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Biological and Fishery Indicators and Models Projection Performance for Eastern Georges Bank Cod (TOR 1 and 2)

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ABSTRACT

This document addresses 2016 TRAC terms of reference (ToR) 1 and 2.

ToR 1: *Provide a summary of biological and fishery indicators of the state of cod in the eastern GB management area.*

ToR 2: *Provide a review of projection performance for VPA and ASAP since the benchmark meeting in 2013, including a comparison of projection assumptions against subsequent assessment results.*

The analyses conducted in Part A to address ToR1 provide a means of assessing the status of cod on eastern Georges Bank outside a model framework, and can also aid infor interpreting the results of ToR 3: *Develop and apply an empirical approach.* The analyses conducted in Part B, to address ToR 2 provide a means of evaluating projection performance relative to rebuilding.

The results of analyses from Part A mostly indicate that stock status of cod on eastern GB is in poor condition, and analyses from both Part A and Part B indicate that rebuilding has not occurred (supported by trends in data and both assessment models). Cod on eastern GB are at a similar stock status as when the population was at a low level in the mid-1990s, during the same time frame that the GB cod stock was nearly collapsed (NEFSC 1994).

If one assumes that the current benchmark assessment models more accurately reflects the population dynamics, then the review of projection performance indicates a tendency toward overestimation of projected SSB, which causes quotas to be overestimated. There is no consensus on interpretation for this analysis.

INTRODUCTION

This document describes analyses conducted to address the following two 2016 TRAC terms of reference (ToR).

ToR 1: *Provide a summary of biological and fishery indicators of the state of cod in the eastern GB management area.*

ToR 2: *Provide a review of projection performance for VPA and ASAP since the benchmark meeting in 2013, including a comparison of projection assumptions against subsequent assessment results.*

In Part A, a suite of analyses of biological and fishery indicators was performed to examine indicators that provide information on cod status, population and fishery trends. The metrics analyzed include: survey biomass, survey abundance, relative depletion, recruitment, age diversity, mean length, maturity and juvenile growth, condition, depth and temperature, and catch curves. In Part B, an analysis of the performance of projections from the ASAP and VPA models is presented.

The analyses conducted in Part A, to address ToR1, provide a means of assessing the status of cod on eastern Georges Bank outside a model framework and could help aid in the interpretation of the results of ToR 3: Develop and apply an empirical approach. The analyses conducted in Part B, to address ToR 2, provide a means of evaluating projection performance relative to rebuilding.

METHODS AND RESULTS

Many of the analyses performed are based on data alone, to highlight trends that are not dependent on model assumptions. In a few instances, trends in the data are compared with relative trends in the model to demonstrate that the signals are consistent between data and models, and by comparing on a relative scale that there is agreement even among the models (the difference resides in absolute abundance, which is impacted by differences in model assumptions).

Part A. BIOLOGICAL AND FISHERY INDICATORS

Survey Biomass trends

All three indices in biomass (DFO, NMFS spring, NMFS fall) were examined for years 1991-2014. Each index was scaled to its mean over the period 1991-2014, so that each index had a mean relative biomass=1.0 for this time interval. Scaling each index by its mean puts all of the indices on the same scale. Two time periods of duration 12 years were defined within this interval: 1991-2002 and 2003-2014. Management of eastern Georges Bank cod in the TRAC/TMGC framework began around year 2002, therefore the two time periods can be referred to as “pre-TRAC” and “post-TRAC.” In each of these two time periods, an average of all three scaled indices (with inverse CV weights) was calculated to characterize mean relative biomass. The question of interest is whether there is any indication that biomass has increased since the first time period (i.e. has rebuilding occurred since the TRAC/TMGC framework was initiated).

Results: The mean relative biomass in period one (1991-2002) is 1.08 (se=0.11), while the mean relative biomass in period two (2003-2014) is 0.92 (se=0.11) (Figure 1). This offers no evidence of progress towards rebuilding cod on eastern Georges Bank. There are many possible explanations for this pattern, including but not limited to high Z, poor recruitment and declining condition, though some improvements in condition have been seen since 2009.

As a point of comparison, the same approach was taken for haddock in Eastern Georges Bank and yellowtail flounder on Georges Bank (Figure 2), though this comparison is limited by the fact that the population dynamics for these species differ in some aspects from cod (e.g. growth rate, strong pulse year recruitment, etc). For haddock, the mean relative biomass in the first period was 0.22 (se=0.05) and in the second period it was 1.78 (se=1.44), signaling a very strong increase in biomass between the two periods. We note that annual index-specific CVs were not available for haddock at the writing of this WP, so a straight arithmetic average was used in calculations; this is not expected to change the conclusion regarding the strong increase in haddock biomass. For yellowtail flounder, the mean relative biomass in the first period was 0.98 (se=0.25) and in the second period it was 1.12 (se=0.20) showing that, similar to cod, there is no evidence of progress towards rebuilding for this stock since 2002. We note that by averaging mean relative biomass for 12 years in each period, any pattern in annual trend is not captured (e.g., a consistent decline in the last four years for yellowtail flounder, Figure 2).

Survey abundance indices trend

Abundance indices at age were examined for years where all three surveys had complete coverage (1978-2015 for the two NMFS surveys, 1987-2015 for the DFO survey). Each index was scaled to its mean from 1994-2015, so that each abundance index at age had a mean relative to 1.0 for this time interval. This period was chosen as stricter fishery management measures have been implemented in Canada and USA since 1994 (e.g. reduced quota, USA closed area, Canadian winter fishery closure, etc; see fishery management measures table in Andrushchenko et al. 2016).

Results: Generally the population numbers at ages 1-3 have been low due to poor recruitment since the mid-1990s (Fig. 3), while the population numbers at age for ages 4-6 have stayed at comparable or even higher levels compared to pre mid-1990s; this is consistent with the expected impact of the decrease in relative fishing mortality. However, the population numbers at older ages 7-8 showed a declining trend despite lower relative fishing mortality. This implies that some factors other than the fishery may be contributing to the lack of rebuilding of numbers of older fish or that reductions in fishing require time to be reflected in population rebuilding.

Relative Depletion

The three surveys (NMFS fall and spring, DFO) were used to derive relative depletion indices. For NMFS fall and spring, the time series from 1968 onwards was used, while the DFO index values from 1987 onwards were used. Each index was scaled by the mean of the first five years, thus the mean of each scaled index is 1.0 over the first five years. Five years was chosen to reflect an average at the start of the series, so that scaling was not affected by a single large year class or year effect. Next, the mean of the last five years of each scaled index was calculated, and this result reflects a relative depletion from the beginning of each index time series. Although we cannot say what absolute depletion was at the start of any of the indices, with this simple approach we can at least characterize what the relative depletion has been in recent years compared to the beginning of each time series. The same was done for calculating relative depletion in landings, to compare the relative decrease in landings over the same time period.

Results: The fall biomass index declined to 25% of the average 1968-1972 abundance, the spring biomass index declined to 15% of the average 1968-1972 abundance, and the DFO biomass index declined to 21% of the average 1987-1991 abundance (Figure 4). While the length of the time series differs, all three indices reveal substantial depletion from the beginning of their respective time series. Biomass of the cod resource was not at unexploited conditions in 1968, so we can conclude that these relative depletions are a minimum value for the absolute amount of depletion in the population. To illustrate how relative depletion relates to absolute depletion, if, as a hypothetical example, we knew that eastern GB cod were at half of unexploited conditions at the start of 1968, then fall and spring absolute depletion would be 12.5% and 7.5%, respectively.

By comparison, landings have declined to 5% of their 1978-1983 average, driven primarily by reductions in quota. The relative decrease in landings is steeper than the decrease in any of the relative biomass indices (95% reduction in landings, compared to 75-85% reduction in biomass). Explanations for this might include that factors other than fishing may be contributing to the depletion seen in survey biomass indices or that reductions in fishing require time to be reflected in population rebuilding, particularly for cod where mature spawners require several years before they measurably contribute to recruitment.

For comparison, relative depletion of total biomass was calculated for both the VPA and ASAP outputs based on the 2015 TRAC assessment (Wang et al. 2015). Since ASAP produces Jan-1 biomass for terminal year minus one, the recent biomass depletion was calculated for 2010-2014, excluding the final year estimated by the VPA (Figure 4). The depletions were estimated as 5% and 16% for ASAP and VPA respectively.

Recruitment trends

Survey indices of numbers at age 1 were plotted to compare trends over time. All indices were scaled to their respective means over the last 29 years (1987-2015 for spring, 1986-2014 for fall) so that they were on the same scale. Because of missing catches on age 1 from both DFO and NMFS spring survey in recent years, the estimated number of cod at age 2 from the 2015 TRAC cod assessment models were plotted to compare with the indices at age 2, and to compare between the assessment models. The survey abundance indices at age 2 from three surveys were averaged and then normalized using the mean 1987-2015 when full survey coverage available for the three surveys. The estimated population number at age 2 from both models were normalized in the same way.

Results: Survey indices indicate that recruitment prior to 1990 was higher, with more frequent large year classes (Figure 5). 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. The recruitment estimates from both VPA and ASAP show the same low recruitment trend observed in the surveys since the 1990s, and only recently diverge as a consequence of different assumptions about natural mortality.

Age Diversity

A Shannon-Weiner Age Diversity Index was estimated for cod on eastern GB from the DFO, NMFS spring, and NMFS autumn survey. The formula applied was:

$$H = (n \log n - \sum_{i=1}^{k} fi \log fi) / n$$

Where k =number of age-groups, n = number of fish in all age-groups, and f = number of fish in each age group. Age diversity has been shown to account for variance in the stock recruit relationship for Georges Bank cod (O'Brien et al. 2003) and for Icelandic cod (Marteinsdottir and Thorarinnsson 1998). Increased age diversity in the population provides for higher recruitment success given that older, larger females spawn larger eggs that experience higher hatch success and thus larger larvae with higher survivability (Trippel 1998), than spawn from smaller, younger females.

Results: Age diversity was variable but declining since about 1992 in the DFO survey for ages 1-10+ (Figure 6). In the NEFSC spring survey age diversity has been variable and generally declining since 1985 for ages 1-10+ (Figure 6). The NMFS fall survey for age 1-6+ does not show a strong trend (Figure 6). Spawning occurs in the spring for cod on eastern GB, so the spring surveys would be more indicative of the spawning biomass. The declining trend in age diversity in spring (DFO and NMFS spring survey) reflects the age truncation seen in other metrics and likely contributes to the poor productivity of cod on eastern GB for the last two decades.

Mean Length Trend

Mean length of cod, weighted by numbers, was estimated for cod from GB and eastern GB (eGB), with maximum and minimum lengths from the DFO, NMFS spring and NMFS autumn surveys.

Results: In all three surveys, weighted mean length is variable but does not show any notable trends, however, maximum length shows a decline since the early 1990s in the DFO survey (Figure 7) and since the early 1970s in the NMFS spring and fall surveys (Figures 8-9). A comparison of mean and maximum length between GB and eGB from the DFO survey shows very similar trends in contrast to the NMFS spring, which shows more variability within eGB than for GB as a whole. The autumn survey shows a similar pattern as the spring survey with more variability in length metrics in the eGB area. The differences in DFO and NMFS spring could be a function of the low DFO coverage of GB, or related to distribution of cod; earlier in the year during the DFO survey the cod are more aggregated in the eastern part of the Bank for spawning, whereas later during the NMFS spring survey toward the end of spawning, the cod are more dispersed throughout the Bank. The trend of a declining maximum length can be attributed, in part, to a truncated age structure, and fishery selectivity from long-term fishing. Given that growth has been shown to be heritable (Reznick et al. 1997, Svensson 1997), long term selectivity would potentially remove the faster growing fish from the population (Hanson and Chouinard 1992, Sinclair et al. 2002). The decrease in maximum length over the time series ranges from 70 cm (spring), to 44 cm (DFO), to 36 cm (fall); on average about a 50 cm change in maximum length from early to late in the time series.

Maturity and Juvenile Growth

Median maturity at age (A50) and length (L50) were estimated for cod on eastern GB by applying a logistic regression to 5-year moving averages of maturity data from the DFO and NMFS spring surveys. Median maturity was estimated from 1970 (spring survey) and from 1986 (DFO survey) to 2015. A metric of juvenile growth was estimated as L50/A50.

Results: Median maturity at age (A50) has been variable in recent years, ranging between ages 2.0 and 2.5, and juvenile growth has been increasing since about 2005. The NMFS spring and DFO survey estimates both show similar trends in A50 and L50 between females and males within a survey (Figures 10-11). A comparison of the A50 between the NMFS spring and DFO survey indicate variable, but similar trends since 1990, with the exception of the strong drop in 2001 in the DFO survey estimate (Figure 12). The two survey estimates agree for both female and male juvenile growth, particularly from about 2000 onward. As noted in the mean length section, differences between the estimates could be due to the surveys sampling different segments of the population relative to the spawning season, as fish are generally more aggregated during the DFO survey and more dispersed during the NMFS spring survey. Differences in biomass during the early and latter part of the time series, and fine scale distributions of the fish by age between the two surveys would have an effect on the observed proportion mature at age and the estimation of A50 and L50 within the logistic regression.

Condition

Fulton's condition factor (K) was estimated for all post-spawning fish for all three surveys.

