number), followed by the 2012 year class at age 5 (17%) and 2014 year class at age 3 (10%). The 2016 NMFS fall survey catch increased from 2015 and is above the time series mean (1970-2016) (Table 7). The age 3 fish (2013 year class) dominated the catch by number (82%), followed by the 2014 year class at age 2 (8% 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). Survey abundance at age 1 and age 2 indicate that recruitment prior to 1990 was higher, with more frequent larger year classes (Figure 20). Since 1990, there have only been three noticeable recruitment events (2003, 2010, 2013), but the magnitude of these is far less than what was produced in the period before 1990. 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 21. The 2017 NMFS spring and 2016 NMFS fall surveys had smaller CVs compared to the 2017 DFO survey which had one of the highest values in the time series. The high variability in catches from the DFO 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 (Table 9; Figure 22). Swept area biomass from the 2017 NMFS spring and 2017 DFO surveys increased from 2016, but are still below their respective time series means (DFO: 1986-2017; NMFS spring: 1970-2017). The 2016 NMFS fall survey increased from 2015 to above the time series mean (1970-2016) (Table 9; Figure 22).

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 23). 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 24). In 2016, NMFS fall survey decreased from the series high in 2015, but remains above the long term mean. Cod condition from the 2017 NMFS spring survey was similar to 2016 and remains above the long term mean. The condition of cod in the DFO survey showed high variability and a slower rate of increase since 2009, reaching the series average in 2016 before decreasing again in 2017 (Figure 24).

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 25). It showed that Z of ages 4 and 5 has been generally lower than the older age group, except in 2015 and 2016 for the NMFS spring survey when Z has been higher for ages 4 and 5 (Figure 25). Total survey Z was also calculated using the Sinclair (2001) approach for all three surveys as was suggested for Georges Bank Yellowtail at the 2016 TRAC (Sinclair 2001; Brooks and Curran 2016). Age groups used in the calculation varied by survey

(DFO: ages 6-9; NMFS spring: ages 5-9; NMFS fall: ages 3-6). Recent Z values from the DFO and NMFS spring surveys remain high relative to earlier years, while Z from the NMFS fall survey continues to decrease (Figure 26). 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 27).

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 2016 (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*=1978-2016, 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… 2016.17, 2017.00.
>
> $I_{2,a,t}$ = 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… 2016.28, 2017.00.
>
> $I_{4,a,t}$ = NMFS fall survey for ages *a*=1 to 5 and time *t*=1978.69, 1979.69… 2015.69, 2016.69.

The population was calculated to the beginning of 2017; therefore the DFO and NMFS spring survey indices for 2017 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 2017 assessment, fishing mortality on age 9 for 1978-2013 and 2015-2016 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 and 2016 assessments).

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:

$v_{a,t} = lnN_{a,t} = ln$ population abundance for ages a=2 to 9 at beginning of 2017; age 9 in 2014.

$K_{1,a} = ln$ DFO survey catchability for ages a=1 to 8 at time t=1986-2017.

$K_{2,a} = ln$ 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=1982-2017.

$K_{4,a} = ln$ NMFS fall survey catchability for ages a=1 to 5 at time t=1978-2016.

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 2017, the population abundance estimate of the 2015 year classes at age 2 exhibited the largest relative bias of 11% and relative error of 57% (Table 11). The relative bias for other ages ranged between 0% and 10% and the relative error ranged between 24% and 50%. The population abundance of the 2005 year class at age 9 in 2014 was estimated as 0.08 million, with relative bias of 1% and relative error of 24%. 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 28).

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 29), though at-age residual patterns suggest obvious year effects (Figure 30). Average fishing mortality (F4-9) by time blocks for 1978-1993, 1994-2011 and 2012-2016 was 0.48, 0.26 and 0.08 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 31). 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 32); 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 2011-2017. The values for Mohn’s rho were 0.69 for SSB, -0.42 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 the 2015 and 2016 assessments (Figure 33). The average Mohn's rho was calculated for the seven retrospective relative differences in years 2011-2017 The values for Mohn's rho were 0.58 for SSB, -0.37 for F, and -0.08 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 2017assessments from the "M 0.8" model (Figure 34); 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.

Palmer (2017) indicated there was a high possibility of misreported U.S. fishery catch for eastern Georges Bank cod from 2010-2015. Although more research to quantify the misreported catch is planned, the errors in catch were not assumed in the current assessment VPA "M 0.8" model. The uncounted misreported catch would potentially impact the retrospective analysis, and subsequently impact characterizing stock status and providing catch advice.

STATE OF RESOURCE

The estimates presented below were from the 2017 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 35). 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, 2010 and 2013 year classes. The adult population biomass at the beginning of 2017 was estimated to be 13,944 mt (80% confidence interval: 11,257 – 17,896 mt) by the 2017 "M 0.8" model, or one-fourth of the 1978 biomass (Table 13; Figure 35). 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. The current estimate of the 2013 year class at 6 million fish is the highest estimated recruitment since 1990, but is still about half the average recruitment seen between 1978 and 1990 (Table 14; Figure 35). The 2017 "M0.8" model estimate of the 2003 year class at age 1 is 4.3 million fish, which is approximately two thirds of the current recruitment estimate for the 2013 year class (Table 14; Figure 35). The 2010 year class at age 1 is 3.2 million which is about half of the 2013 year class based on the 2017 assessment (Table 14). Recruitment for the 2002, 2004, 2007, 2012 and 2015 year classes are the lowest on record and the current biomass remains below the level above which chances of higher recruitment increase (Figure 36).

Fishing mortality (population number weighted average of ages 4-9) was high prior to 1994 (Table 15; Figure 37) but declined in 1995 to F=0.11 due to restrictive management measures. F in 2016 was estimated to be 0.05 (80% confidence interval: 0.044-0.067). The assessment showed that F has been declining since 2007 and has been at or below F=0.11 since 2012.

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 27), 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 35). 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 2018 and 2019 (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 2018 and 2019, as well as the change in adult biomass from 2018 to 2019 and from 2019 to 2020. 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 2017-2019 PR is based on the most recent five years of estimated PR (Table 16). The 2012-2016 average recruitment at age 1 is used for 2017-2020 projections. The uncertainties for this estimate are not reflected in the projection.

2018 Projection and Risk Analysis

Assuming a 2017 catch equal to the 730 mt total quota, both deterministic (Table 17) and stochastic (Table 18; Figure 38) projections based on F reference point 0.11 are provided. In 2018, a 50% risk of not exceeding F=0.11 corresponds to a catch of 1,270 mt, and a lower risk (25%) corresponds to a catch of 1,072 mt (Table 18; Figure 38). Due to the expected contribution of the 2013 year class, which is larger compared to other recent year classes, the higher catch of 1,270 mt results in a <25% chance of a biomass decrease from 2018 to 2019 (Table 18, Figure 38).

2019 Projection and Risk Analysis

Assuming a 2017 catch equal to the 730 mt total quota and a 2018 fishing mortality of 0.11, the deterministic projection for 2019 is shown in Table 17. In 2019, a 50% risk of not exceeding F=0.11 corresponds to a catch of 1,032 mt, while a lower risk (25%) corresponds to a catch of 892 mt (Table 18; Figure 39). Even with no fishing in 2019, there is a 90% risk of a decrease in adult biomass from 2019 to 2020 (Figure 39). This is due to the 2013 year class entering the ages of high natural mortality.

Consequence Analysis (Risks Associated with 2018-2019 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 2018, a catch of 1270 mt at F=0.11 would result in the 2019 biomass increasing by 1.8% in the VPA “true state” and decreasing by 0.2% in the ASAP “alternate state”. A catch of 636 mt at F_{ref}=0.18 would result in the 2019 biomass increasing by 15% based on the ASAP “true state” and an increase of 6% in the VPA “alternate state”.

In 2019, a catch of 1032 mt at F=0.11 would result in 2020 biomass decreasing by 12.8% in the VPA “true state” and increasing by 8.7% in the ASAP “alternate state”. A catch of 632 mt at Fref=0.18 would result in the 2020 biomass increasing by 16% based on the ASAP “true state”, and decreasing by 10.9% based on the VPA “alternate state”.

Empirical Approach for Providing Catch Advice

In 2016, an empirical method was developed as one of the approaches for providing quota advice for Eastern Georges Bank cod. This approach was developed collaboratively between the TRAC scientists and is described in Brooks *et al*. 2016. The empirical method adjusts recent quotas by recent population biomass trends from three research surveys (DFO spring, NMFS spring, and NMFS fall). The combined CV weighted biomass index from 1987 onward is fit by a robust least square *loess* smoother, and the slope in 3 year intervals is calculated (on log-scale). The most recent 3-year block trend is used to adjust recent quotas and uncertainty around the trend was derived by bootstrapping from the original loess fit. This method is essentially a constant exploitation approach, which relies on recent quotas.

The three normalized biomass indices are reported in Table 20 and are plotted in Figure 40. All three indices showed substantial increases from 2016 to 2017 (2015 to 2016 for fall). The 2017 NMFS spring and 2016 NMFS fall biomass indices are well above the series average while the DFO index is just below the series average. The combined biomass index increased in 2017 to the second highest in the time series (Table 20, Figure 41).

The *loess* fit and 90% confidence intervals from 1000 bootstrap replicates are shown in Figure 42. The estimated 3 year block slope and uncertainties are shown in Figure 43. The values of the median slope and other percentiles are reported in Table 21. Percentiles reflect uncertainty in the estimated 3-year average biomass trend from the robust loess smooth, rather than risk. The percentiles reflect the probability that the true average 3-year trend is within a given bound.

The recent three year average of quotas is 658.3 mt (700 mt in 2014; 650 mt in 2015; 625 mt in 2016). The median of bootstrap bias-adjusted slope estimates for survey years 2014-2016 (NMFS fall) and 2015-2017 (DFO and NMFS spring) is 1.76 using the robust regression fit. The 25th and 75th percentiles are 1.72 and 1.77, respectively. Applying the median slope to the recent average quota (658.3 mt) produces a 2018 quota advice of 1,156 mt. Applying the 25th and 75th percentiles of bootstrapped slope estimates produces quota advice of 1,133 mt and 1,164 mt, respectively (Table 22).

Model Performance

Catch in 2015 was 608 out of 650 mt. Projections assume the full quota will be caught. For the VPA assessment conducted in 2016 (Figure 44, top), the estimate of 2015 SSB (8,569 mt) was below the projected SSB from the previous year (10,042), indicating that the previous projection was optimistic (updated estimate was about 15% lower). For the ASAP assessment conducted in 2016 (Figure 44, top), the estimate of 2015 SSB was 1577 mt, while the SSB projected from the previous year was 1357, indicating that the previous projection underestimated biomass by about 16%. Catch in 2016 was 537 mt out of a 625 mt quota. The VPA conducted in 2017 (Figure 44, bottom) estimated a 14% increase in 2016 biomass compared to what was projected last year. The ASAP conducted in 2017 predicted a 40% increase in 2016 SSB compared to what was predicted last year; however, the retrospective pattern was large enough to warrant adjustment, and the ρ-adjusted SSB is just 2% greater than what was forecast last year.

SPECIAL CONSIDERATIONS

Table 23 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 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.

In 2016, the TRAC discussed the introduction of a threshold, or cap, on annual increases or decreases in catch advice produced from the empirical method. The purpose of a threshold was to maintain some stability in catches and avoid large fluctuations that could be due to a year effect, especially given that only 3 years are being used to estimate the slope. However, it was felt that there was insufficient justification for the 20% threshold therefore a cap was not accepted at the 2016 TRAC meeting (Brooks and Curran 2016). The 2018 catch advice derived from the empirical method is 1,156 mt which is a 58% increase from the 2017 quota of 730 mt. The lower bound (25th percentile) quota advice for 2018 is 1133 mt, an increase of 55% from 2017. Given productivity, which includes growth and recruitment, is low, and the stock has shown no signs of rebuilding, the TRAC recommends a threshold be considered for 2018 catch advice and that low risk quotas are appropriate for the cod resource.

ACKNOWLEDGEMENTS

We thank B. Hatt of DFO and N. Shepherd of NMFS for providing ageing information for the DFO and NMFS surveys and Canadian and USA fisheries and D. Frotten and K. Underhill of DFO and at sea observers from Javitech Ltd. for providing samples from the Canadian fishery.

REFERENCES

Andrushchenko, I., L. O'Brien, R. Martin and Y. Wang. 2016. Assessment of Eastern Georges Bank Cod for 2016. TRAC Ref. Doc. 2016/02: 89p.

Benoit, H.P. 2006. Standardizing the southern Gulf of St. Lawrence bottom trawl survey time series: Results of the 2004-2005 comparative fishing experiments and other recommendations for the analysis of the survey data. DFO Can. Sci. Advis. Sec.Res. Doc. 2006/008.

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

Brooks, E., I. Andrushchenko, Y. Wang and L. O'Brien. 2016. Developing an empirical approach for providing catch advice for Eastern Georges Bank cod. TRAC Red. Doc. 2016/04: 20p.

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

Claytor, R., and L. O’Brien. 2013. Transboundary Resources Assessment Committee Eastern Georges Bank cod benchmark assessment. TRAC Proceedings 2013/01.

Curran, K.J., and Brooks, E.N. Proceedings of the Transboundary Resource Assessment Committee for Eastern Georges Bank Cod and Haddock, and Georges Bank Yellowtail Flounder. TRAC Proceedings 2015/01.

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

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

Forrester, J.R.S., C.J. Byrne, M.J. Fogarty, M.P. Sissenwine, and E.W. Bowman. 1997. Background papers on USA vessel, trawl, and door conversion studies. SAW/SARC 24 Working Paper Gen 6. Northeast Fisheries Science Center, Woods Hole, MA.

Gavaris, S. 1988. An adaptive framework for the estimation of population size. CAFSAC Res. Doc. 88/29: 12p.

Gavaris S., and A. Sinclair. 1998. From fisheries assessment uncertainty to risk analysis for immediate management actions. *In*: Funk, F., Quin II, T.G., Heifetz, J., Ianelli, J.N., Powers, J.E., Schweigert, J.F., Sullivan, P.J., and Zhang, C.I. [editors]. Fishery Stock Assessment Models. Alaska Sea Grant College Program Report No. AK-SG-98-01. University of Alaska, Fairbanks.

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

Gavaris, S., L. Van Eeckhaute, and K. Clark. 2007a. Discards of cod from the 2006 Canadian groundfish fishery on eastern Georges Bank. TRAC Ref. Doc. 2007/02: 19p.

Gavaris, S., G. Robert, and L. Van Eeckhaute. 2007b. Discards of Atlantic cod, haddock and yellowtail flounder from the 2005 and 2006 Canadian scallop fishery on Georges Bank. TRAC Ref. Doc. 2007/03: 10p.

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

Morin, R. 2014. Testing the effect of alternative codend mesh sizes on the size and age composition of haddock in the trawl fishery on eastern Georges Bank. Groundfish Enterprise Allocation Council report.

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

O’Brien, L., and T. Worcester. 2009. Transboundary Resources Assessment Committee Eastern Georges Bank cod benchmark assessment. TRAC Proceedings 2009/02: 47p.O’Brien, L., and T. Worcester. 2014. Proceedings of the Transboundary Resources Assessment Committee for Eastern Georges Bank Cod and

Haddock, and Georges Bank Yellowtail Flounder. Report of Meeting held 23-26 June 2014. TRAC Proceedings 2014/02.

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

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

Sinclair, A.F. 2001. Natural mortality of cod (Gadus morhua) in the Southern Gulf of St. Lawrence. ICES Journal of Marine Science. 58: 1-10.

Van Eeckhaute, L., and S. Gavaris. 2004. Determination of discards of Georges Bank cod from species composition comparison. TRAC Ref. Doc. 2004/04: 27p.

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

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

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

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

Wang, Y., L. O'Brien, I. Andrushchenko and K. Clark. 2015. Assessment of Eastern Georges Bank Cod for 2015. TRAC Ref. Doc. 2015/03: 90p.

Wigley, S. E, M.C.Palmer, J. Blaylock, P.J.Rago. 2008 . A brief description of the discard estimation of the national bycatch report. NEFSC Ref. Doc 08-02: 35 p.

TABLES

Table 1. Catches (mt) of cod from eastern Georges Bank, 1978 to 2016.

	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
2016	428	9	3	440	92	5	97	537
Minimum	385	9	0	424	24	<1	40	464
Maximum	17,827	200	428	17,898	10,558	279	10,558	26,463
Average	5,068	74	90	5,186	3,172	64	3,139	8,325

[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 1987-2016; 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)
2016	715	149	76,869	990 (282)

[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 1978-2016.

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
2016	0	4	15	99	37	32	21	3	0.2	0.001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	210

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
2016	0.14	0.75	1.83	2.54	4.40	4.59	5.87	7.61	15.15	-	4.76
Min	0.14	0.64	1.52	2.30	2.99	3.44	4.23	5.70	5.33	5.23	3.42
Max	0.90	1.60	2.43	3.93	5.38	7.23	10.10	13.28	15.15	15.35	6.43
Avg.[1]	0.32	1.03	1.88	2.69	3.74	4.41	5.59	7.55	9.58	7.79	4.27

[1]for 2010-2016

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
2017	0	5	52	1660	5897	194	270	188	0	0	0	0	0	0	0	0	0	8266

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.

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	179	1,454	173	168	82	10	0	0	0	0	0	0	0	0	0	2074
2017	0	43	54	469	2681	808	502	165	0	0	0	0	0	0	0	0	0	4274

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
2016	2	9	219	2123	50	143	51	0	0	0	0	0	0	0	0	0	0	2597

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	6.16	0.43	3.77	0.22	9.12	0.23
1971	-	-	-	-	3.02	0.26	7.73	0.42	3.41	0.37	9.54	0.30
1972	-	-	-	-	7.95	0.19	10.21	0.22	6.65	0.59	7.12	0.40
1973	-	-	-	-	60.20	0.64	61.01	0.55	9.16	0.33	22.04	0.45
1974	-	-	-	-	16.18	0.28	20.21	0.28	1.72	0.41	5.27	0.42
1975	-	-	-	-	10.96	0.17	24.23	0.16	2.89	0.41	9.46	0.44
1976	-	-	-	-	6.16	0.25	8.18	0.23	10.97	0.44	9.77	0.32
1977	-	-	-	-	4.79	0.15	6.92	0.22	6.97	0.19	17.15	0.17
1978	-	-	-	-	6.94	0.26	16.85	0.27	7.80	0.24	22.03	0.24
1979	-	-	-	-	4.90	0.21	9.51	0.22	8.13	0.32	23.54	0.25
1980	-	-	-	-	8.87	0.37	16.21	0.32	3.54	0.27	8.11	0.28
1981	-	-	-	-	11.18	0.22	22.77	0.18	7.64	0.26	13.09	0.26
1982	-	-	-	-	68.83	0.83	204.64	0.89	1.63	0.52	4.00	0.41
1983	-	-	-	-	9.48	0.13	15.10	0.24	2.22	0.29	4.42	0.43
1984	-	-	-	-	1.87	0.20	3.80	0.22	4.32	0.43	12.66	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	34.98	0.30	7.20	0.42	9.28	0.42
1990	31.60	0.18	136.44	0.26	8.72	0.42	32.32	0.30	5.10	0.58	9.24	0.70
1991	18.96	0.16	60.36	0.16	9.04	0.15	27.14	0.17	0.91	0.55	0.97	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	1.09	0.58
1994	9.32	0.32	31.64	0.50	1.75	0.37	3.98	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	18.51	0.54	0.67	0.36	1.10	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	2.81	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	0.57	4.69	0.31	9.81	0.33
2017	19.90	0.68	35.07	0.60	8.52	0.39	24.31	0.49	-	-	-	-

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	5,438	3,579	3,656
2017	-	13,479	14,566

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	0.132	0.912	1.157	2.157	3.163	4.334	4.997	6.005	7.050	11.607
2017	0.067	0.545	1.238	2.070	3.166	4.237	4.510	6.224	7.050	11.607
Average	0.097	0.740	1.614	2.538	3.723	5.024	6.432	7.799	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 2017 (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]	82	20	24%	1%
2	N[2017 2]	269	153	57%	11%
3	N[2017 3]	1960	984	50%	10%
4	N[2017 4]	3261	1121	34%	4%
5	N[2017 5]	286	104	36%	6%
6	N[2017 6]	482	147	30%	4%
7	N[2017 7]	423	129	30%	4%
8	N[2017 8]	57	19	33%	5%
9	N[2017 9]	27	7	26%	2%
10	DFO age 1	0.01	0.003	22%	3%
11	DFO age 2	0.11	0.02	19%	1%
12	DFO age 3	0.55	0.10	19%	1%
13	DFO age 4	0.95	0.19	20%	3%
14	DFO age 5	1.02	0.20	19%	2%
15	DFO age 6	0.92	0.17	19%	3%
16	DFO age 7	0.82	0.16	20%	2%
17	DFO age 8	1.11	0.22	20%	2%
18	NMFS Spring Y41 age 1	0.02	0.00	66%	15%
19	NMFS Spring Y41 age 2	0.19	0.02	86%	20%
20	NMFS Spring Y41 age 3	0.22	0.06	67%	19%
21	NMFS Spring Y41 age 4	0.21	0.10	63%	15%
22	NMFS Spring Y41 age 5	0.31	0.10	72%	19%
23	NMFS Spring Y41 age 6	0.30	0.08	71%	16%
24	NMFS Spring Y41 age 7	0.38	0.18	63%	15%
25	NMFS Spring Y41 age 8	0.33	0.16	68%	16%
26	NMFS Spring Y36 age 1	0.02	0.01	22%	1%
27	NMFS Spring Y36 age 2	0.11	0.04	19%	2%
28	NMFS Spring Y36 age 3	0.34	0.07	18%	1%
29	NMFS Spring Y36 age 4	0.54	0.08	18%	1%
30	NMFS Spring Y36 age 5	0.54	0.10	18%	1%
31	NMFS Spring Y36 age 6	0.42	0.11	19%	1%
32	NMFS Spring Y36 age 7	0.39	0.09	19%	2%
33	NMFS Spring Y36 age 8	0.44	0.10	22%	2%
34	NMFS Fall age 1	0.05	0.01	17%	2%
35	NMFS Fall age 2	0.09	0.03	17%	2%
36	NMFS Fall age 3	0.14	0.05	17%	1%
37	NMFS Fall age 4	0.10	0.05	17%	2%
38	NMFS Fall age 5	0.09	0.05	19%	2%

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	0.09	-0.07	-0.03
2	-0.45	0.23	-0.28
3	-0.51	0.52	-0.50
4	-0.39	0.89	-0.48
5	0.83	1.17	-0.62
6	0.01	0.94	-0.52
7	0.26	1.18	-0.49
Mohn's Rho	**-0.02**	**0.69**	**-0.42**

b)

Peel	Age-1	3+ Biomass	F
1	0.11	-0.06	-0.04
2	-0.43	0.26	-0.30
3	-0.49	0.54	-0.49
4	-0.37	0.93	-0.53
5	0.66	1.02	-0.64
6	-0.08	0.77	-0.42
7	0.04	0.63	-0.16
Mohn's Rho	**-0.08**	**0.58**	**-0.37**

Table 13. Beginning of year population biomass (mt) for eastern Georges Bank cod during 1978-2017 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2017. The dash (-) at age 1 in 2017 indicates that age 1 in the final year is not estimated in the model.

Year	Age										
	1	2	3	4	5	6	7	8	9	10+	1+	3+
1978	1391	2962	17458	14216	7106	4461	5335	946	1135	1463	56474	52120
1979	1174	8843	4591	16585	10125	3742	4220	4264	729	2098	56372	46354
1980	2778	6032	14275	4181	16615	8341	2526	2623	3132	2289	62791	53981
1981	1654	7011	11170	15681	4761	11839	6296	3330	2431	4181	68356	59691
1982	524	12411	13223	10171	10866	3433	7952	4124	1382	4906	68993	56058
1983	1144	5256	15969	7040	4992	7152	2137	3897	2561	4256	54402	48003
1984	719	2420	6058	11564	3744	3299	3635	981	2117	4143	38681	35542
1985	460	7538	6160	5816	10057	3773	2802	2528	774	3778	43685	35687
1986	3159	3319	12155	4375	4397	7369	2139	1462	1188	2994	42557	36080
1987	1236	16626	5312	9886	3332	3178	4866	1161	912	3244	49754	31891
1988	2151	6260	22149	5426	8270	2095	1932	3283	1311	3270	56148	47736
1989	730	9609	8947	17662	3711	5529	1198	654	1648	2771	52459	42120
1990	1599	3296	16299	10337	15103	3006	3177	746	444	2889	56895	52000
1991	847	5457	5412	14108	8434	7858	2108	1672	530	2203	48628	42324
1992	464	6637	8366	3820	8011	5025	4523	1154	775	1810	40584	33483
1993	331	2797	7577	6141	3192	4604	2732	1843	653	1774	31645	28516
1994	509	2533	2791	4395	3626	2325	2341	1737	1083	1705	23046	20003
1995	383	2311	4752	2606	2310	2388	746	826	840	1320	18482	15789
1996	315	1435	3619	5811	3383	2749	1181	547	528	1024	20592	18842
1997	1069	2104	2314	3694	4744	3951	1013	867	184	720	20659	17485
1998	170	2991	3138	2109	3239	3997	1356	386	257	392	18034	14874
1999	538	1779	4960	3527	1842	3391	2028	742	119	324	19251	16933
2000	114	3558	2196	5985	3194	1825	1882	851	362	206	20173	16501
2001	12	1190	4529	2670	6353	3424	1103	873	389	212	20755	19553
2002	37	480	1416	4890	2323	4761	1376	433	408	237	16361	15844
2003	9	847	896	1585	4152	1479	1986	578	134	254	11917	11062
2004	92	133	2240	1246	1626	3073	628	744	265	163	10209	9984
2005	36	2043	428	2009	836	836	981	330	218	148	7863	5785
2006	103	155	3196	408	1961	591	426	419	73	191	7521	7263
2007	77	1715	426	3650	373	1791	308	205	231	119	8895	7103
2008	23	672	3185	550	3294	297	592	131	90	152	8987	8292
2009	131	293	1342	4148	448	3009	130	239	40	92	9872	9448
2010	94	610	460	1258	3968	331	1172	39	82	52	8065	7362
2011	120	465	860	315	749	3404	122	495	8	74	6612	6027
2012	34	1308	892	1126	129	465	2093	46	238	38	6369	5028
2013	22	928	2488	1046	1065	38	172	964	19	245	6988	6038
2014	473	352	1348	2867	1178	1441	4	110	568	124	8464	7640
2015	114	2401	557	1913	3365	1020	752	1.4	53	476	10651	8137
2016	39	1975	4540	800	1903	4061	620	359	0.6	250	14548	12533
2017	-	130	2177	6470	855	1966	1838	336	189	113	14225	13944

Table 14. Beginning of year population abundance (numbers in thousands) for eastern Georges Bank cod during 1978-2017 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2017. 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	17481	8224	6117	4692	958	1725	769	262	216	286	40731
1982	5693	14281	5958	3334	2641	534	986	467	128	335	34359
1983	5107	4648	8533	3111	1594	1190	262	450	243	291	25428
1984	14264	4161	3100	4733	1387	801	617	109	206	283	29662
1985	5273	11663	3199	1815	2660	647	319	256	55	258	26145
1986	24077	4309	6978	1360	894	1293	288	163	111	205	39678
1987	8242	19675	3122	3681	588	424	651	174	90	222	36869
1988	14133	6728	12407	1797	1984	334	229	376	106	223	38317
1989	5133	11551	5248	6402	862	860	157	84	146	189	30630
1990	7451	4186	8844	3566	3462	501	370	78	33	197	28688
1991	9650	6086	2773	4454	1988	1605	279	166	53	151	27205
1992	3653	7843	4090	1368	1924	820	648	135	74	124	20679
1993	4723	2929	4108	2113	707	782	390	250	70	121	16193
1994	3561	3858	1948	1672	917	312	319	201	118	116	13021
1995	2093	2910	2994	1161	665	508	111	104	71	90	10708
1996	3592	1713	2331	2238	866	450	216	45	44	70	11565
1997	5629	2936	1366	1697	1474	637	163	89	18	49	14059
1998	2177	4600	2271	934	1068	885	233	50	31	27	12275
1999	4862	1777	3675	1576	620	732	311	90	14	22	13679
2000	1888	3973	1384	2573	988	409	290	104	31	14	11653
2001	1188	1543	3195	1033	1764	673	160	116	39	18	9728
2002	2347	970	1166	2155	657	1086	235	51	41	20	8728
2003	563	1921	785	842	1363	440	388	86	17	22	6427
2004	4262	461	1541	509	471	752	146	118	27	14	8300
2005	622	3469	366	1135	281	254	249	43	34	13	6466
2006	3353	506	2776	259	748	186	92	89	13	16	8038
2007	1425	2742	397	2070	142	437	53	30	29	10	7335
2008	496	1165	2197	269	1315	86	142	17	9	13	5709
2009	1142	405	913	1671	166	853	29	43	5	8	5234
2010	1181	928	292	568	1243	95	296	7	13	4	4626
2011	3155	964	721	155	277	950	33	110	2	6	6373
2012	1656	2575	750	522	44	124	410	7	45	3	6137
2013	762	1354	2047	519	383	11	40	180	3	21	5319
2014	5951	623	1084	1574	378	304	1	17	81	11	10024
2015	2646	4869	495	813	1196	284	134	0.2	7	41	10486
2016	297	2165	3926	371	602	937	124	60	0.1	22	8502
2017	-	239	1759	3125	270	464	408	54	27	10	8593

Table 15. Annual fishing mortality rate 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.