Results: A notable downward trend is seen in K throughout the series for all three surveys until 2009, when condition began to increase rapidly for the NMFS surveys (Figure 13); in 2015, the NMFS fall survey K reached a time series high. The condition of cod in the DFO survey since 2009 showed high variability and a slower rate of increase, but did reach the series average in 2016 (Figure 13).

Mean Depth and Temperature

Biomass- and abundance-weighted mean depth and temperature occupied by cod when sampled were estimated from the 1970-2015 NMFS spring and autumn survey data. The minimum and maximum depth and temperature where cod were sampled is also reported.

Results: Cod occupy depths ranging from 32 m - 417 m in the spring and 33 m – 329 m in the fall (Figure 14). Biomass-weighted and abundance-weighted mean depths occupied were similar in both seasons, although maximum biomass-weighted depth was greater than abundance-weighted depth; implying that larger fish occupy deeper water which is commonly known. Cod were captured at temperatures ranging from 2.8 – 12.5 °C in the spring, and 4.8 - 16.9 °C in the fall (Figure 15). Biomass weighted and abundance weighted mean temperatures occupied in the spring were the same, ranging from 4.3 - 7.2 °C. In the fall, the weighted mean temperature occupied by cod was similar for biomass (7.1 – 13.9 °C) and for abundance (7.2 – 13.2 °C). Although cod on eastern GB can occupy a large range of depth, on average they have remained in similar depths each season over the years, occupying a narrower range of temperature in the spring than in the fall. Cod appear to remain in a preferred depth, rather than changing their habitat, even though temperature fluctuates, or increases, as in recent years in the spring (Figure 15).

Total mortality (Z) and relative fishing mortality (F)

Total mortality (Z) at fully recruited ages for each cohort was calculated using both DFO and NMFS spring surveys (1986-2015 DFO; 1978-2015 for NMFS spring) by a regression to the natural log of the catch for ages (4+). Also Z was calculated by two age groups to show the temporal trend: ages 4 through 5 and for ages 6 through 8. Relative fishing mortality (F = fishery catch at age/survey abundance at age) was also calculated for the two age groups, separately. These indicators are independent of model assumptions of M and assume survey catchability has remained unchanged throughout the time series.

Results: Catch curve analyses from both DFO and NMFS spring surveys show high Z on fully recruited fish (Figures 16-17), often exceeding 1. Although the NMFS spring survey shows consistently high fully recruited Z on all cohorts throughout the time period, the DFO survey shows a further increase in Z on fully recruited fish since 2006 (Figure 16-17).

Similarly, total mortality Z derived from the two age groups remains at or above 1 with a further increase in Z for recent years (Figure 18). Unlike DFO, which continues to show total mortality on older fish (ages 6-8) being substantially above total mortality on younger fish (ages 4-5), the NMFS spring survey shows the two being comparable in the most recent years (Figure 18). Despite differences in age group trends between surveys, both indicate that total mortality remains at or above the level seen throughout the early time period, with no indication of a decrease.

In contrast, relative fishing mortality (F) for both surveys shows a substantial decline from the early time period to the more recent one, with no evident differences between age groups (Figure 19). The discrepancy in trends between total mortality (Z) and relative fishing mortality (F) implies that other factors may be responsible for the consistently high levels of Z.

Part B. PROJECTION RETROSPECTIVE

Quota retrospective

Quotas and catch since 2004 were compared with the calculation of "retrospective quota." The retrospective quota was calculated deterministically for VPA and ASAP, assuming that each model is correct. The estimated numbers at age for each model from the 2015 TRAC meeting was used to calculate retrospective quotas from 2004-2014. The status quo assumptions were used to make these calculations (as described in EGB cod WP: "For projections, the average of the most recent three years of fishery and survey weights at age is used for fishery and beginning year population biomass for 2015-2017. The 2015-2017 PR is based on the most recent five years of estimated PR (Table 18). The 2010-2014 average recruitment at age 1 is used for 2015-2018 projections."). To calculate a quota corresponding to VPA, an F=0.11 was used, with M=0.2 for ages 1-5, and 0.8 for ages 6+; for ASAP, Fref=0.18 was used, with M=0.2 for all ages. The point of this analysis is to compare these retrospective quotas with the historic quotas and realized catches. We recognize that the models have evolved over time since 2004, and that is the point of this analysis. If we believe that the current models are correct, then we expect our results to show the impact of model changes on what our current perception is of the scale of abundance and the scale of quotas over time (assuming, in turn, that each model is correct).

Results: If either current assessment model is correct (VPA or ASAP), then historic quotas were set too high (Figure 20). From 2004-2011, the retrospective quotas are, on average, about 50% lower than the quotas that were set. This reflects the fact that quotas in those years were based on a VPA with different M assumptions (and varying degree of retrospective bias) than the current models. From 2012-2014, the retrospective quotas for the ASAP model are about a third of the real quotas, likely because recent quota was based on the VPA. The retrospective and real quotas are similar for the VPA from 2012-2014 again because the recent quota was based on this modeling approach, but also because the retrospective bias for this model is lowest in the most recent years.

Alternately, if neither of the current assessment models (VPA or ASAP) truly reflect the population dynamics, then the conclusion that the historic quotas were set too high might be different.

Performance of projections

The current assessment models for cod were introduced at the 2013 benchmark for eastern Georges Bank cod. The performance of projections made at the 2013 benchmark, and the update assessments at the TRAC in 2013-2015 were evaluated. The final adult biomass estimate from each model was plotted with the projected biomass and the quotas assumed to be removed in those projections. Subsequent updates of the model were then compared to those projections to evaluate accuracy.

Results: If it is assumed that the current year's assessment is less biased than previous assessments, then for both models the terminal year estimates of biomass are usually biased high (i.e. SSB is overestimated compared to later assessments), leading to overoptimistic projections for SSB and catch (Figures 22-24). If the projections were accurate, and if realized catches were less than assumed in projections, then we would expect SSB to be greater than projected. This was not the case. Realized catch was always less than the catch amount assumed in the projections, yet the resulting SSB was lower than projected.

Alternately, if it is assumed that the initial estimates of year class strength based on survey indices are closer to the truth than the converged estimates in the most recent assessment, then the retrospective would be a result of additional unaccounted for mortality, higher than the 0.8 level on older ages currently incorporated in the VPA model. Under this assumption, the SSB might not have been over-estimated originally but projections based on this SSB, and which do not take additional mortality into account, would be unrealistically optimistic regardless of the catch.

SUMMARY

Part A: Biological and Fishery Indicators

1. **Rebuilding** has not occurred (supported by trends in data and both assessment models); cod on eastern GB are at a similar stock status as when the population was at a low level in the mid-1990s**,** during the same time frame that the GB cod stock was nearly collapsed (NEFSC 1994).

2. **Recruitment** is poor (supported by trends in data and both assessment models).

3. **Age diversity** has declined over the time series for eastern GB cod and is reflected in the truncation of the age structure seen in the fishery and in the survey population estimates and is likely a major contributor to the lack of productivity seen in recent years.

4. **Mean length** has fluctuated around the average; however, maximum length of cod on eastern GB has declined, on average about 50 cm from early to late in the time series.

5. **Median maturity** at age has fluctuated over the time series and is currently around age 2. **Juvenile growth** has been variable and declining, but in recent years shows an increase.

6. **Condition** factor (K) showed a consistent decline until about 2009 when K started to increase in all three surveys, being about the long-term average in the most recent surveys.

7. Cod on eastern GB seem to prefer to stay within a narrow **depth** range on average even though **temperature** changes occur within that depth range

8. **Total mortality (Z)** from catch curves indicates high total mortality for the entire time period, often Z >1, while **relative fishing mortality (F)** has shown a substantial decline since the early time period, with no difference in trends between age groups

Part B: Review of quota and projection performance

1. If the current assessment models are correct (either VPA or ASAP), then **quota** advice in the past has been too high, likely inhibiting rebuilding (along with other biological factors).

2. Looking at **projection** performance since the 2013 benchmark, both models (VPA and ASAP) have a tendency to overestimate projected SSB. Depending on whether it is assumed that the current year's assessment is less biased, or that the initial estimates of year class strength based on survey indices were closer to the truth than the converged estimates in the most recent assessment, then either the catch advice was over-estimated or the mortality resulting from something other than reported catch was under-estimated.

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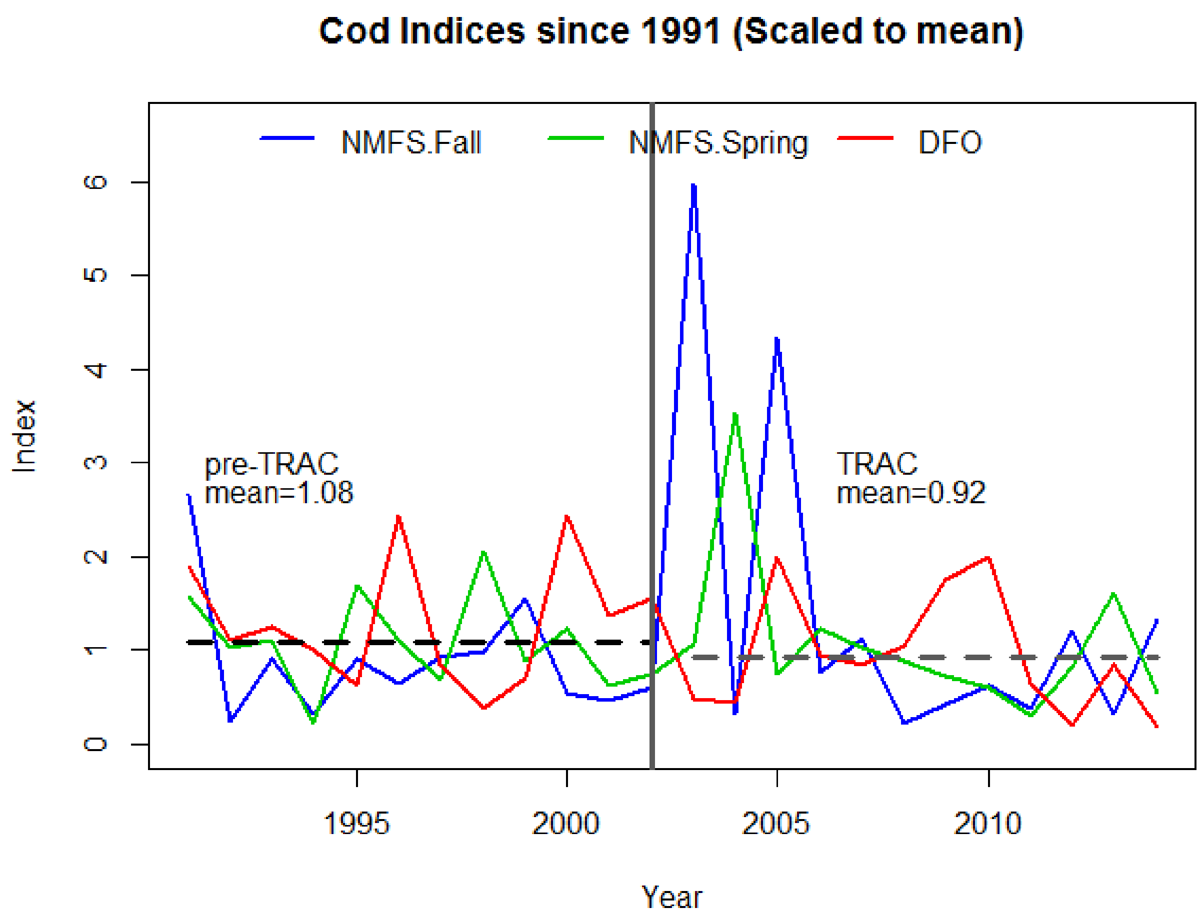


Figure 1. Relative biomass indices for Eastern Georges Bank cod, with mean values calculated for two 12-year periods (pre-TRAC 1991-2002; TRAC 2003-2014).

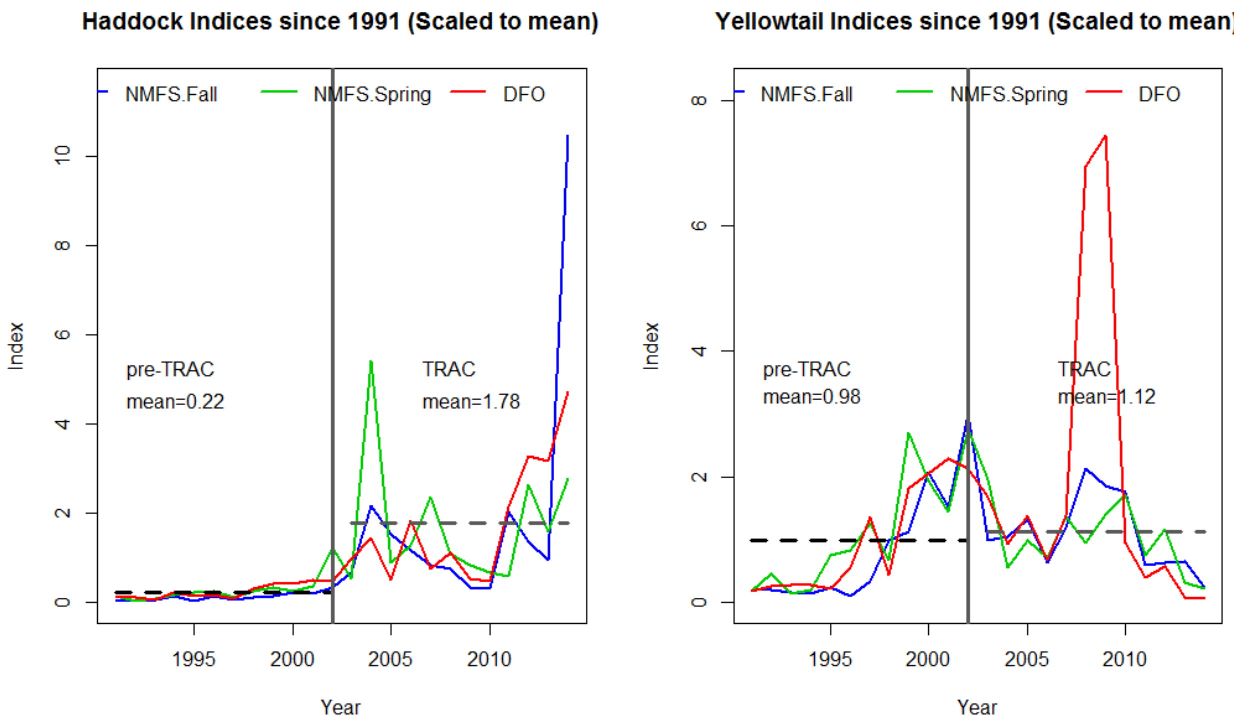


Figure 2. Relative biomass indices for Eastern Georges Bank haddock (left) and Georges Bank yellowtail (right), with mean values calculated for two 12-year periods (**pre-TRAC** 1991-2002; **TRAC** 2003-2014).

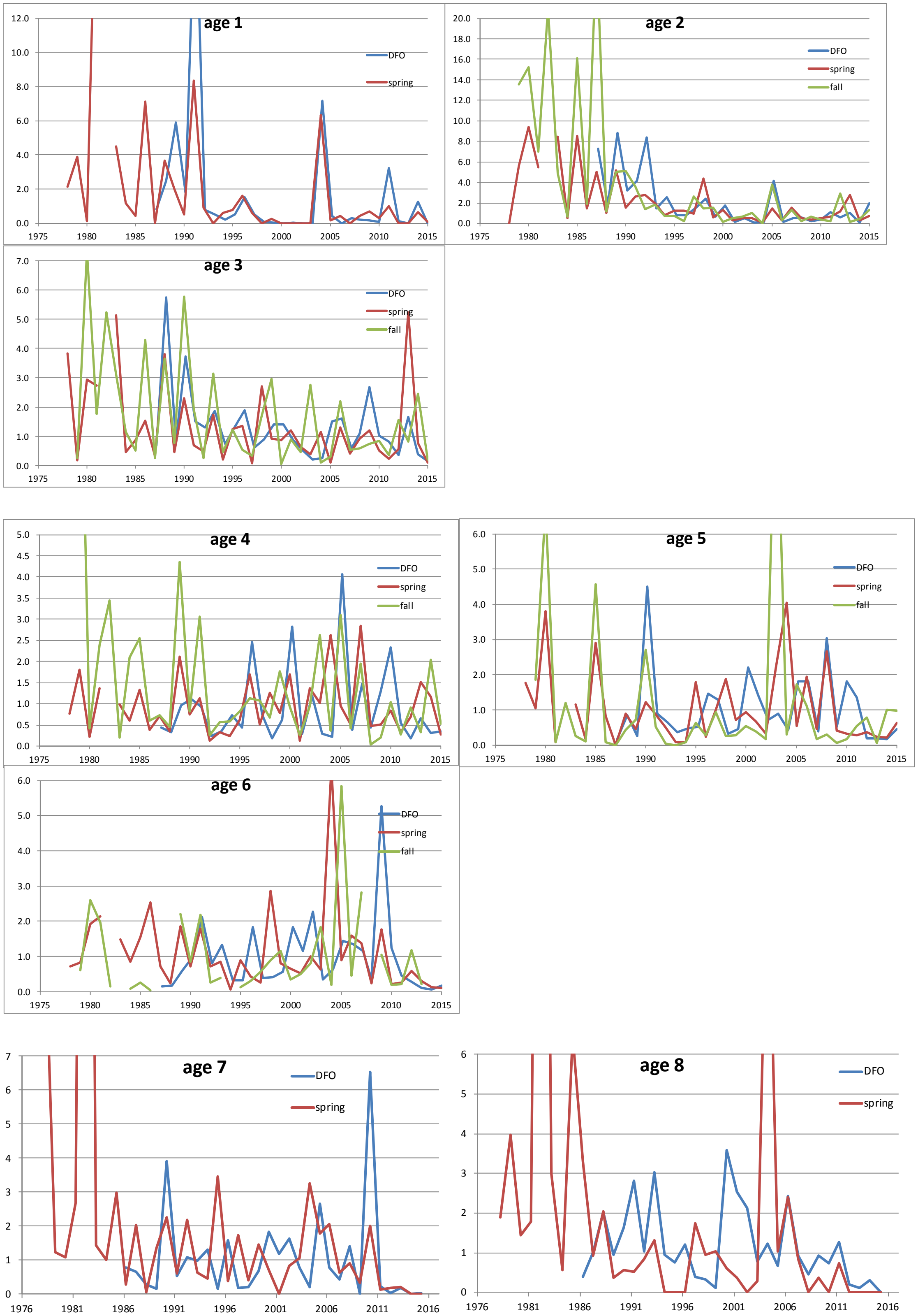


Figure 3. Normalized survey abundance indices at age trends for each survey.

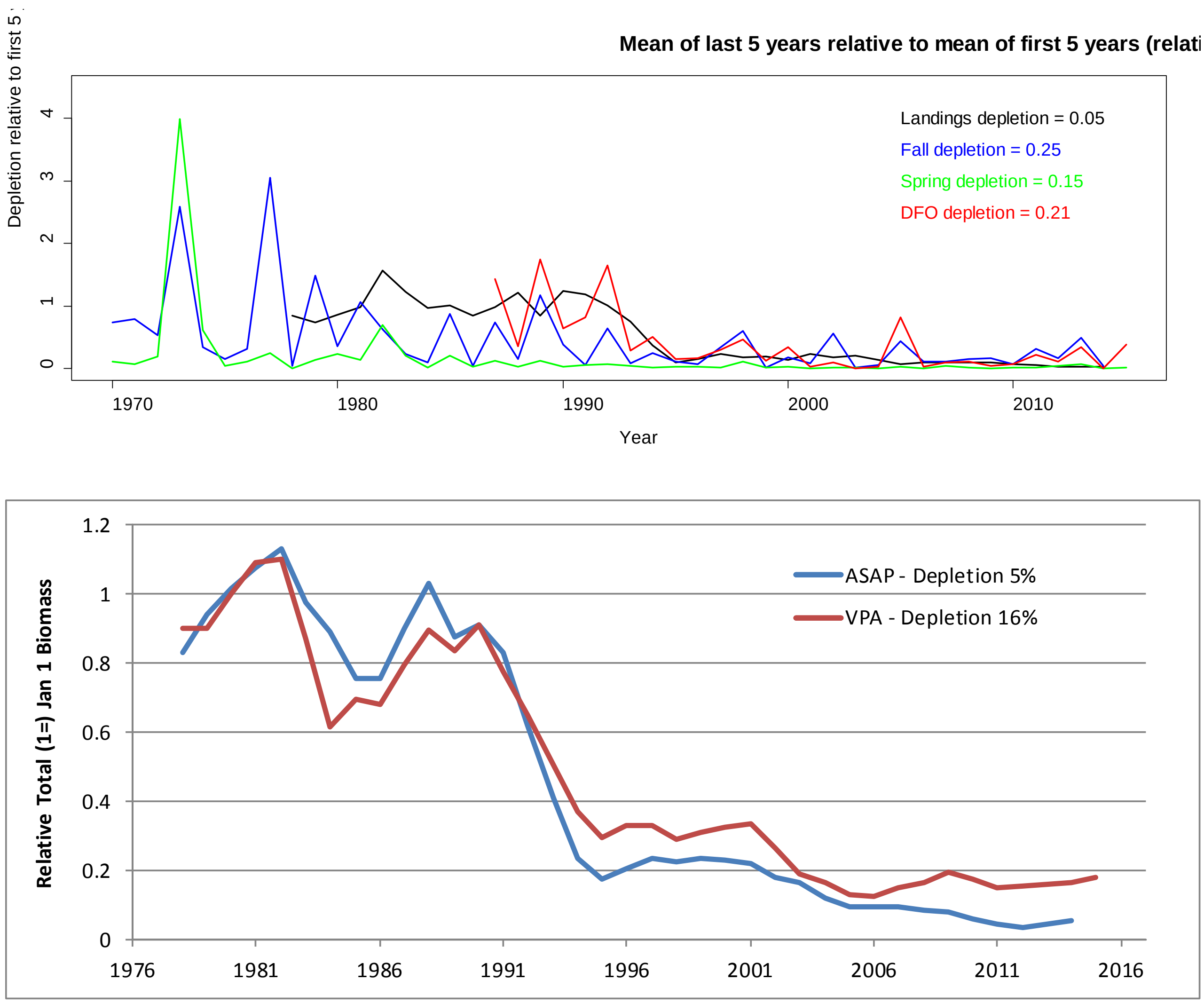


Figure 4. Relative biomass index of depletion from the three surveys and fishery catch (top panel) and Jan 1 biomass outputs from the models (bottom panel). All indices are scaled to the mean of the first five years of each time series (1968-1972 for NMFS spring and fall; 1987-1990 for DFO; 1978-1982 for landings and models). The values in the legend are the 5 year recent average, which is relative to the first five years of each time series. For example, the NMFS spring index indicates that it is only 15% of the level observed in the 1968-1972 period.

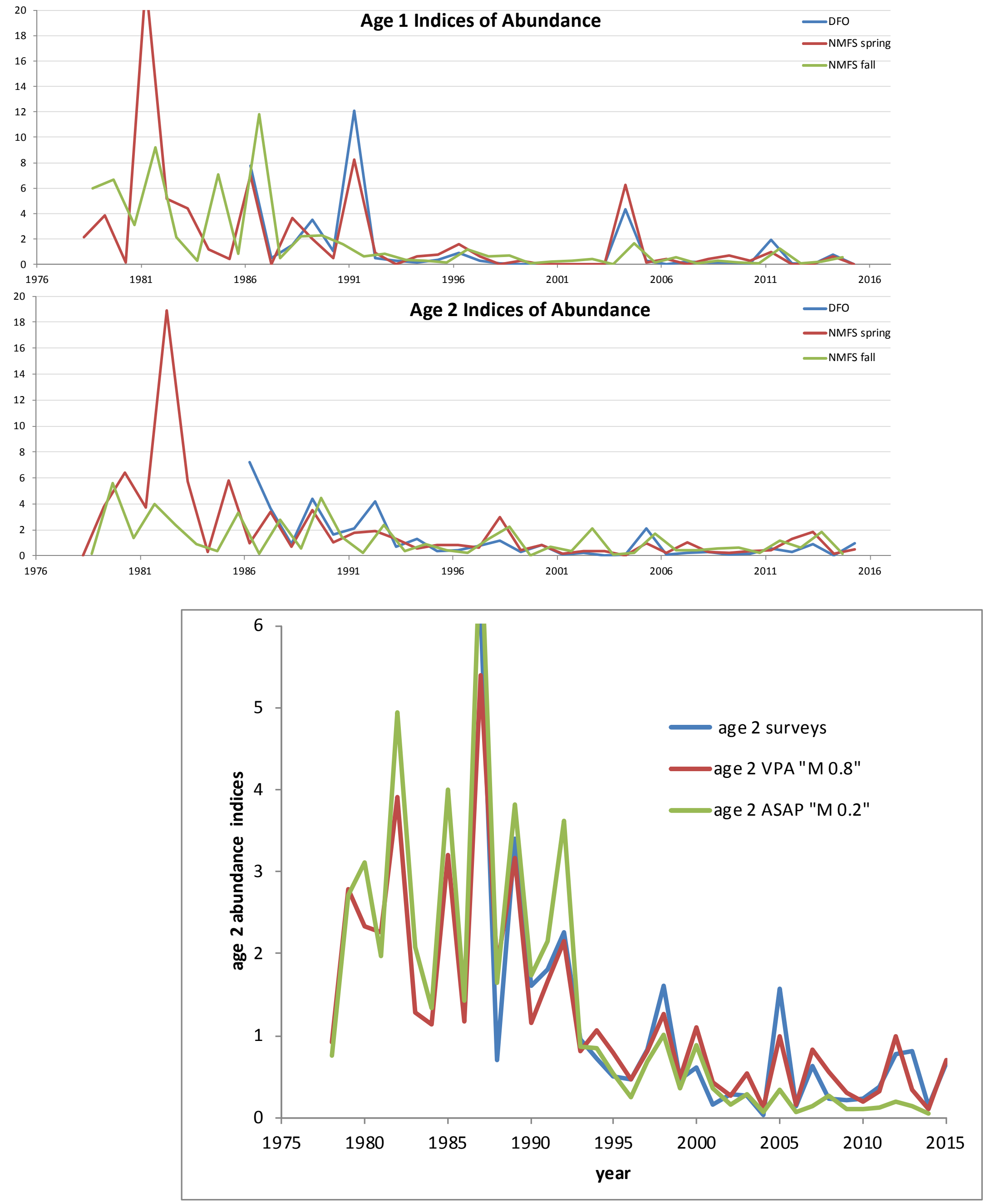


Figure 5. Numbers of age 1 and age 2 cod from the NMFS fall, spring, and DFO surveys (top and middle) and as estimated in the VPA and ASAP assessment models (bottom). The indices were scaled by the mean of years 1986-2014 so that they have the same scale. The trends in recruitment estimates between the surveys and the models are very similar; the trends are also very similar between the two assessment models, and only recently diverge as a consequence of different assumptions about natural mortality.