Year	Age									
	1	2	3	4	5	6	7	8	9	10+	F4-9
1978	0.00	0.04	0.46	0.39	0.40	0.29	0.26	0.26	0.26	0.11	0.36
1979	0.00	0.10	0.36	0.36	0.31	0.32	0.20	0.19	0.20	0.05	0.33
1980	0.00	0.13	0.27	0.25	0.41	0.35	0.29	0.10	0.21	0.16	0.33
1981	0.00	0.12	0.41	0.37	0.38	0.36	0.30	0.51	0.35	0.10	0.37
1982	0.00	0.32	0.45	0.54	0.60	0.51	0.58	0.45	0.54	0.18	0.56
1983	0.00	0.20	0.39	0.61	0.49	0.46	0.67	0.58	0.62	0.30	0.55
1984	0.00	0.06	0.34	0.38	0.56	0.72	0.68	0.49	0.65	0.31	0.48
1985	0.00	0.31	0.66	0.51	0.52	0.61	0.47	0.63	0.55	0.17	0.53
1986	0.00	0.12	0.44	0.64	0.54	0.49	0.30	0.39	0.33	0.07	0.53
1987	0.00	0.26	0.35	0.42	0.36	0.42	0.35	0.29	0.34	0.06	0.40
1988	0.00	0.05	0.46	0.53	0.64	0.55	0.81	0.75	0.77	0.20	0.61
1989	0.00	0.07	0.19	0.41	0.34	0.64	0.50	0.73	0.58	0.17	0.44
1990	0.00	0.21	0.49	0.38	0.57	0.38	0.60	0.19	0.53	0.18	0.47
1991	0.01	0.20	0.51	0.64	0.69	0.71	0.53	0.61	0.56	0.22	0.66
1992	0.02	0.45	0.46	0.46	0.70	0.54	0.75	0.46	0.70	0.11	0.61
1993	0.00	0.21	0.70	0.63	0.62	0.70	0.47	0.55	0.50	0.19	0.62
1994	0.00	0.05	0.32	0.72	0.39	0.23	0.32	0.24	0.29	0.03	0.51
1995	0.00	0.02	0.09	0.09	0.19	0.05	0.10	0.06	0.08	0.00	0.11
1996	0.00	0.03	0.12	0.22	0.11	0.21	0.09	0.12	0.10	0.01	0.18
1997	0.00	0.06	0.18	0.26	0.31	0.21	0.39	0.24	0.34	0.05	0.28
1998	0.00	0.02	0.17	0.21	0.18	0.24	0.15	0.47	0.21	0.12	0.21
1999	0.00	0.05	0.16	0.27	0.22	0.13	0.30	0.25	0.29	0.05	0.23
2000	0.00	0.02	0.09	0.18	0.18	0.14	0.12	0.19	0.14	0.07	0.17
2001	0.00	0.08	0.19	0.25	0.29	0.25	0.33	0.24	0.30	0.08	0.27
2002	0.00	0.01	0.13	0.26	0.20	0.23	0.20	0.28	0.22	0.26	0.24
2003	0.00	0.02	0.23	0.38	0.39	0.31	0.39	0.37	0.39	0.12	0.38
2004	0.01	0.03	0.11	0.39	0.42	0.30	0.42	0.45	0.43	0.25	0.37
2005	0.01	0.02	0.15	0.22	0.22	0.21	0.22	0.41	0.25	0.20	0.22
2006	0.00	0.04	0.09	0.40	0.34	0.45	0.32	0.33	0.32	0.19	0.36
2007	0.00	0.02	0.19	0.25	0.30	0.32	0.37	0.41	0.38	0.09	0.27
2008	0.00	0.04	0.07	0.28	0.23	0.28	0.40	0.44	0.40	0.11	0.26
2009	0.01	0.13	0.27	0.09	0.36	0.25	0.59	0.41	0.48	0.13	0.17
2010	0.00	0.05	0.43	0.52	0.06	0.25	0.18	0.74	0.19	0.12	0.21
2011	0.00	0.05	0.12	1.05	0.59	0.04	0.70	0.09	0.23	0.05	0.26
2012	0.00	0.03	0.16	0.10	1.22	0.33	0.02	0.18	0.02	0.01	0.14
2013	0.00	0.02	0.06	0.11	0.03	1.69	0.06	0.01	0.01	0.005	0.08
2014	0.00	0.03	0.08	0.07	0.08	0.02	0.51	0.01	0.00	0.00	0.06
2015	0.00	0.01	0.08	0.09	0.04	0.03	0.01	0.19	0.01	0.01	0.06
2016	0.01	0.01	0.03	0.11	0.05	0.03	0.03	0.00	0.02	0.00	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										
2017-2019	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)										
2017-2019	0.01	0.19	0.64	1.00	0.77	0.68	0.25	0.10	0.10	0.06
Fishery Weight at Age										
2017-2019	0.29	0.97	1.97	2.78	3.96	4.72	6.58	9.72	12.78	11.61
Population Beginning of Year Weight at Age										
2017	0.07	0.54	1.24	2.07	3.17	4.24	4.51	6.22	7.05	11.61
2018-2020	0.08	0.65	1.17	2.19	3.05	4.05	5.04	6.11	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													
2017	0.001	0.012	0.037	0.062	0.05	0.043	0.012	0.006	0.006	0.006	-	-	-
2018	0.001	0.022	0.066	0.11	0.088	0.077	0.022	0.011	0.011	0.011	-	-	-
2019	0.001	0.022	0.066	0.11	0.088	0.077	0.022	0.011	0.011	0.011	-	-	-
Projected Population Numbers													
2017	2237	239	1759	3125	270	464	408	54	27	10	-	-	-
2018	2237	1830	194	1388	2405	210	200	181	24	16	-	-	-
2019	2237	1829	1466	148	1018	1803	88	88	80	18	-	-	-
2020	2237	1829	1465	1124	109	763	750	38	39	44	-	-	-
Projected Population Biomass													
2017	157	129	2181	6469	856	1968	1838	336	189	113	-	14078	13949
2018	179	1190	226	3039	7334	852	1006	1105	170	189	-	15112	13922
2019	179	1189	1715	325	3104	7302	441	536	567	209	-	15387	14198
2020	179	1189	1714	2461	332	3090	3780	235	275	507	-	13584	12395
Projected Catch Numbers													
2017	1	3	58	171	12	14	3	0	0	0	-	-	-
2018	2	36	11	131	184	11	3	1	0	0	-	-	-
2019	2	36	85	14	78	92	1	1	1	0	-	-	-
Projected Catch Biomass													
2017	0	3	115	474	47	64	23	2	1	0	730	-	-
2018	1	35	22	365	728	51	20	13	2	1	1238	-	-
2019	1	35	167	39	308	436	9	6	8	2	1011	-	-

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 2018 and 2019; and b) risk of ages 3+ biomass will not increase from 2018 to 2019 and from 2019 to 2020.

a)

Probability	0.25	0.5	0.75
2018	1,072 mt	1,270 mt	1,488 mt
2019(F_{2018}=0.11)	892 mt	1,032 mt	1,192 mt

b)

Probability	0.25	0.5	0.75
2018 to 2019	1,288 mt	1,558 mt	1,854 mt
2019 to 2020 (F_{2018}=0.11)	0 mt	0 mt	0 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 2018-2020 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 2016		537 mt		
Quota 2017		730 mt		
			VPA 0.8	**ASAP**
2016 biomass (3+)			12,533	3,539
2017 biomass (3+)			13,944	3,684
Projected catch				
VPA F=0.11 at neutral risk			"true state"	"alternate state"
2018 catch = 1270 mt		2018 F	0.11	0.39
		2019 Biomass (mt)	14,169	3,676
		% B from 2018	1.8%	-0.2%
2019 catch = 1032 mt		2019 F	0.11	0.39
		2020 Biomass (mt)	12,355	3,996
		% B from 2019	-12.8%	8.7%
ASAP F=0.18			"alternate state"	"true state"
2018 catch = 636 mt		2018 F	0.055	0.18
		2019 Biomass (mt)	14,756	4,238
		% B from 2018	6.0%	15%
2019 catch = 632 mt		2019 F	0.065	0.18
		2020 Biomass (mt)	13,141	4,925
		% B from 2019	-10.9%	16%
(green)		F<=Fref & biomass increase > 10%		
(blue)		F< =Fref & biomass increase < 10%		
(pink)		F> Fref and biomass increase < 10%		
(grey)		F> Fref and biomass increase > 10%		

Table 20. Normalized ('Norm') swept area biomass indices and their associated coefficients of variation (CV), and the combined index and its CV.

	NMFS Fall		NMFS Spring		DFO		Combined	
Year	Norm	CV	Norm	CV	Norm	CV	Norm	CV
1987	0.84	0.50	1.10	0.27	0.57	0.36	0.87	0.20
1988	1.02	0.50	1.35	0.35	1.27	0.32	1.23	0.21
1989	2.61	0.48	1.75	0.32	0.95	0.21	1.55	0.21
1990	1.98	0.45	1.57	0.31	3.69	0.28	2.52	0.20
1991	1.97	0.73	1.36	0.19	1.63	0.25	1.54	0.18
1992	0.17	0.56	0.89	0.22	0.95	0.25	0.78	0.16
1993	0.67	0.49	0.96	0.33	1.08	0.23	0.95	0.18
1994	0.23	0.61	0.19	0.33	0.86	0.51	0.40	0.35
1995	0.67	0.85	1.47	0.50	0.53	0.35	0.86	0.33
1996	0.47	0.64	0.96	0.43	2.09	0.31	1.36	0.24
1997	0.69	0.46	0.59	0.24	0.72	0.27	0.66	0.18
1998	0.72	0.99	1.78	0.48	0.33	0.23	0.79	0.33
1999	1.15	0.32	0.77	0.26	0.60	0.36	0.84	0.18
2000	0.40	0.68	1.07	0.28	2.10	0.46	1.25	0.27
2001	0.35	0.39	0.54	0.46	1.17	0.45	0.67	0.29
2002	0.45	0.61	0.64	0.28	1.32	0.43	0.81	0.25
2003	4.44	0.69	0.93	0.55	0.40	0.20	1.22	0.45
2004	0.23	0.48	3.05	0.63	0.37	0.30	0.94	0.47
2005	3.22	0.80	0.64	0.25	1.71	0.60	1.37	0.39
2006	0.56	0.47	1.06	0.28	0.82	0.30	0.85	0.19
2007	0.83	0.81	0.88	0.30	0.73	0.28	0.81	0.21
2008	0.16	0.41	0.77	0.28	0.89	0.29	0.66	0.19
2009	0.31	0.34	0.63	0.33	1.51	0.68	0.68	0.33
2010	0.46	0.42	0.52	0.24	1.72	0.66	0.73	0.32
2011	0.28	0.44	0.25	0.36	0.55	0.27	0.39	0.20
2012	0.89	0.73	0.70	0.28	0.16	0.22	0.47	0.26
2013	0.23	0.42	1.39	0.63	0.72	0.50	0.71	0.38
2014	0.99	0.67	0.47	0.33	0.16	0.29	0.43	0.32
2015	0.53	0.54	0.25	0.24	0.23	0.39	0.31	0.24
2016	1.38	0.43	0.52	0.58	0.24	0.25	0.62	0.30
2017	2.10	0.37	1.95	0.50	0.95	0.61	1.75	0.27

Table 21. Estimated slope from the robust least squares fit (bc=bias corrected; bs=bootstrap) for 5-25-50-75-95 percentiles, for the robust least square loess fit.

Year	Slope	Mean_bs	Bias_adj	bc_0.5	bc_0.05	bc_0.95	bc_0.25	bc_0.75
1991	0.96	0.95	0.98	0.97	0.88	1.01	0.91	1.00
1992	0.83	0.84	0.82	0.81	0.71	0.92	0.76	0.88
1993	0.69	0.79	0.59	0.60	0.54	0.85	0.56	0.70
1994	0.83	0.85	0.80	0.77	0.62	0.94	0.71	0.84
1995	1.13	1.01	1.25	1.32	0.96	1.54	1.16	1.44
1996	1.14	1.08	1.20	1.26	0.93	1.46	1.09	1.39
1997	1.01	1.05	0.98	1.00	0.90	1.20	0.93	1.09
1998	0.95	1.03	0.86	0.92	0.88	1.06	0.90	0.94
1999	1.02	1.03	1.00	1.01	0.83	1.25	0.93	1.12
2000	1.06	1.02	1.10	1.08	0.92	1.19	1.01	1.16
2001	1.00	1.01	0.99	0.99	0.92	1.07	0.95	1.03
2002	0.99	1.03	0.94	0.94	0.90	1.08	0.91	1.00
2003	1.07	1.08	1.05	1.06	0.90	1.28	0.99	1.15
2004	1.14	1.09	1.20	1.19	1.04	1.28	1.14	1.24
2005	1.05	1.03	1.06	1.07	0.97	1.15	1.03	1.12
2006	0.91	0.94	0.89	0.90	0.84	0.99	0.87	0.94
2007	0.85	0.87	0.82	0.81	0.78	0.91	0.79	0.86
2008	0.85	0.86	0.84	0.84	0.79	0.93	0.81	0.89
2009	0.93	0.89	0.96	0.95	0.88	0.97	0.93	0.96
2010	0.92	0.91	0.93	0.92	0.82	1.01	0.90	0.97
2011	0.89	0.92	0.86	0.87	0.82	0.97	0.85	0.91
2012	0.94	0.92	0.96	0.97	0.84	1.06	0.91	1.03
2013	0.98	0.93	1.04	1.02	0.86	1.16	0.98	1.12
2014	0.91	1.01	0.80	0.82	0.77	1.03	0.79	0.90
2015	1.09	1.24	0.94	1.00	0.98	1.14	0.98	1.03
2016	1.49	1.42	1.56	1.55	1.35	1.73	1.47	1.68
2017	1.60	1.46	1.74	1.76	1.52	1.77	1.72	1.77

Table 22.Quota advice (mt) resulting from application of the empirical method.

Year	5%	25%	50%	75%	95%
2018	1002	1133	1156	1164	1168

Table 23. 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

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch[1] /Compared to Risk Analysis	Actual F Result[2]
2013	2014	600mt	(1) low risk of exceeding Fref (2) Neutral risk of stock not increase by10% from 2014 – 2015	700mt	Low risk of exceeding Fref, and stock biomass increase close to 10%	574 mt	*F=0.04; 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		537 mt	*F=0.05 Biomass increased by 11%*
2016	2017	700mt		730mt			

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

FIGURES

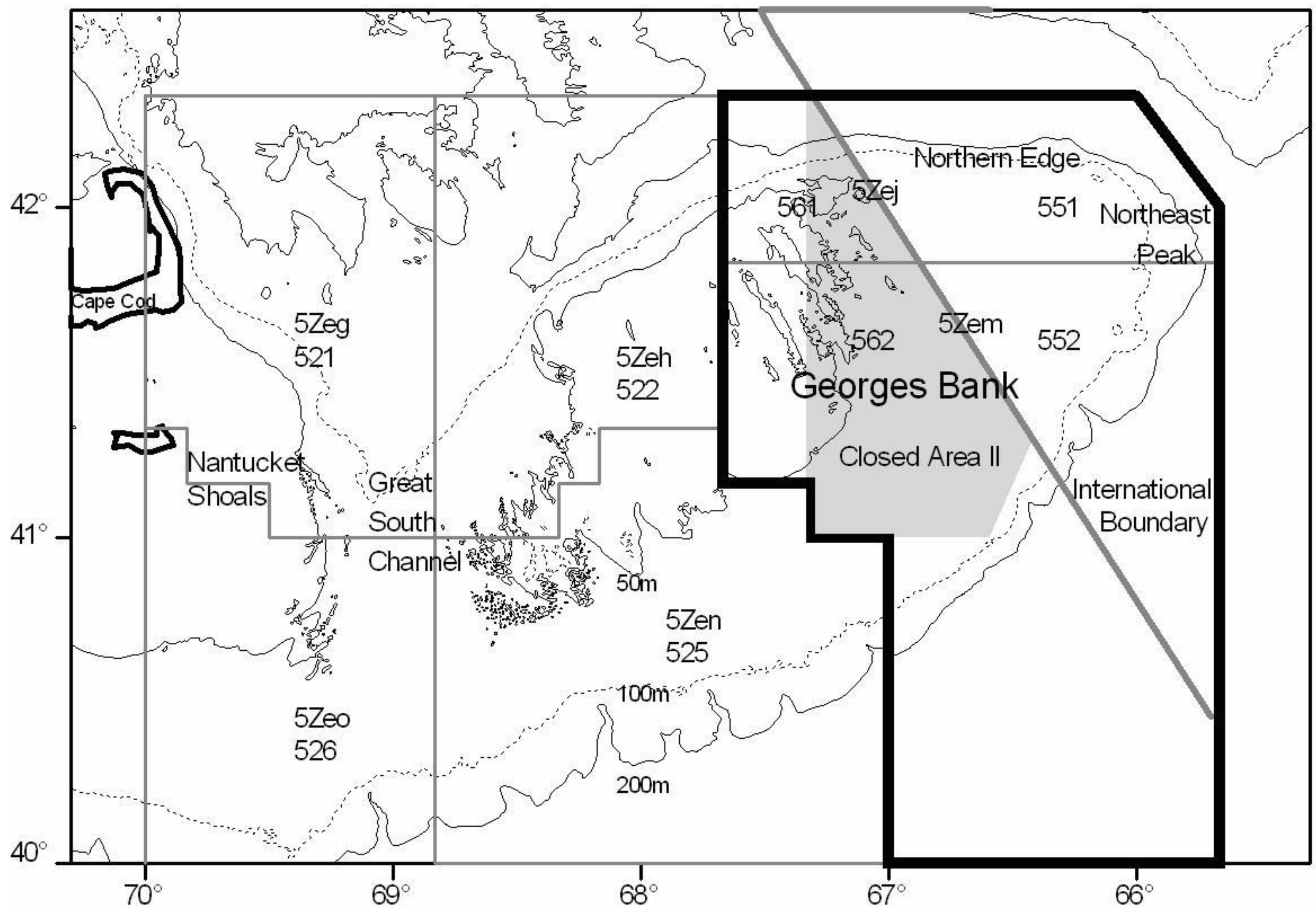


Figure 1. Fisheries statistical areas (Canada and USA) in NAFO Subdivision 5Ze. The eastern Georges Bank Atlantic Cod management unit is outlined by a heavy black line.

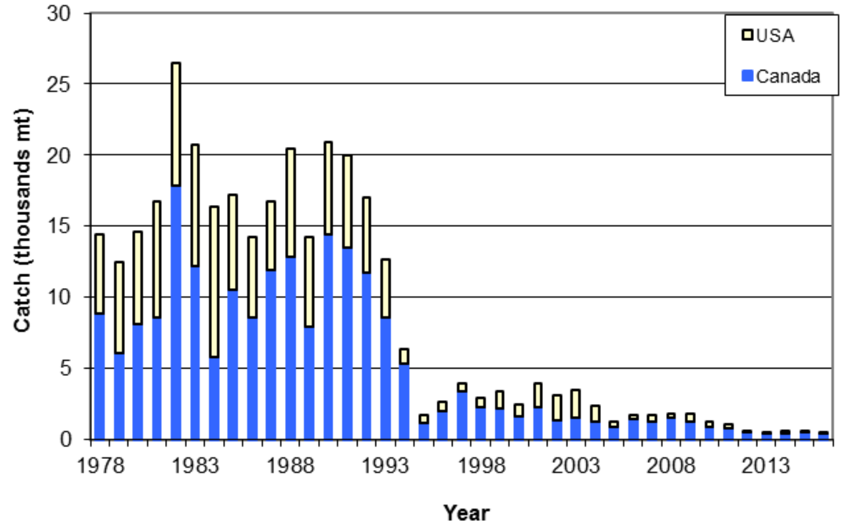


Figure 2. Catches eastern Georges Bank cod, 1978 to 2016.

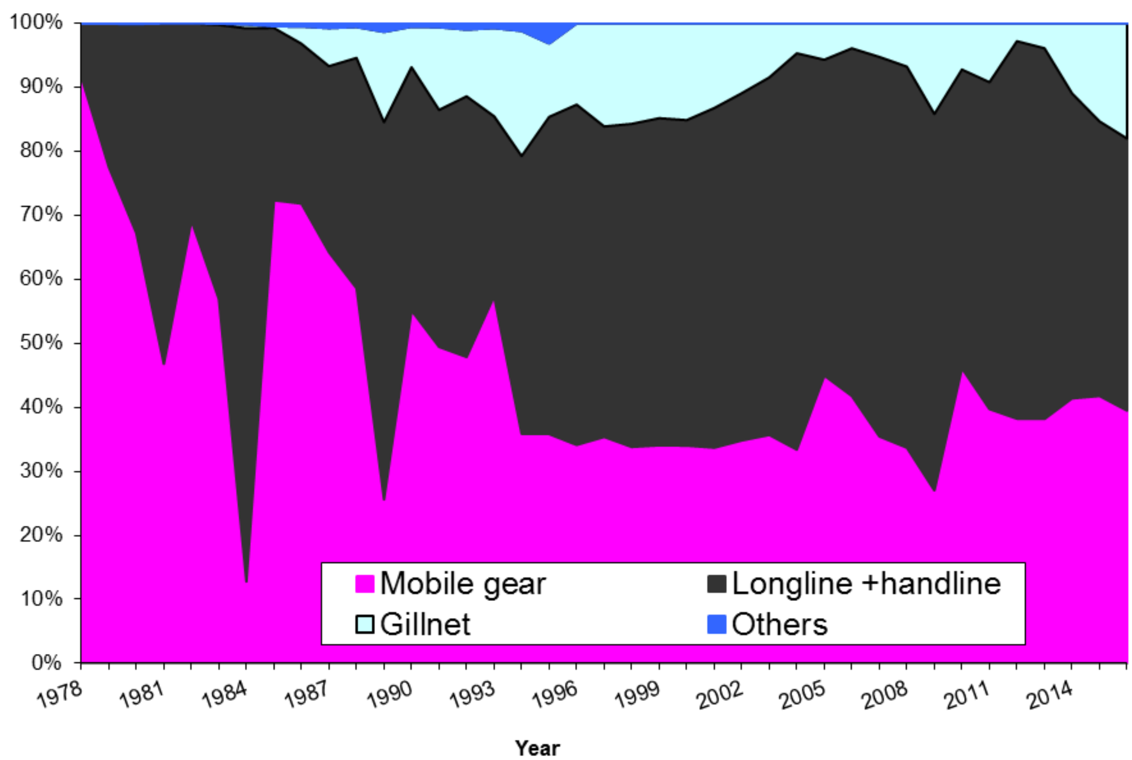
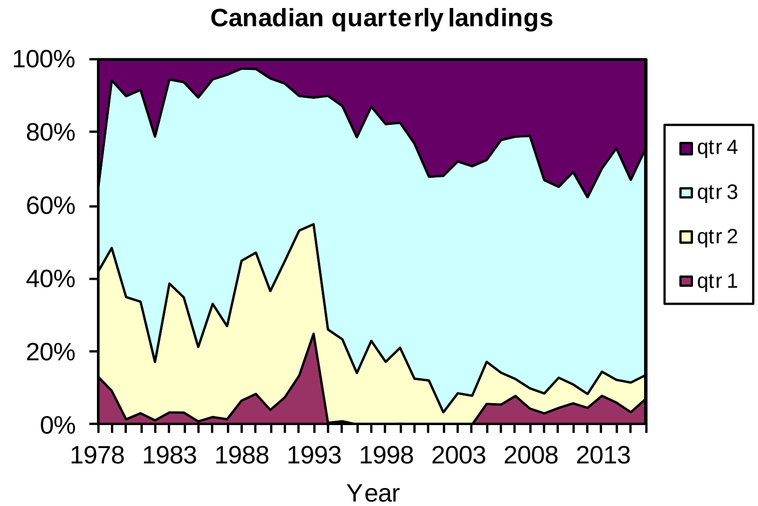


Figure 3. Proportion of Canadian gear specific landings of cod from eastern Georges Bank for 1978 to 2016.



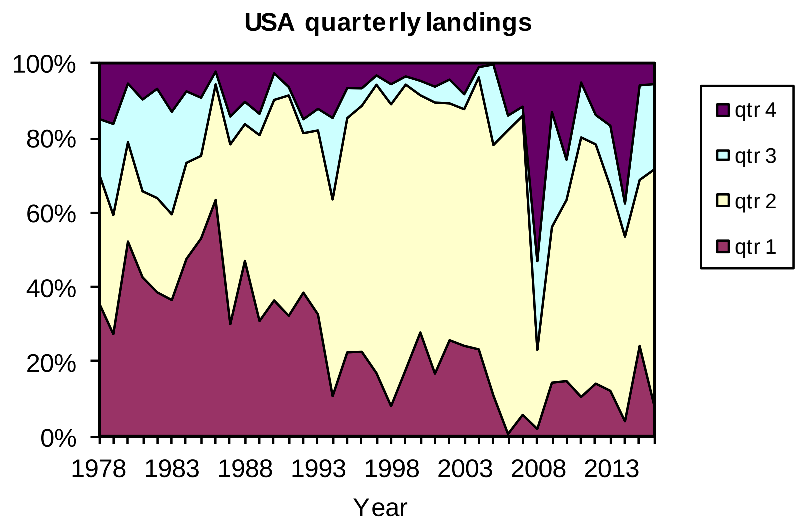
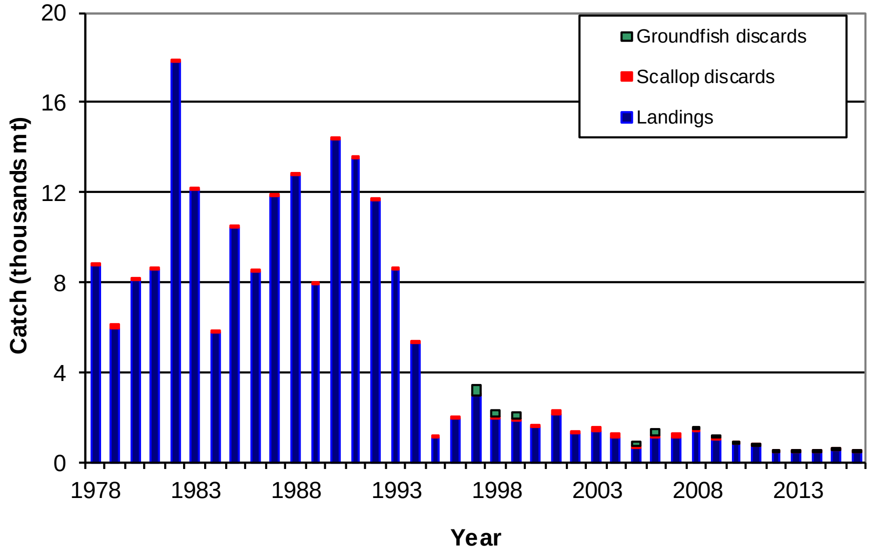


Figure 4. Proportion of Canadian (upper) and USA (lower) quarterly landings of cod from eastern Georges Bank, 1978 to 2016.



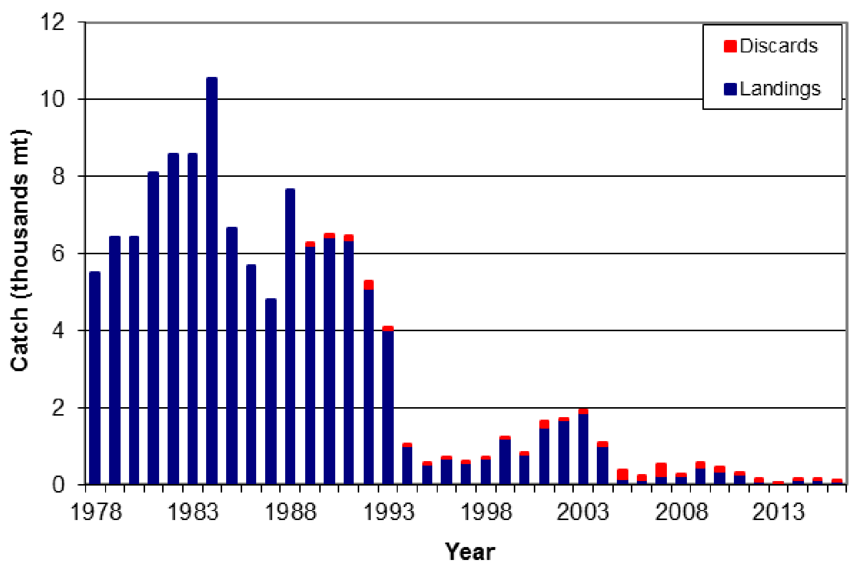


Figure 5. Canadian (upper) and USA (lower) landings and discards of eastern Georges Bank cod, 1978 to 2016.

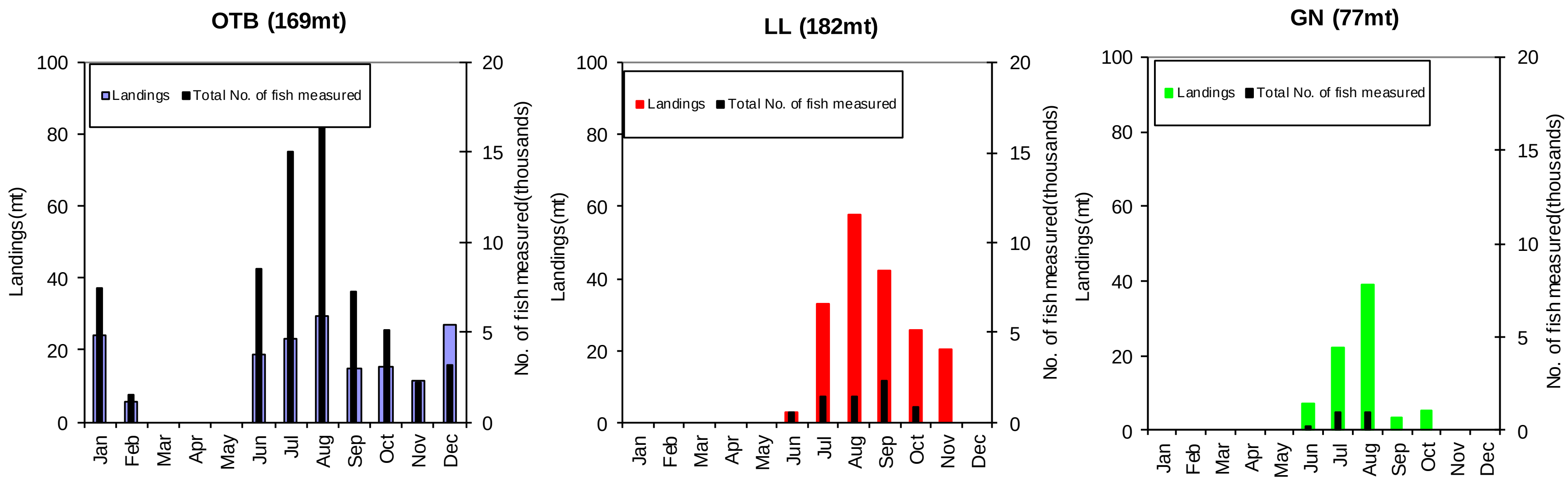


Figure 6. Landings (wide bars) and sampling (narrow dark bars) of cod by gear and month from the 2016 Canadian bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on eastern Georges Bank.

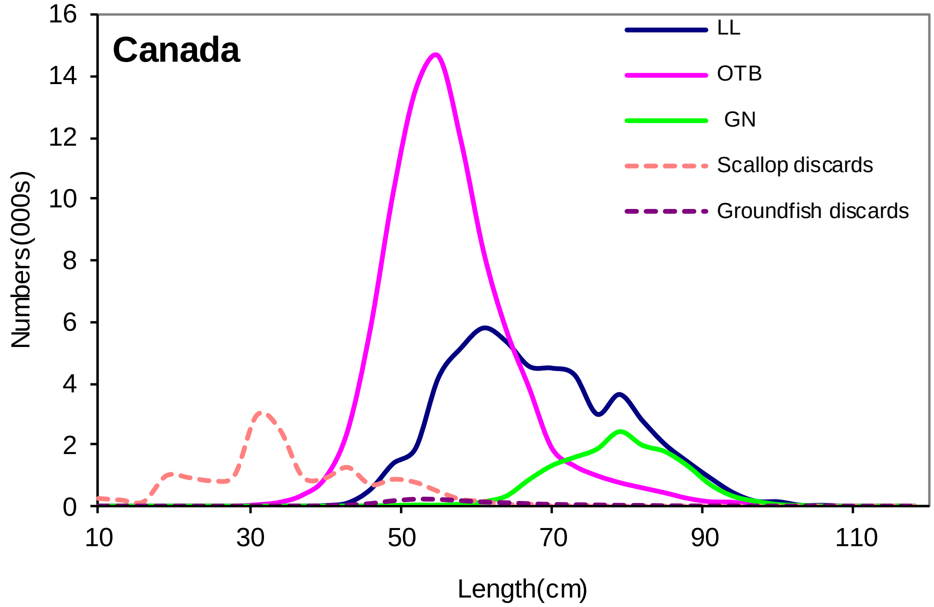


Figure 7. Cod catches at length by gear from the 2016 Canadian fisheries bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on eastern Georges Bank

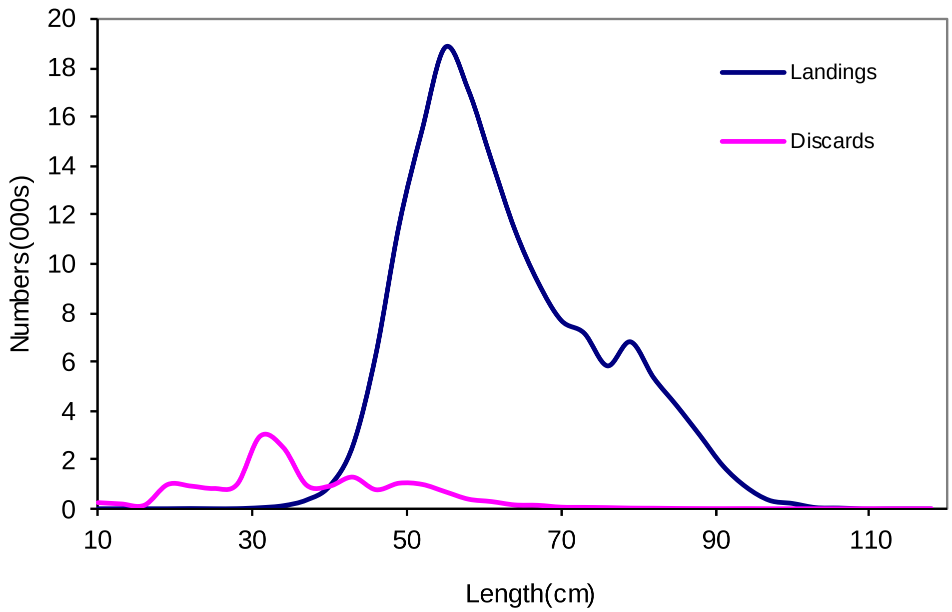


Figure 8. Cod landings and discards at length from the 2016 Canadian fisheries on eastern Georges Bank.

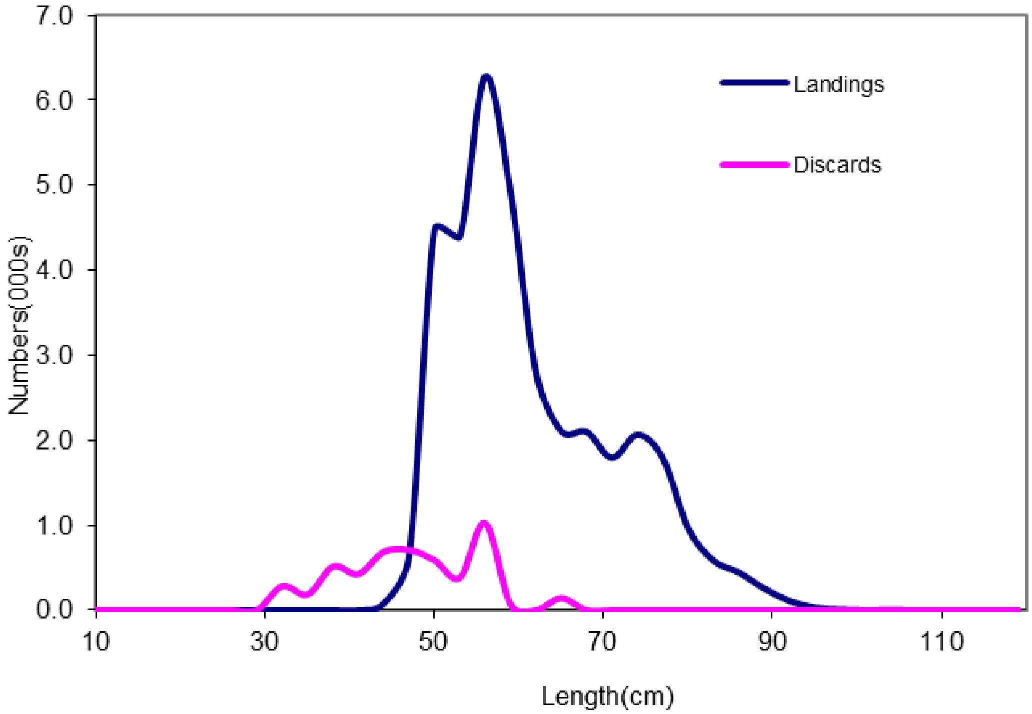


Figure 9. Cod landings and discards at length from the 2016 USA fisheries on eastern Georges Bank.

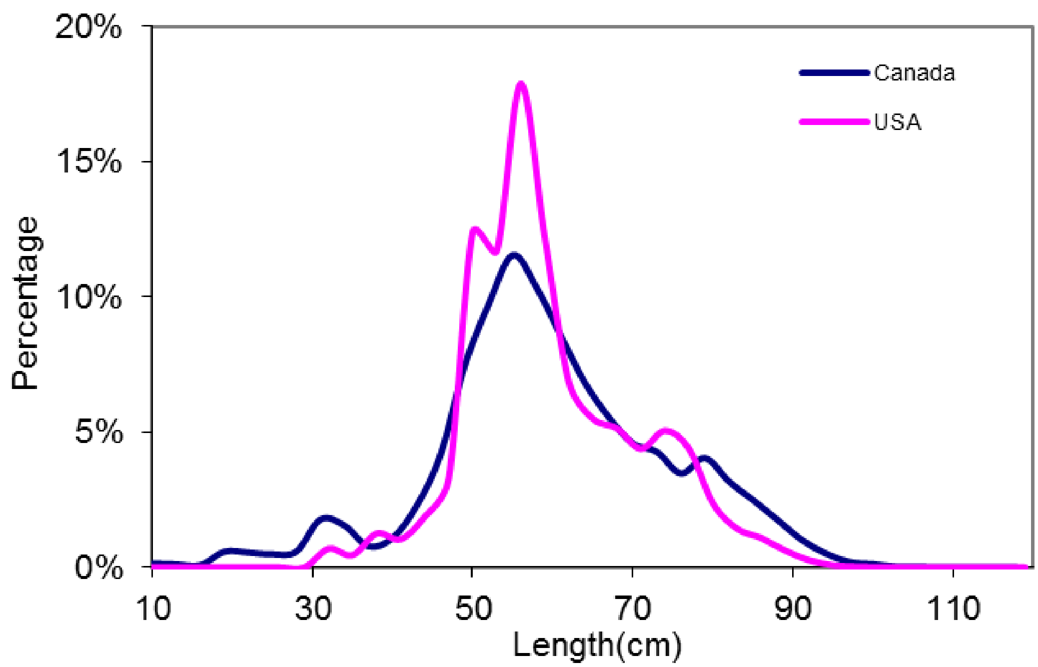


Figure 10. Cod length frequency from the 2016 Canadian and USA fisheries on eastern Georges Bank.

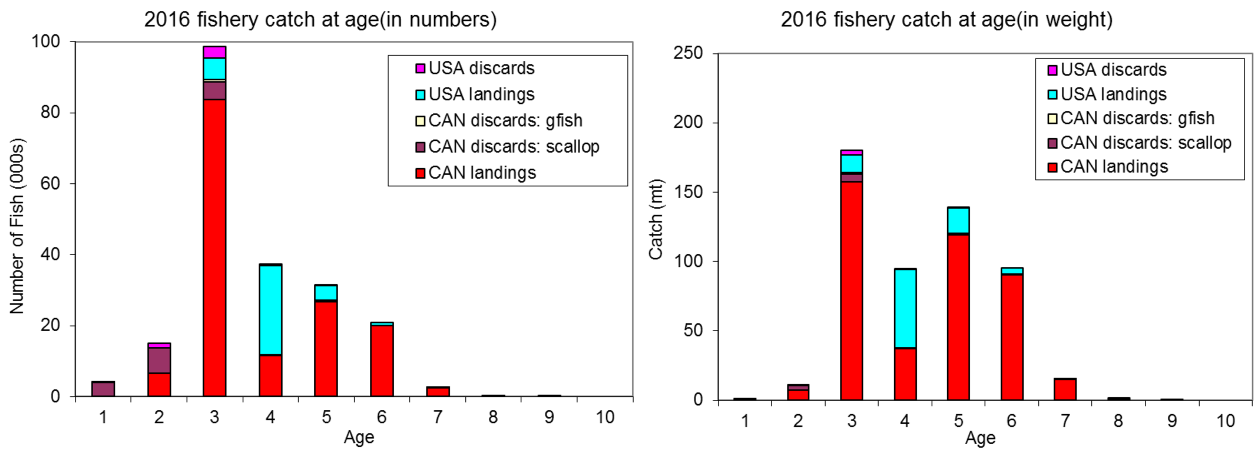


Figure 11. Catch at age in numbers (left) and weight (right) for landings and discards of cod from the 2016 eastern Georges Bank fisheries.

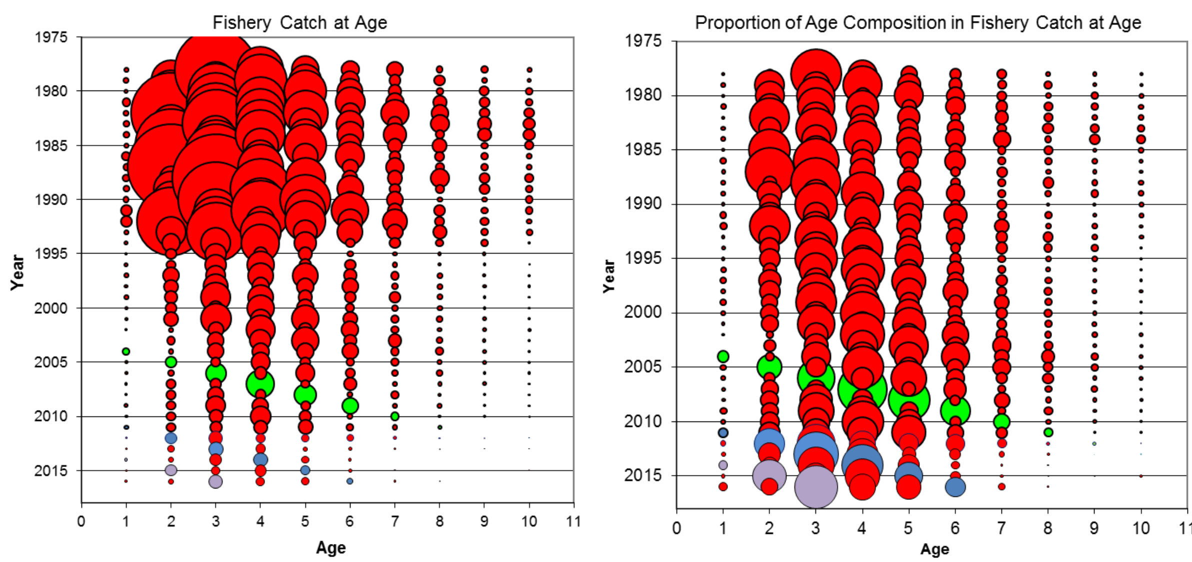


Figure 12. Total catch at age (numbers) of cod (left) and proportion of catch at age from eastern Georges Bank for 1978 to 2016. The bubble area is proportional to the magnitude. The green denotes the 2003 year class, the blue denotes the 2010 year class and the purple denotes the 2013 year class.

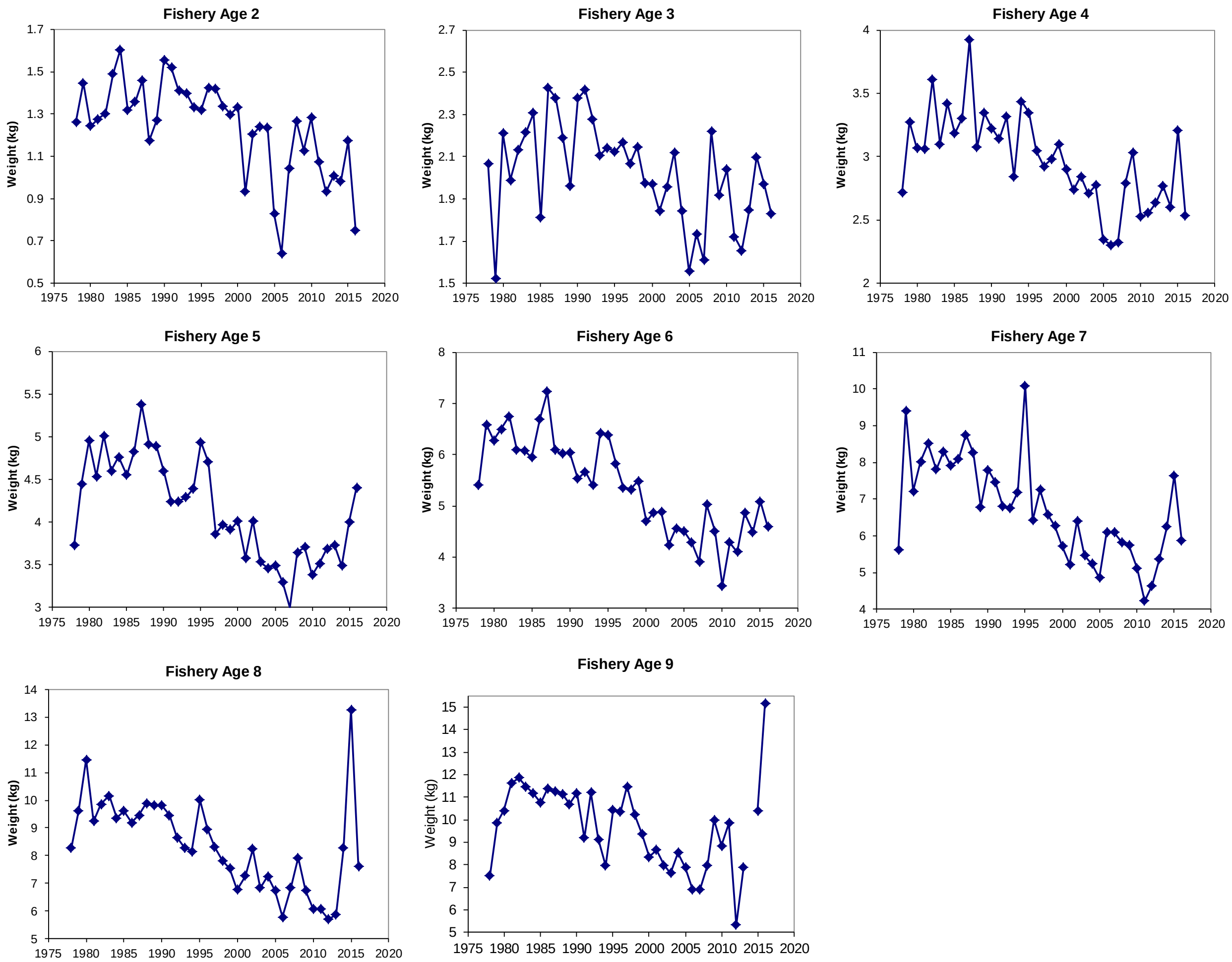


Figure 13. Average weight at age for ages 2 to 9 of cod from the eastern Georges Bank fishery, 1978-2016

.

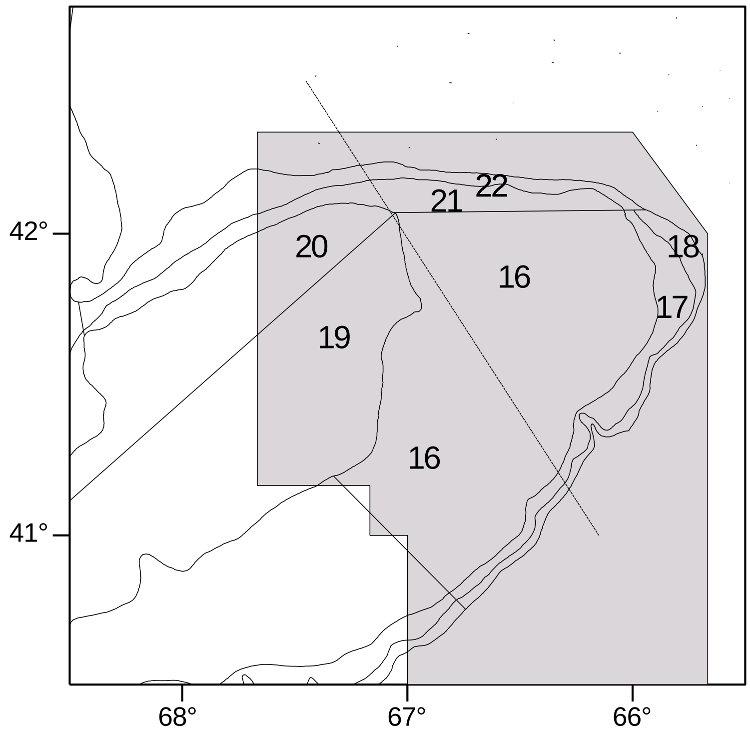


Figure 14. Stratification used for the NMFS surveys. The eastern Georges Bank management unit is indicated by shading.

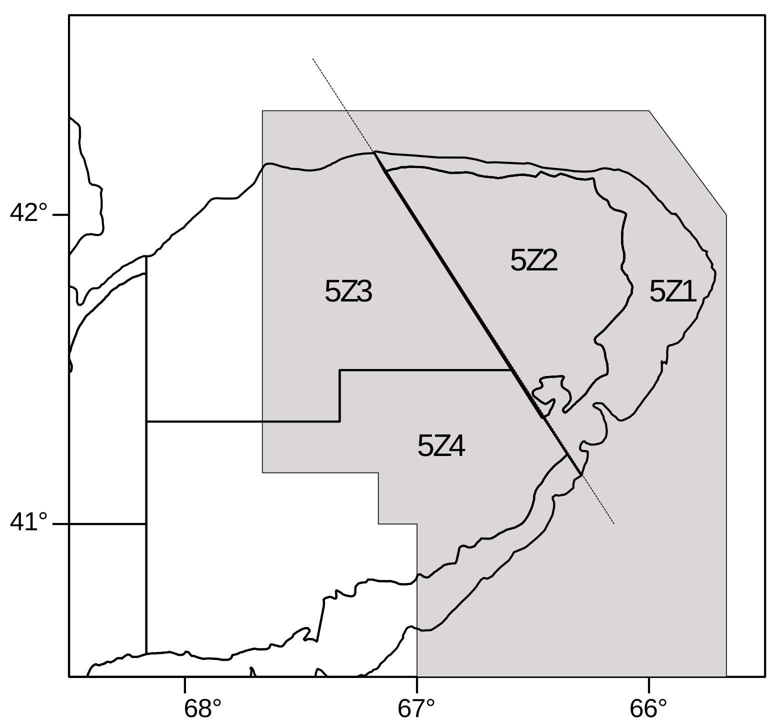


Figure 15. Stratification used for the DFO survey. The eastern Georges Bank management unit is indicated by shading.