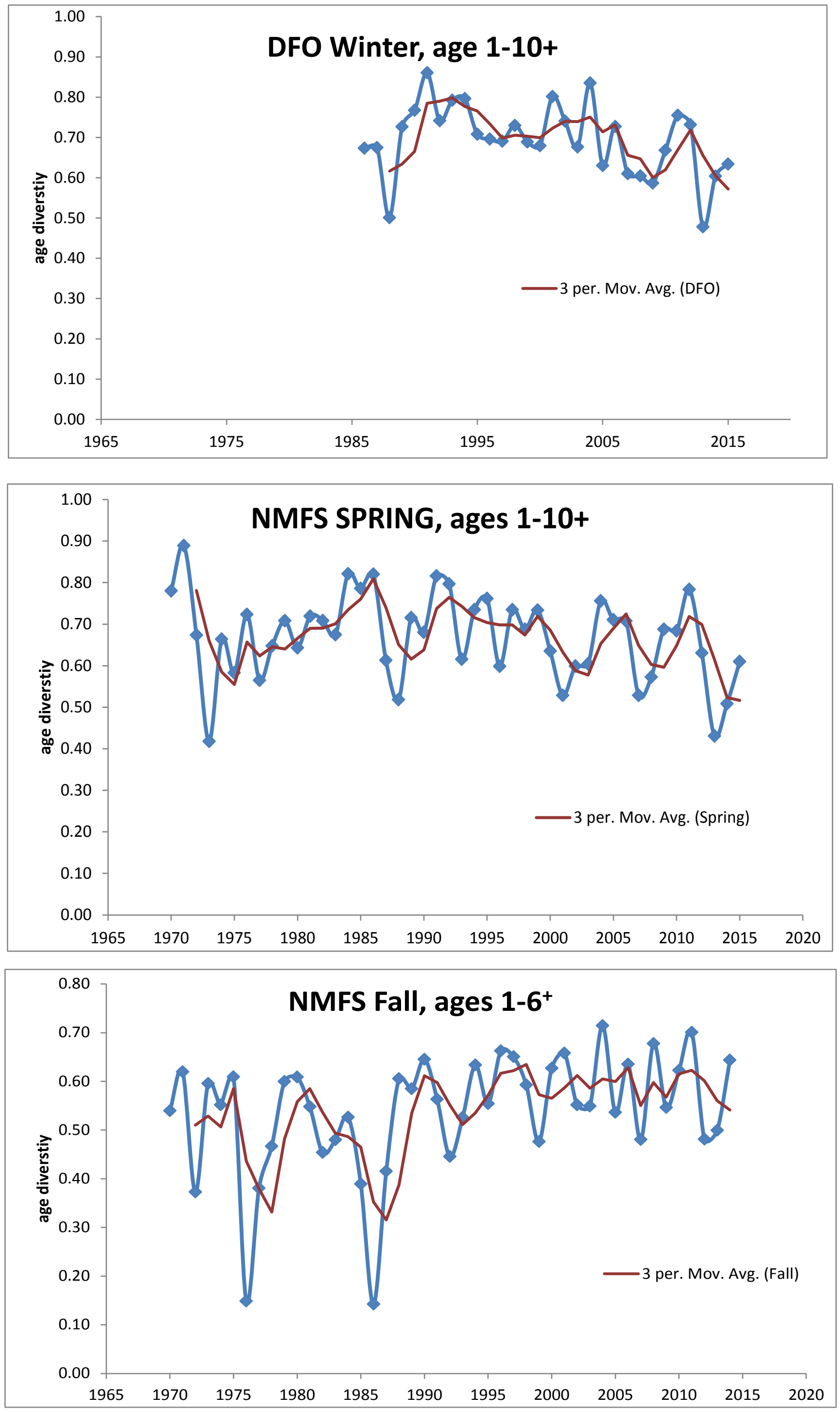
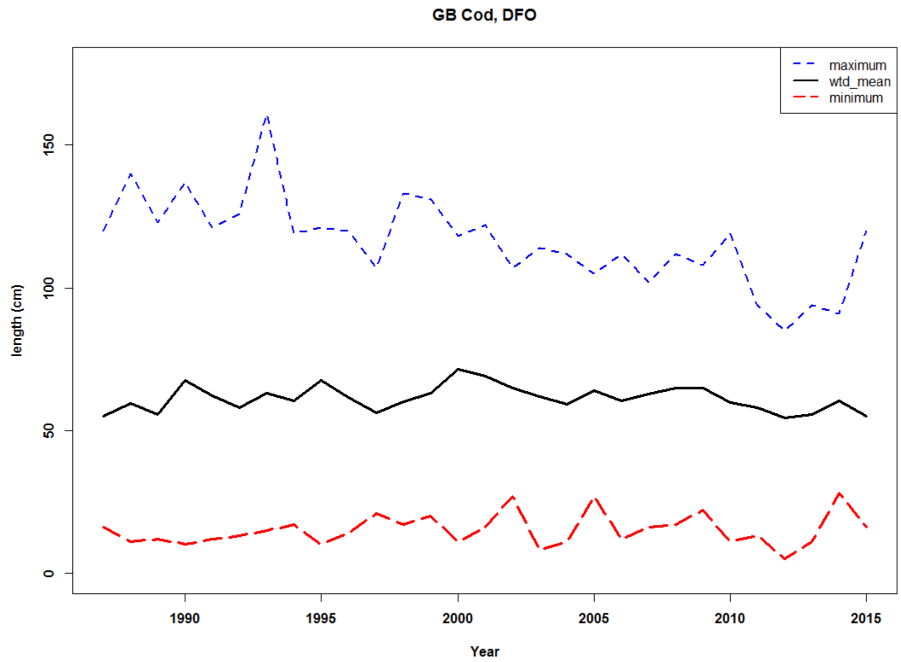


Figure 6. Age diversity of cod from eastern GB from the DFO, NEFSC spring, and NEFSC autumn survey, 1970-2015.



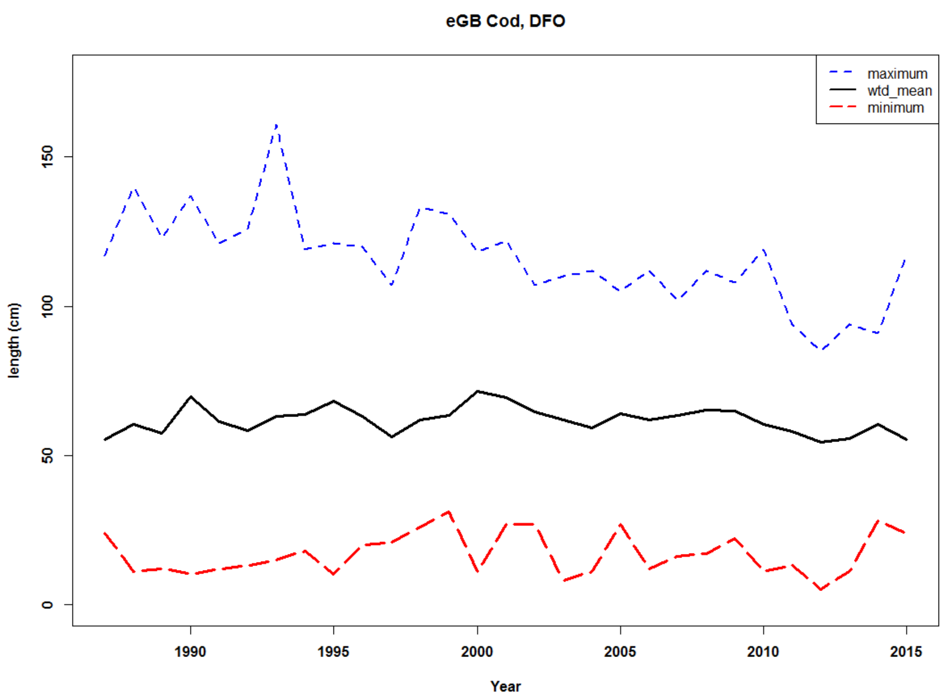
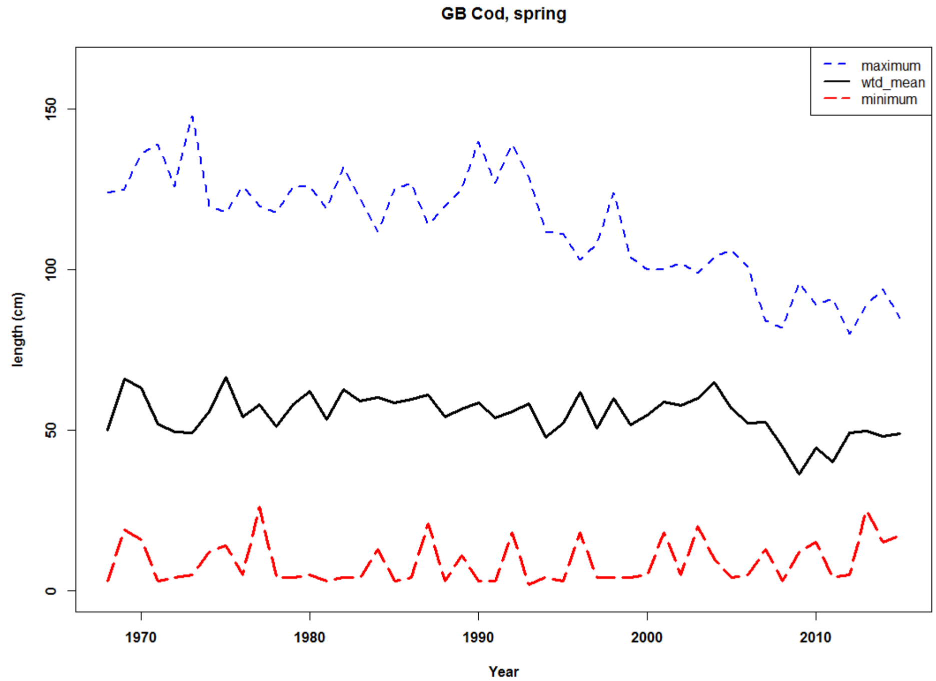


Figure 7. Weighted mean length of cod from GB and eastern GB from the DFO spring survey, during 1986-2015.



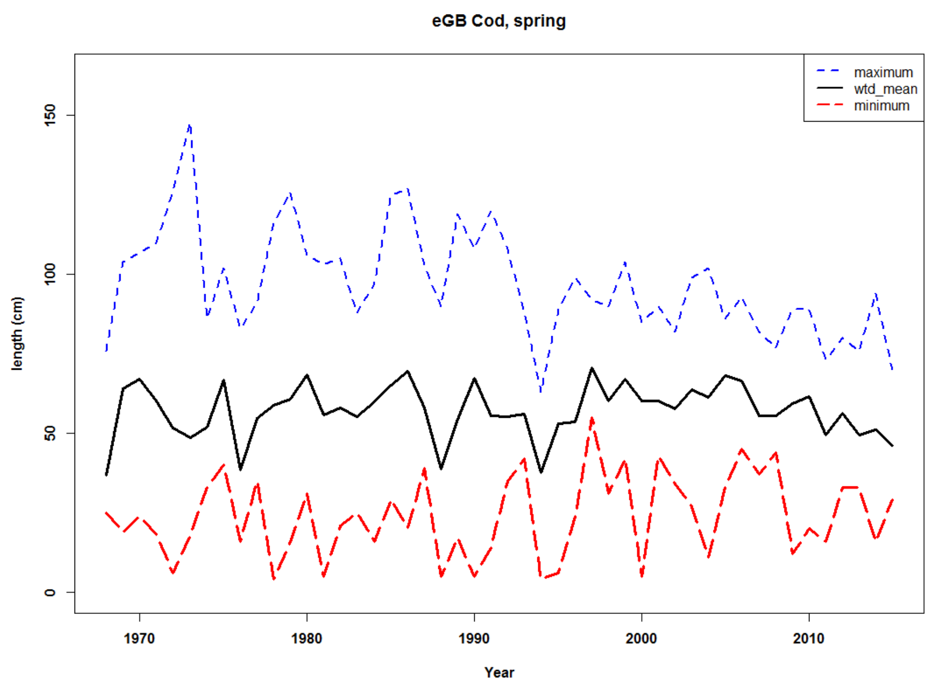
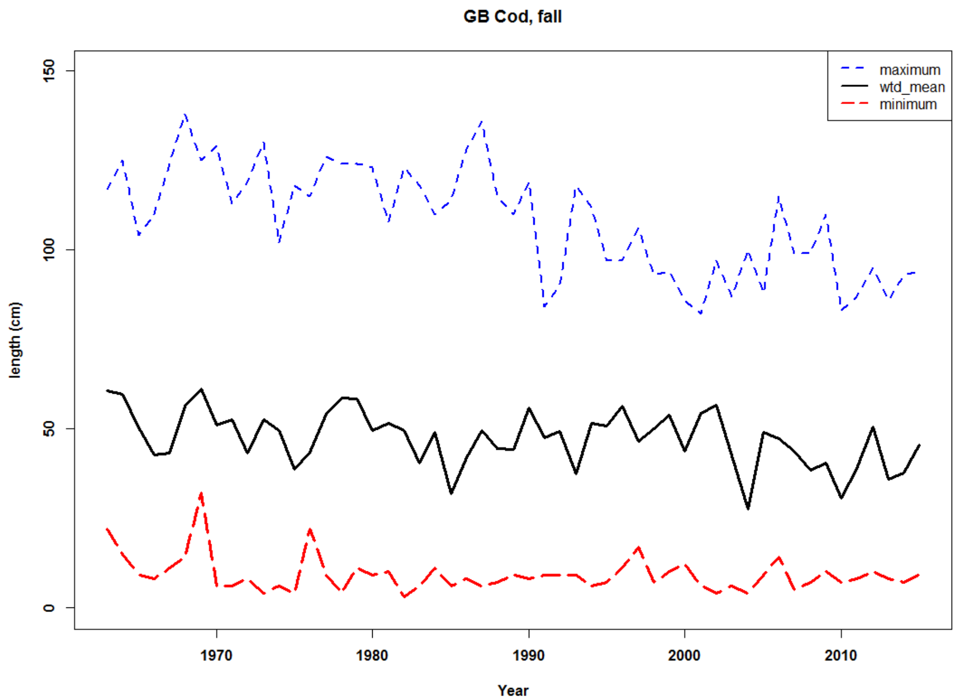


Figure 8. Weighted mean length of cod from GB and eastern GB from the NEFSC spring survey**,** during 1970-2015.