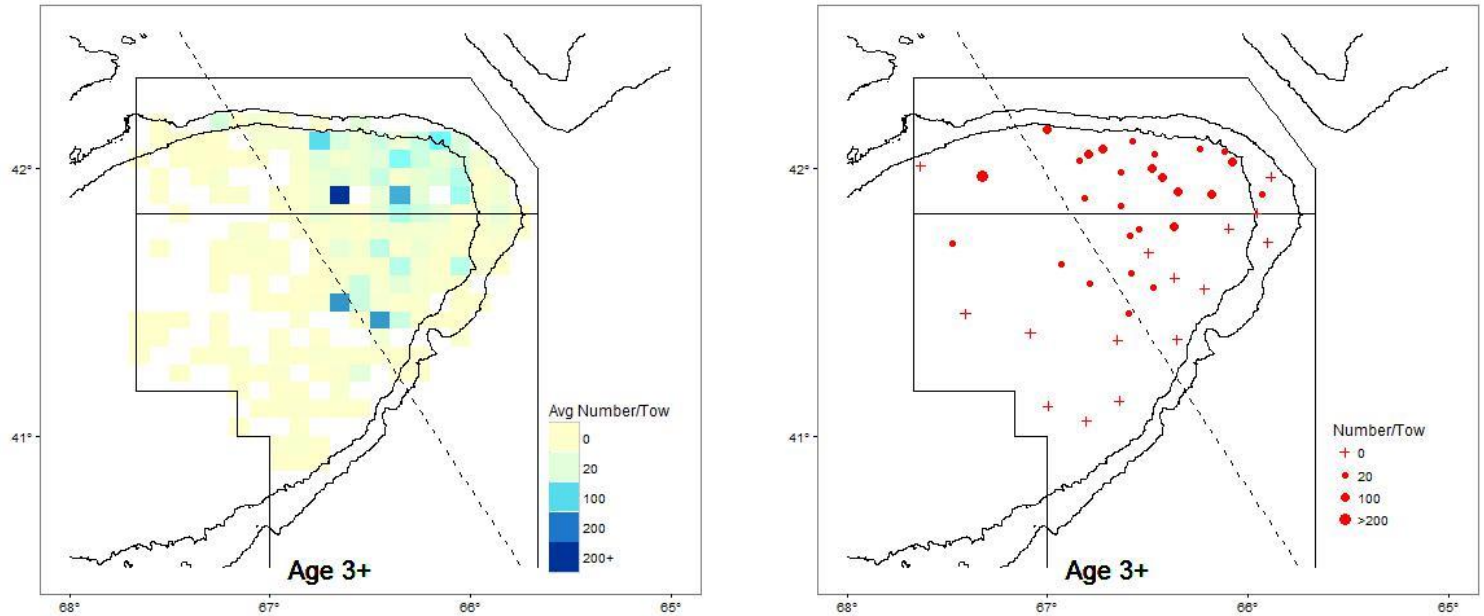


Figure 16. Spatial distribution of age 3+ cod on eastern Georges Bank from the DFO survey for 2017 (right) compared to the average for 2007-2016 (left).

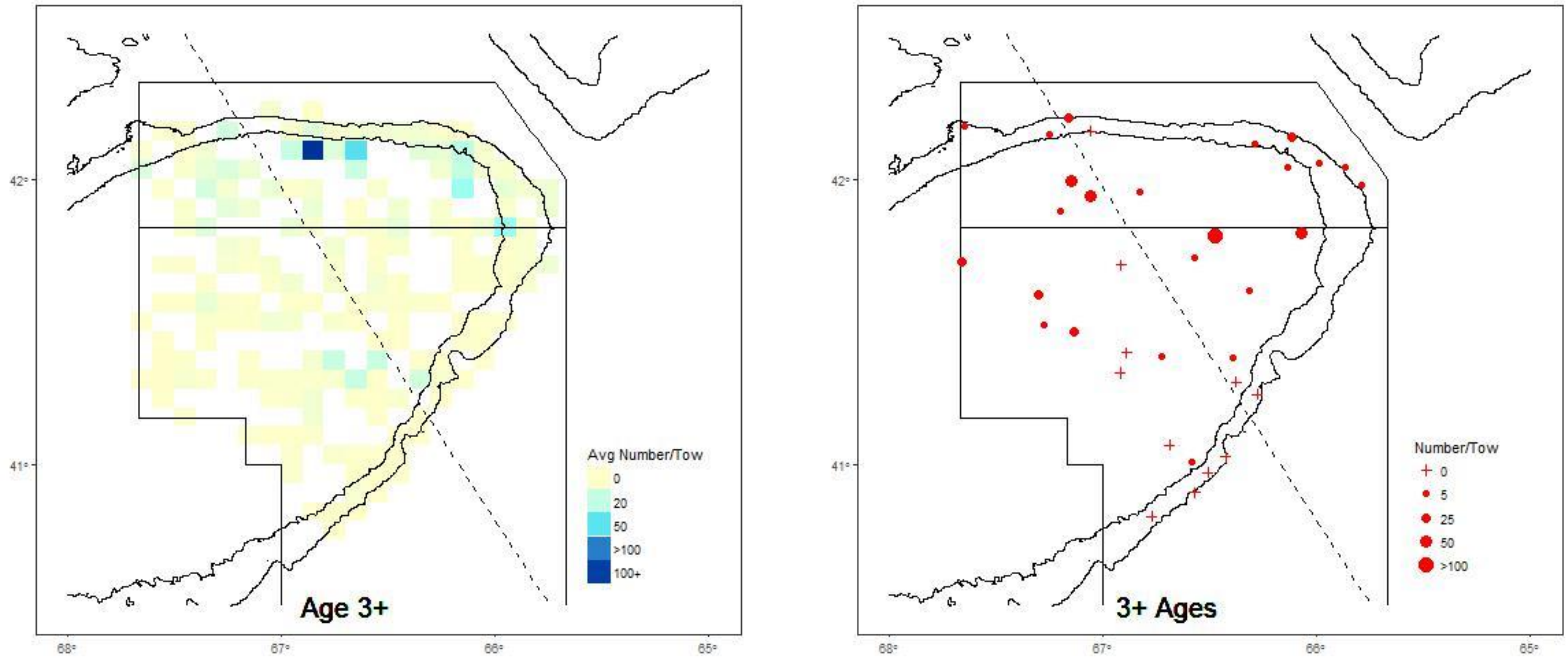


Figure 17. Spatial distribution of cod (all ages) on eastern Georges Bank from the NMFS spring survey for 2017 (right panel) compared to the average age 3+ cod for 2007-2016 (left panel).

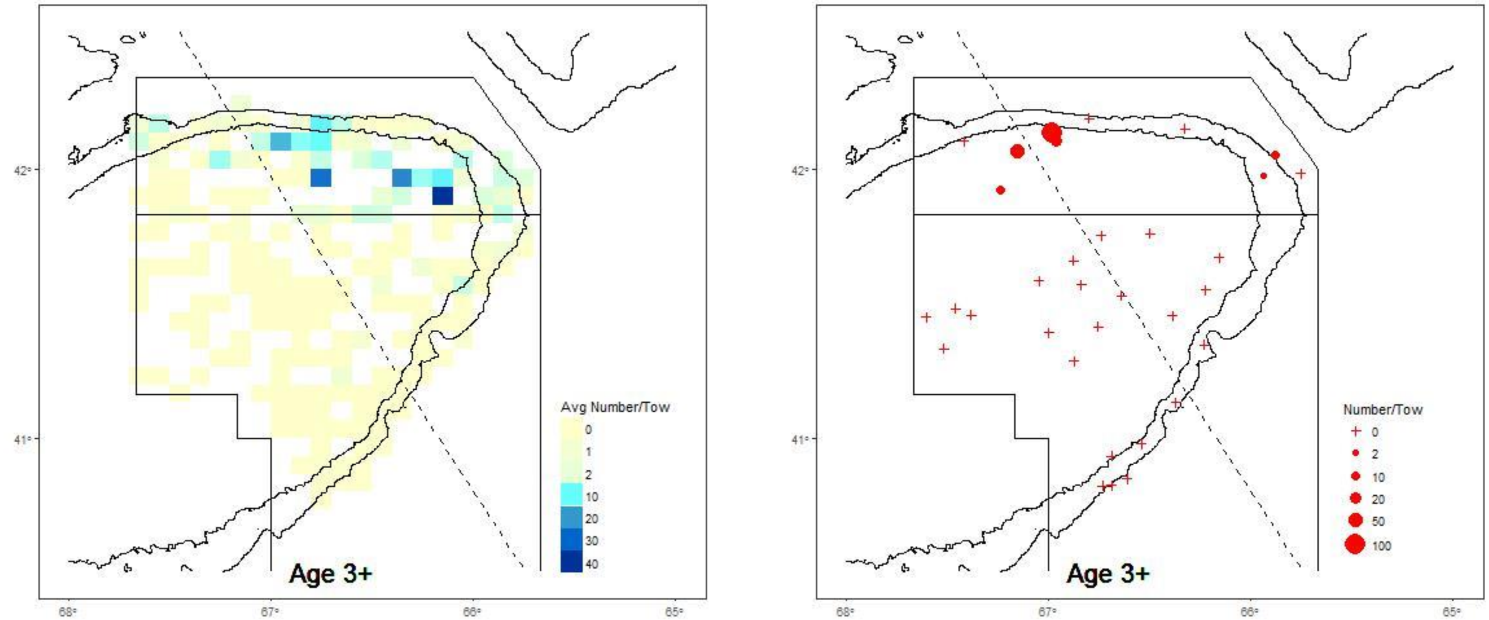


Figure 18. Spatial distribution of age 3+ cod on eastern Georges Bank from the NMFS fall survey for 2016 (right) compared to the average for 2006-2015 (left).

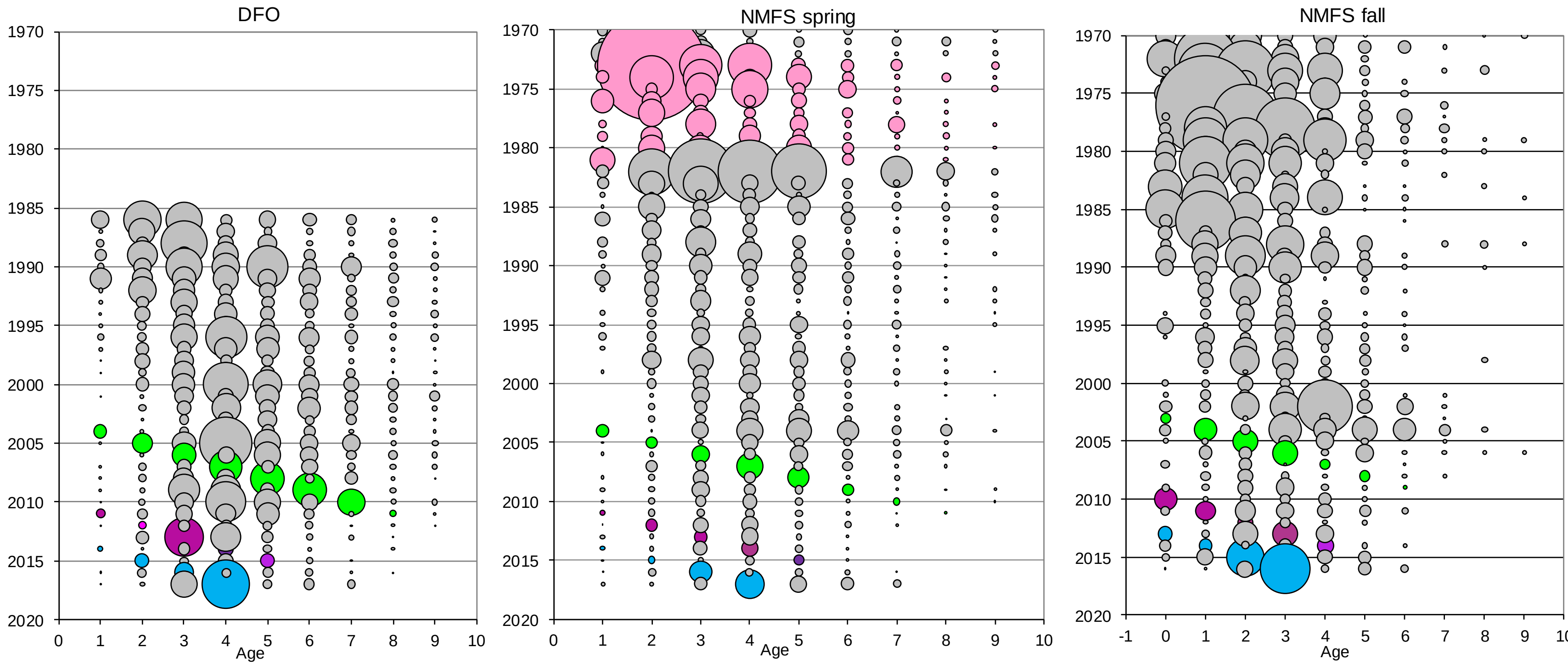


Figure 19. Survey abundance at age (numbers) of eastern Georges Bank cod. The bubble area is proportional to magnitude within each survey. Conversion factors to account for changes in door type, net and survey vessel were applied to the NMFS surveys. The NMFS spring survey was conducted using a modified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

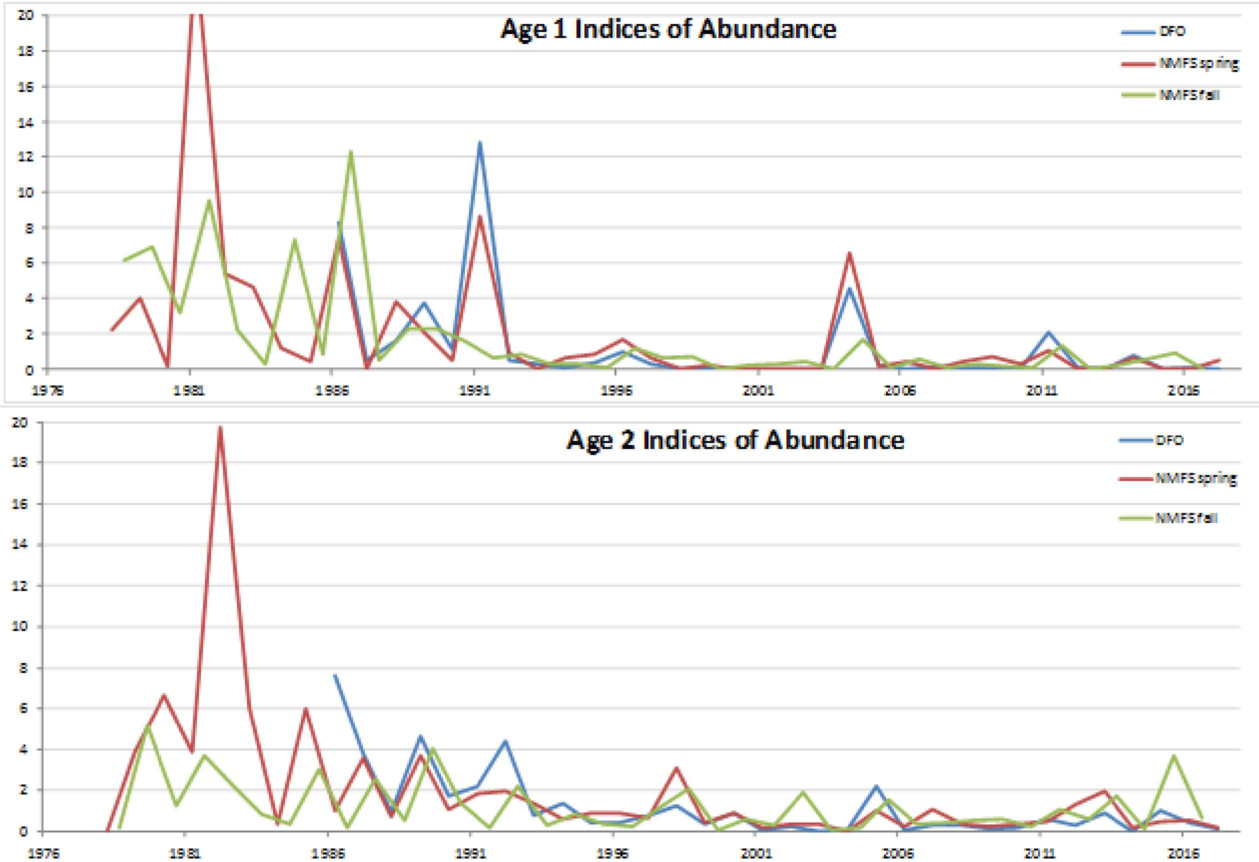


Figure 20. Numbers of age 1 (top) and age 2 (bottom) cod from the NMFS fall, spring, and DFO surveys scaled to the mean (1987-2017).

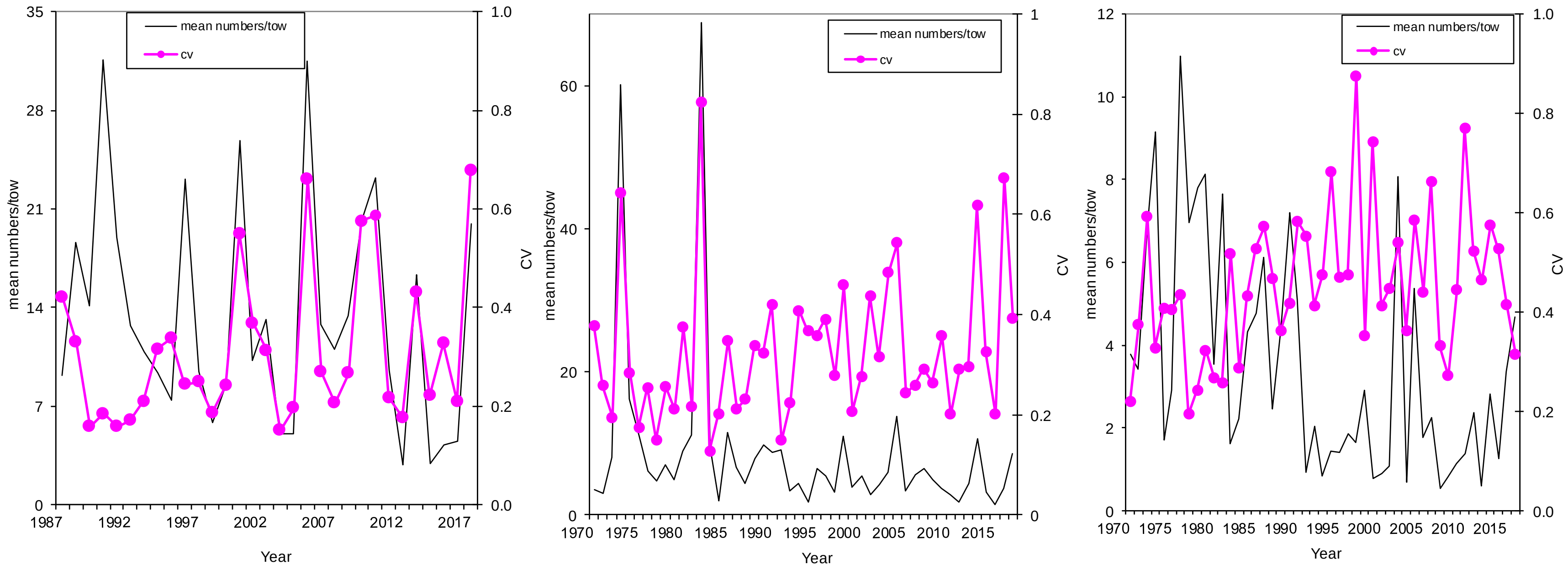


Figure 21. Stratified mean number per tow and coefficient of variation (CV) for DFO (left), NMFS spring (middle) and NMFS fall (right) survey catch of eastern Georges Bank cod.

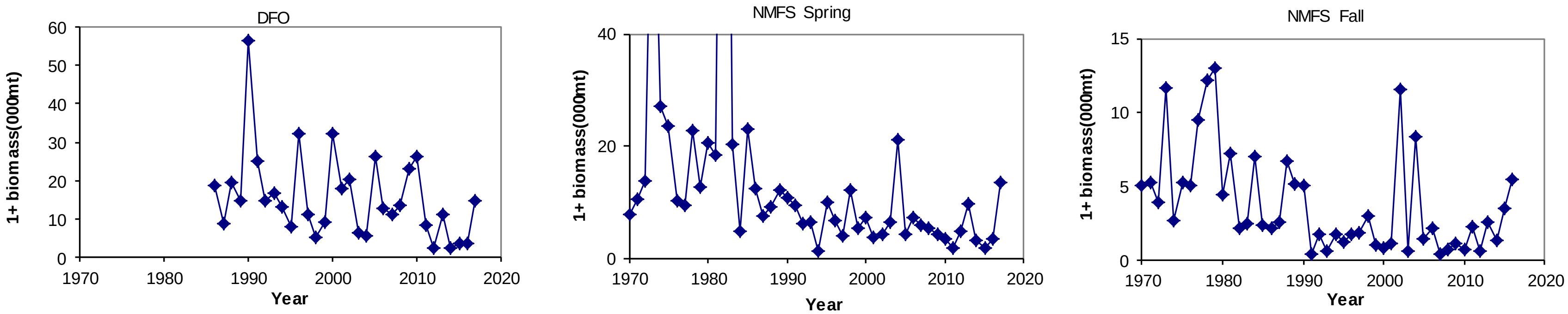


Figure 22. Survey biomass indices (ages 1+) for eastern Georges Bank cod from the DFO spring (left), NMFS spring (middle) and NMFS fall (right) surveys, 1970-2017.

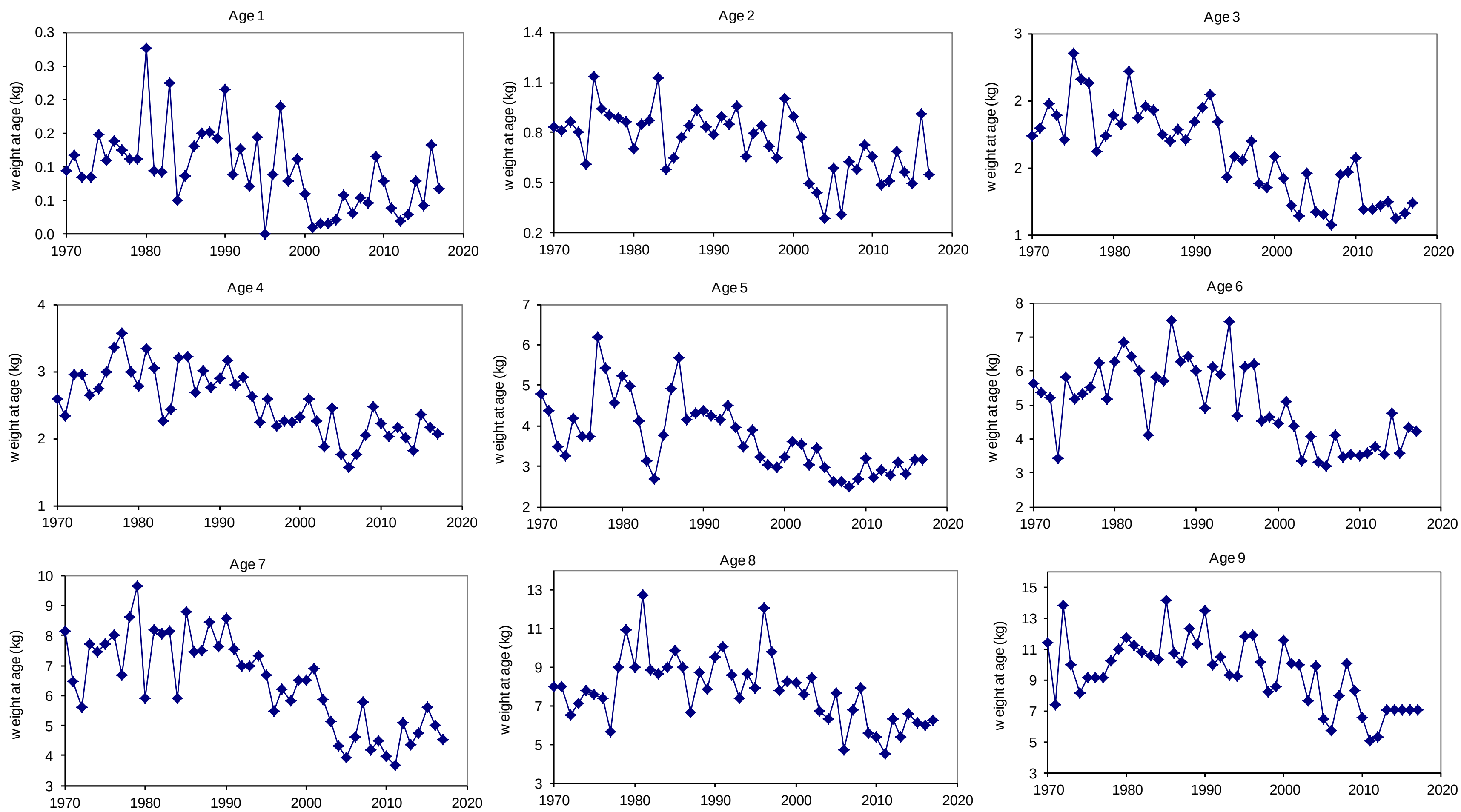


Figure 23. Beginning of year weight at age of eastern Georges Bank cod from DFO and NMFS spring surveys.

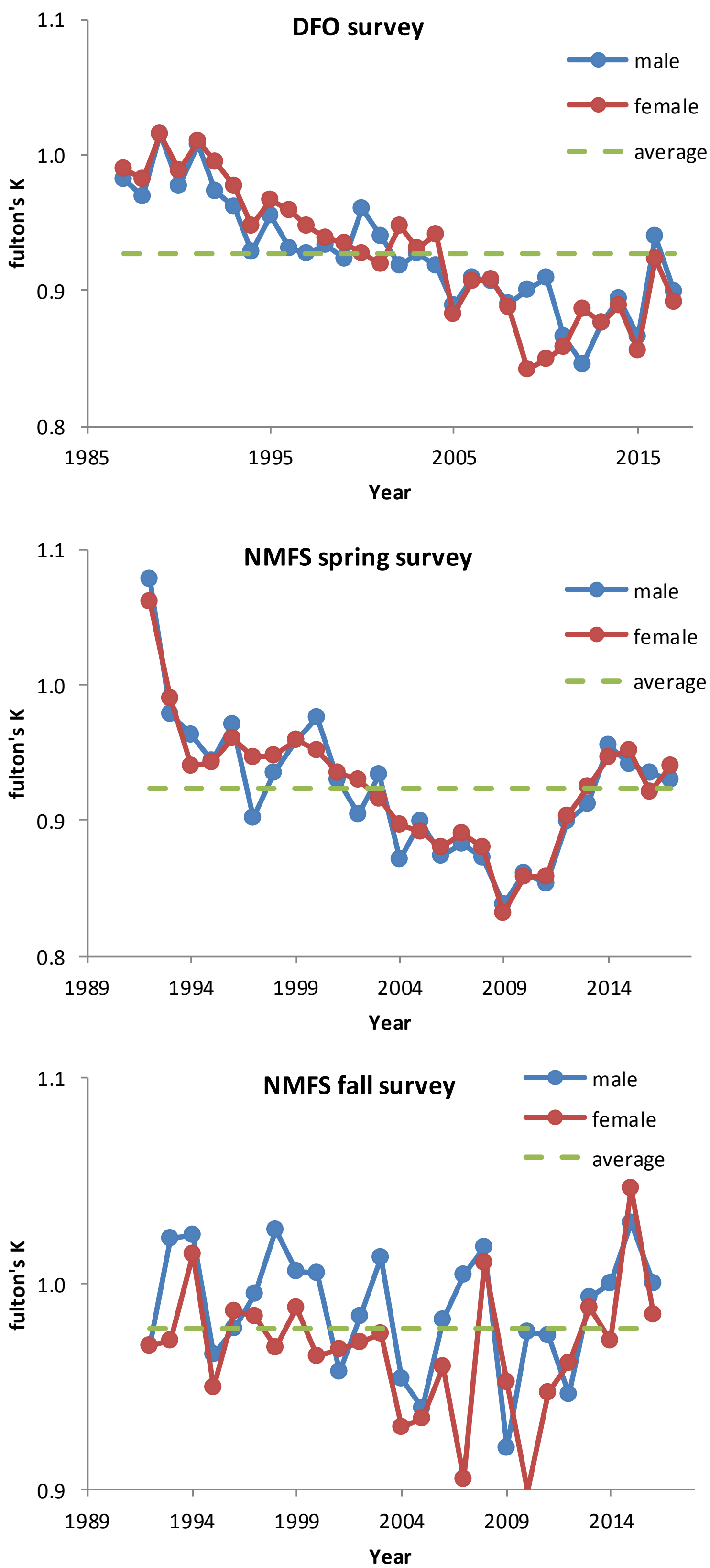
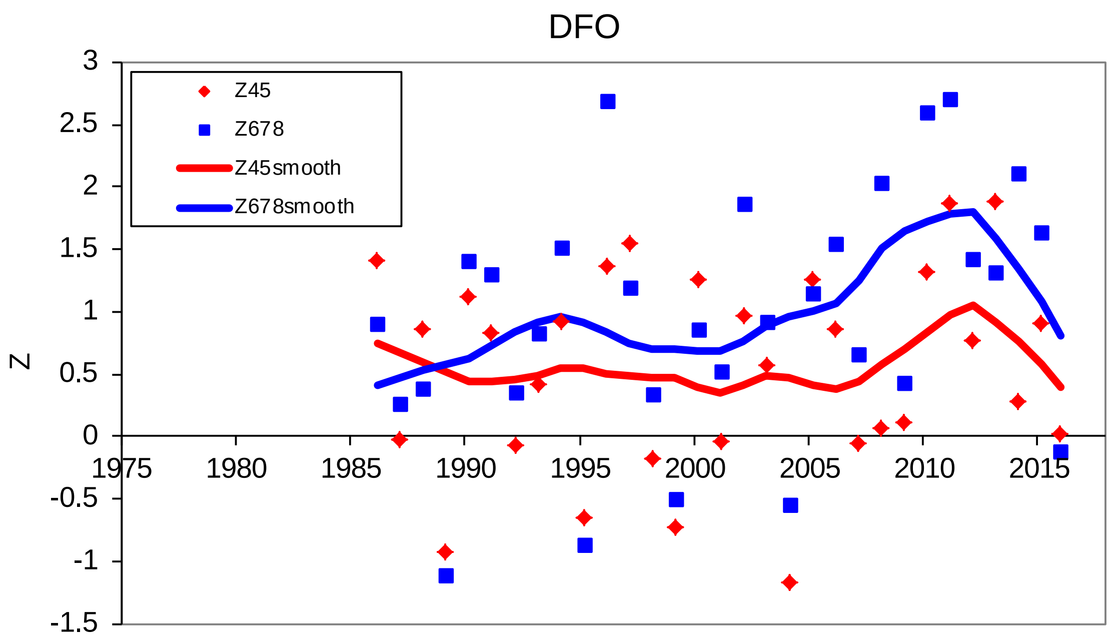


Figure 24. Fish condition (Fulton's K) of post-spawning cod for eastern Georges Bank.



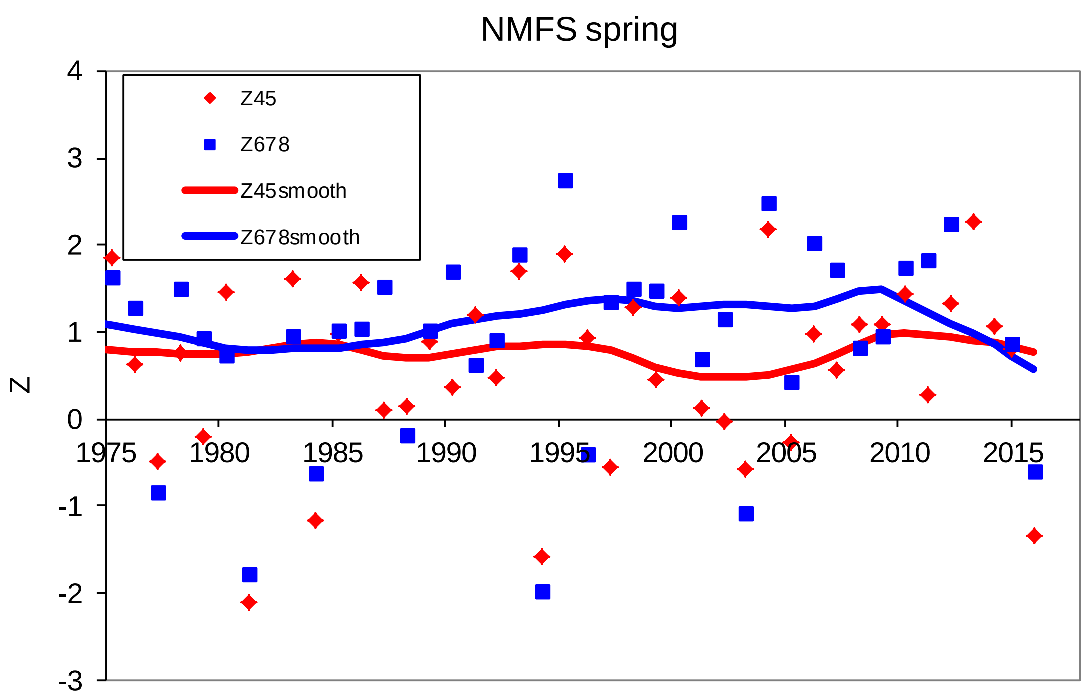


Figure 25. Total mortality(Z) calculated using the DFO and NMFS spring surveys data for eastern Georges Bank cod.

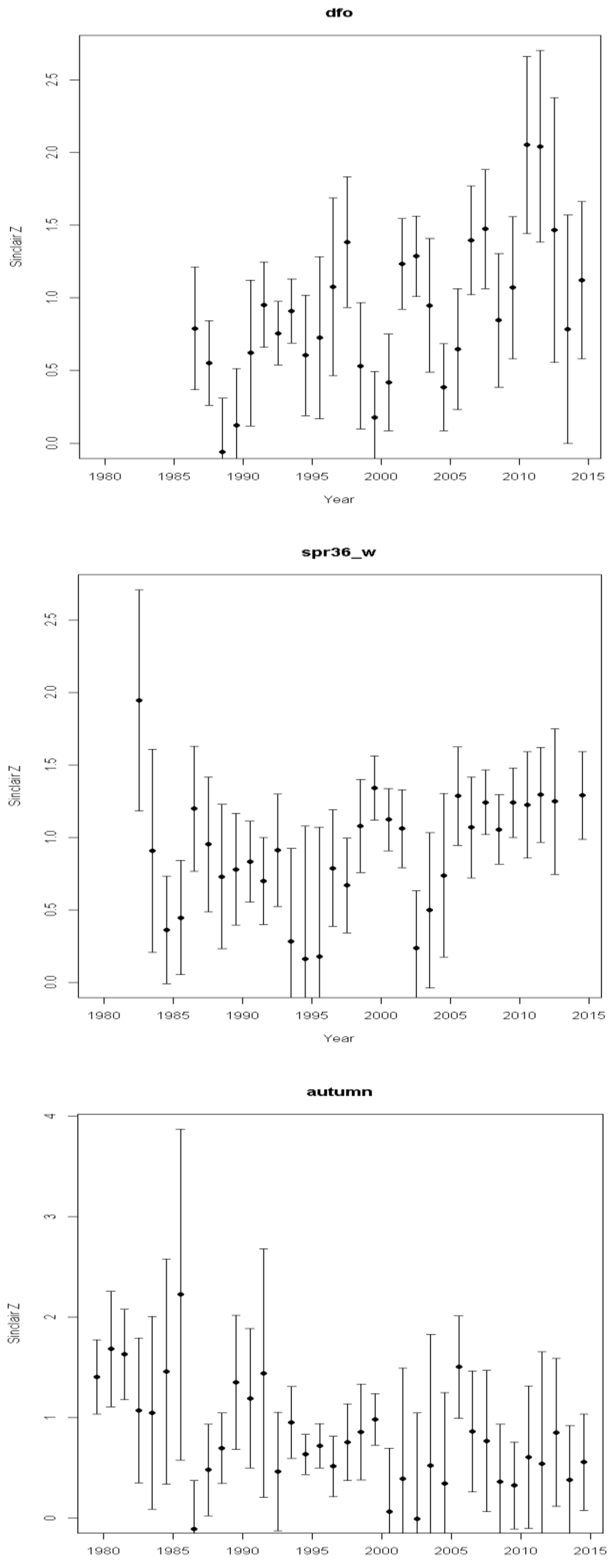


Figure 26. Total mortality (Z) calculated using the Sinclair (2001) approach for the DFO (top), NMFS spring (middle) and NMFS fall (bottom) surveys.

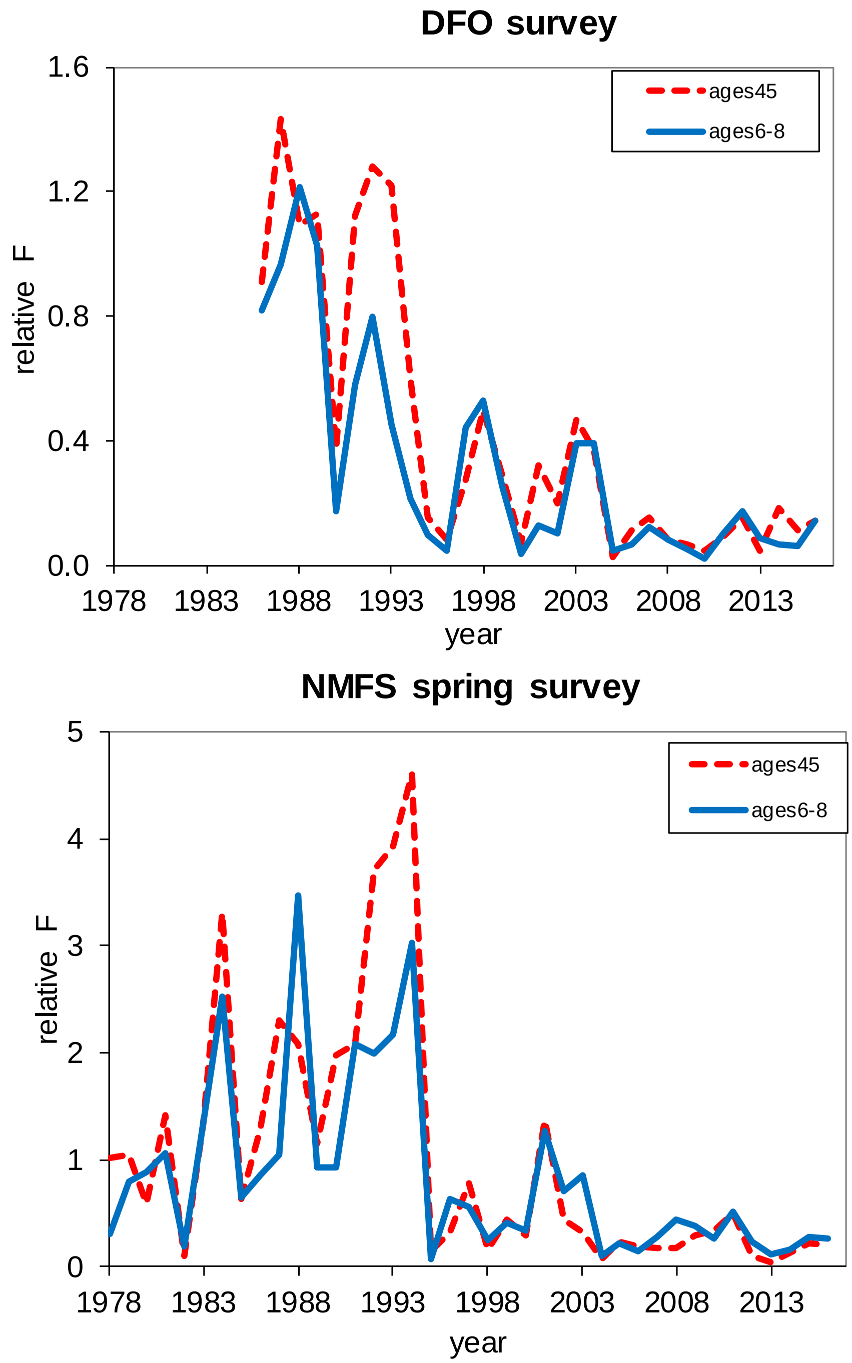


Figure 27. Relative F for eastern Georges Bank cod.

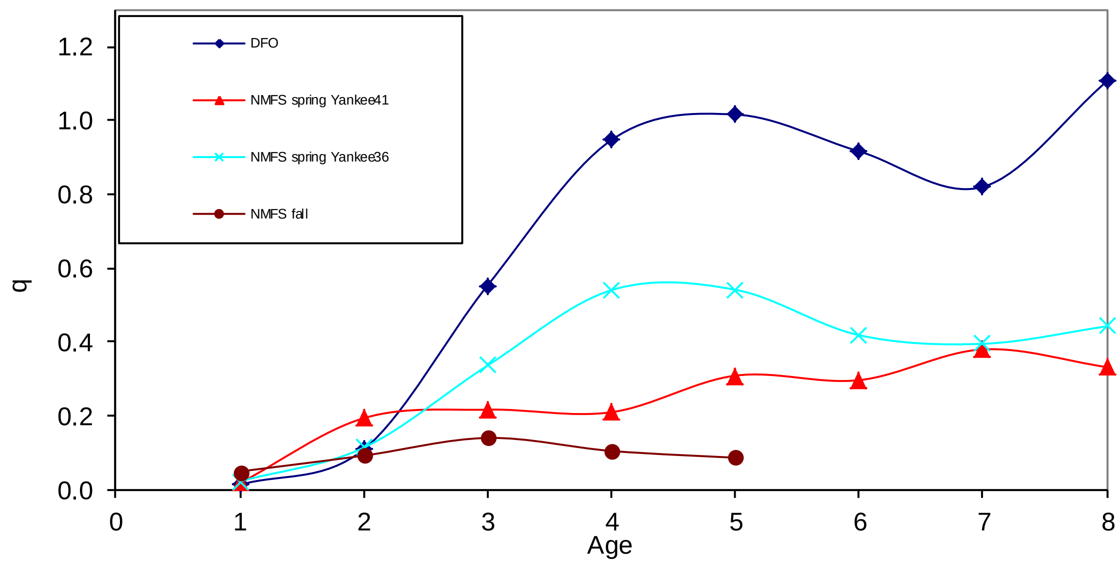


Figure 28. Survey catchability (q) of the DFO, NMFS spring and NMFS fall surveys for eastern Georges Bank cod.

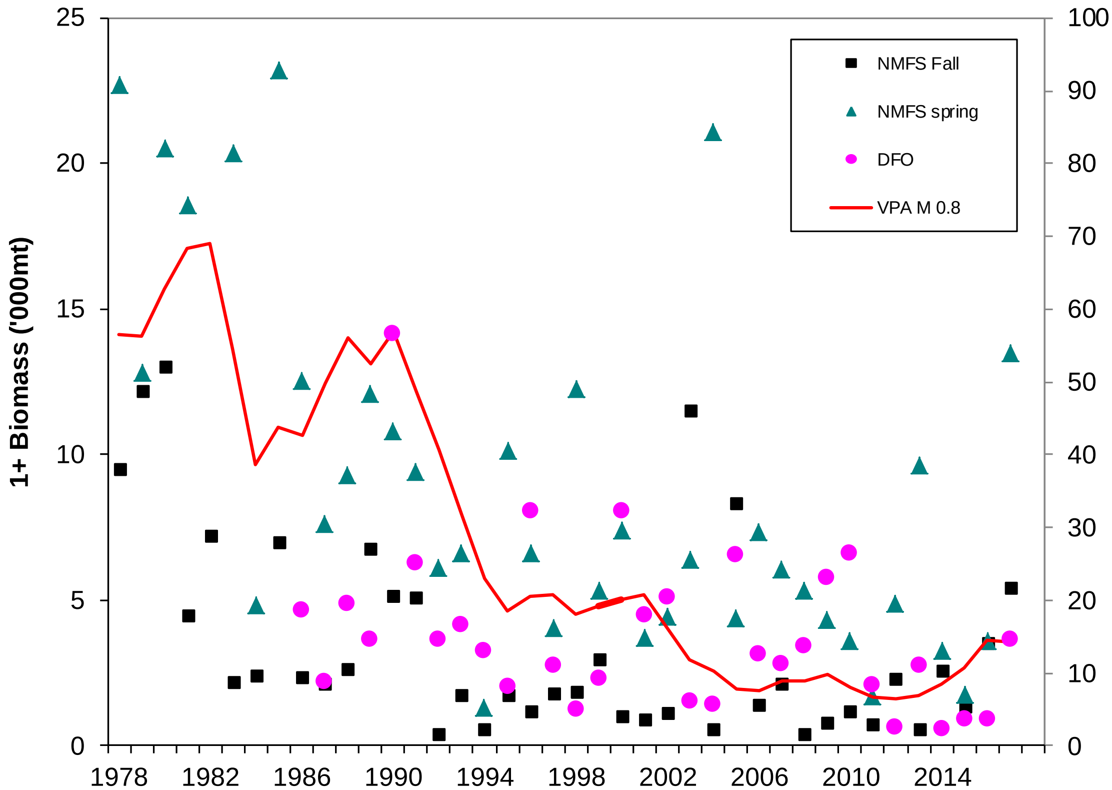


Figure 29. Age 1+ biomass from survey and VPA estimation.

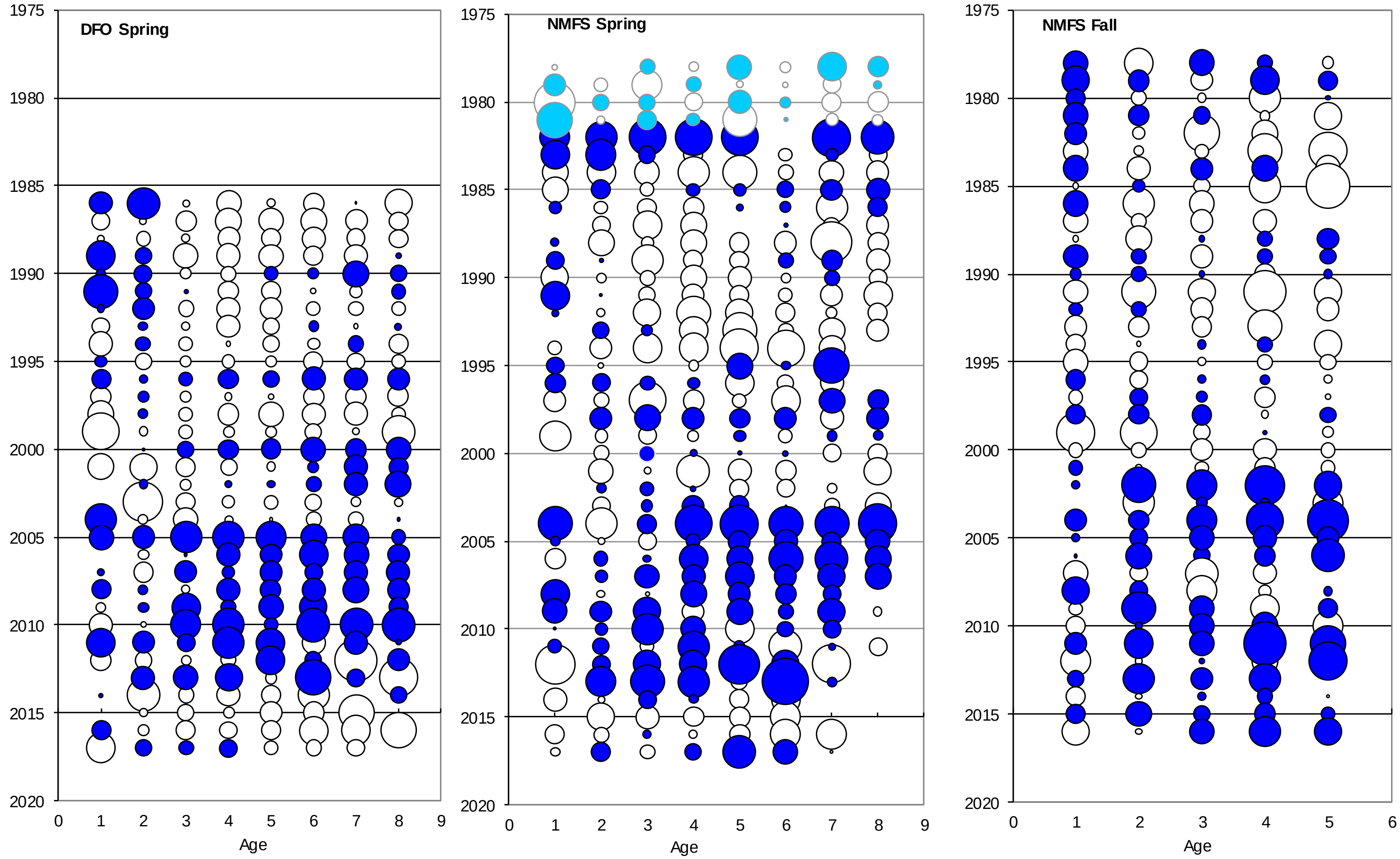


Figure 30. Residuals by year and age group from survey indices for eastern Georges Bank cod. Solid bubbles indicate positive values, open bubbles indicate negative values and the bubble area is proportional to magnitude. The NMFS spring survey was conducted using a modified Yankee 41 from 1978 to 1981 (light blue bubbles).

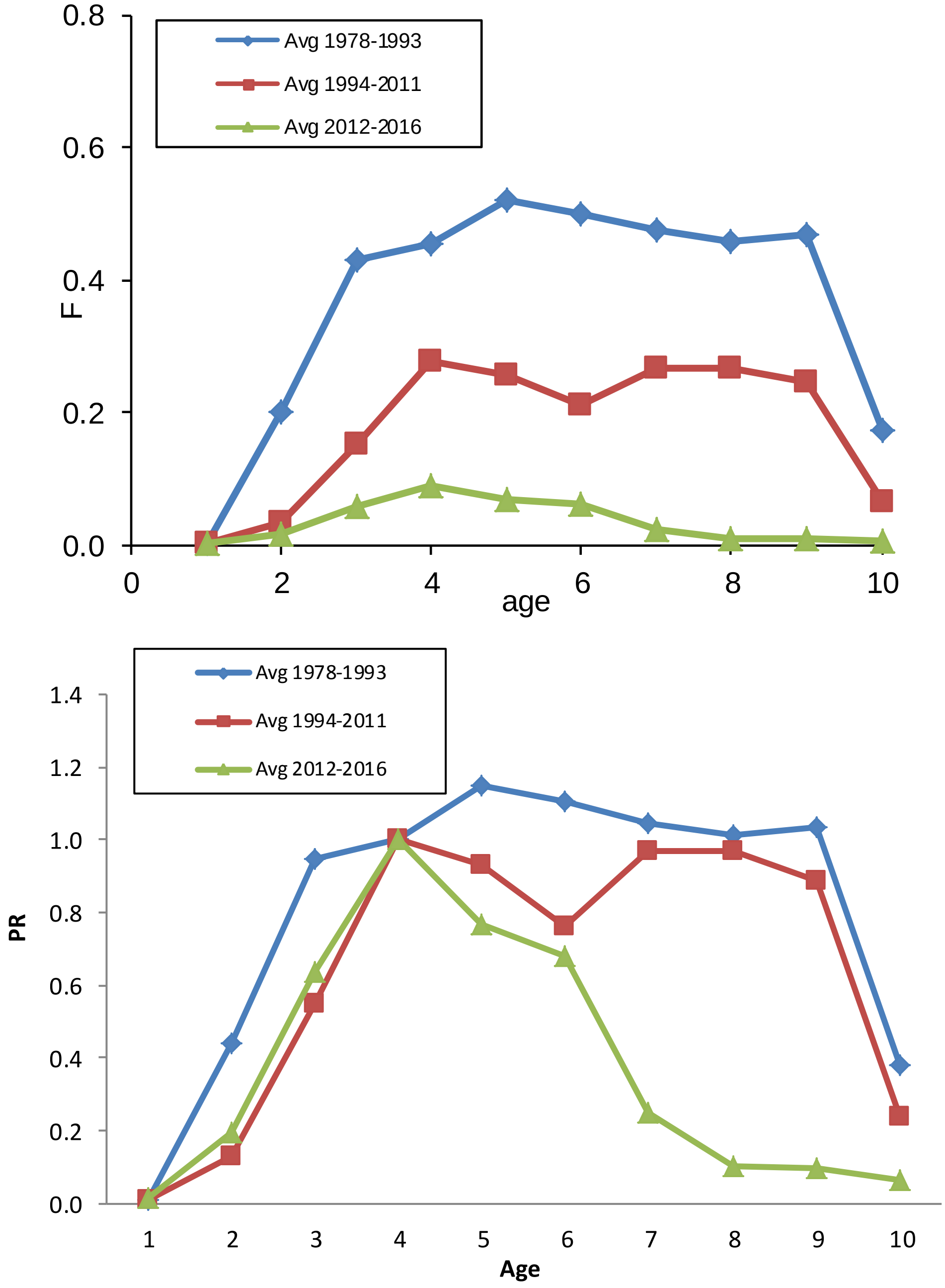


Figure 31. Average fishing mortality (F, upper panel) for eastern Georges Bank cod in three time series blocks (1978-1993, 1994-2010, 2011-2015).

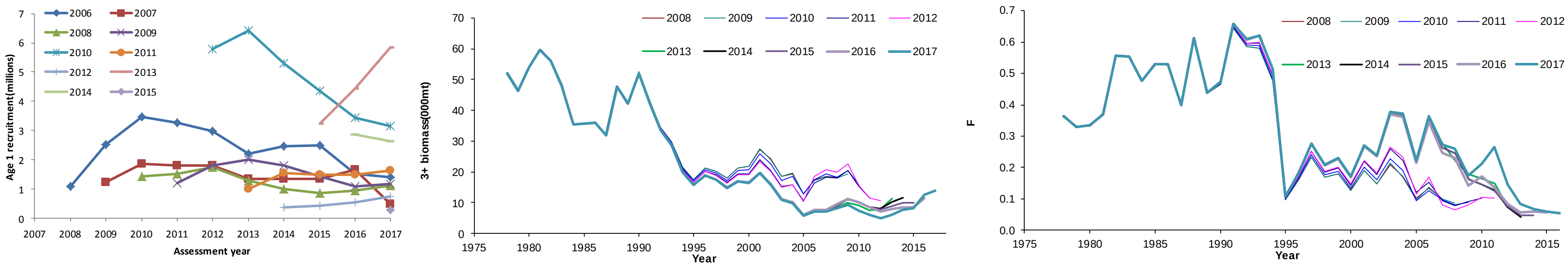


Figure 32. Retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the "M 0.8" model in 2017 assessment.