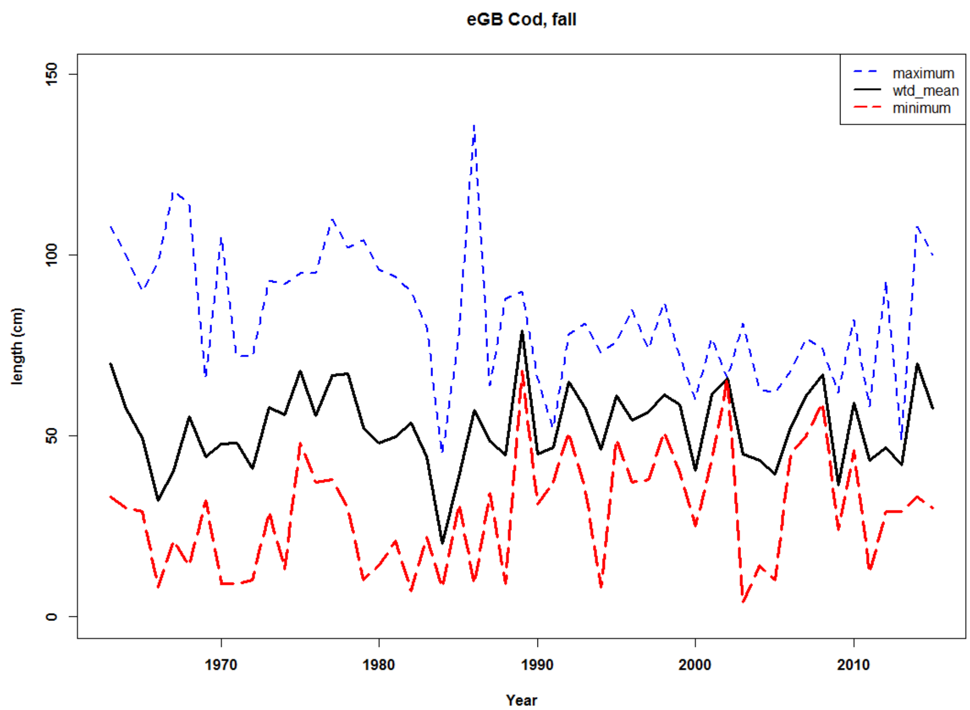


Figure 9. Weighted mean length of cod from GB and eastern GB from the NEFSC fall survey, during 1970-2015.

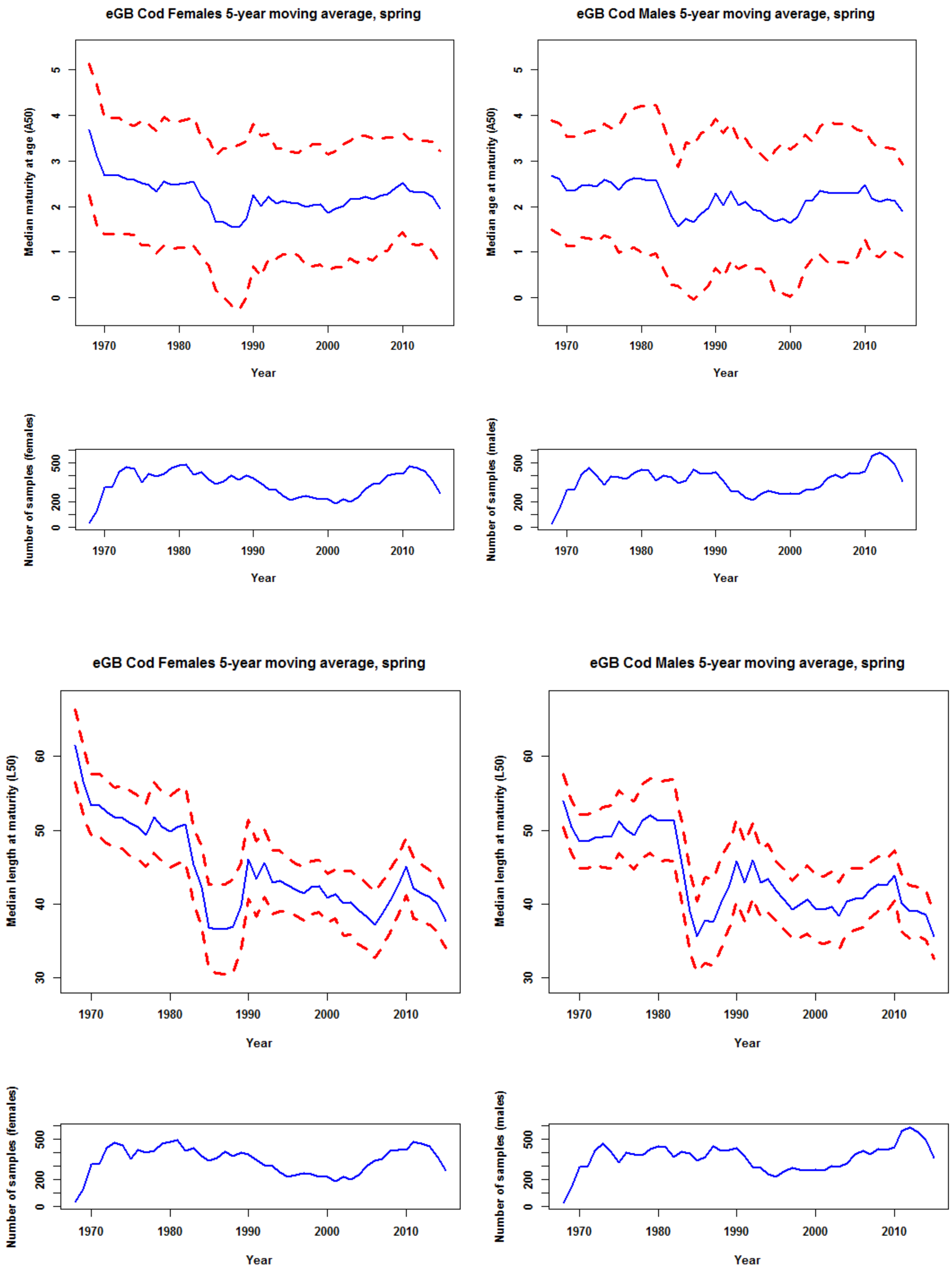


Figure 10. Proportion mature at age (top panel) and length (bottom panel) from NEFSC spring survey.

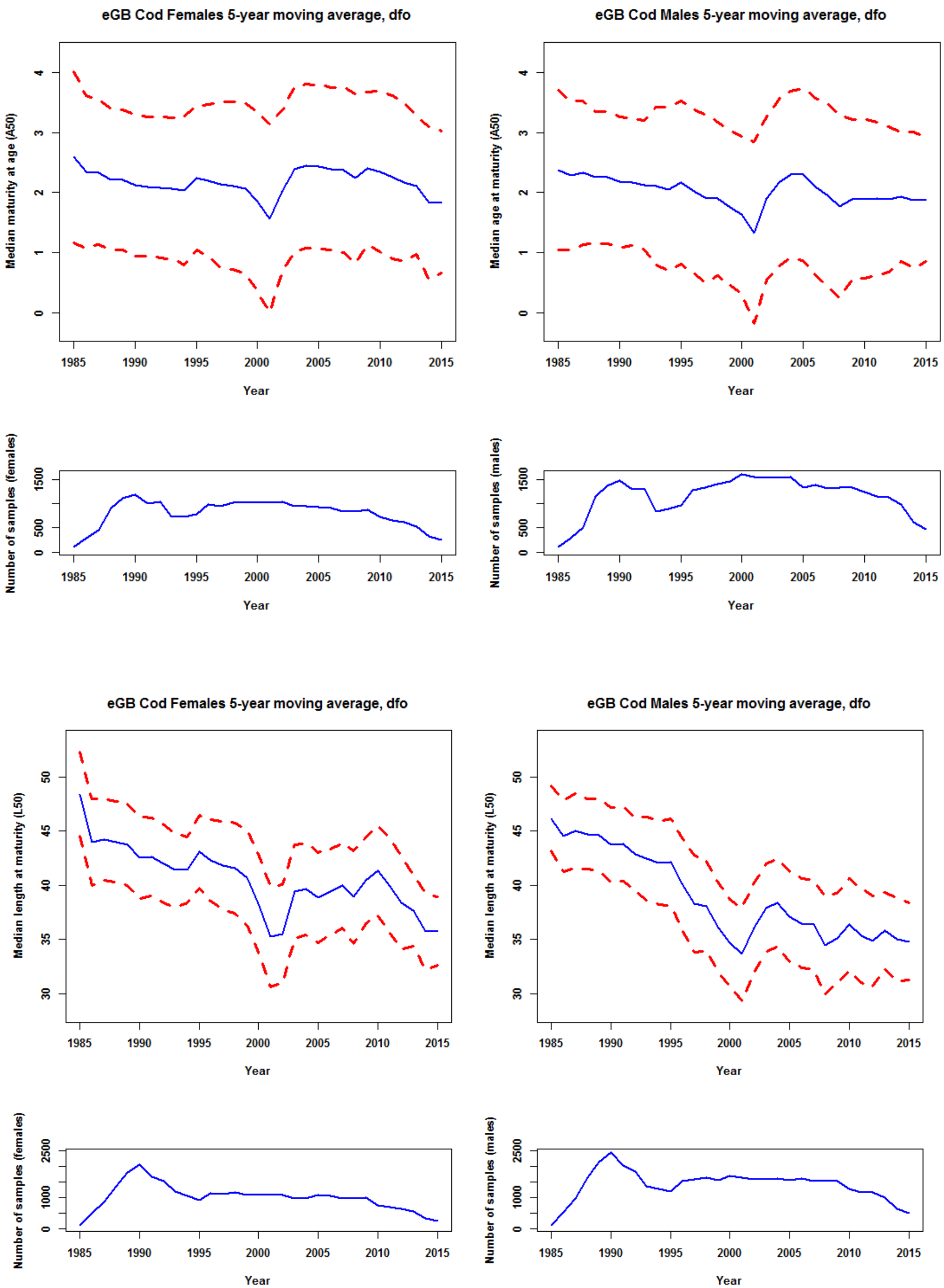


Figure 11. Proportion mature at age (top panel) and length (bottom panel) from DFO survey.