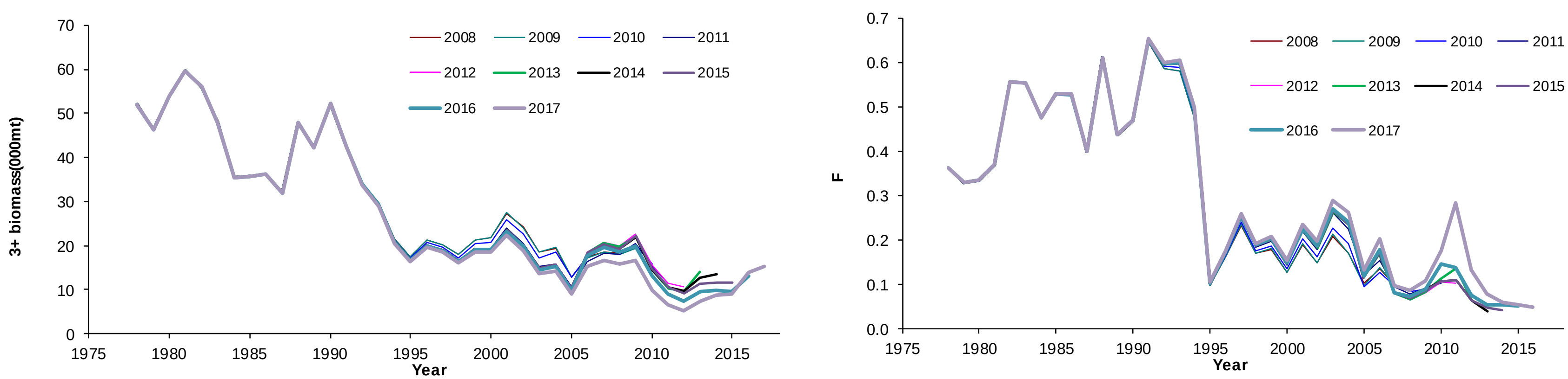
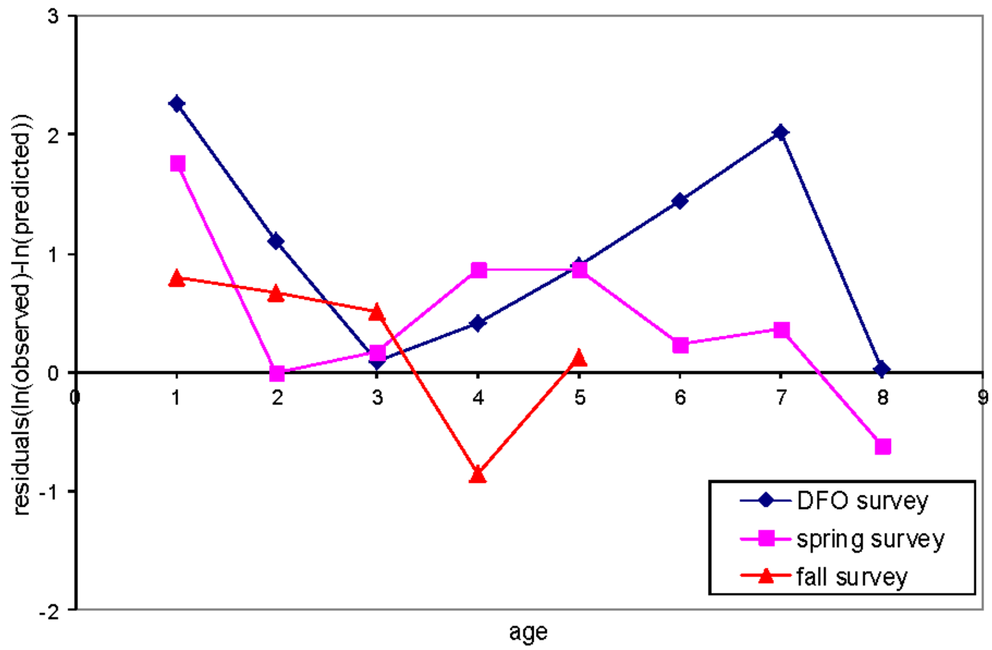


Figure 33. Retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the sensitivity run "2017 est 2003yc" in the 2017 assessment.



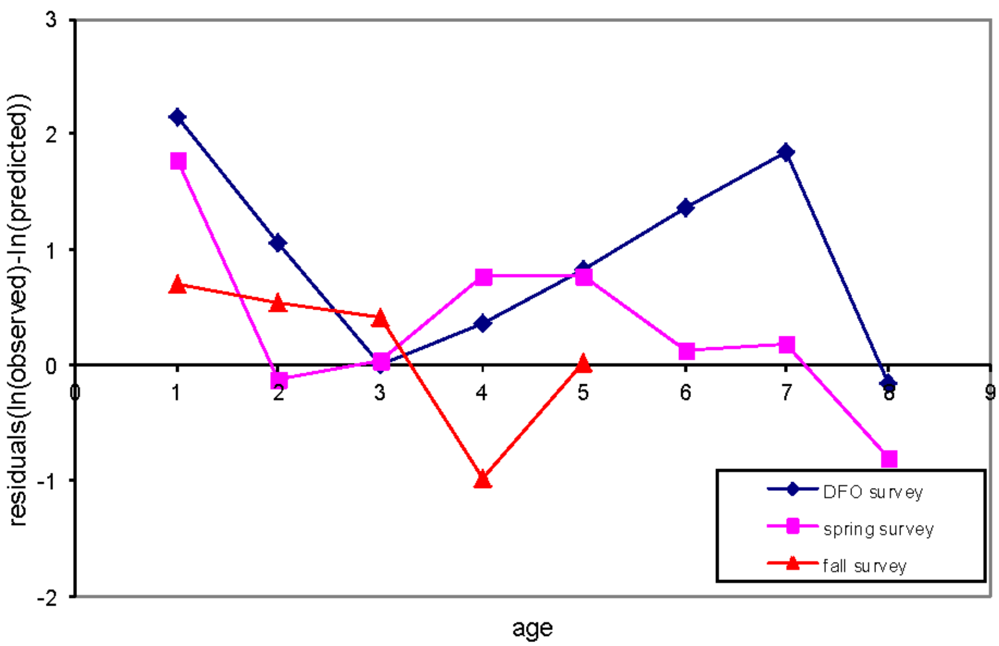


Figure 34. Residuals of the predicted survey values of the 2003 year class for the "M 0.8" model in 2013 (upper) and 2014 (lower) assessment.

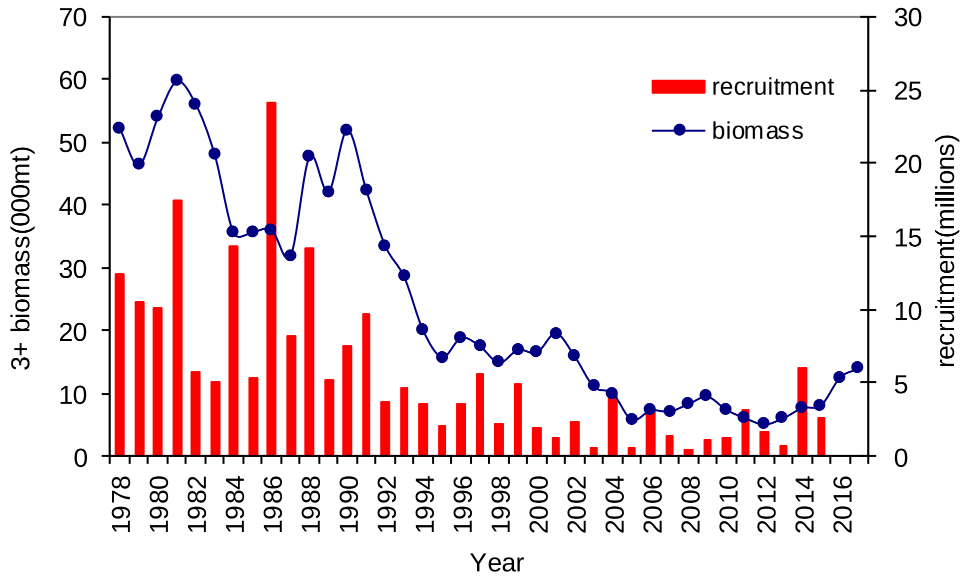


Figure 35. Adult biomass (ages 3+) and year class abundance at age 1 for eastern Georges Bank cod.

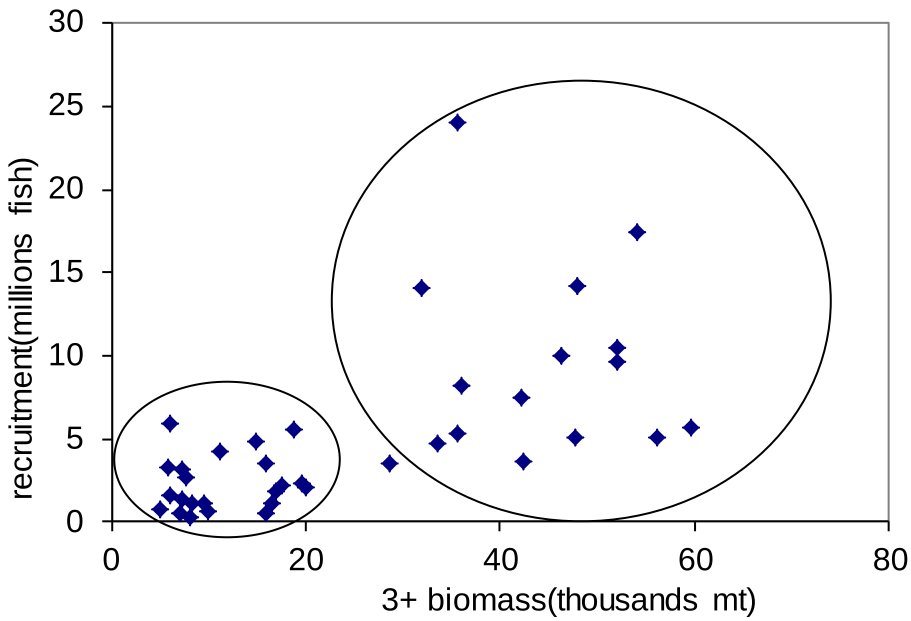


Figure 36. Relationship between adult biomass (ages 3+) and recruits at age 1 for eastern Georges Bank cod.

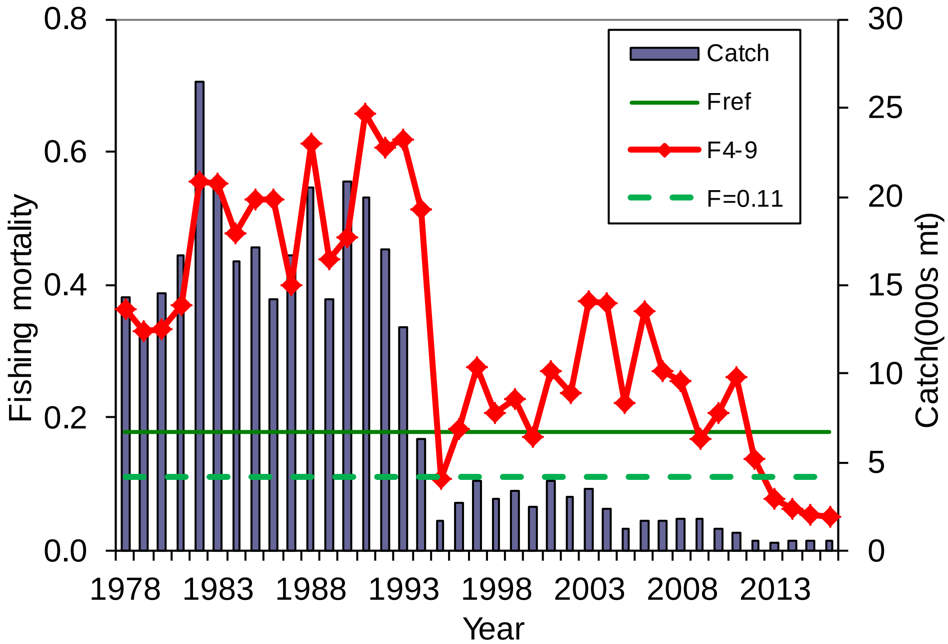


Figure 37. Average fishing mortality rate at ages 4 to 9 and catches for eastern Georges Bank cod. The established fishing mortality threshold reference, Fref=0.18. The F reference point for the "M 0.8" model is 0.11.

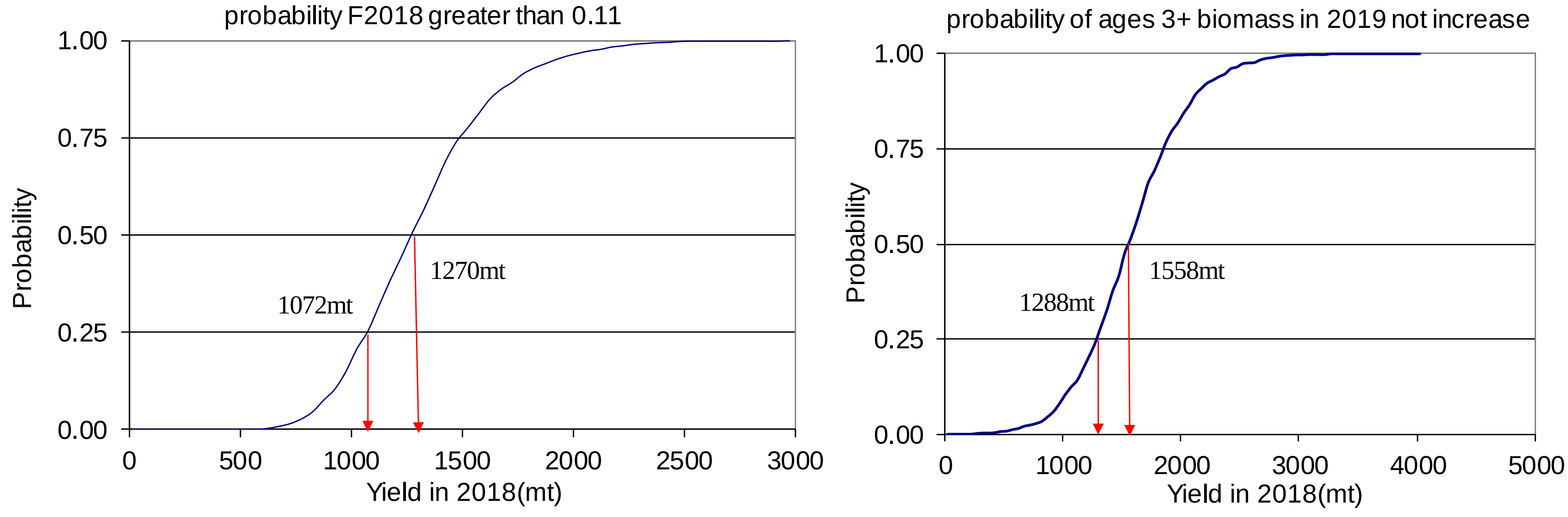


Figure 38. Risk of 2018 fishing mortality exceeding F reference point 0.11 and 2019 biomass not increasing from 2018 for alternative total yields of eastern Georges Bank cod from the "M 0.8" model formulation.

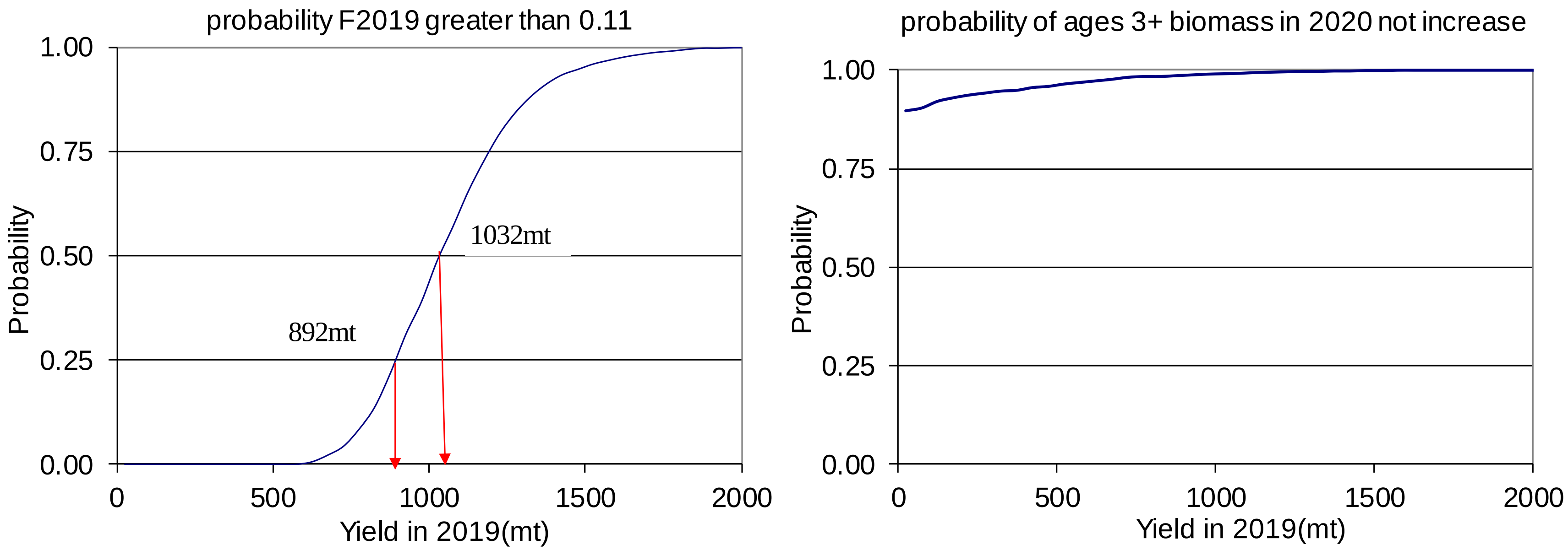


Figure 39. Assuming F2018=0.11, risk of 2019 fishing mortality exceeding F reference point 0.11 and 2020 biomass not increasing from 2019 for alternative total yields of eastern Georges Bank cod from the "M 0.8" model formulation.

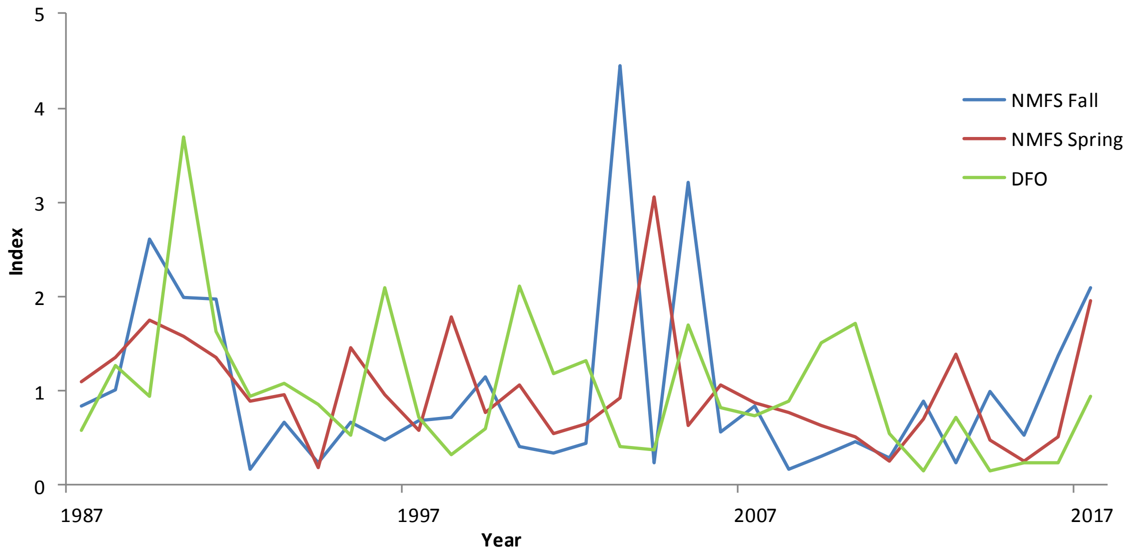


Figure 40. Plot of the normalized NMFS fall, DFO, and NMFS spring indices from 1987 (1986 fall) through 2017 (2016 fall). All three indices were divided by their mean and are plotted on the same scale.

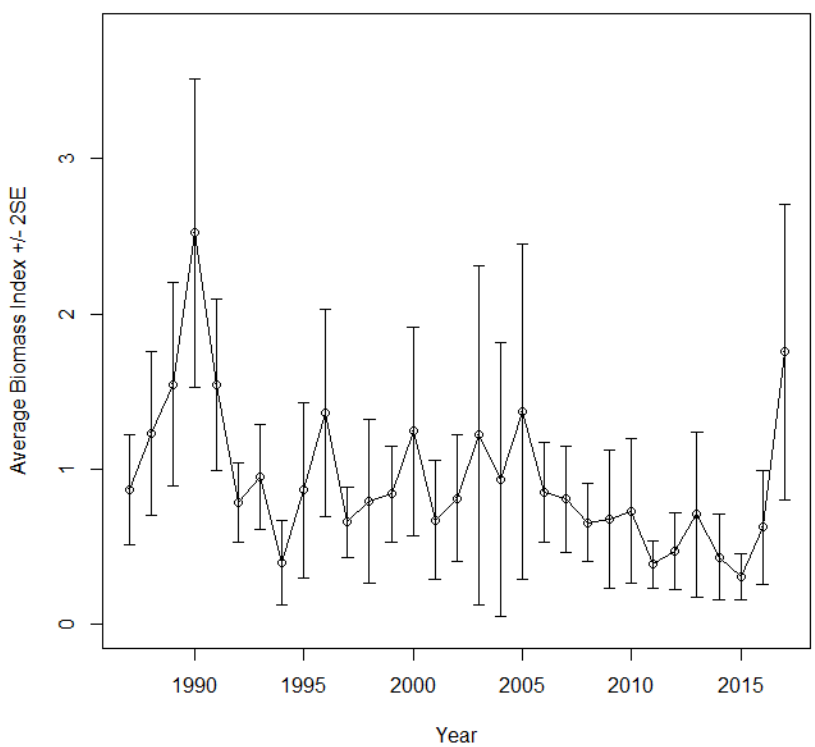


Figure 41. Plot of the combined index from CV weighted average of the three surveys (NMFS fall, DFO, and NMFS spring).

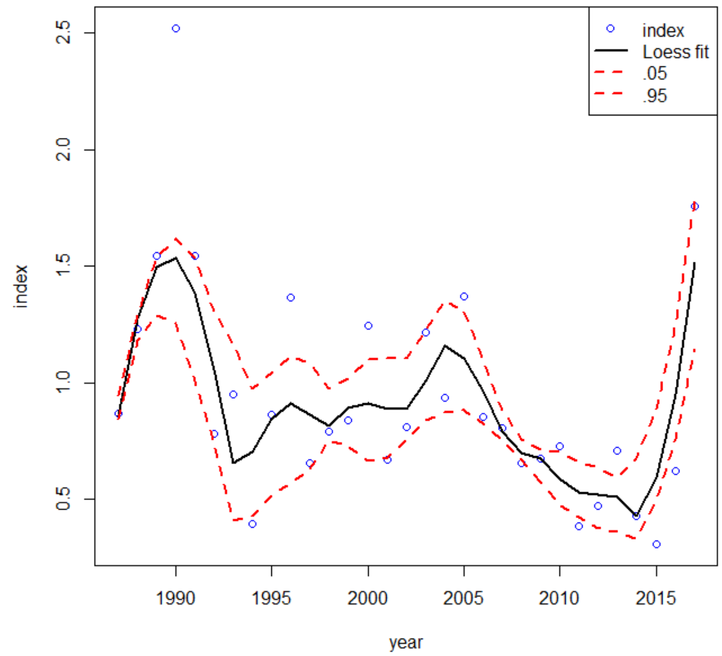


Figure 42. Bootstrap CI for the loess fits of robust least squares.

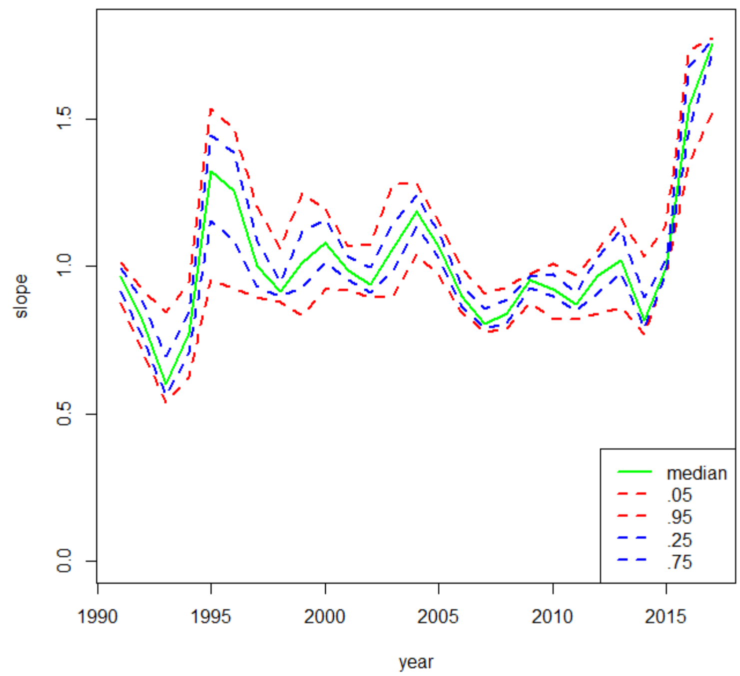


Figure 43. Bootstrap CI for the estimated slope of robust least squares.

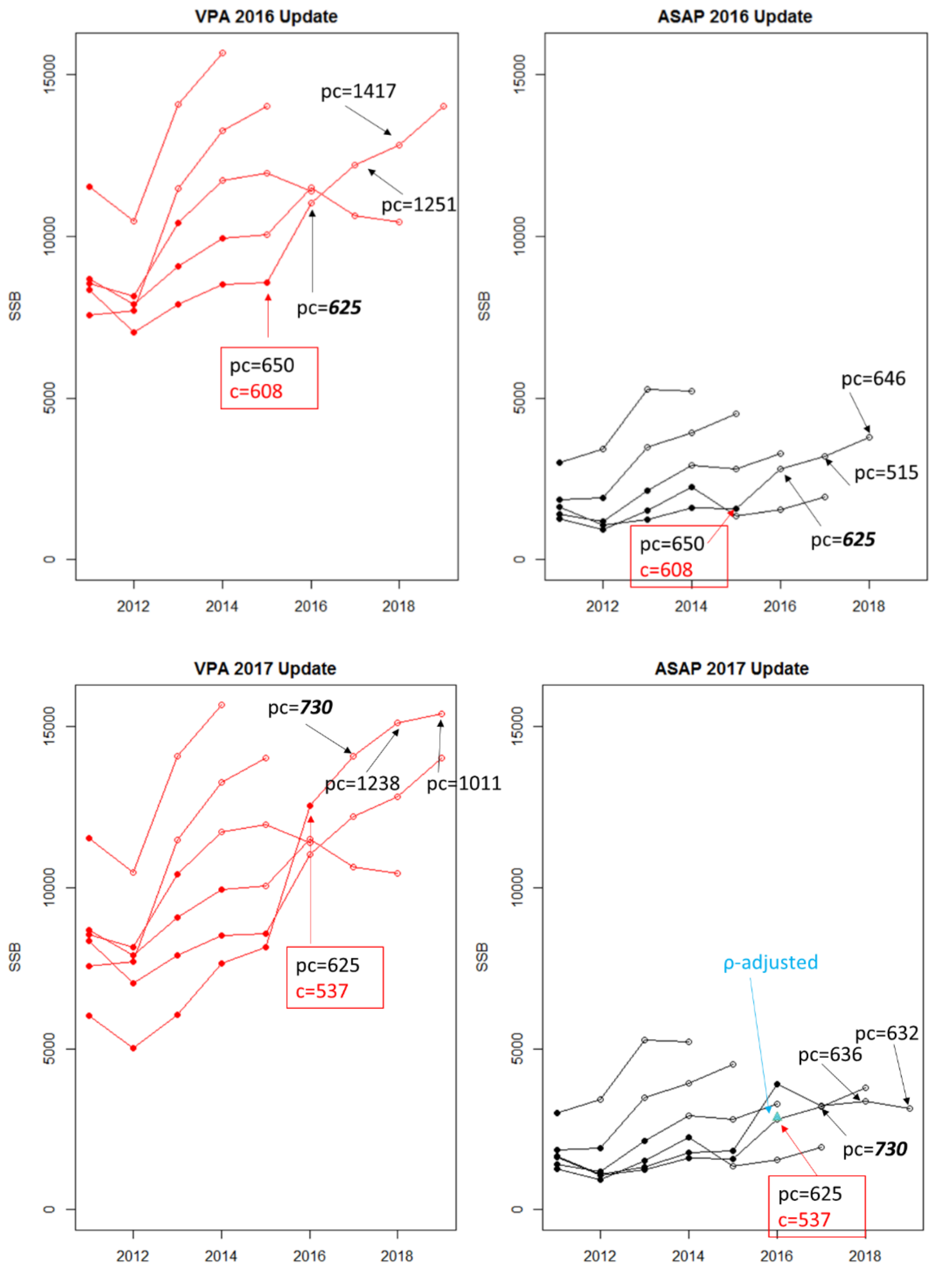


Figure 44. Deterministic projection results from VPA and ASAP models at TRAC 2016 (top) and TRAC 2017 (bottom). Solid circles indicate the last model estimate of adult biomass (SSB), open circles indicate projected SSB, light blue triangle is the 2016 SSB in ASAP adjusted for retrospective pattern. Projected catch amounts ("pc") are indicated for each year of removal; bold italic values are quotas that were agreed to previously, while non-bold values represent catch (mt) that results from applying F=0.11 (VPA) or F=0.18 (ASAP). In the red 'box,' the realized catch ("c") is indicated for comparison with the quota that had been assumed in the previous assessment projection.