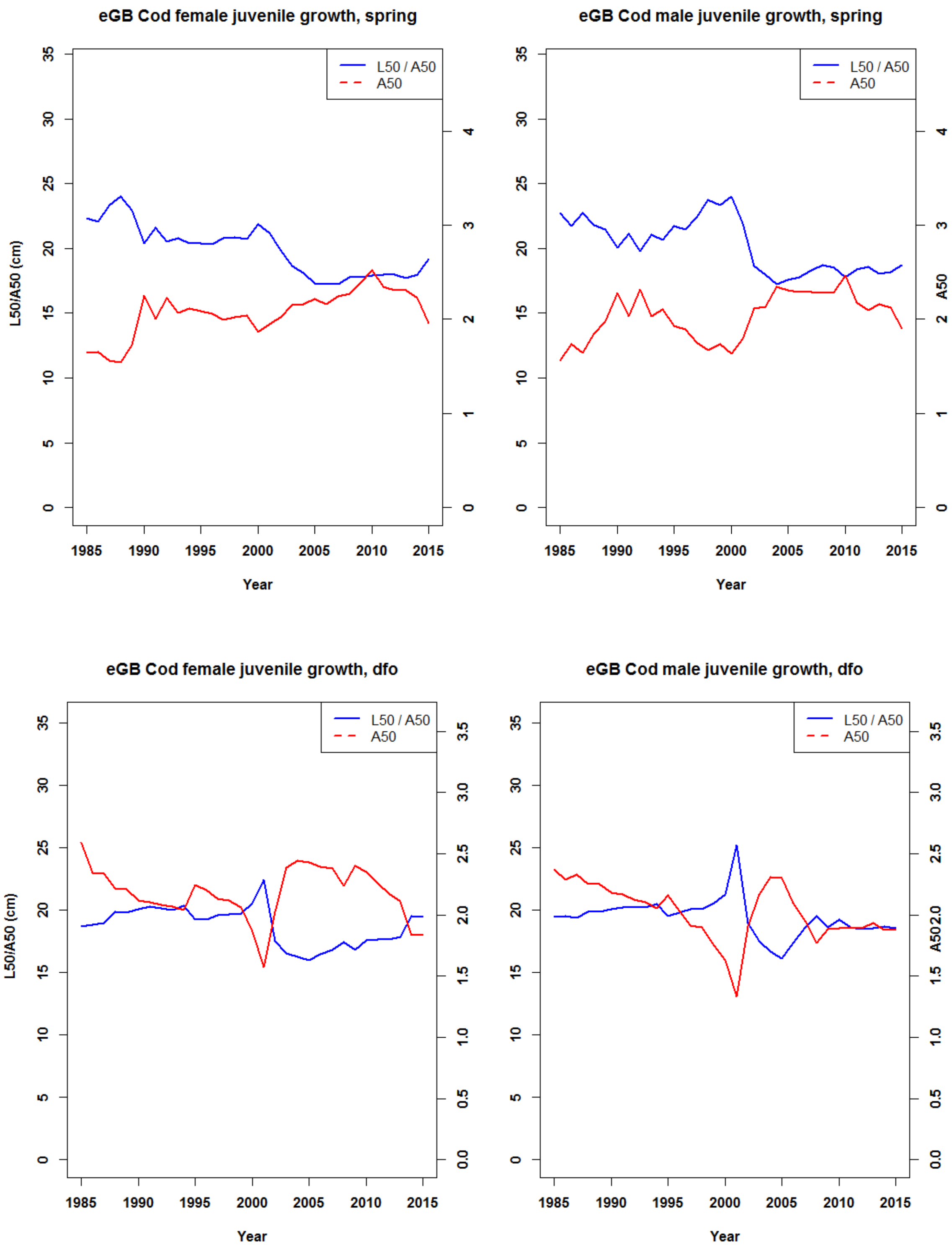


Figure 12. Juvenile growth (L50/A50) of cod from eastern GB from NEFSC spring and DFO surveys.

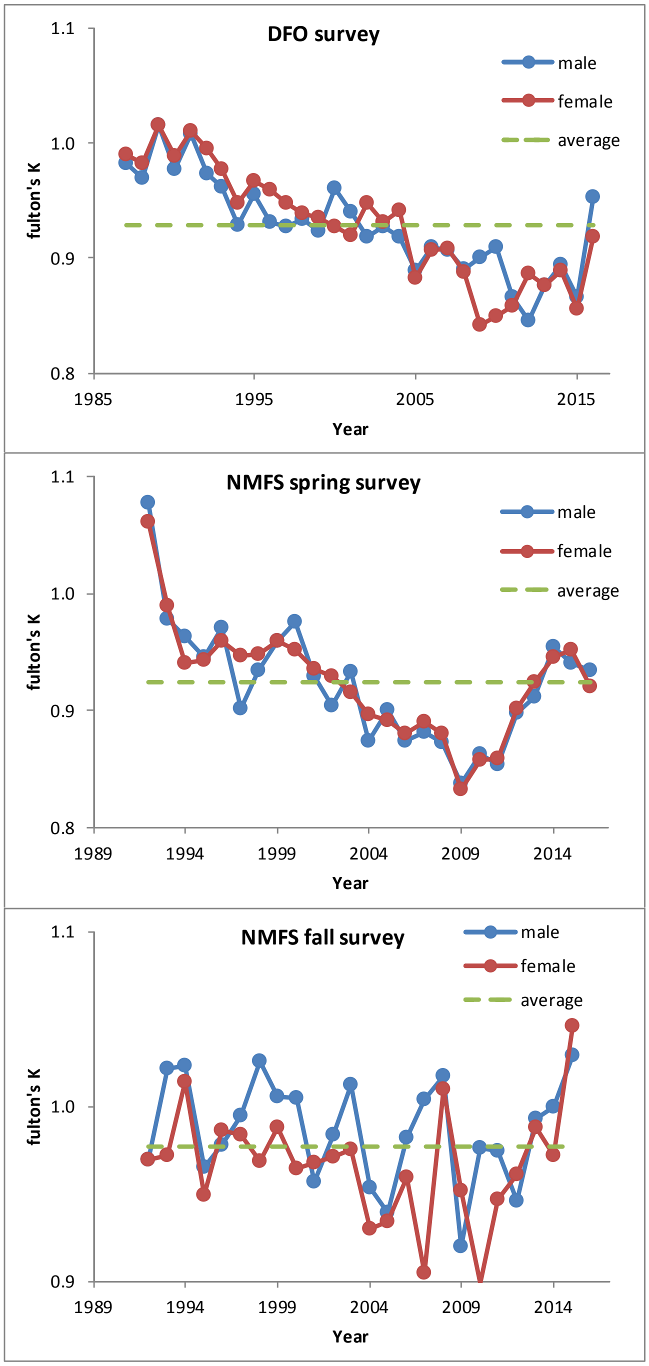
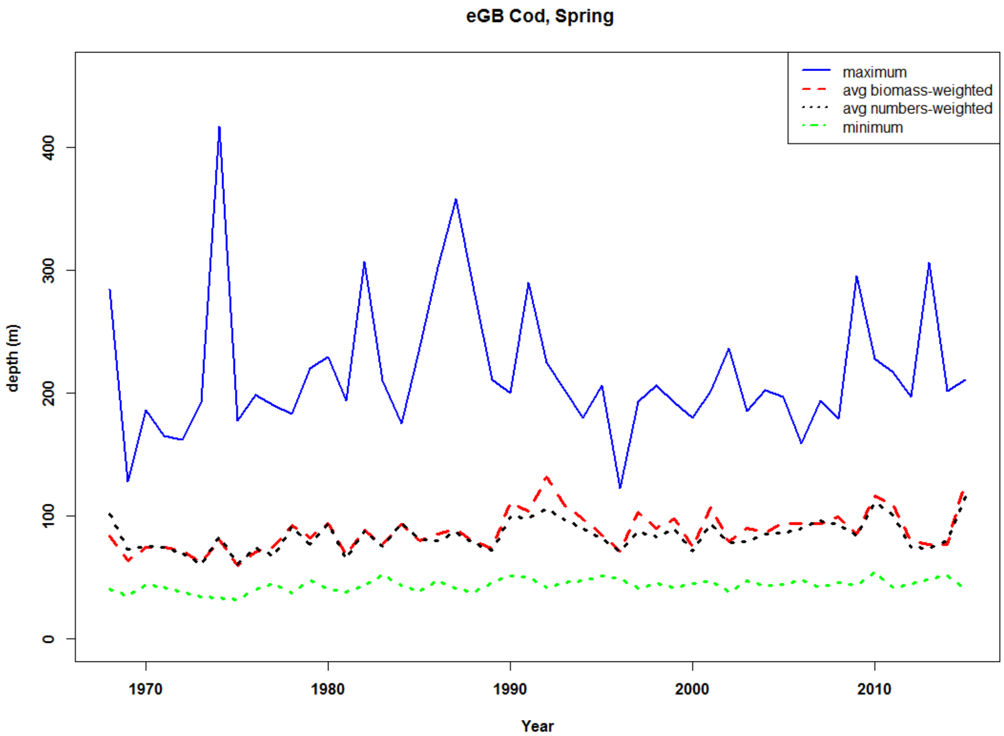


Figure 13. Fultons's condition factor of post spawning eastern Georges Bank cod from DFO, NMFS spring and NMFS fall surveys.



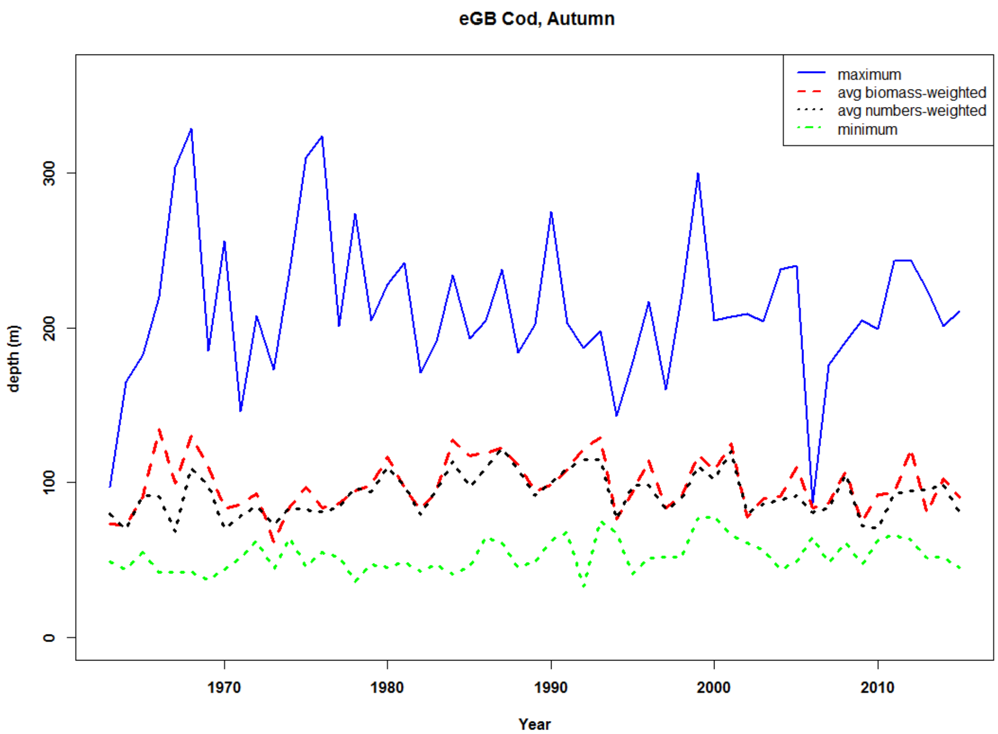


Figure 14. Biomass and abundance weighted mean depth occupied by cod during spring and autumn, during 1970-2015.

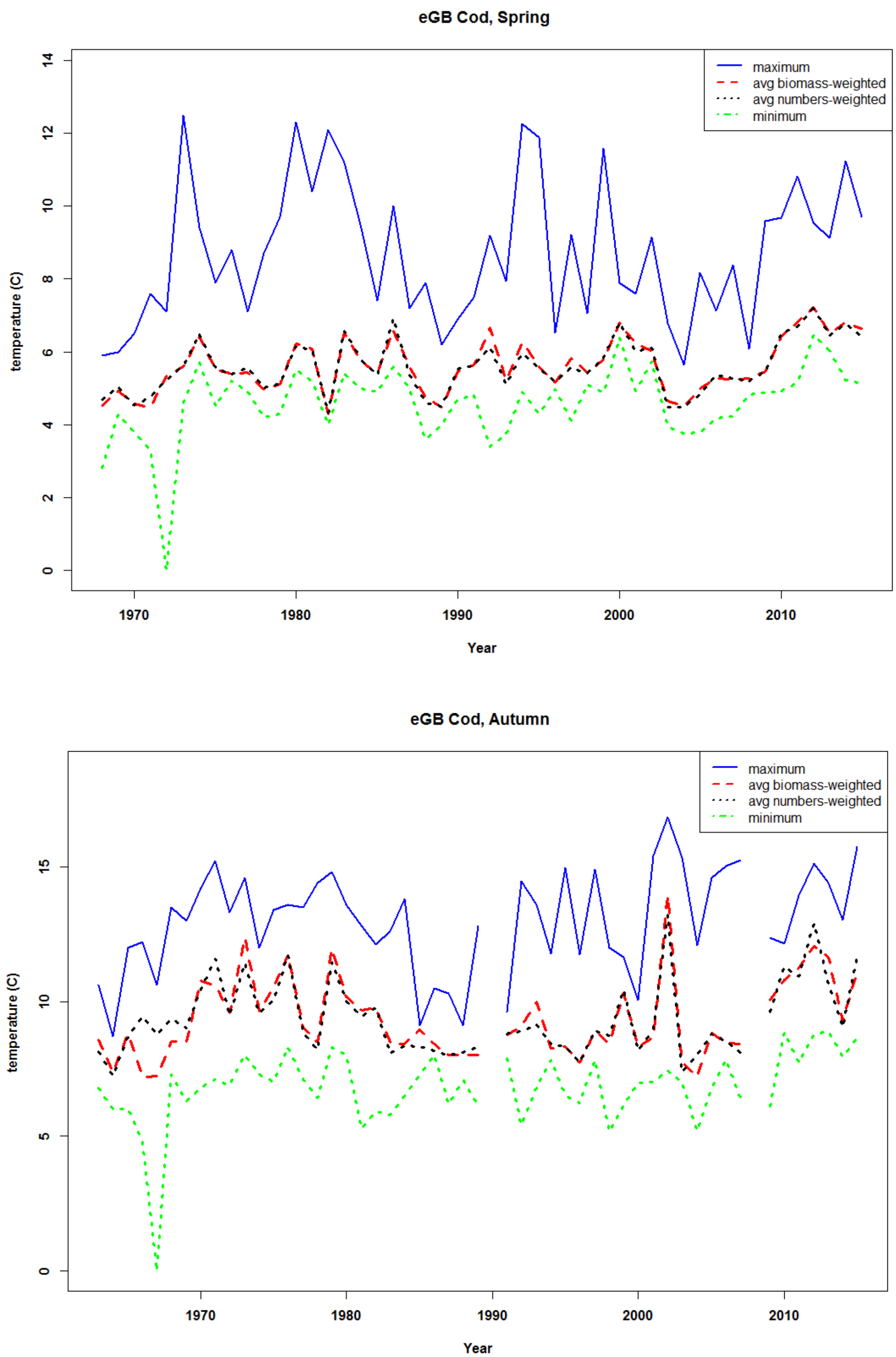


Figure 15. Biomass and abundance weighted mean temperature occupied by cod during spring and autumn, during 1970-2015.