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 2016.

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.

Year	Canadian Management History
2016	TAC=730 Winter fishery from Jan. 1 to Feb. 7, 2016. Based on results of the 2014 test project 125mm square mesh was approved for use in 2016. At sea observer coverage was 67% by weight for the mobile gear fleet, 21% by weight for fixed gear and 4% by weight for 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

2017 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 2016. 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 2018-2020.

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 2017 and NEFSC 2017).

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 (run8) presented and reviewed at the 2016 TRAC (Andrushchenko et al. 2016) was updated for the 2017 assessment.

Model Results

Terminal year (2016) estimates of SSB and F, Mohn's rho for SSB and F, and retrospective adjusted values of SSB and F show the strong influence of applying the retrospective adjustment (Appendix Table 2).

Model diagnostics are very similar to last years' assessment (Andrushchenko et al. 2016). 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 0.22 in 2016 (Appendix Table 3, Appendix Figure 9), a 41% decrease from 2015. SSB in 2016 was estimated at 3,918 mt, a 113% increase from 2015 (Appendix Table 3, Appendix Figure 9). Recruitment (millions of age 1 fish) of the 2015 year class is estimated at 0.303 million, the smallest year class. The 2013 year class is estimated at 2.505 million fish , the largest year class since the 2003 year class, now estimated at 2.543 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 (2009-2015) prior to the terminal year, 2016. 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). The retrospective rho values, the average of the last 7 years of the relative retrospective peels, were 0.37 for SSB, -0.38 for F_{5+}, and -0.17 for recruitment. Since the retrospective adjusted values of SSB and F are outside the 90% probability intervals (see below), the model results need to be adjusted for retrospective bias (Figure 12).

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 2017 ASAP model results to estimate landings and SSB during 2018-2020. The input values for mean catch and stock weights, partial recruitment (PR), and maturity were estimated as 3-year averages from 2014-2016. Recruitment was estimated from a 2-stage cumulative distribution function (CDF) based on either 24 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 2017 was estimated based on the assumption that the 2017 quota of 730 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 2018. SSB is projected to increase in 2017 and decrease in 2018.

Year	SSB	F	Catch
2017	3231	0.25	730

2018	3358	0.18	636
2019	3137	0.18	632

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).

Literature Cited

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

Claytor, R. and L. O'Brien, L. (2013). Transboundary Resources Assessment Committee (TRAC) Eastern Georges Bank Cod Benchmark Assessment and TRAC Benchmark Criteria Discussion: Report of a Meeting held 9-11 April 2013. *TRAC Ref.Doc 2013/01*: 29 p.

Dean, M. J., W.S. Hoffman, and M. P. Armstrong. 2012. Disruption of an Atlantic Cod Spawning Aggregation Resulting from the Opening of a Directed Gill-Net Fishery. No.Am.J.Fish. Manage. **32**:124-134.

Lawson, G. L. and G. A. Rose. 2000. Small-scale spatial and temporal patterns in spwaning of Atlantic cod (gadus morhua in coastal Newfoundland waters. Can. J. FIsh. Aquat. Sci. **57**:1011-1024.

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

Legault, C.M. and V.R. Restrepo. 1998. A flexible forward age-structured assessment program. ICCAT. Col. Vol. Sci. Pap. 49:246-253.

McAllister, M. K. and J. N. Ianelli. 1997. Bayesian stock assessment using catch-age data and
the sampling-importance resampling algorithm. Can. J. FIsh. Aquat. Sci. **54**:284-300.

Miller, T, D. Clark, and L.O'Brien 2013. Estimates of mortality and migration from Atlantic cod tag-recovery data in NAFO areas 4X, 5Y, and 5Z in 1984-1987 and 2003-2006. TRAC WP 2013/02, 20 p

Northeast Fisheries Science Center. 2013. 55th Northeast Regional Stock Assessment Workshop (55th SAW) Assessment Report. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 13-11; 845 p (http://www.nefsc.noaa.gov/publications/)

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

Palmer, M. C. & Wigley, S. E. 2007. Validating the stock apportionment of commercial fisheries landings using positional data from Vessel Monitoring Systems (VMS). . US Dept Commer, Northeast Fish Sci Cent Ref Doc. 07-22.: 35.

Palmer, M. C. & Wigley, S. E. 2009. Using Positional Data from Vessel Monitoring Systems to Validate the Logbook-Reported Area Fished and the Stock Allocation of Commercial Fisheries Landings. North American Journal of Fisheries Management 29(4): 928-942.

Rivard, D. 1982. APL programs for stock assessment (revised). Can. Tech. Rep. Fish. Aquat.Sci. 1091:146 p.

TMGC. 2002. Development of a Sharing Allocation Proposal for Transboundary Resources of Cod, Haddock, and Yellowtail Flounder on Georges Bank. Fisheries Management Regional Report **2002/01**:60. http://www2.mar.dfo-mpo.gc.ca/science/tmgc/sharing.html

Trippel, E. A. 1998. Egg size and viability and seasonal offspring production of young Atlantic cod. Tran. Am. Fish. Soc. **127**:339-359.

Wang, Y. & O'Brien, L. (2012). Assessment of Eastern Georges Bank Atlantic Cod for 2012. *TRAC Res. Doc. 2012/05*: 83 p.

Wang, Y. , L. O'Brien, I. Andrushchenko, and K. J.Clark. 2015. Assessment of Eastern Georges Bank Atlantic Cod for 2015.TRAC Res. Doc. 2015/03.

Windle, M. J. S. and G. A. Rose. 2007. Do cod form spawning leks? Evidence from a Newfoundland spawning ground. Mar. Biol. **150**:671–680.

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

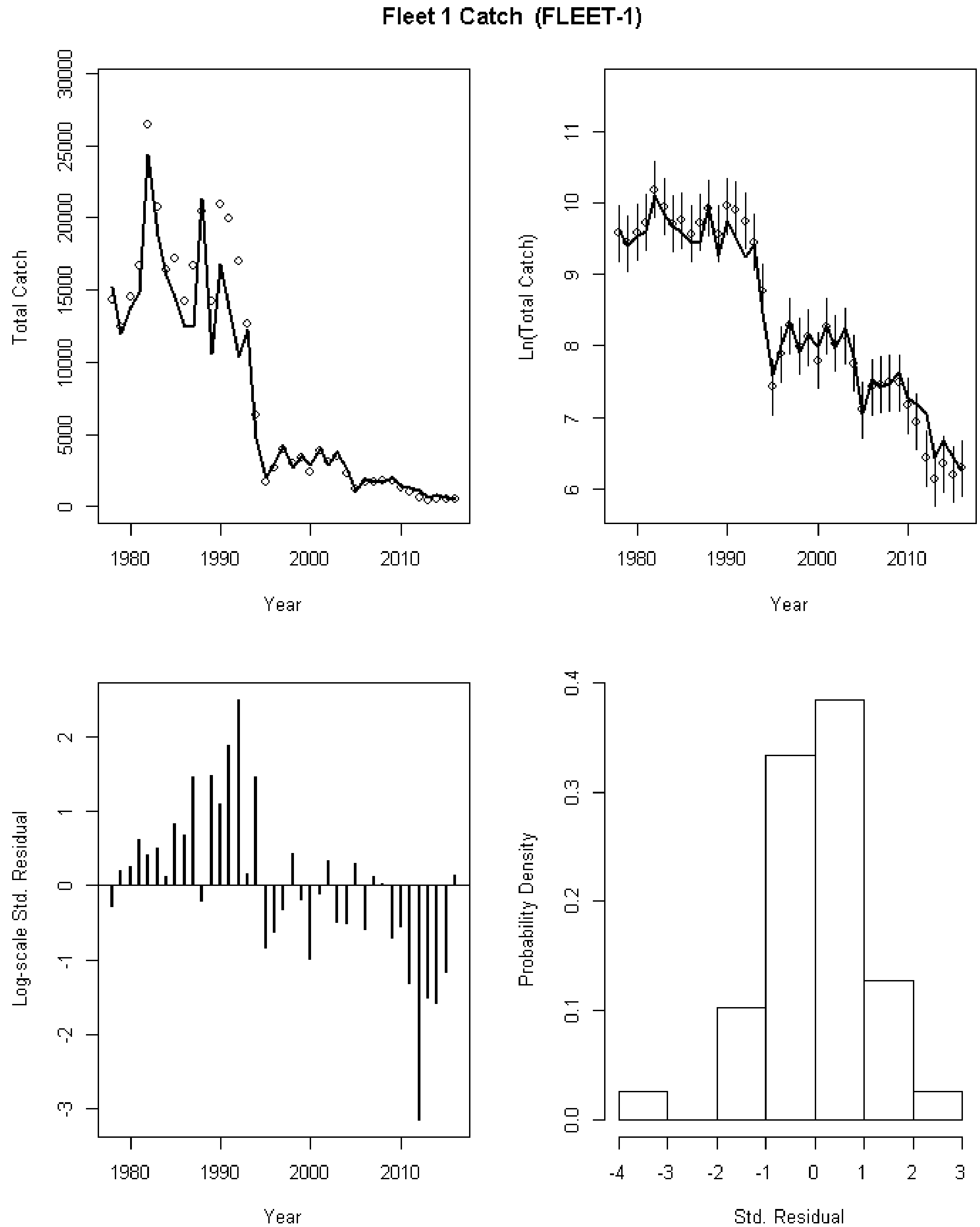
	Age									
Year	1	2	3	4	5	6	7	8	9	10+
1978	0.245	1.149	1.639	2.121	2.799	4.103	4.285	7.587	7.881	12.907
1979	0.564	0.8	1.386	2.601	3.477	4.954	7.137	7.347	9.036	14.362
1980	0.207	0.955	1.789	2.161	4.03	5.289	6.898	10.385	10.008	13.455
1981	0.331	0.697	1.572	2.603	3.731	5.675	7.101	8.17	11.537	15.92
1982	0.34	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	15.04
1984	0.486	1.202	1.853	2.753	3.843	5.29	7.116	8.545	10.646	13.621
1985	0.337	0.945	1.705	2.712	3.946	5.322	6.938	8.93	10.03	13.758
1986	0.326	0.853	1.787	2.446	3.922	5.522	6.933	8.529	10.454	12.262
1987	0.41	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	7.73	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
1990	0.469	0.981	1.738	2.513	3.921	5.435	6.849	8.163	10.475	13
1991	0.544	1.027	1.937	2.732	3.695	5.041	6.711	8.587	9.494	14
1992	0.675	1.026	1.861	2.831	3.65	4.898	6.13	8.033	10.299	15
1993	0.403	1.097	1.723	2.544	3.773	4.787	6.186	7.504	8.896	12
1994	0.41	0.895	1.731	2.691	3.532	5.249	6.232	7.421	8.125	13
1995	0.153	0.893	1.682	2.679	4.119	5.293	8.052	8.482	9.223	17
1996	0.307	0.677	1.69	2.543	3.97	5.365	6.399	9.51	10.178	11
1997	0.475	0.852	1.715	2.518	3.43	5.023	6.505	7.303	10.139	11
1998	0.511	0.947	1.745	2.48	3.409	4.536	5.945	7.535	9.22	14
1999	0.341	0.952	1.625	2.579	3.413	4.666	5.78	7.05	8.566	14
2000	0.485	0.846	1.599	2.393	3.527	4.288	5.599	6.517	7.936	13
2001	0.087	0.75	1.566	2.323	3.221	4.423	4.954	6.449	7.654	11
2002	0.169	0.501	1.351	2.288	3.316	4.18	5.589	6.554	7.617	11
2003	0.138	0.638	1.598	2.303	3.169	4.123	5.167	6.622	7.924	9
2004	0.133	0.595	1.512	2.425	3.063	4.013	4.709	6.293	7.643	10
2005	0.312	0.45	1.387	2.079	3.113	3.948	4.703	5.941	7.556	10
2006	0.134	0.504	1.198	1.894	2.78	3.867	5.24	5.296	6.817	7
2007	0.277	0.526	1.016	2.006	2.626	3.588	5.109	6.458	6.318	10
2008	0.156	0.763	1.523	2.119	2.909	3.879	4.77	6.947	7.382	9
2009	0.475	0.582	1.559	2.596	3.215	4.055	5.374	6.259	8.897	11
2010	0.321	0.921	1.516	2.201	3.202	3.57	4.798	5.908	7.713	11
2011	0.179	0.719	1.486	2.283	2.98	3.803	3.812	5.564	7.738	10
2012	0.155	0.539	1.334	2.131	3.07	3.798	4.457	4.908	5.685	5.23
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	7.33	6.772
2015	0.302	0.592	1.391	2.595	3.228	4.21	5.858	9.102	9.275	6.371
2016	0.034	0.563	1.465	2.237	3.76	4.285	5.464	7.625	14.184	6.238

Appendix.Table 2. ASAP model diagnostics and results.

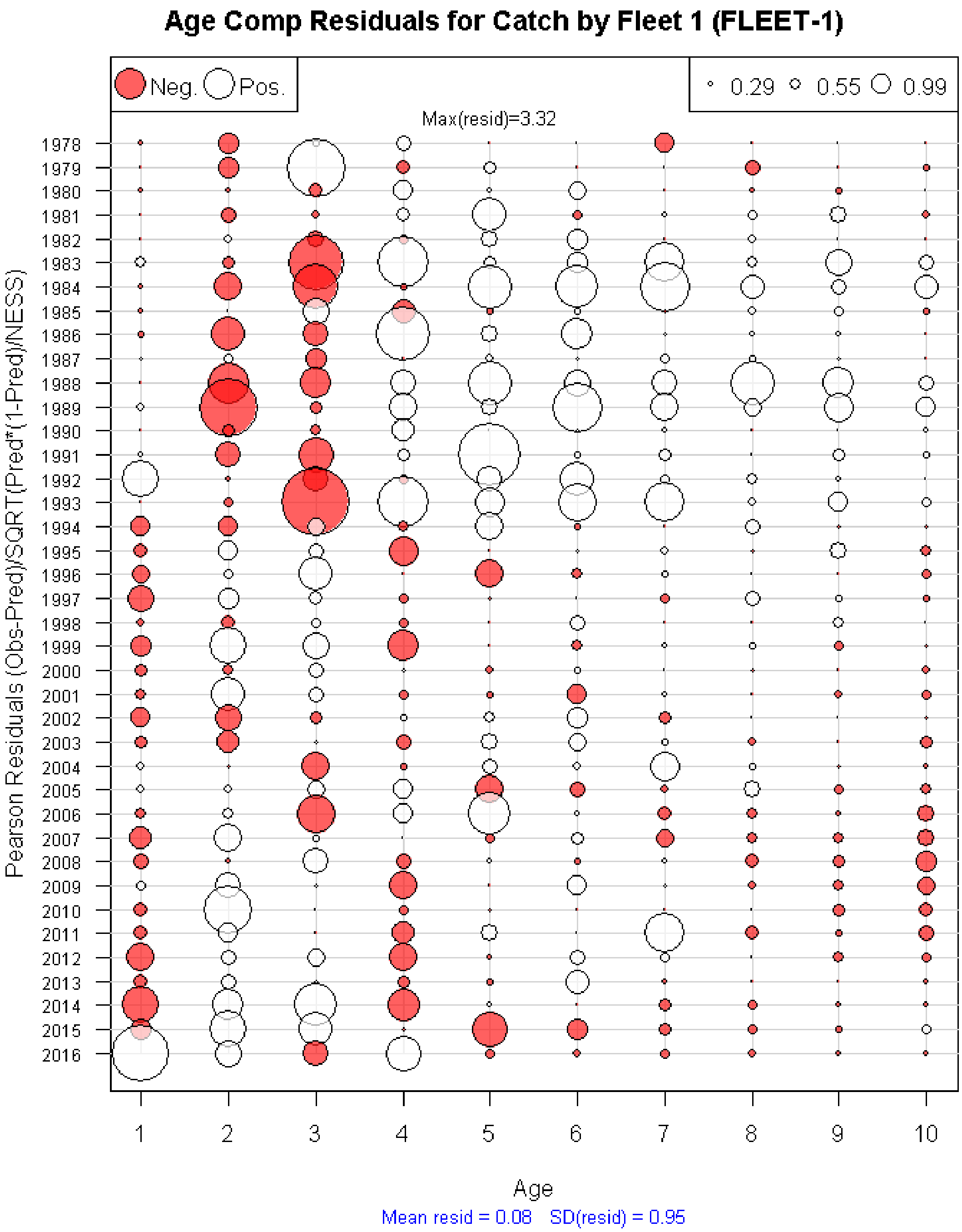
	SSB (mt)	F
Mohn's rho	0.368	-0.376
2016 Estimate	3918	0.22
2016 rho adjusted	2865	0.35

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

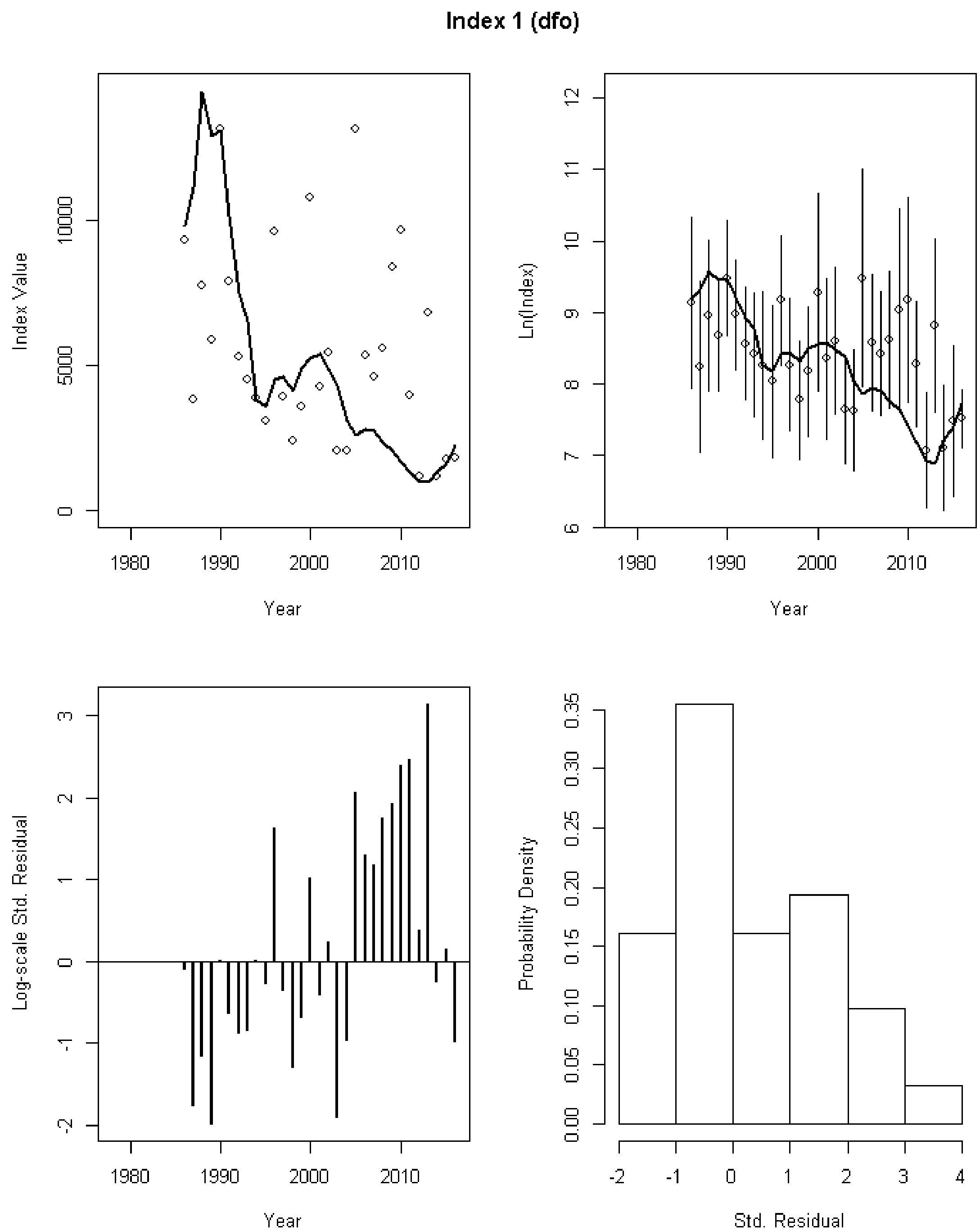
Year	Jan 1 B	SSB	F	Recr
1978	37569	29561	0.49	10194
1979	40727	25934	0.39	9704
1980	43569	30966	0.41	8356
1981	45670	31461	0.45	17696
1982	48392	29237	0.74	6774
1983	41281	29778	0.62	3193
1984	37275	24641	0.66	11779
1985	30218	16481	0.84	4593
1986	30245	16975	0.68	22700
1987	35818	15243	0.53	5353
1988	42087	28643	0.80	10786
1989	31450	19669	0.46	4289
1990	32755	23203	0.71	5000
1991	29135	16491	0.88	9597
1992	23052	11358	0.78	2440
1993	18237	11663	1.23	3174
1994	10118	5825	1.22	2041
1995	8732	6518	0.45	1258
1996	9987	7660	0.56	2689
1997	11355	6650	0.89	3688
1998	10688	6502	0.61	1281
1999	11528	8403	0.66	3526
2000	11484	7499	0.50	1611
2001	10691	8515	0.74	1114
2002	8683	7220	0.50	1561
2003	8180	6291	0.85	409
2004	6004	4779	0.80	2543
2005	4642	3249	0.44	450
2006	4820	4024	0.71	950
2007	4573	3355	0.66	1339
2008	4530	3179	0.69	656
2009	4486	3386	0.99	507
2010	3359	2376	0.94	683
2011	2624	1650	1.30	1201
2012	2043	1104	1.89	747
2013	1877	1336	0.81	383
2014	2517	1763	0.68	2505
2015	3447	1843	0.37	806
2016	4518	3918	0.22	303



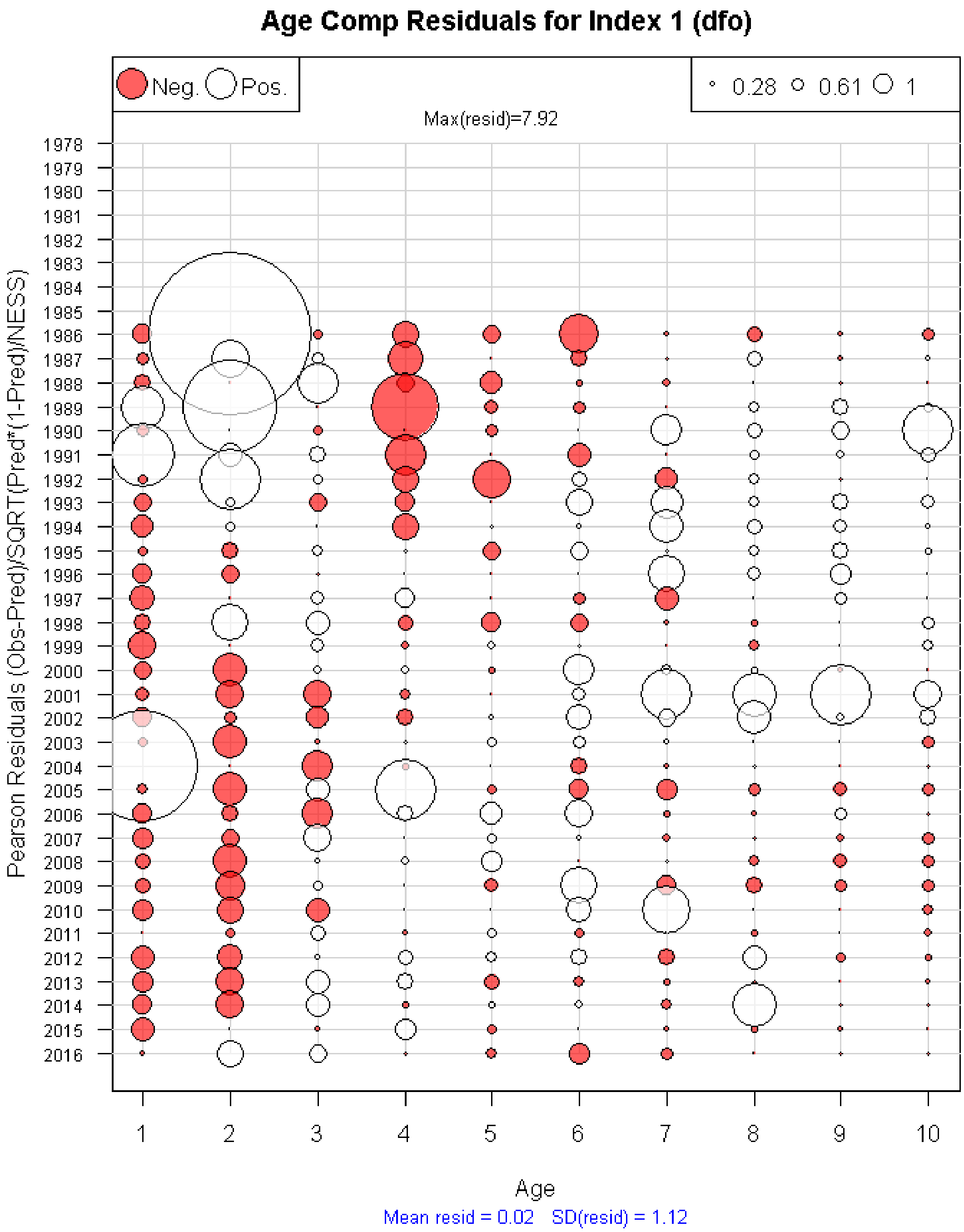
Appendix Figure 1. ASAP model fit to total catch of eastern Georges Bank cod.



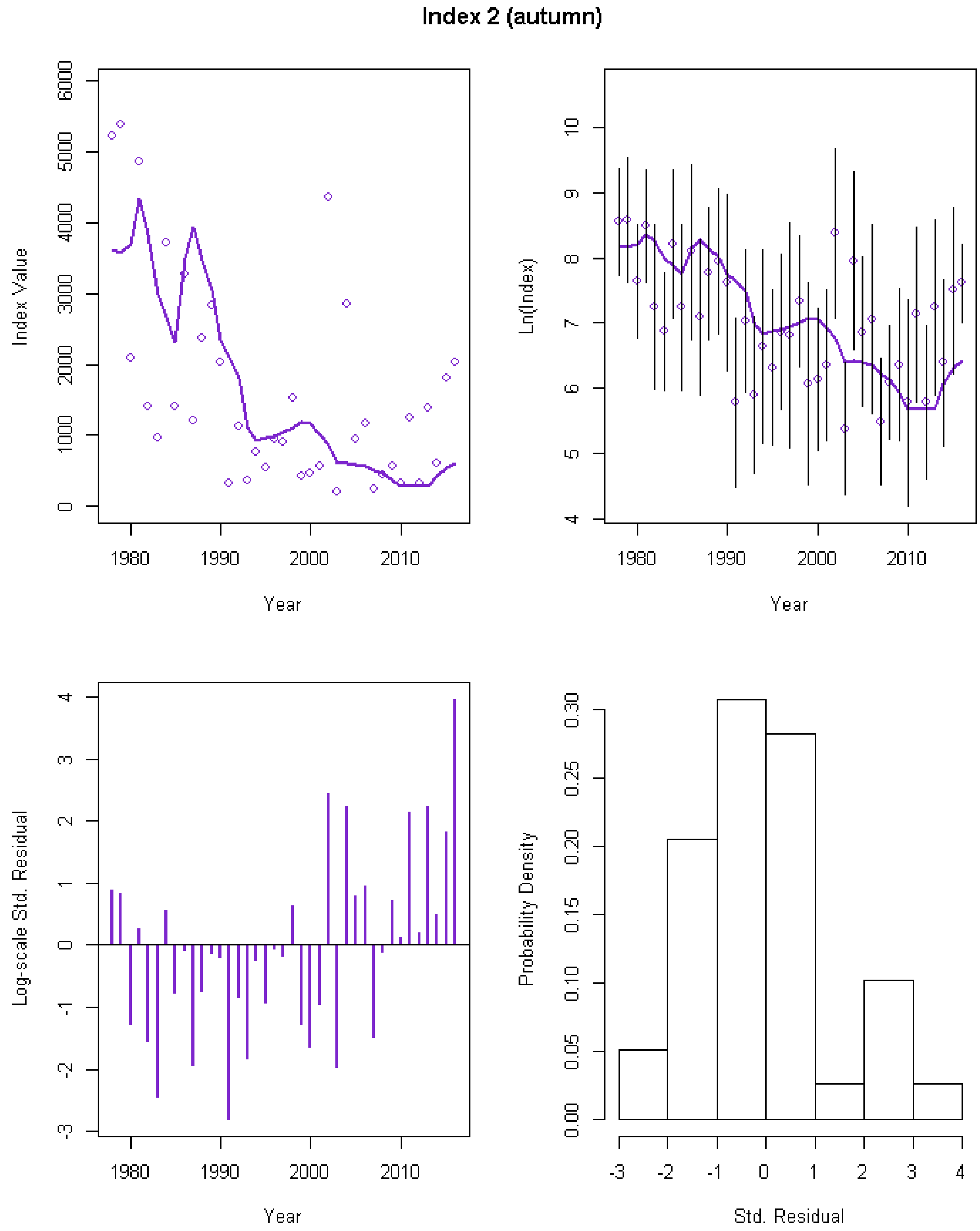
Appendix Figure 2. ASAP model residuals for the commercial catch age composition of eastern Georges Bank cod.



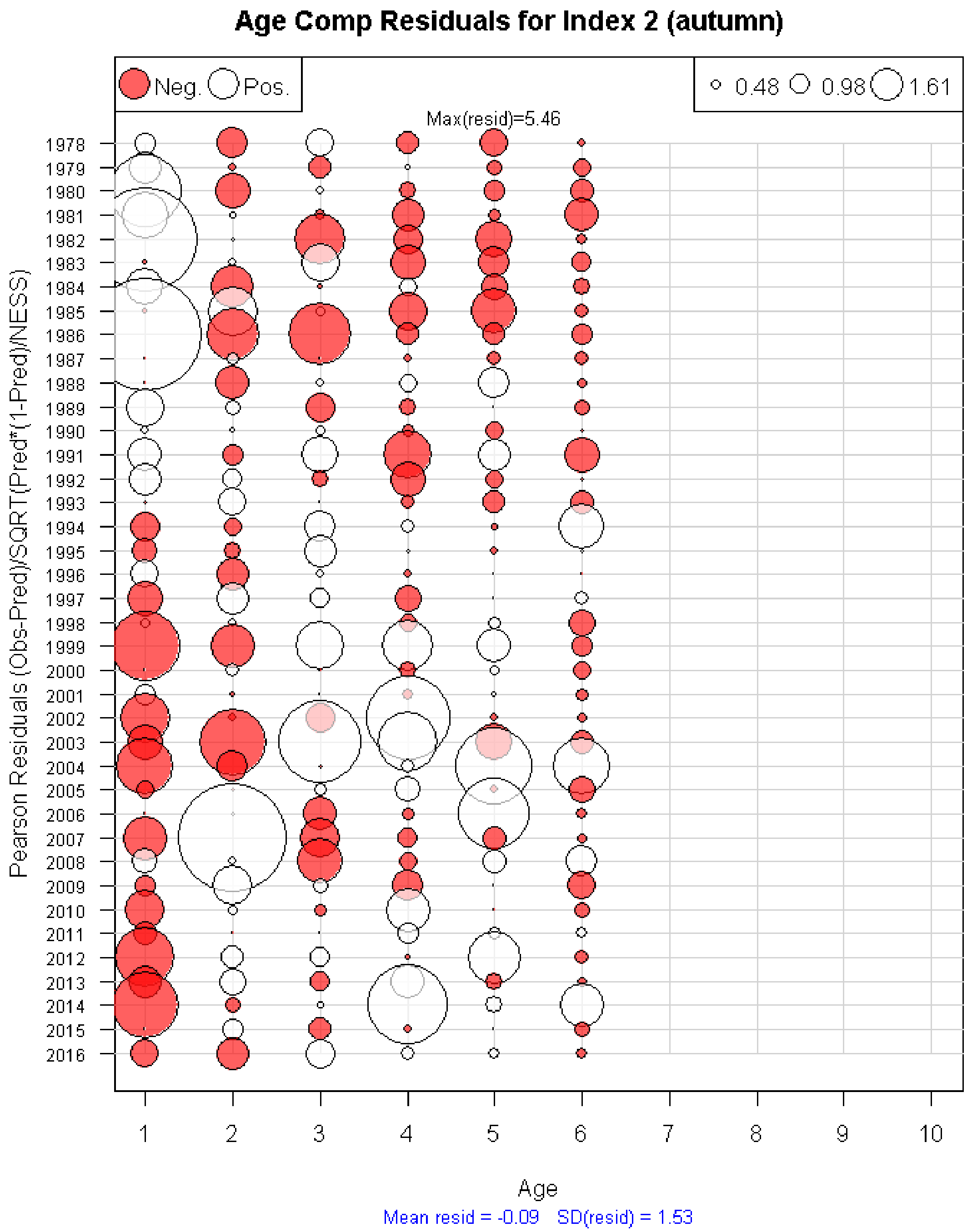
Appendix Figure 3. ASAP model fit to DFO survey indices of eastern Georges Bank cod.



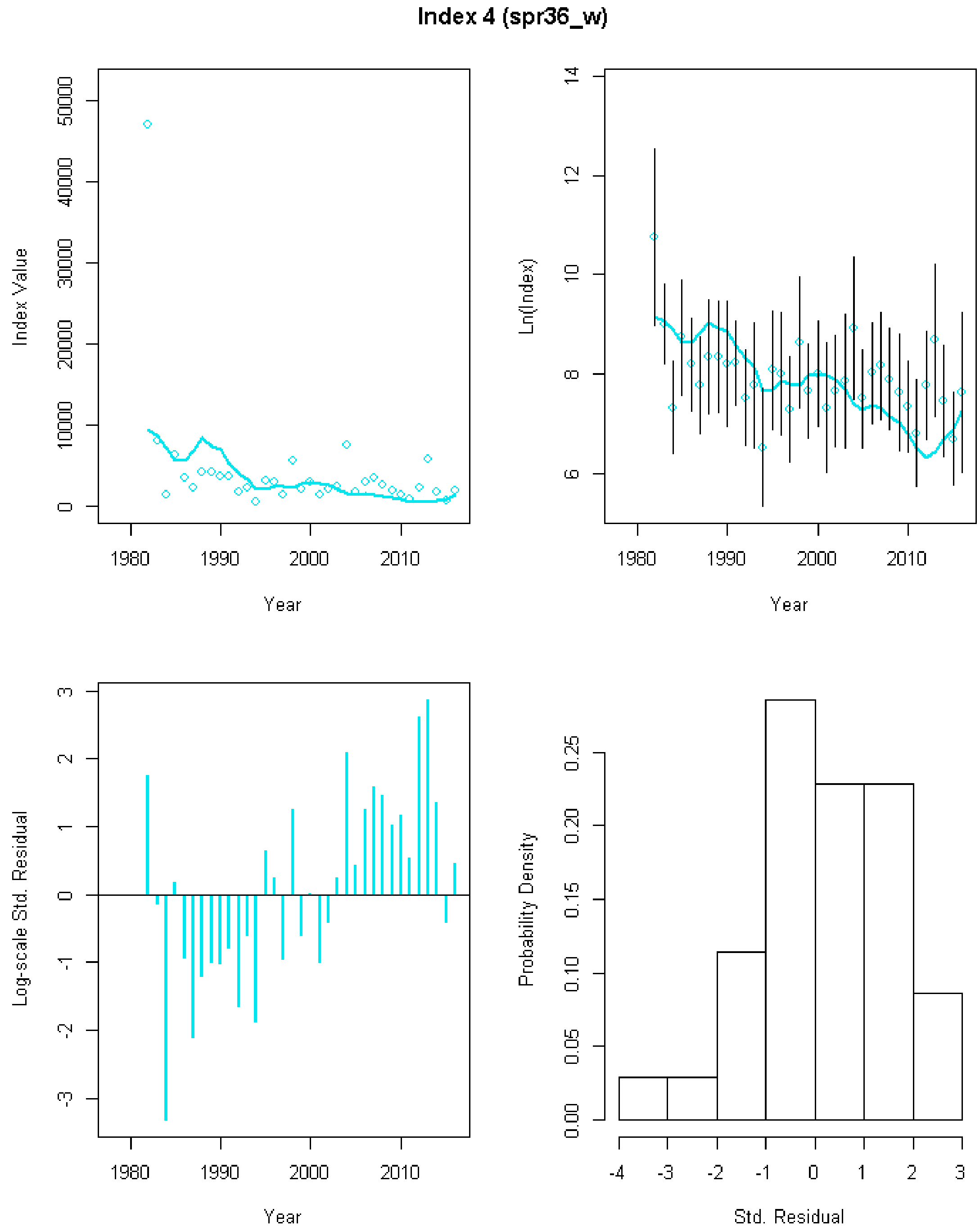
Appendix Figure 4. ASAP model run age composition residuals for DFO survey index of eastern Georges Bank cod.



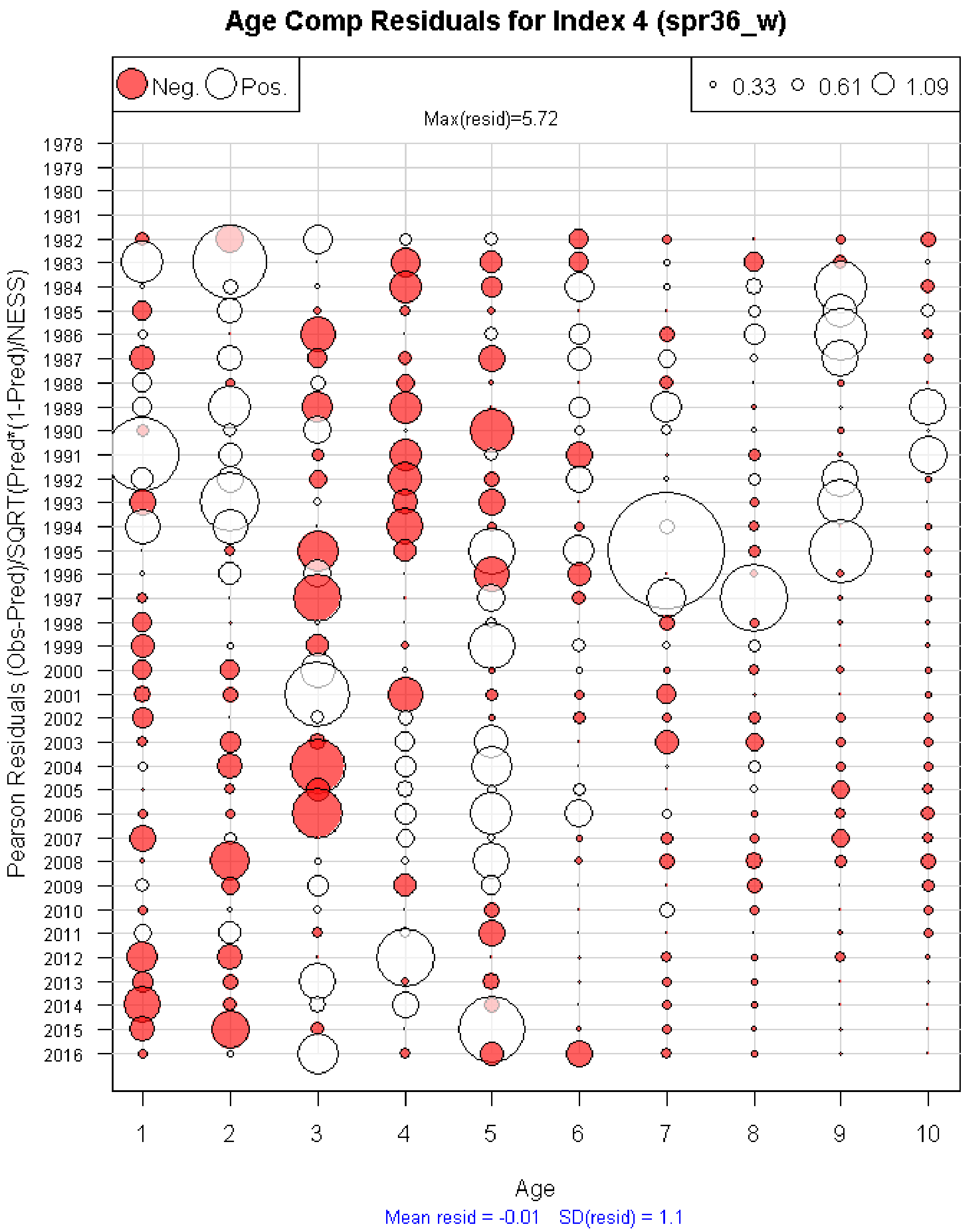
Appendix Figure 5. ASAP model fit to NEFSC autumn survey indices of eastern Georges Bank cod.



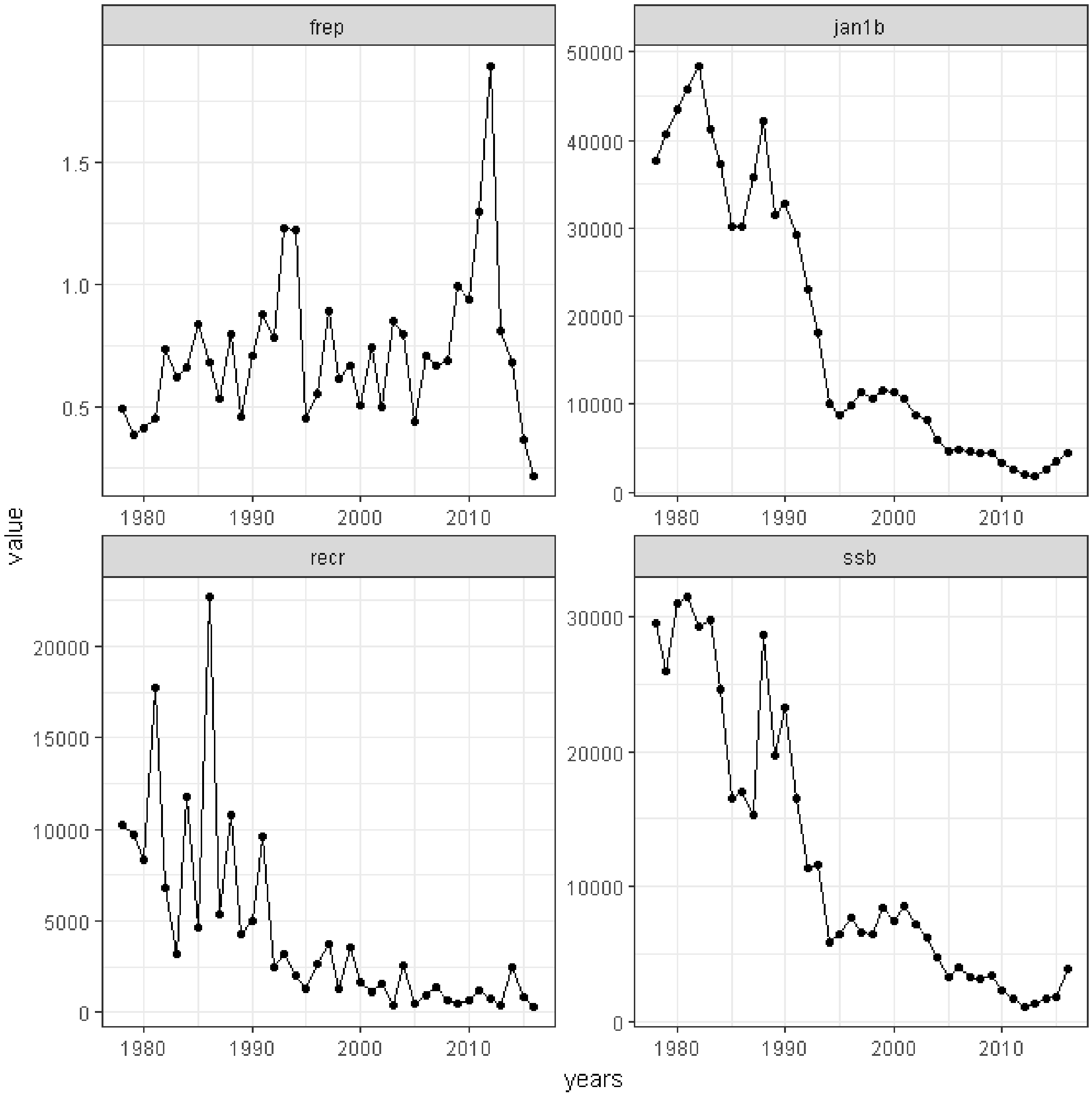
Appendix Figure 6. ASAP model age composition residuals for NEFSC autumn survey index of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1978-2015.



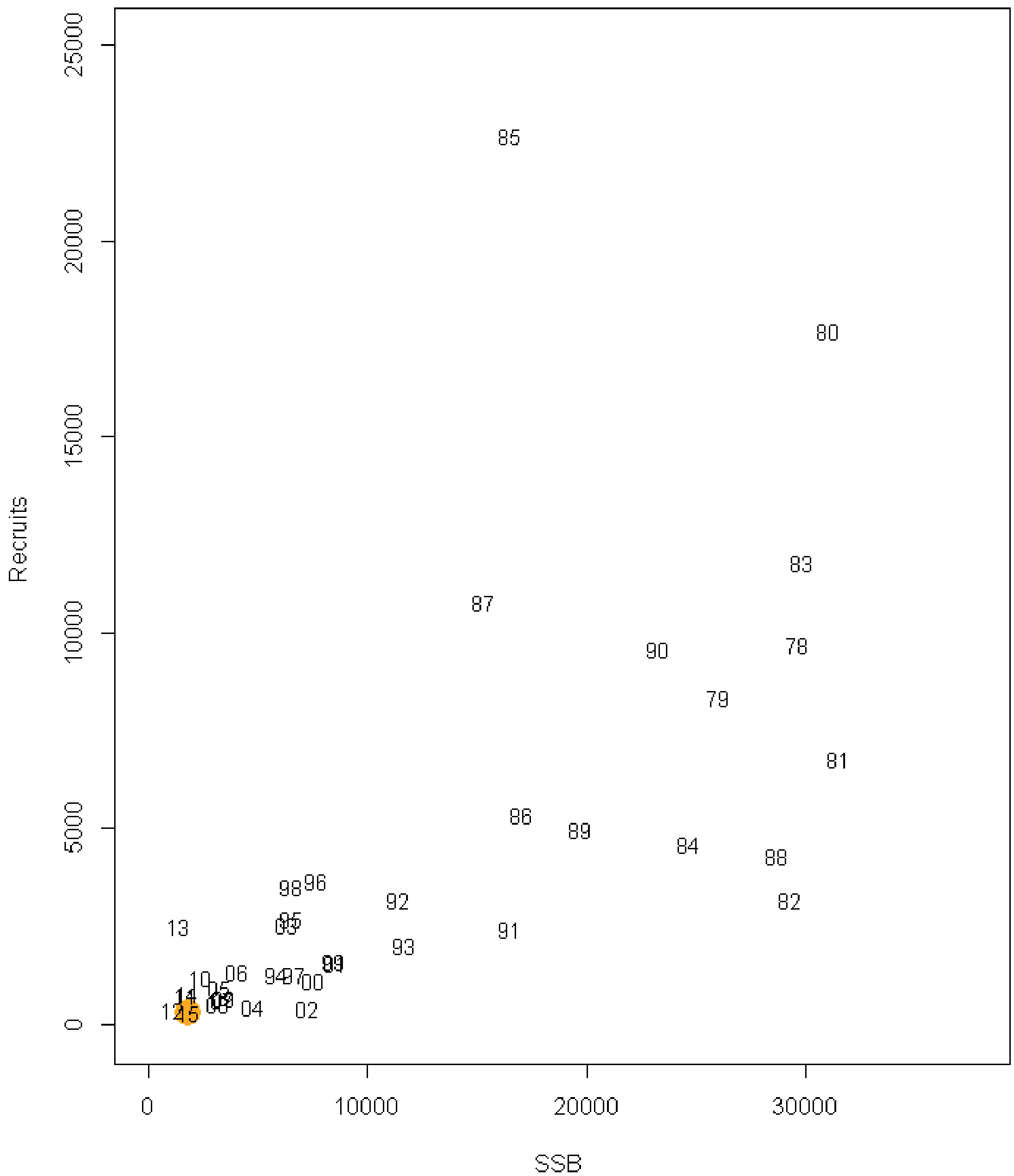
Appendix Figure 7. ASAP model fit to NEFSC spring Yankee #36 trawl survey indices of eastern Georges Bank cod.



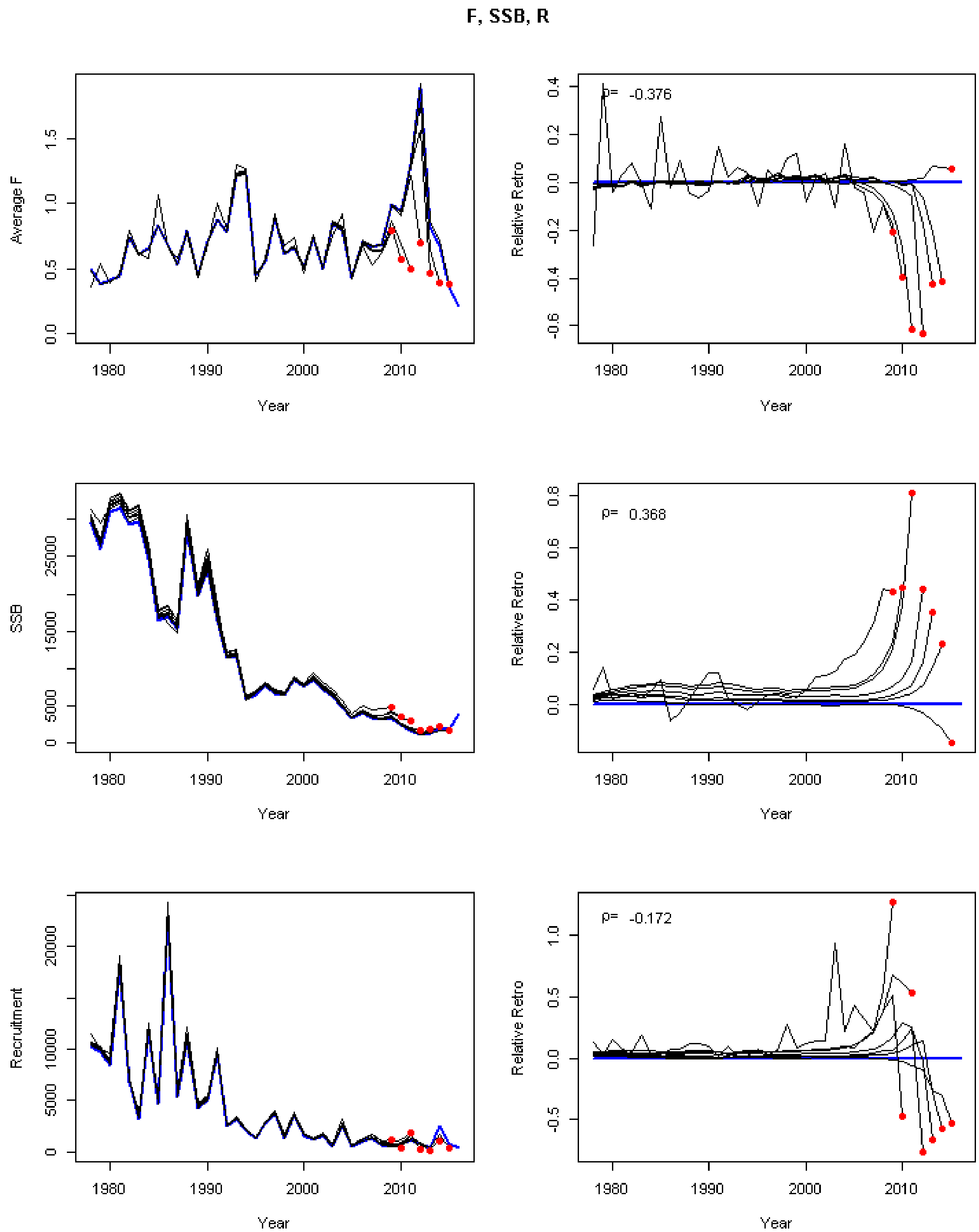
Appendix Figure 8. ASAP model age composition residuals for NEFSC spring Yankee #36 trawl survey index of eastern Georges Bank cod.



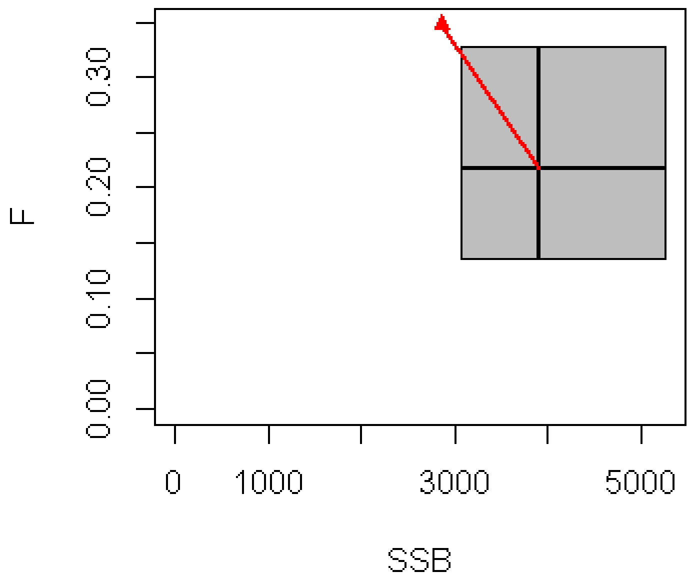
Appendix Figure 9. ASAP model results for fishing mortality (ages 5+), January 1 biomass (mt), spawning stock biomass (mt), and recruitment (age1, 000s fish).



Appendix Figure 10. ASAP stock – recruitment plot.



Appendix Figure 11. ASAP model results of retrospective bias of fishing mortality (F), spawning stock biomass (SSB), and age1 recruitment.



Appendix Figure 12. Terminal year 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.