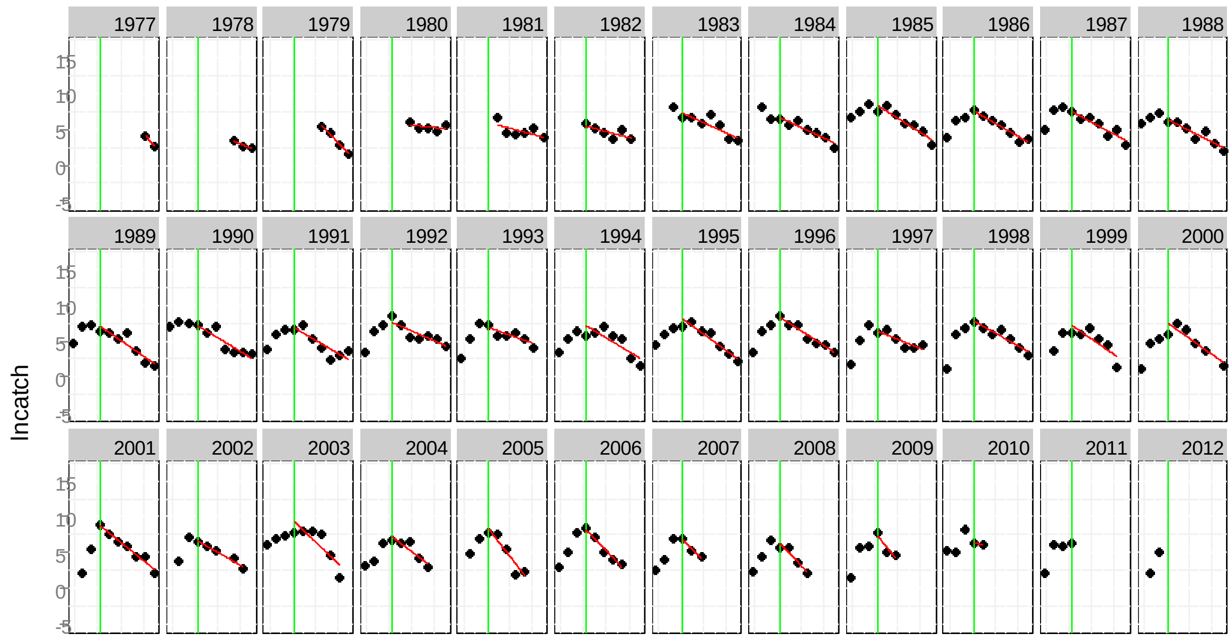


Figure 16. Catch curve by cohort for the DFO survey.

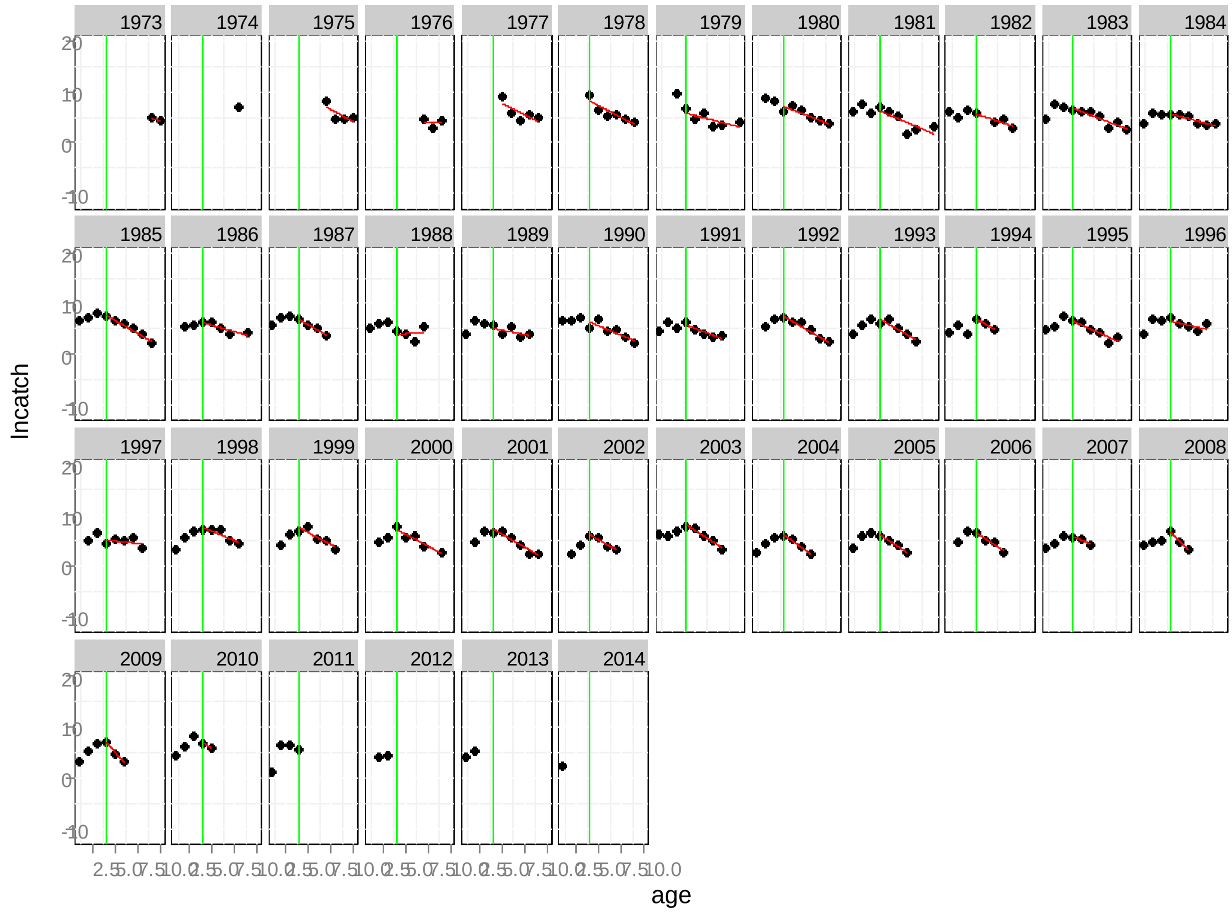


Figure 17. Catch curve by cohort for NMFS spring survey.

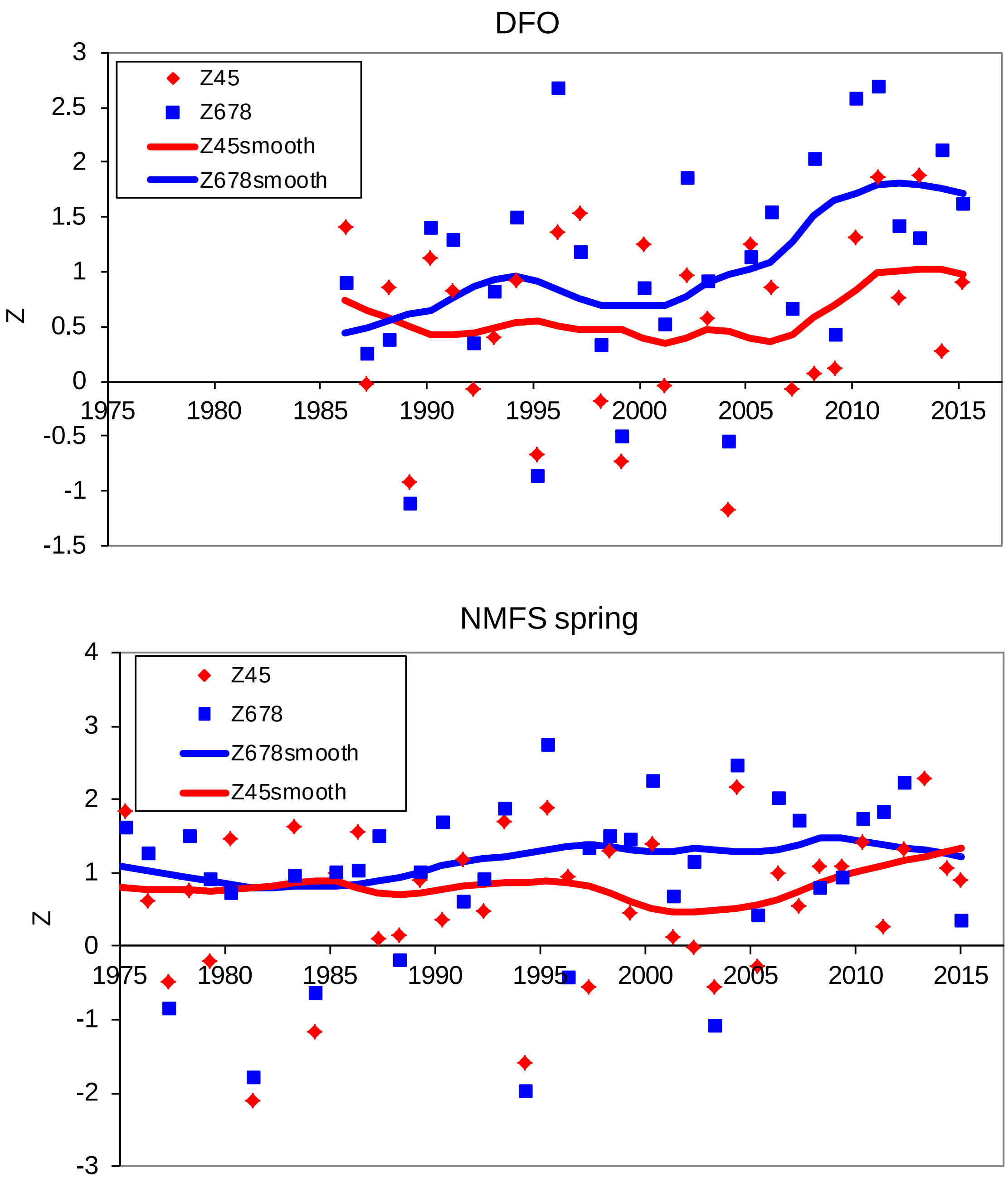


Figure 18. Total mortality (Z) calculated using the DFO and NMFS spring surveys data for eastern Georges Bank cod. The lines show the smoothed curves.

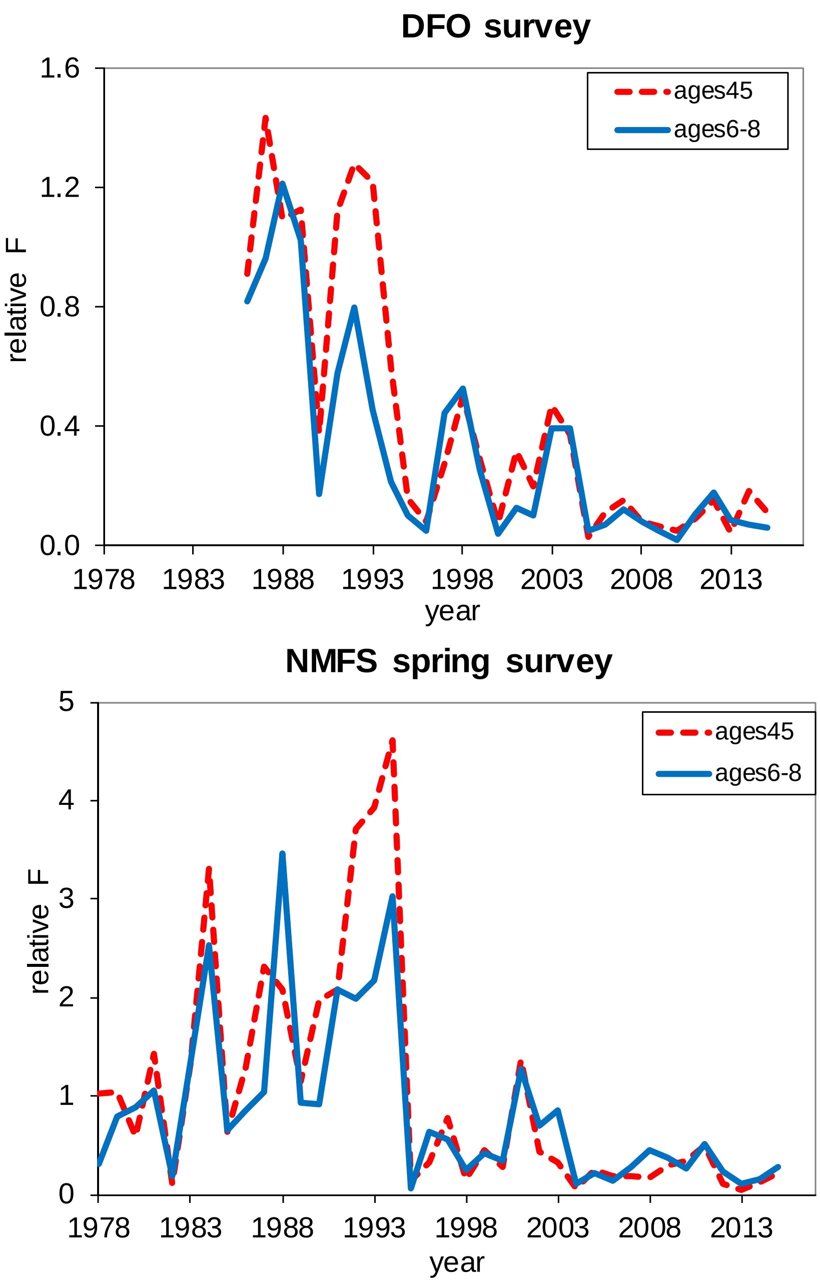


Figure 19. Relative F (fishery catchat age/survey abundance indices at age) calculated using the DFO and NMFS spring surveys data for eastern Georges Bank cod.

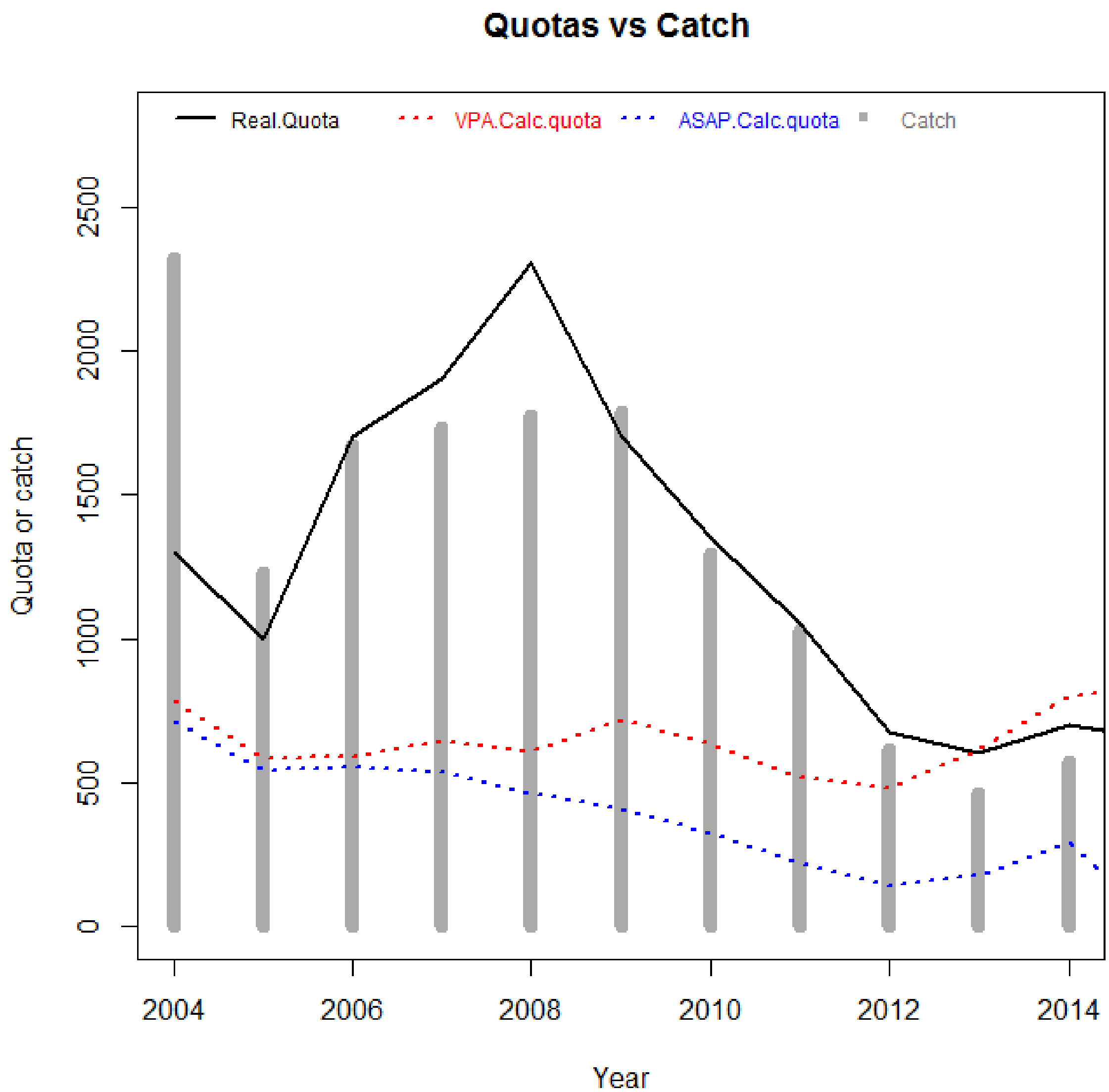


Figure 20. Comparison of Eastern Georges Bank cod quota (solid black line), calendar year catch (light grey bars), and "retrospective quota" calculated for VPA (dashed red line) and ASAP (dashed blue line). The retrospective quota is a deterministic calculation from results of the 2015 TRAC cod assessment models, and comparison with the solid black line demonstrates the difference in population abundance between of the current models and the models that were in place when the historic quotas were calculated.

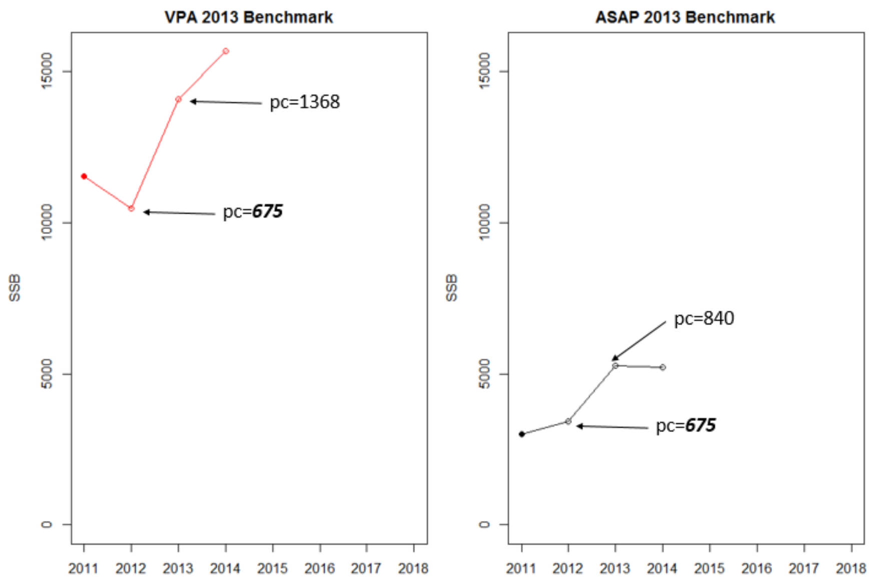


Figure 21. Deterministic projection results from VPA and ASAP models at the 2013 benchmark meeting. Solid circles indicate the last model estimate of adult biomass (SSB), open circles indicate projected SSB. The projected catch amounts ("pc") are indicated for each year of removal; bold italic values 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).

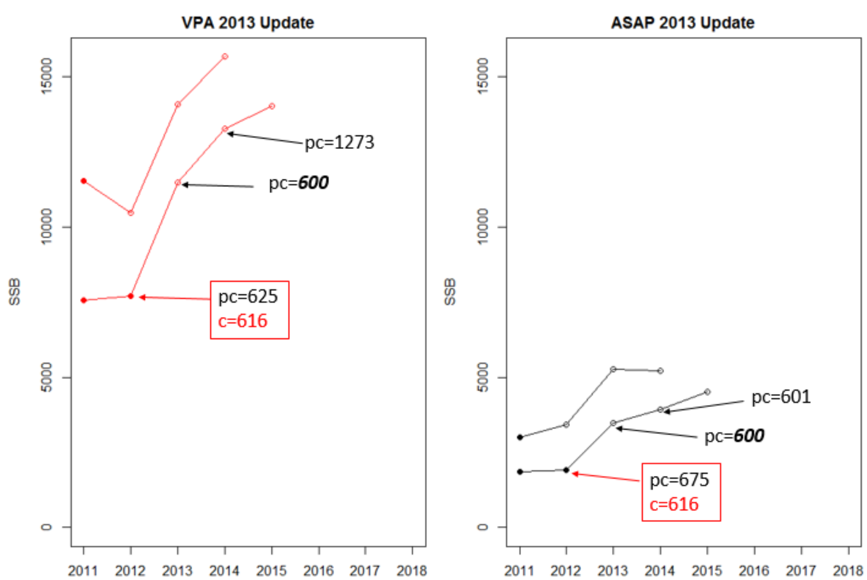


Figure 22. Deterministic projection results from VPA and ASAP models at TRAC 2013. Solid circles indicate the last model estimate of adult biomass (SSB), open circles indicate projected SSB. Projected catch amounts ("pc") are indicated for each year of removal; bold italic values are quotas that were 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.

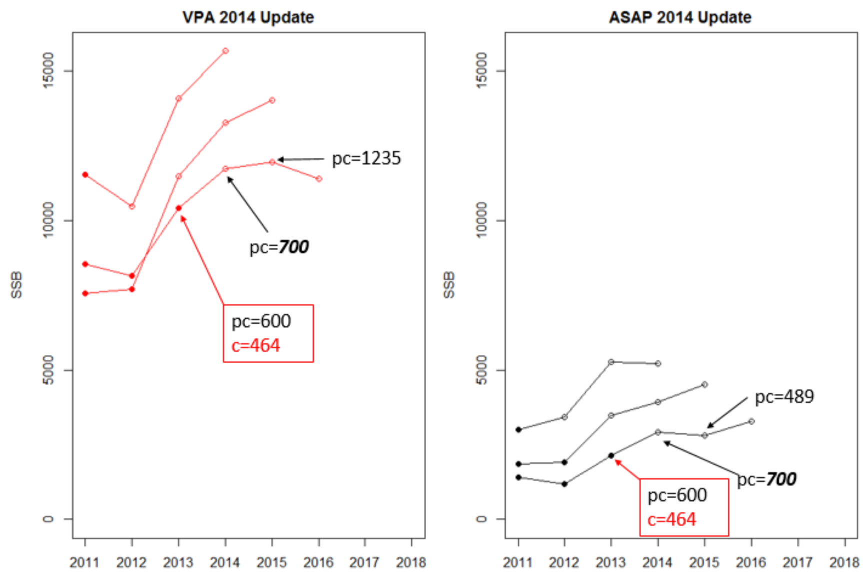


Figure 23. Deterministic projection results from VPA and ASAP models at TRAC 2014. Solid circles indicate the last model estimate of adult biomass (SSB), open circles indicate projected SSB. Projected catch amounts (“pc”) are indicated for each year of removal; bold italic values are quotas that were 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.

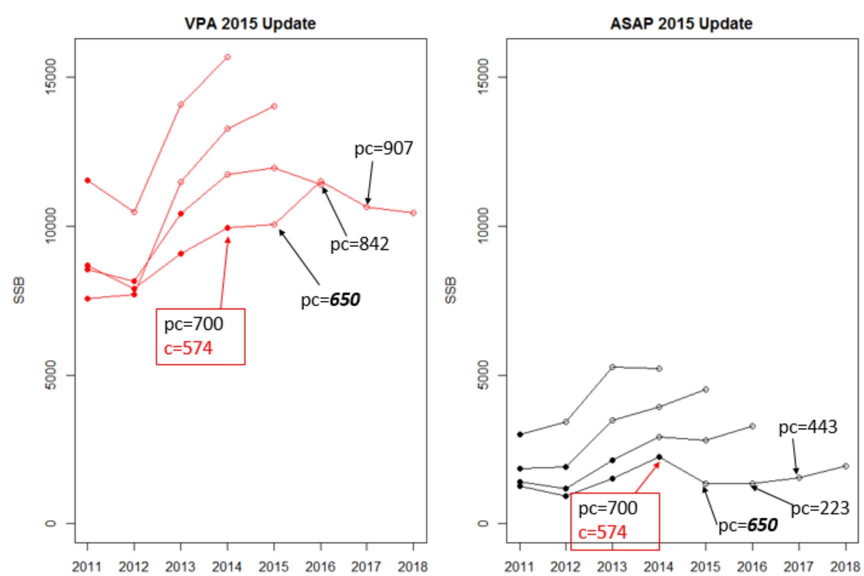


Figure 24. Deterministic projection results from VPA and ASAP models at TRAC 2015. Solid circles indicate the last model estimate of adult biomass (SSB), open circles indicate projected SSB. Projected catch amounts (“pc”) are indicated for each year of removal; bold italic values are quotas that were 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.